Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance, and Technology Innovations

FINAL REPORT

Authors

Timothy Gates, Tongbin Teresa Qu, Jonathan Kay, Dan Seguin, Chang Xu, Peter Savolainen, and Jon Burley

Sponsoring Organization

Michigan Department of Transportation

Performing Organization

Michigan State University
Department of Civil and Environmental Engineering
428 South Shaw Lane
East Lansing, MI 48824

January 27, 2022

MDOT Michigan Department of Transportation

College of Engineering MICHIGAN STATE UNIVERSITY

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SPR-1708	N/A	Steve Shaughnessy

4. Title and Subtitle	5. Report Date
Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance, and Technology Innovations	January 27, 2022
	6. Performing Organization Code N/A
7. Author(s) Timothy Gates, Tongbin Teresa Qu, Jonathan Kay, Dan Seguin, Chang Xu, Peter Savolainen, Jon Burley	**8. Performing Organization Report No.** N/A
9. Performing Organization Name and Address Michigan State University Department of Civil and Environmental Engineering 428 S. Shaw Lane East Lansing, Michigan 48824	**10. Work Unit No.** N/A **11. Contract or Grant No.** Contract 2019-0369
12. Sponsoring Agency Name and Address Michigan Department of Transportation (MDOT) Research Administration 8885 Ricks Road P.O. Box 33049 Lansing, Michigan 48909	**13. Type of Report and Period Covered** Final Report 4/22/2019 to 12/31/2021 **14. Sponsoring Agency Code** N/A

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MDOT research reports are available at www.michigan.gov/mdotresearch.

16. Abstract

In order to accelerate progress towards the state's *Towards Zero Death* vision, MDOT sponsored this research effort, *Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance, and Technology Innovations* (OR19-072). The primary goal of this project was to assess national best practices related to pedestrian and bicyclist planning and design, culminating in the development of recommendations to allow MDOT to explicitly consider the needs of such non-motorized users. A series of tasks were conducted towards this end by the MSU research team in consultation with the MDOT panel, including a review of current practices, the collection of information from Michigan's stakeholders, the identification of updates to MDOT planning and design materials, and the development of materials to promote pedestrian and bicycle innovations. This report summarizes these efforts as a comprehensive reference for implementing the research and recommendations developed as a part of the project.

17. Key Words	18. Distribution Statement
Pedestrian design, bicycle design, towards zero death, vision zero, crossing enhancements, COVID-19 impacts, bicycle facilities, safety programs	No restrictions. This document is also available to the public through the Michigan Department of Transportation.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	399	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance, and Technology Innovations

FINAL REPORT

December 31, 2021

Principal Investigator
Timothy J. Gates, Ph.D., P.E., P.T.O.E.
Professor
Michigan State University

Authors
Timothy Gates, Teresa Qu, Jonathan Kay, Dan Seguin, Chang Xu,
Peter Savolainen, and Jon Burley

Sponsored by
Michigan Department of Transportation

A report from
Michigan State University
Department of Civil and Environmental Engineering
428 South Shaw Lane
East Lansing, MI 48824

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DISCLAIMER

This publication is disseminated in the interest of information exchange. The Michigan Department of Transportation (hereinafter referred to as MDOT) expressly disclaims any liability, of any kind, or for any reason, that might otherwise arise out of any use of this publication or the information or data provided in the publication. MDOT further disclaims any responsibility for typographical errors or accuracy of the information provided or contained within this information. MDOT makes no warranties or representations whatsoever regarding the quality, content, completeness, suitability, adequacy, sequence, accuracy or timeliness of the information and data provided, or that the contents represent standards, specifications, or regulations.

This material is based upon work supported by the Federal Highway Administration under SPR-1683. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Federal Highway Administration.

ACKNOWLEDGEMENTS

The research team would like to acknowledge the Michigan Department of Transportation (MDOT) for sponsoring this research and the Federal Highway Administration for State Planning and Research (SPR) funds used for this project. The authors also acknowledge the contributions of the members of the MDOT Research Advisory Panel (RAP) for guidance and direction on project tasks, with special recognition to project manager, Steve Shaughnessy, and research supervisor, Mary Hoffmeyer.

EXECUTIVE SUMMARY

In order to accelerate progress towards the state's *Towards Zero Death* vision, MDOT sponsored this research effort, *Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance, and Technology Innovations* (OR19-072). The primary goal of this project was to assess national best practices related to pedestrian and bicyclist planning and design, culminating in the development of recommendations to allow MDOT to explicitly consider the needs of such non-motorized users. A series of tasks were conducted towards this end by the MSU research team in consultation with the MDOT panel. This report summarizes these efforts as a comprehensive reference for implementing the research and recommendations developed as a part of the project. An overview of key findings identified as a part of this project include:

- Both MDOT and local roadway agencies in Michigan have either previously implemented or considered most the innovative non-motorized design treatments identified as a part of this effort to some extent. These practices are also included in the revised *Best Design Practices for Walking and Bicycling in Michigan*. However, there remains a considerable opportunity to expand the use of many treatments identified within the review of current practices across the state.
- The information obtained from Michigan residents and advocacy groups offers additional context to the review of current practices and helps to provide a benchmark for public opinion specific to Michigan's non-motorized transportation network. The findings obtained from Michigan's stakeholders can help the department in future decision-making related to non-motorized planning and design.
- Despite MDOT's recent *Multi Modal Development and Delivery (M2D2)* efforts which have helped to further incorporate innovative treatments into the department's policies and procedures, there also remains a considerable opportunity to further expand and revise these key planning and design materials. This includes both the review of documents conducted by the MSU team as a part of this effort as well as future efforts by MDOT.
- The materials developed to help disseminate guidance to encourage the use of pedestrian and bicycle innovations represent tools which can be employed by both MDOT and local roadway agencies in Michigan. This includes the update to MDOT's *Best Design Practices for Walking and Bicycling in Michigan* as well as the development of a new document entitled *Tools for the Planning and Design of Pedestrian Crossing Enhancements*.

A series of project deliverables are provided within **Appendices 1-8** and key details of these materials are discussed within the report. **The following table** provides a summary of major tasks associated with the project as well as specific recommendations for MDOT to consider in order to implement project deliverables into the department's processes.

Summary of Recommendations to Implement OR19-072 Findings

Task	Recommendation for Implementation
Comprehensive Literature Review	MDOT staff can refer to the literature review (**Appendix 1**) as a comprehensive resource for pedestrian and bicycle design information, including a detailed overview of specific practices as well as links to more than 400 key references.
Identification of MDOT's Existing Relevant Materials	The list of MDOT materials included in **Appendix 2** represents a resource which defines the department's current guidance with respect to pedestrians and bicyclists. This list could be referenced by staff when examining the department's overall non-motorized program.
Survey of State and Local Agency Non-Motorized Staff	The survey of non-motorized staff provides detailed information related to the use of specific design strategies, the use of national and jurisdiction-specific guidance documents, the availability of non-motorized master plans, non-motorized data resources, and micromobility considerations. These findings can be reviewed by the department to guide future decision-making related to these topics.
Best Practices for Bicycle Signal Detection	The detailed review of best design practices for bicycle signal detection can be used by the department as a part of expanding the use of bicycle signals and detection systems in Michigan (**Appendix 4**).
Statewide Survey of Michigan Residents	The survey of residents provides detailed information related to general behavioral patterns, satisfaction with existing facilities, safety perceptions, intentions with improvements, preferred routes, and the impact of COVID-19. This information can be reviewed by the department to guide future decision-making related to these topics.
Focus Groups with Michigan Pedestrian and Bicycle Advocacy Groups	The information obtained from the focus groups supplement the findings of the survey of residents by targeting key demographics of non-motorized road users in Michigan. This included representation from the AARP of Michigan, disability advocacy groups, and bicycling and trails advocacy groups. This information can be reviewed by the department to guide future decision-making which impacts these key demographic groups.

Task	Recommendation for Implementation
Generalized Activities from USDOT *Pedestrian Safety Action Plan*	The list of generalized activities which can be considered at the state-level, as well as the status of these activities in Michigan and associated recommendation for implementation, can be reviewed by the department to identify potential opportunities to improve non-motorized policies and procedures related to non-motorized planning and design (**Appendix 6.2**).
Review of 12 Selected MDOT Documents	The elements within each of the 12 documents identified for potential revision and associated recommendations for improvement can be considered by the department to help explicitly consider the needs of non-motorized road users within the agency's planning and design processes (**Appendices 6.3-6.14**).
Update of MDOT's *Best Design Practices for Walking and Bicycling in Michigan*	The comprehensive update of MDOT's *Best Design Practices for Walking and Bicycling in Michigan* to reflect new research and other publications can be used to help disseminate guidance to encourage the use of pedestrian and bicycle innovations. There are also additional practices which have been added to the document which were not widely used when the document was first developed (**Appendix 7**).
Development of *Tools for the Planning and Design of Pedestrian Crossing Enhancements*	The draft Michigan-specific version of FHWA's *STEP Studio* entitled *Tools for the Planning and Design of Pedestrian Crossing Enhancements* can be used as a "pocket guide" or reference for the design of pedestrian crossing enhancements that does not replace existing materials. It should be noted that MDOT requested the MSU team to only complete a draft with appropriate content and the department would work to finalize the presentation of the materials for subsequent publication (**Appendix 8**).

1.0 INTRODUCTION AND OVERVIEW

Despite pedestrian and bicycle safety representing a key element of the national *Towards Zero Death* strategy on highway safety [*1*], fatalities and injuries to non-motorized road users continue to be on the rise in the United States [*2*]. A total of 7,154 pedestrians and bicyclists were killed in traffic crashes in 2019, representing approximately 20 percent of all traffic fatalities [*2*]. Additionally, approximately 125,000 pedestrians and bicyclists were injured in traffic crashes across the country in 2019 [*2*]. While considerable progress has been made within the state of Michigan with respect to reducing the frequency of serious injuries to non-motorized road users, pedestrian and bicycle fatalities have been on the rise over the last decade (**Figure 1**).

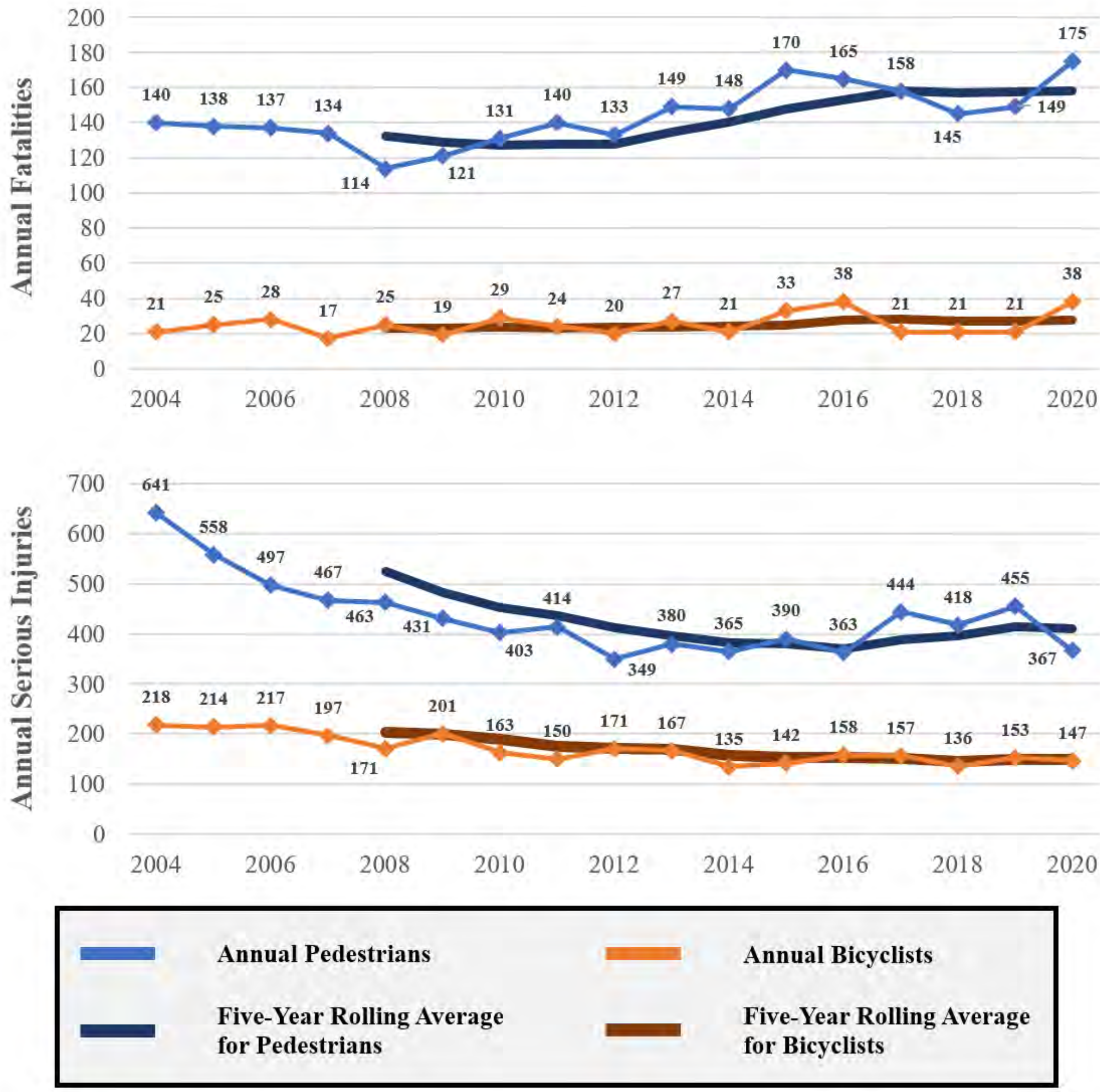


Figure 1. Non-Motorized Road User Fatalities and Serious Injuries in Michigan (2004-2020) [*3*]

Further, the state did not meet the non-motorized fatality and serious injury target identified as a part of the *Highway Safety Improvement Program* (HSIP) 2020 Annual Report [*4*]. These trends emphasize that despite a series of accomplishments coordinated by the Governor's Traffic Safety Advisory Commission (GTSAC) *Pedestrian and Bicycle Safety Action Team* [*5*], there remains an important opportunity to improve the safety performance of Michigan's non-motorized transportation network.

Michigan's *Strategic Highway Safety Plan* (SHSP) identifies "at-risk road users" as one of four broad emphasis areas [*6*]. Pedestrian and bicycle safety is a specific focus within this emphasis area, including the strategy to "Identify and promote the use of best practices when designing and operating facilities" [*6*]. Additionally, supporting mobility for all users of the transportation system is key to MDOT's mission of "providing the highest quality integrated transportation services for economic benefit and improved quality of life" [*7*]. While the Michigan Department of Transportation (MDOT) has a variety of completed [*8-10*] and ongoing [*11*] efforts towards improving multimodal design guidance following context sensitive principles, there may be opportunities to improve the agencies current guidance and design processes by examining best practices conducted both across the United States and abroad.

In order to accelerate progress towards the state's *Towards Zero Death* vision [*6, 12*], MDOT sponsored this research effort, *Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance, and Technology Innovations* (OR19-072). The primary goal of this project was to assess national best practices related to pedestrian and bicyclist planning and design, culminating in the development of recommendations to allow MDOT to explicitly consider the needs of such non-motorized users. A series of tasks were conducted towards this end by the MSU research team in consultation with the MDOT panel, including:

- A detailed review of current practices in non-motorized planning and design, both by other agencies as well as MDOT's existing guidance.
- The collection of information from Michigan's non-motorized transportation stakeholders, including both the state's road users as well as advocacy groups.
- The identification of potential updates to MDOT's relevant planning and design materials which impact non-motorized road users.
- The development of materials to promote the use of pedestrian and bicycle design innovations by both MDOT and local agency staff.
- A summary of the key findings and recommendations to implement project deliverables.

1.1 Overview of the Report

This report summarizes these efforts as a comprehensive reference for implementing the research and recommendations developed as a part of the project. The report also details **Appendices 1-8** which comprise specific project deliverables. **Table 1** summarizes the report content and the deliverables.

Table 1. Summary of Report Content

Section		Content
2	**Review of Current Practices**	Several deliverables were developed to identify the current state of the practice with respect to pedestrian and bicycle planning and design, including: • A comprehensive literature review • The identification of MDOT's existing relevant materials which impact non-motorized planning and design • A survey of state and local agency non-motorized staff • A detailed review of best practices in bicycle signal detection
3	**Collection of Information from Michigan's Stakeholders**	In order to provide additional context to the current state of the practice and benchmark public opinion specific to the non-motorized transportation network, a variety of information was also collected from Michigan's pedestrian and bicycle stakeholders, including: • A statewide survey of Michigan residents • Focus groups conducted with a range of pedestrian and bicycle advocacy groups within Michigan
4	**Identification of Potential Updates to MDOT's Planning and Design Materials**	In consultation with the MDOT panel, 12 MDOT documents were identified for review to identify elements which could be updated to reflect current practices with respect to non-motorized planning and design. Specific elements within each document were identified which could be improved and provided a series of recommendations to help explicitly consider pedestrians and bicyclists within the department's processes.
5	**Development of Materials to Promote Pedestrian and Bicycle Innovations**	Materials were also developed in consultation with the MDOT panel to help disseminate guidance to encourage the use of pedestrian and bicycle innovations. These materials included: • An update of MDOT's *Best Design Practices for Walking and Bicycling in Michigan* document initially developed in 2012 as a part of a prior research effort • The development a new draft document entitled *Tools for the Planning and Design of Pedestrian Crossing Enhancements*
6	**Summary and Conclusions**	A summary is provided which highlights the major findings identified as a part of OR19-072 as well as specific recommendations to implement the deliverables associated with the project.

2.0 REVIEW OF CURRENT PRACTICES

A detailed review of the current state-of-the-practice in non-motorized planning and design was conducted to inform subsequent project tasks. This included planning and design concepts across a range of roadway contexts, from effectively accommodating bicyclists along rural highways to enhancing pedestrian crossings in urban environments. Concepts were explored specific to facility planning, traffic control devices, geometric design, intersection design, and other policies that improve accessibility, mobility, and safety among non-motorized users. This process initiated with a comprehensive literature review (**Section 2.1**) and the identification of MDOT's existing relevant materials (**Section 2.2**). A survey of state and local agency non-motorized staff across the United States was also conducted to identify current non-motorized practices in use by highway agencies (**Section 2.3)**. During the course of project activities, the MDOT panel also requested that the MSU research team conduct a detailed review of best practices in bicycle signal detection (**Section 2.4**).

2.1 Comprehensive Literature Review

At the outset of the project, a comprehensive literature review was conducted to identify best practices in pedestrian and bicycle design and planning efforts. The existing literature was critically reviewed with a focus on the following:

- Best practices in Michigan, the United States, and abroad.
- Processes that have led to successful projects by other state and local agencies.
- Compliance with the Americans with Disabilities Act (ADA).

The review ultimately included a search of guidelines for pedestrian and bicycle design, project reports from agencies including the Federal Highway Administration (FHWA), United States Department of Transportation (USDOT), Transportation Research Board (TRB), State DOTs, and other governmental or quasi-governmental organizations in Michigan, the United States, and elsewhere, as well as a review of relevant articles from transportation engineering journals. The Transport Research International Documentation (TRID) bibliographical database and other relevant search engines were also utilized to identify relevant publications. These selected materials were categorized by national references (155 resources), international references (24 resources) state and local resources (113 resources), as well as journal articles and conference proceedings (134 resources). Given that this literature review was conducted early in the project period, it is important to recognize that several key references were published after the completion of the literature review. While these materials have been considered as a part of project tasks, they were not included in the literature review deliverable.

A copy of the comprehensive literature review summary is provided in **Appendix 1**. Given the relative length of this effort, a summary of the major planning and design concepts which impact non-motorized users is provided in **Table 2** for reference. It is important to note that many of these concepts have multifaceted impacts on non-motorized road users and full details can be found in **Appendix 1**.

Table 2. Summary of Planning and Design Aspects which Impact Non-Motorized Road Users

Planning and Design Concept	Summary of Impact on Non-Motorized Road Users
Lane Width	Given that the Green Book allows for considerable flexibility in selecting lane widths (ranging from 9 to 12 feet depending on a variety of design considerations) [*13*], implementing narrower lane widths can provide benefits to non-motorized road users while not significantly impacting safety performance in urban environments [*14, 15*]. Narrower lanes may allow designers to implement bicycle-specific facilities, widen sidewalks, and reduce crossing distances [*14, 16*]. However, lane widths of less than 12 feet should be considered with caution for scenarios without bicycle-specific facilities where considerable bicycle traffic is expected to share the road with vehicles [*17*].
Paved Shoulders and Shoulder Width	The inclusion of paved shoulders along a highway can provide a variety of benefits, including those related to non-motorized road users (such as providing space for travel, facilitating safer passing behaviors and increasing comfort) and unrelated to non-motorized road users (such as serving as a recovery area for errant vehicles, lengthening pavement lifespans and reducing maintenance costs) [*14*].
Sidewalks	Sidewalks are intended to provide a dedicated space for pedestrians that is safe, comfortable, accessible for all potential users [*18*]. Typically, sidewalks are physically separated from highways via curb and gutter (generally in urban environments) or an unpaved buffer space (generally in suburban or rural environments) [*18*]. Sidewalks serve a variety of key functions in cities, including providing access and mobility for pedestrians, enhancing connectivity and promoting walking [*15*].
Shared Use Paths and Sidepaths	Shared use paths provide a travel area away from traffic for non-motorized road users, resulting in a low stress environment for a variety of modes – including bicyclists, pedestrians, skaters, wheelchair users, joggers and other forms of non-motorized travel [*18*]. Shared use paths have a variety of applications, but are often included adjacent to parks, rivers, beaches, greenbelts or utility corridors [*18*]. Sidepaths are shared use paths which are located immediately adjacent and parallel to a highway, providing a low stress experience for non-motorized road users [*13, 18*].
On-Street Parking	While on-street parking is key to serving the needs of certain land uses adjacent to urban streets, the presence of on-street parking can have both positive and negative impacts related to pedestrian safety [*19, 20*]. Specifically, on-street parking can result in lower travel speeds, reduce the crossing width, and serve as a buffer between vehicles and pedestrians walking along a sidewalk [*19, 20*]. On-street parking can also reduce walking distances to destinations for disabled persons [*19*]. However, the presence of on-street parking can create a visual barrier between drivers and crossing pedestrians and reduce the available width that could be used for other pedestrian-friendly design elements. [*19, 20*].

Planning and Design Concept	Summary of Impact on Non-Motorized Road Users
Design Speed	Design speed is one of the fundamental criteria used in establishing a variety of roadway design elements, including horizontal alignment, vertical alignment as well as cross sectional features [*14*]. In the context of designing pedestrian-friendly transportation facilities, higher design speeds can result in less comfortable environments for non-motorized road users [*14*]. Further, National Association of City Transportation Officials (NACTO) guidance notes that "there is a direct correlation between higher speeds, crash risk and the severity of injuries" [*15*]. Research has also shown that drivers visual field reduces at higher speeds, which combined with decreased available time to take corrective action, increases the risk of collisions between vehicles and non-motorized road users [*14, 18*].
Road Diets and Other Reconfigurations	Road diets have been defined as "the reallocation of road space through the reduction of the number of motorized traffic lanes" [*21*]. The implementation of a road diet can also offer safety benefits specific to pedestrians as crossing widths are reduced and refuge islands can be introduced within the right-of-way [*22*]. With respect to bicyclists, road diet conversions can allow for dedicated space to implement bicycle facilities [*14*].
Access Management	While safely accommodating all road users is a fundamental principle of the transportation system, it is also required to provide access connections to the roadway system [*23*]. Additionally, the location and design of these access points impact both safety and mobility for each road user [*23*]. There are a variety of potential driveway design characteristics which may have impacts specific to non-motorized road users, including wide or sloped driveways, relatively large turning radii, adjacent driveways, driveways which are not well-defined, as well as driveways which require driver attention to select an appropriate gap to complete turning movements [*20*].
Intersection Design	Highway intersections are a critical element of the transportation network but also can result in potentially serious conflicts between non-motorized road users and motor vehicles [*15*]. Ultimately, accommodating non-motorized road users at intersections is a complex topic which includes a variety of design aspects which need to be considered.
Crossing Treatments	Pedestrian crossings, including both midblock and at intersections, "should provide safe and comfortable locations to cross the street." [*14*]. NACTO notes that in situations where a signalized or stop-controlled crossing is not warranted but potential crossing demand may exist, enhanced crossing treatments or actuated crossings should be considered [*15*]. An important concept specific to crossing design is that pedestrians will often cross where necessary to conveniently access their destination, particularly in cases where the spacing of crossings is high or the desire line is directly across the street [*19*]. This can expose pedestrians to conflicts with vehicles in situations where drivers are not expecting them [*19*]. Midblock crossings represent an important consideration to respond to this potential behavior, providing for crossing environments that both protect pedestrians and warn drivers of the presence of potential pedestrians [19]. There are a variety of potential treatments to enhance pedestrian crossings, ranging from high-visibility crosswalk markings to pedestrian hybrid beacons.

Planning and Design Concept	Summary of Impact on Non-Motorized Road Users
Transit Considerations	All transit trips must start and end with a walking or bicycling trip, making the consideration of pedestrians critical to transit design [*24*]. Further, bus stops are often located in urban areas adjacent to transportation centers or business districts which serve relatively high pedestrian volumes [*14*]. Bus stops may also be located in rural or suburban areas where they represent the only available transit service [*14*]. It is important to ensure bus stops are designed for local context, are safe and accessible for pedestrians and compliment the overall transportation network [*14*].
Bridge Consideration	While bridge crossings may represent a significant investment, accommodating crossings is critical as bridges without access can result in impractical trips for non-motorized road users [*14*]. Policy statements from USDOT encourage considering both existing and future demand for crossings when considering accommodations [*14*].
School Zones	Families, staff and student trips to and from school facilities, including trips which occur during school hours as well as evenings or weekends, result in multiple modes of travel interacting around the school zone as well as adjacent roadway facilities [*14*]. It is therefore critical for designers, planners and engineers to consider vehicle speeds, geometry, crossings and other non-motorized facilities along routes to schools [*14*].
Work Zones	Pedestrians in work zones can present "special safety and mobility concerns" and therefore it is critical to consider pedestrians during the planning, design and operation of work zones [*25*]. Work zone designs which do not follow standards or best practices "can sometimes provoke pedestrians and bicyclists to take risks that they would ordinarily avoid, resulting in preventable casualties" [*26*].
Bicycle Facilities	As noted by AASHTO, all roadway facilities in the United States "should be designed and constructed under the assumption they will be used by bicyclists." [*13*]. AASHTO defines bicycle facilities as "a general term denoting improvements and provisions to accommodate or encourage bicycling, including parking and storage facilities, and shared roadways not specifically defined for bicycle use." [*13*]. Typically bicycle facilities range from shared environments to physically separated bicycle lanes. Bicycle facilities are a complex topic which includes a variety of design aspects which need to be considered.
Bicycle Networks and Wayfinding	The FHWA has defined bicycle networks as the "connected system made up of facilities such as separated bike lanes, bike lanes, bike boulevards, low-volume, streets, shared use paths, and paved shoulders" [*14*]. Additionally, the FHWA has also recognized that "a well-connected bicycle network can encourage people to bike to key area destinations" [*14*]. Bicycle wayfinding systems incorporate "comprehensive signing and/or pavement markings to guide bicyclists to their destinations along preferred bicycle routes." [*15*].

2.2 Identification of MDOT's Existing Relevant Materials

A list of existing relevant MDOT materials which impact the planning and design of roadway facilities for non-motorized road users was identified in order to define the department's current guidance. These materials were identified based upon the items noted in prior MDOT publications [*8*], reviewing MDOT publications available on the web, as well as discussions with the MDOT RAP. A summary of the 50 MDOT documents identified via this process and their role in non-motorized design and planning is provided in **Appendix 2.**

2.3 Survey of State and Local Agency Non-Motorized Staff

Pedestrian and bicycle professionals representing state and local agencies across the United States were surveyed in order to obtain information related to the current design and planning practices employed by their respective agency. Survey topics included the use of specific design strategies focused on non-motorized road users (**Section 2.3.1**), the use of national and jurisdiction-specific guidance (**Section 2.3.2**), the availability of non-motorized master plans (**Section 2.3.3**), non-motorized data resources (**Section 2.3.4**), and micromobility considerations (**Section 2.3.5**). While each survey was similar in nature, three distinct surveys were developed in Qualtrics [*27*] and provided to:

1. Each state DOT's pedestrian and bicycle coordinator (including Washington, D.C.) [*28*]
2. Staff from 39 local agencies outside of Michigan prioritized based upon Smart Growth America's (SGA) *The Best Complete Streets Policies* lists [*29*]
3. Staff from local agencies within Michigan which maintain distinct complete streets policies

A total of 41 responses were received from state and local agency staff around the United States, shown in **Figure 2**. This included responses from 20 state agencies, 14 out-of-state local agencies, and seven local agencies within Michigan. The sample of responses included state and local agency representation from both coasts as well as the Midwest. While the subsections that follow provide an overview of the key findings obtained from the survey, complete details (including a copy of the survey instrument and full results) can be found in **Appendix 3**.

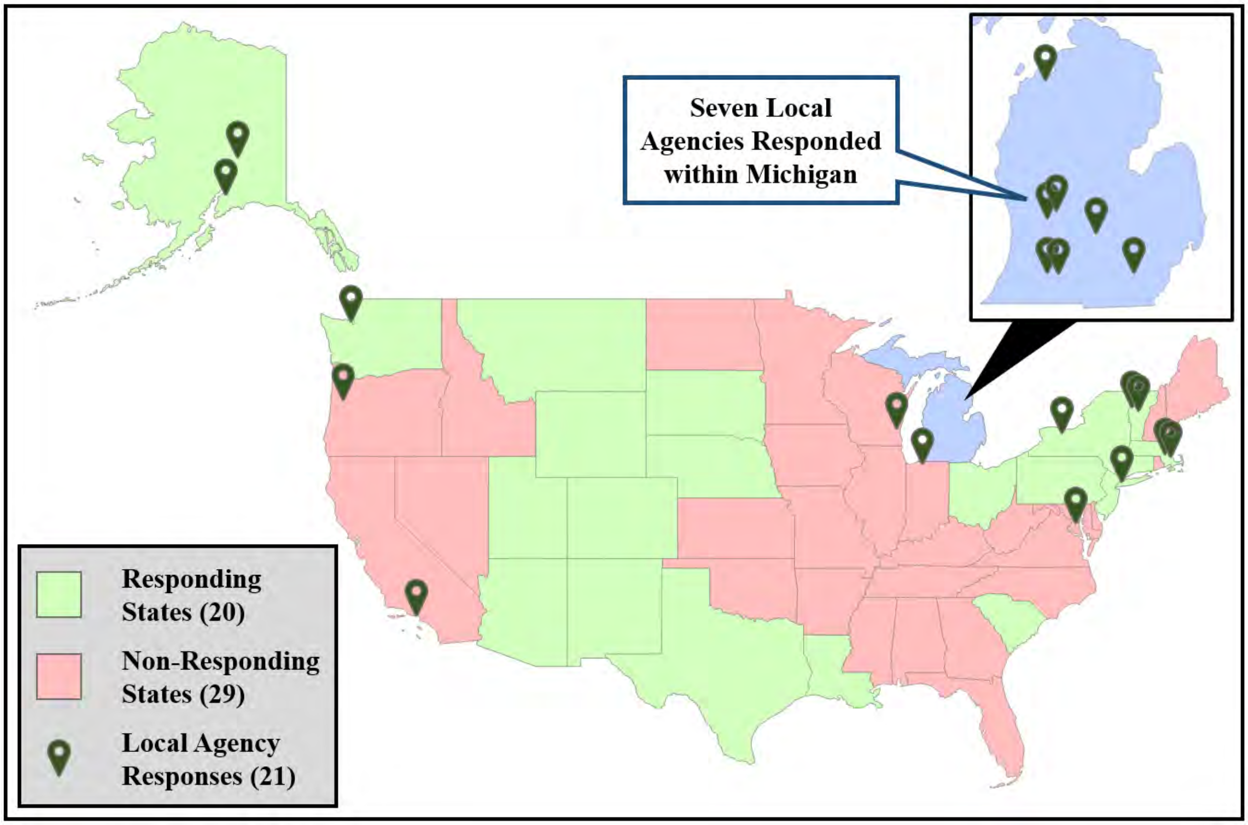


Figure 2. Map of Responding State (20) and Local Agencies (21)

2.3.1 Use of Pedestrian, Bicycle, and Traffic Calming Design Strategies

First, respondents were asked to quantify the use of various design strategies intended to improve safety and mobility for non-motorized road users. Due to the range of available treatments, the topic was subdivided into five groups, including:

- Bicycle treatments along segments or corridors
- Bicycle treatments specific to intersections
- Pedestrian treatments at crosswalks or midblock areas
- Pedestrian treatments at traffic signals
- Traffic calming measures

State pedestrian and bicycle coordinators were asked to describe the frequency of use of these treatments in their state. Local agencies were asked to describe the frequency of use of these treatments by their local agency. A series of commonly-used treatments specific to each of the five groups was provided, including the option to write-in two additional treatments. A hyperlink was provided for each treatment to a national design resource which described the treatment in detail to ensure clarity among respondents. Frequency of use of each treatment was indicated on a Likert

Scale including the following options; Never (0), Rarely (1), Sometimes (2), Frequently (3), and Unsure. Two open-ended essay-style questions were also provided for respondents to comment on successful treatments as well as treatments which have produced failures or mixed results.

The findings specific to **corridor bicycle treatments** are provided in **Figure 3** and a summary of the detailed comments is provided in **Table 3**.

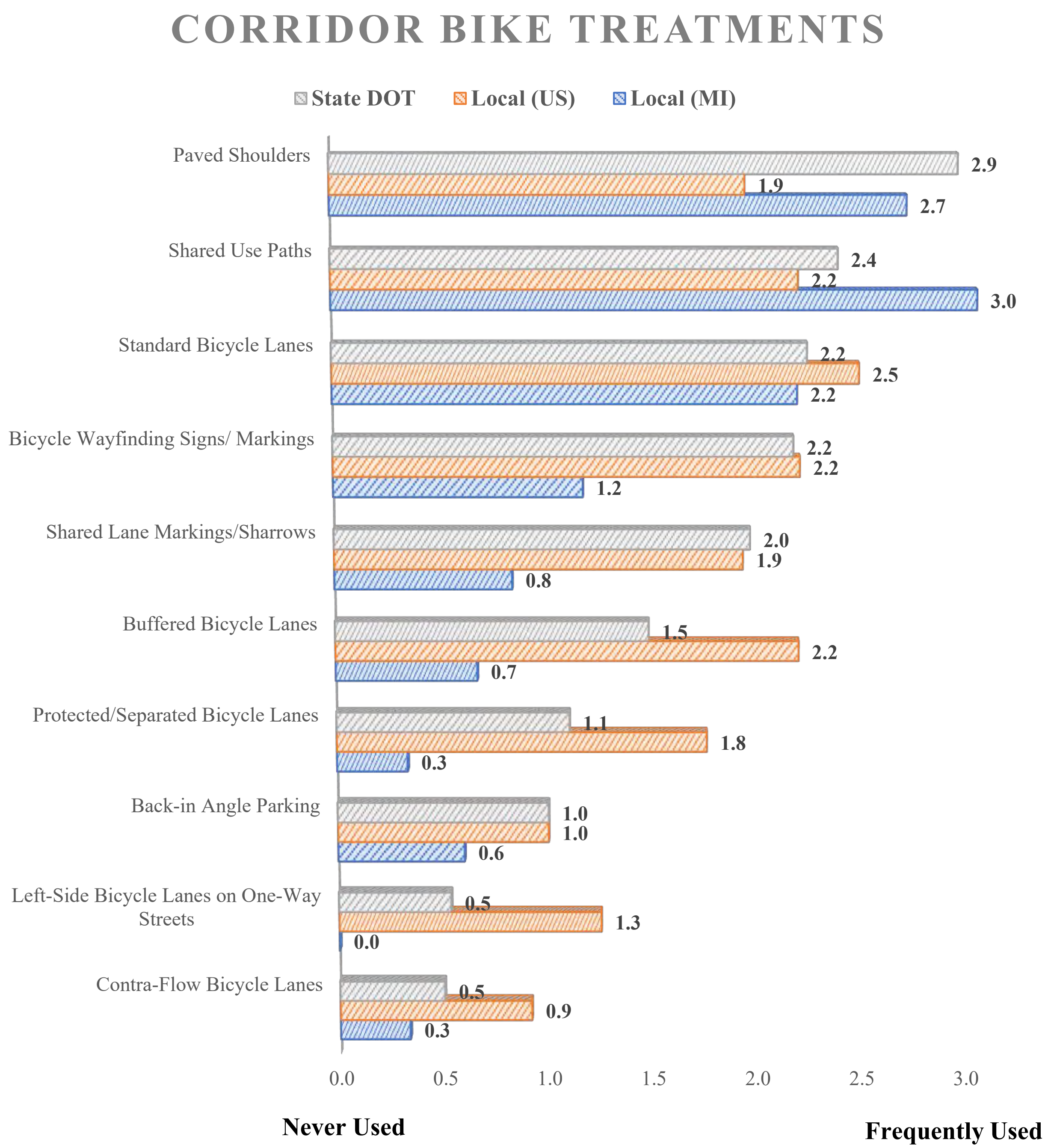


Figure 3. Summary of Corridor Bicycle Treatments Employed by State and Local Agencies

Table 3. Summary of Comments Specific to Corridor Bicycle Treatments

Treatment	Summary of Comments
Paved Shoulders	While paved shoulders represent a common treatment employed by both state and local agencies which can help to provide space for bicyclists, respondents did note a variety of concerns ranging to incorporating intersections to the presence of shoulder rumble strips.
Standard Bicycle Lanes	Respondents noted that conventional bicycle lanes are a relatively low-cost treatment which is generally accepted by the public. However, several respondents noted that agencies are moving towards buffered or separated bicycle lanes to accommodate a greater variety of users. Additionally, respondents noted some concerns specific to pavement markings, maintenance, and the presence of parked cars or delivery vehicles.
Sharrows	Sharrows were generally viewed as unsuccessful by respondents, particularly among state agency personnel.
Buffered Bicycle Lanes	Respondents noted that buffered bicycle lanes were associated with an increase in bicycle volumes. Respondents also noted success in reducing vehicular operating speed by implementing buffered bicycle lanes in conjunction with a road diet.
Separated or Protected Bicycle Lanes	Respondents noted that separated bicycle lanes have been associated with a reduction in crash frequency and an increase in bicycle volumes after implementation. While there have been some concerns specific to snow removal, sidewalk plows have been used successfully. There are also design concerns related to intersections or transit stops which can be mitigated but require consideration.
Shared Use Paths and Sidepaths	Shared use paths were recognized as an effective treatment which was popular with the public. Respondents did note concerns specific to scenarios where motor vehicles cross sidepaths, including intersections and driveways.

The findings specific to **intersection bicycle treatments** are provided in **Figure 4** and a summary of the detailed comments is provided in **Table 4**.

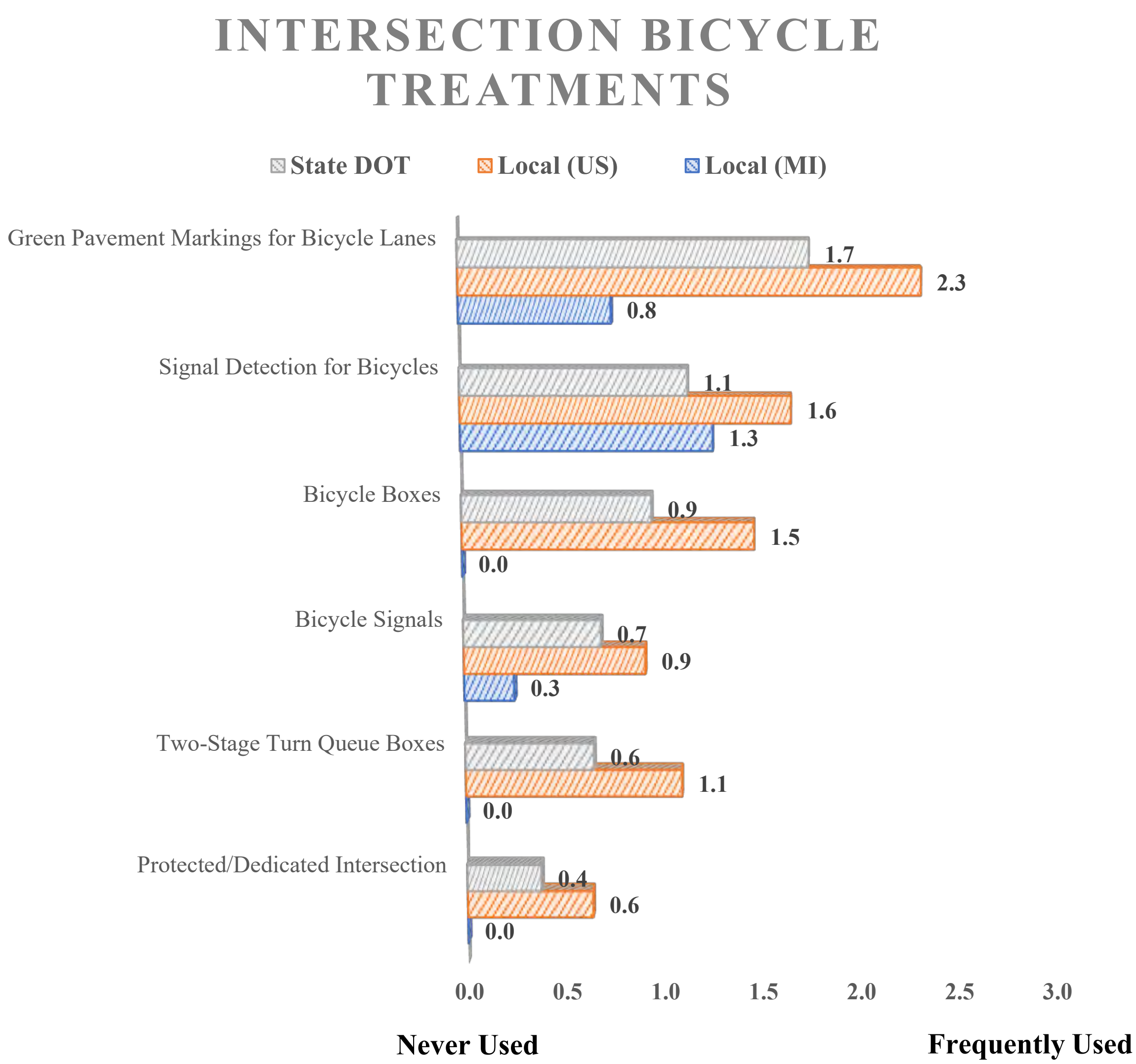


Figure 4. Summary of Intersection Bicycle Treatments Employed by State and Local Agencies

Table 4. Summary of Comments Specific to Intersection Bicycle Treatments

Treatment	Summary of Comments
Bicycle Signals and Detection	Respondents noted that bicycle signals and associated detection devices have been used successfully in a variety of settings.
Bicycle Boxes	While bicycle boxes have been used successfully by multiple state agencies, there were concerns noted related to driver behavior and pavement marking materials.
Green Pavement Markings	Respondents enthusiastically supported the use of green pavement markings due to considerable anecdotal impacts on driver behavior. However, it should be noted that the cost to maintain the thermoplastic markings has been a concern.

The findings specific to **pedestrian crosswalk or midblock treatments** are provided in **Figure 5** and a summary of the detailed comments is provided in **Table 5**.

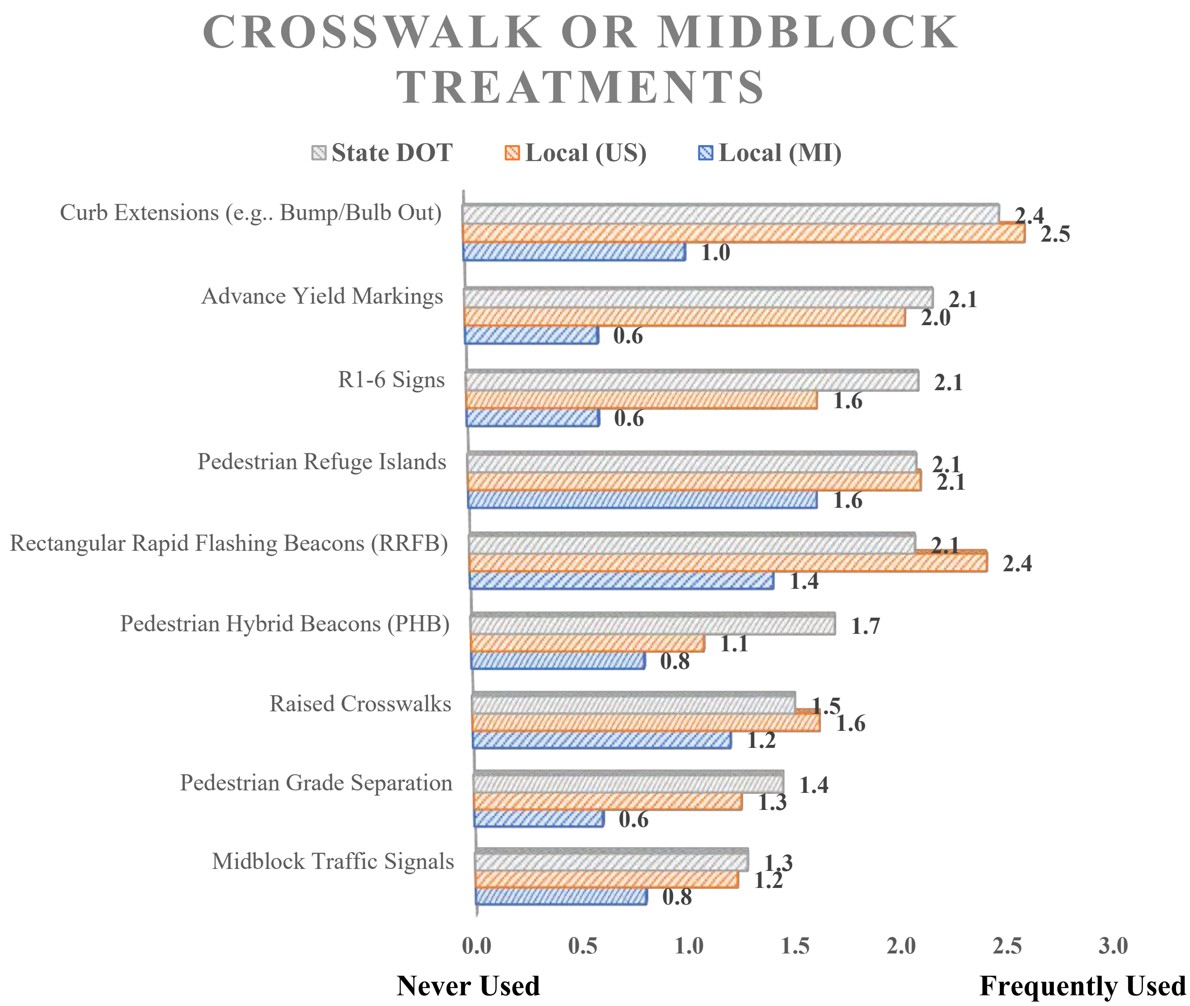


Figure 5. Summary of Pedestrian Crosswalk or Midblock Treatments Employed by State and Local Agencies

Table 5. Summary of Comments Specific to Pedestrian Crosswalk or Midblock Treatments

Treatment	Summary of Comments
Pedestrian Refuge Islands	Respondents noted that refuge islands have been a successful treatment used in a variety of design scenarios, particularly in conjunction with other treatments (such as high visibility markings or lane reductions).
Raised Crosswalks	While some agencies have had success with raised crosswalks, other respondents noted that their use has either been discontinued or discouraged within their jurisdiction. Concerns have included a lack of impact on behavior, weather or maintenance issues, geometric design limitations, and emergency vehicle clearance conflicts.

Treatment	Summary of Comments
Curb Extensions	While curb extensions were noted as an effective treatment, respondents also noted a variety of concerns specific to snow removal.
Rectangular Rapid Flashing Beacons	The implementation of RRFBs had broad support among respondents from both state and local agencies.
Pedestrian Hybrid Beacons	Support for PHBs was more mixed among respondents, noting behavioral concerns specific to both motorists and pedestrians. While some agencies provided positive feedback, others responded that the use of PHBs was limited due to the relative cost or to specific design scenarios (such as higher-speed suburban routes).

The findings specific to **pedestrian intersection treatments** are provided in **Figure 6** and a summary of the detailed comments is provided in **Table 6**.

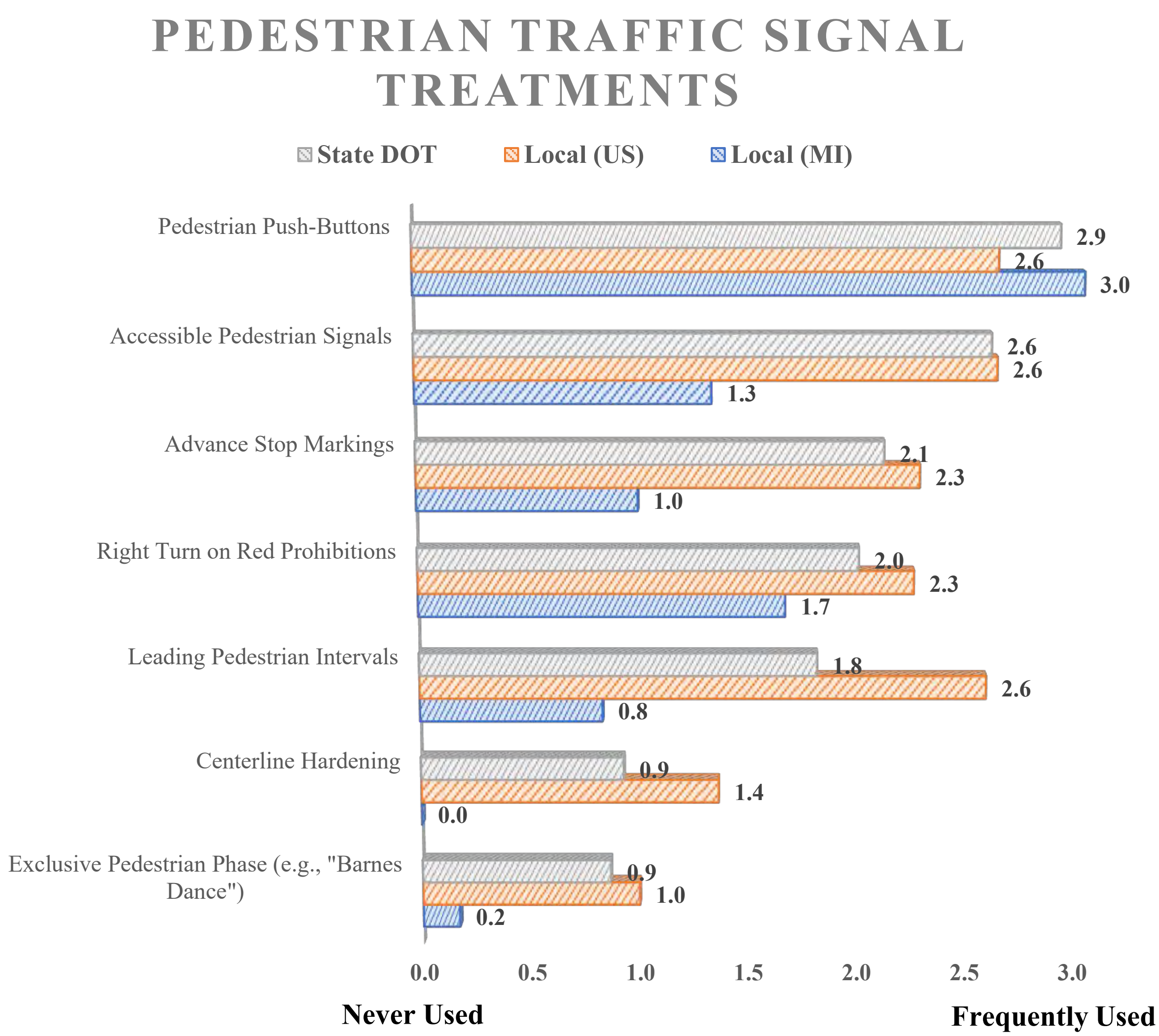


Figure 6. Summary of Pedestrian Intersection Treatments Employed by State and Local Agencies

Table 6. Summary of Comments Specific to Pedestrian Intersection Treatments

Treatment	Summary of Comments
Pedestrian Pushbuttons and Accessible Pedestrian Signals	Respondents from local agencies within Michigan noted that signals with pushbuttons are often in pedestrian recall mode and do not require actuation, guidance specific to placement frequently changes which makes implementation and maintenance more difficult, and offered mixed feedback related to audible pedestrian signals.
Leading Pedestrian Intervals	Leading pedestrian intervals were broadly supported as a low-cost approach to improve pedestrian safety by respondents from both state and local agencies.
Right-Turn on Red Prohibitions	A range of right-turn on red prohibitions have been implemented successfully by state and local agencies, from dynamic signs to citywide bans.

The findings specific to **traffic calming treatments** is provided in **Figure 7** and a summary of the detailed comments is provided in **Table 7**.

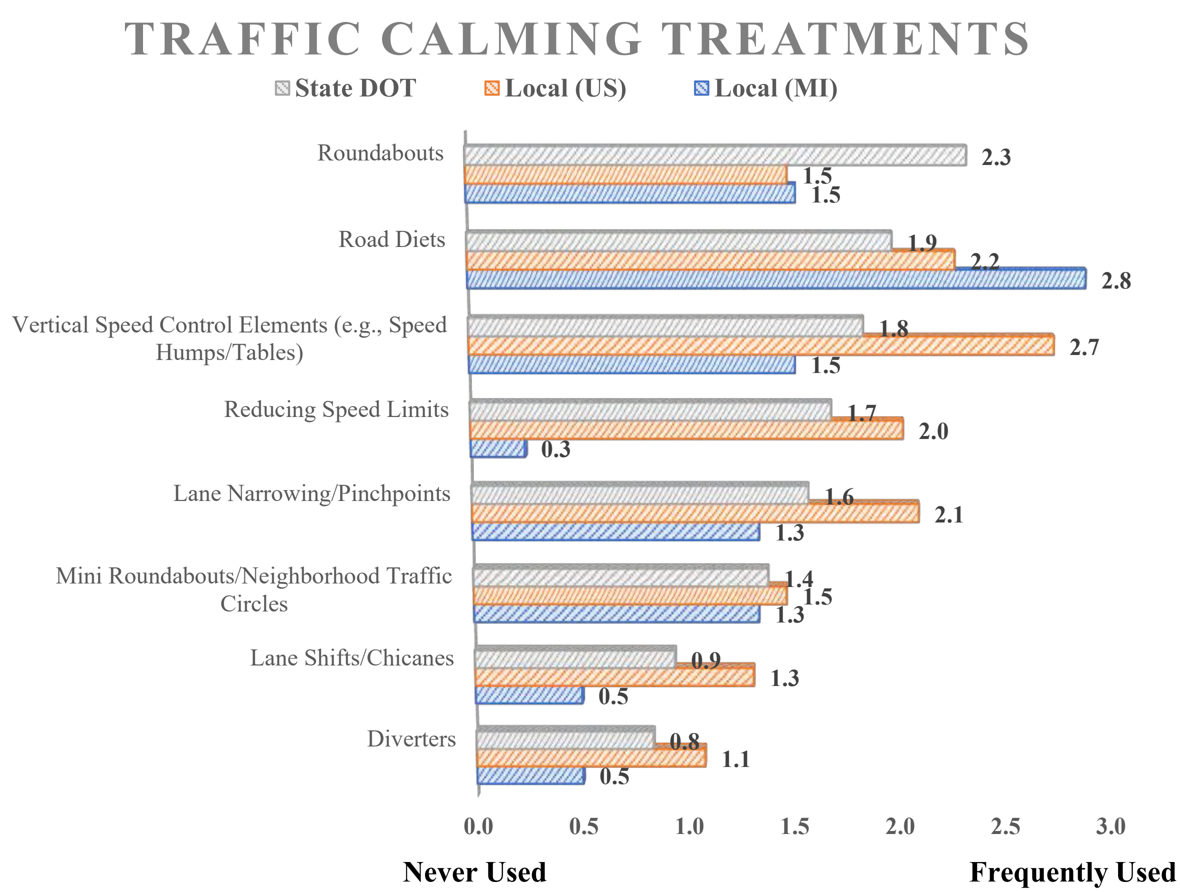


Figure 7. Summary of Traffic Calming Treatments Employed by State and Local Agencies

Table 7. Summary of Comments Specific to Traffic Calming Treatments

Treatment	Summary of Comments
Road Diets	Road diets have been implemented successfully by both state and local agencies. Respondents generally noted decreased vehicular operating speeds and increased safety performance.
Roundabouts	While respondents noted that roundabouts implemented within their jurisdictions improved safety performance, implementation can be difficult due to public acceptance, space limitations, and accessibility concerns.
Vertical Speed Control Elements	Respondents provided generally mixed feedback with respect to the use of vertical elements. While many agencies do not currently implement such treatments, others noted that public acceptance was relatively high.

2.3.2 Use of National and Jurisdiction-Specific Guidance Documents

State and local agencies were also asked about their use of specific design guidance documents. First, the current use of national design documents was obtained for all three agency types. Frequency of use of each national design guide was indicated on a Likert Scale including the following options; Never (0), Rarely (1), Sometimes (2), Frequently (3), Always (4), and Unsure. These findings are summarized in **Figure 8**.

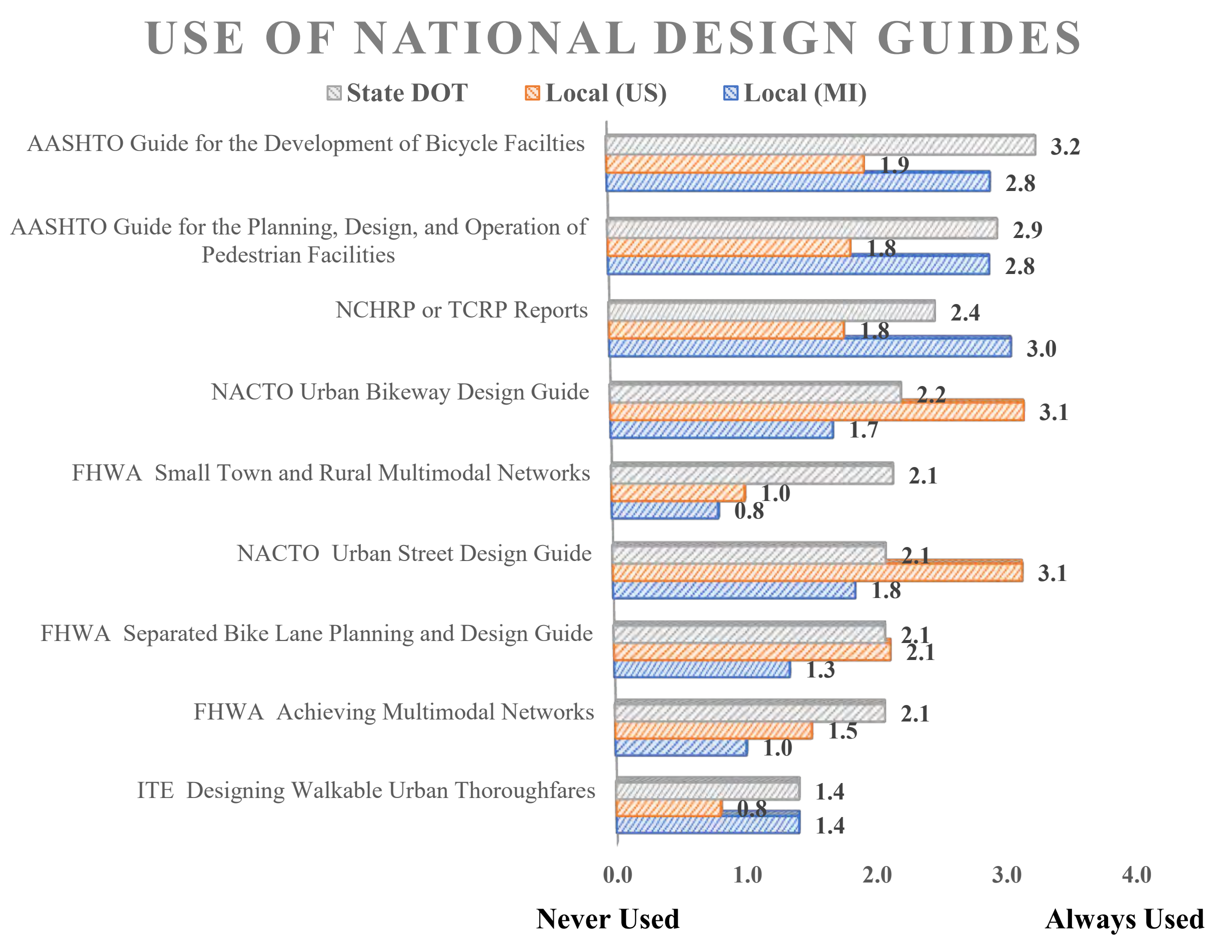


Figure 8. Summary of National Design Guides Used by State and Local Agencies

Respondents were asked if their respective agencies maintained a series of non-motorized-focused guidelines, standards, or policies. These results are summarized in **Table 8**.

Table 8. Summary of State and Local Agency Non-Motorized Guidelines

Agency	Pedestrian Design Guide	Bicycle Design Guide	Transit Facility Design Guide	Complete Streets Policy/ Guide	Context Sensitive Design Policy/ Guide
State Agency	76%	69%	20%	44%	46%
Local Agency (US)	67%	67%	14%	92%	55%
Local Agency (MI)	20%	33%	0%	100%	17%

State agencies were also asked if their respective agency had reviewed internal transportation practices, standards, guidance documents or other manuals (such as a road design manual or project scoping guidance) to identify content that can be modified to better address the needs of non-motorized road users. Respondents indicated that many state agencies have either recently completed or are in the process of updating guidance materials specific to non-motorized road users. This includes either updates to existing documents (six states) or the development of new guidance documents (three states). Full details and links to related documents or materials provided by the respondents is provided in **Appendix 3.37**.

Local agencies were instead asked about the sources of funding for non-motorized improvement projects. Respondents indicated a variety of federal, state, and local funding sources ranging from federal Highway Safety Improvement Program (HSIP) [*30*] funds to city-specific transportation levies. Michigan local agencies were asked if there are elements of Michigan-specific guidance which represented a potential barrier to implementing non-motorized improvements. While one agency noted that the acquisition and certification of right-of-way was a hurdle, a second agency noted that the department has been flexible with granting design exceptions to accommodate treatments. Full details of these responses are provided in **Appendices 3.38 and 3.39**.

2.3.3 Availability of Non-Motorized Master Plans

Both state and local agency staff were asked if their respective agency maintains a non-motorized master plan. Additionally, respondents were asked how often this plan has been evaluated and updated. These findings are summarized in **Table 9**. Full details can be found in **Appendices 3.40-3.42**, including links to each agency's master plan, if provided.

Table 9. Summary of Non-Motorized Master Plans by Agency

Agency	Does your agency maintain a master plan for non-motorized travel?	How often is this master plan evaluated and updated?				
		Less Than 5 Years	5 Years	6-9 Years	10 Years	More Than 10 Years
State Agency	61%	1	3	2	2	2
Local Agency (US)	77%	2	3	1	3	1
Local Agency (MI)	20%	-	-	1	-	-

2.3.4 Non-Motorized Data Resources

Respondents were asked what types of data collection or monitoring systems (including crowd sourcing systems) specific to non-motorized users are employed by their respective agency. These findings are summarized in **Table 10** and full details are provided in **Appendices 3.43-3.45**.

Table 10. Summary of Comments Specific to Non-Motorized Data Collection Systems

Treatment	Summary of Comments
State Agency	State agencies responding to the survey indicated they use a mix of manual non-motorized count programs as well as probe or crowd-sourced resources such as Strava. Field count programs tended to be limited or specific to project needs and employ both permanent and portable counting systems.
Local Agency (US)	Similar to the state agencies, local agencies outside of Michigan also indicated they use a mix of manual non-motorized count programs as well as probe or crowd-sourced resources such as Strava. Several local agencies also indicated the collection of data along shared use paths or trails.
Local Agency (MI)	Local agencies within Michigan noted that they use data collected by a metropolitan planning organization (MPO) or conduct manual counts. Two agencies did not maintain non-motorized counts.

Additionally, respondents were also asked if their respective agency maintained an inventory of pedestrian and/or bicycle infrastructure. These findings are summarized in **Table 11** and full details are provided in **Appendices 3.43-3.45**.

Table 11. Summary of Comments Specific to Non-Motorized Data Inventory

Treatment	Summary of Comments
State Agency	While most state agencies which responded to the survey maintain or are currently developing an inventory of non-motorized facilities, these inventories tend to be limited to only specific types of facilities or along a limited sample of the transportation network.
Local Agency (US)	Most local agencies outside of Michigan responded that they maintain either complete or partial databases of specific non-motorized facilities. These inventories are updated on a regular basis and/or involve receiving data from municipalities.
Local Agency (MI)	Local agencies within Michigan noted that they either use Roadsoft or maintain distinct inventories in a spatial data format.

2.3.5 Micromobility Considerations

Both state and local agencies were asked to describe any considerations or accommodations regarding infrastructure design to minimize conflicts between modes (bikes, pedestrians, and e-scooters) and improve safety. These findings are summarized in **Table 12** and full details are provided in **Appendices 3.46-3.48**.

Table 12. Summary of Comments Specific to Micromobility

Treatment	Summary of Comments
State Agency	Several state agencies noted that they were in the process of developing guidance or standards specific to micromobility or are working with their respective legislature to develop legislation related to micromobility.
Local Agency (US)	Local agencies outside of Michigan incorporated designated parking areas or corrals to address conflicts between parked scooters or bicycles and curb ramps or sidewalks. One agency noted it is developing stencils to indicate the intended users of the roadway, bicycle lanes, and sidewalk.
Local Agency (MI)	Micromobility experience was more limited among local agencies within Michigan. One community noted that there has been a history of conflicts between pedestrians and scooters.

2.4 Best Practices for Bicycle Signal Detection

During project activities, MDOT requested the MSU research team to identify current best practices in bicycle signal detection to assist in the development of more detailed guidance in order to expand the use of bicycle detection in Michigan. A review of the available national guidance specific to bicycle signal detection as well as practices being employed by roadway agencies was conducted, including (1) a review of detection systems and (2) common detection applications. It should be noted that this review was focused on bicycle detection systems and concepts as opposed to the fundamental signal timing parameters (such as bicycle minimum green time) which are covered in the American Association of State Highway and Transportation Officials' (AASHTO) *Guide for the Development of Bicycle Facilities* [*13*] or NCHRP Report 812: *Signal Timing Manual* [*31*]. A copy of this best practices review is provided in **Appendix 4**.

3.0 COLLECTION OF INFORMATION FROM MICHIGAN'S STAKEHOLDERS

In order to provide additional context to the current state of the practice and benchmark public opinion specific to the non-motorized transportation network, a variety of information was collected from Michigan's pedestrian and bicycle stakeholders, including:

- A statewide survey of Michigan residents to capture opinions specific to walking and bicycle-related subjects (**Section 3.1**)
- Focus groups conducted with various pedestrian and bicycle advocacy groups within Michigan (**Section 3.2**)

3.1 Statewide Survey of Michigan Residents

A statewide survey was conducted to capture residents' opinions on walking and biking-related subjects. The Michigan State University Institute for Public Policy and Social Research, in collaboration with the Office for Survey Research, has regularly conducted the State of the State Survey (SOSS) since 1994. Ten questions about personal walking and biking behaviors, ranging from travel behavior to facility satisfaction, were developed for the purposes of this research. These questions were included in the 80th round of the SOSS, which was conducted between October and December 2020. The survey respondents represented the general population of Michigan residents. In addition, the margin of sampling error for the SOSS was ±3.2 percent for the last three years. A copy of the ten survey questions can be found in **Appendix 5.1**. A total of 1,000 responses were collected as a part of the 80th round of the SOSS. **Figure 9** shows the total number of SOSS respondents within each Michigan county. **Table 13** provides demographic characteristics for the 1,000 respondents.

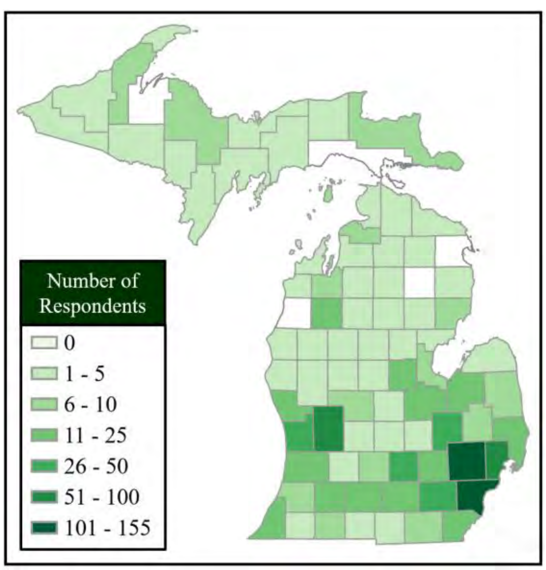


Figure 9. Michigan Resident Survey Respondents by County

Table 13. Socio-Demographic Characteristics of Michigan Resident Survey Respondents

Variable		Number of Respondents	Percent
Gender	Male	487	48.7%
	Female	507	50.7%
	Missing	6	0.6%
Age	18 - 29	209	20.9%
	30 - 39	151	15.1%
	40 - 49	165	16.5%
	50 - 59	190	19.0%
	60 - 69	150	15.0%
	Above 69	135	13.5%
Race	White or Caucasian	839	83.9%
	African American or Black	123	12.3%
	Other	28	2.8%
	Missing	10	1.0%
Ethnicity	Hispanic	47	4.7%
	Non-Hispanic	948	94.8%
	Missing	5	0.5%
Marital Status	Married/ Living together	511	51.1%
	Single	479	47.9%
	Missing	10	1.0%
Children in the House	Yes	247	24.7%
	No	744	74.4%
	Missing	10	1.0%
Employment Status	In labor force	493	49.3%
	Not in labor force	492	49.2%
	Missing	15	1.5%
Income	Below $30,000	290	29.0%
	$30,000 to $59,999	324	32.4%
	Above $59,999	366	36.6%
	Missing	20	2.0%
Education	≤ High school graduate	374	37.4%
	Some college	315	31.5%
	≥ College graduate	309	30.9%
	Missing	2	0.2%
Place of Residence	Rural community	217	21.7%
	Small city or town, village	230	23.0%
	A suburb	414	41.4%
	Urban community	130	13.0%
	Missing	9	0.9%

3.1.1 Analysis Methods

First, the raw sample data were weighed to represent Michigan's demographic distribution. Weights for demographic variables were developed by the Institute for Public Policy and Social Research College of Social Science (IPPSR) who administered the 80th round of the SOSS. Findings were ultimately developed based upon (1) an analysis of the descriptive statistics from the weighted survey data and (2) a series of multinomial logistic regression models developed specific to each of the ten questions using the weighted data.

The data collected from the SOSS are categorical and are well suited for analysis using discrete outcome models such as the multinomial logistic (MNL) model. Within the context of this study, a linear-in-parameters function is specified to examine how Michigan residents' preference and opinion on walking and bicycling related objectives vary with respect to various socio-demographic characteristics (e.g., age, gender, race, etc.). This function is of the following form:

$$U_{ijt} = \alpha_j + X_{it}\beta_j + \varepsilon_{ij}, \qquad (1)$$

where α_j is a constant term that is specific to the residents' preferences category *j*, X_{it} is a vector of variables (e.g., age, gender, race, etc.) that are related to the preferences, β_j is a vector of estimable parameters, and ε_{ij} is an error term that is assumed to follow a generalized extreme value (GEV) type I distribution. In this setting, the probability of the residents' preferences category *j* is given by the following expression:

$$P_{ij} = \frac{exp(\alpha_j + X_{it}\beta_j)}{\sum_{k=1}^{J} exp(\alpha_k + X_{it}\beta_k)}, \qquad j = 1, 2, 3. \qquad (2)$$

Ten MNL models that correspond to the ten survey questions were used to analyze Michigan residents' walking and bicycling behaviors and preferences. It is important to note that response categories were aggregated as a part of the modeling process according to the aggregation scheme outlined in **Appendix 5.2**. While full model results are provided in **Appendix 5.3**, associated findings from the models are discussed in **Sections 3.1.2 – 3.1.8**.

3.1.2 General Behavioral Patterns (Questions 1 and 2)

Survey respondents were asked how often they traveled on foot (Question 1) and by bicycle (Question 2) for the purposes of (1) recreation or exercising, (2) going to a store, restaurant or other business, or (3) commuting to school. The distribution of responses within each of these three categories for walking is shown in **Figure 10** and bicycling in **Figure 11**.

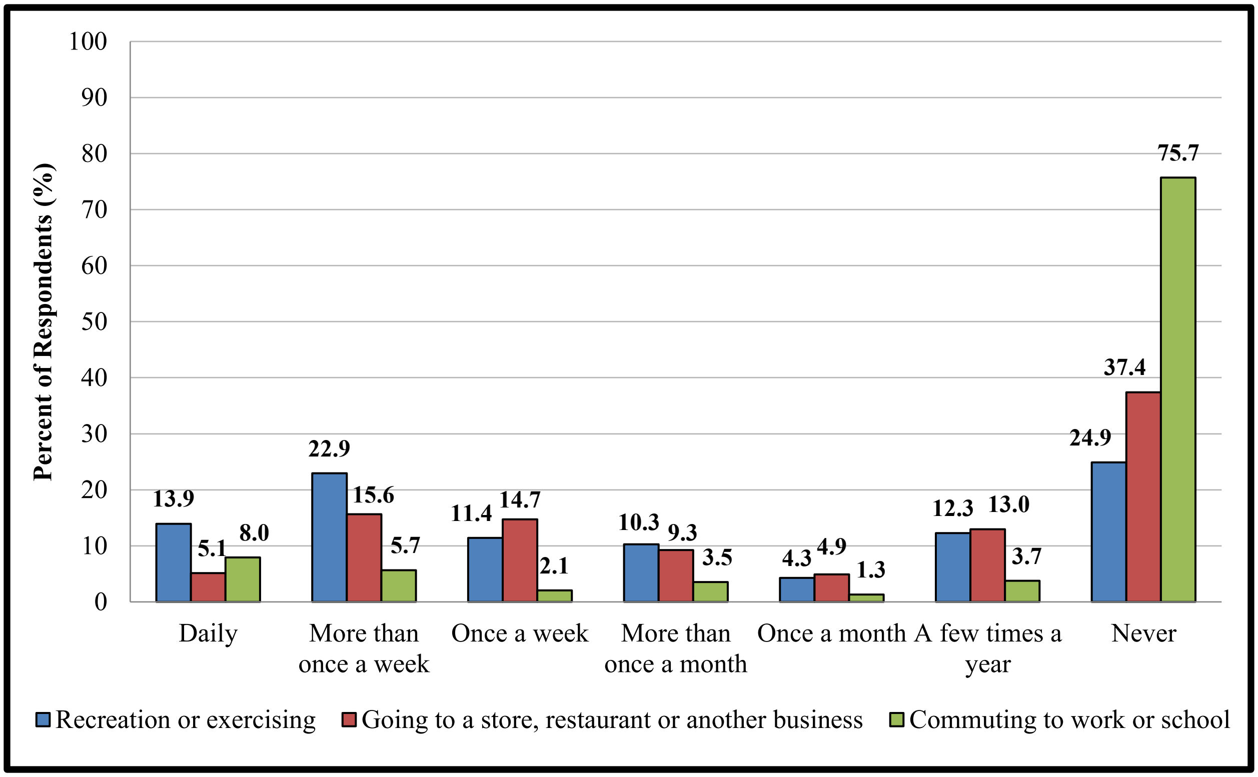


Figure 10. Frequency of Travel on Foot – Distribution of Responses

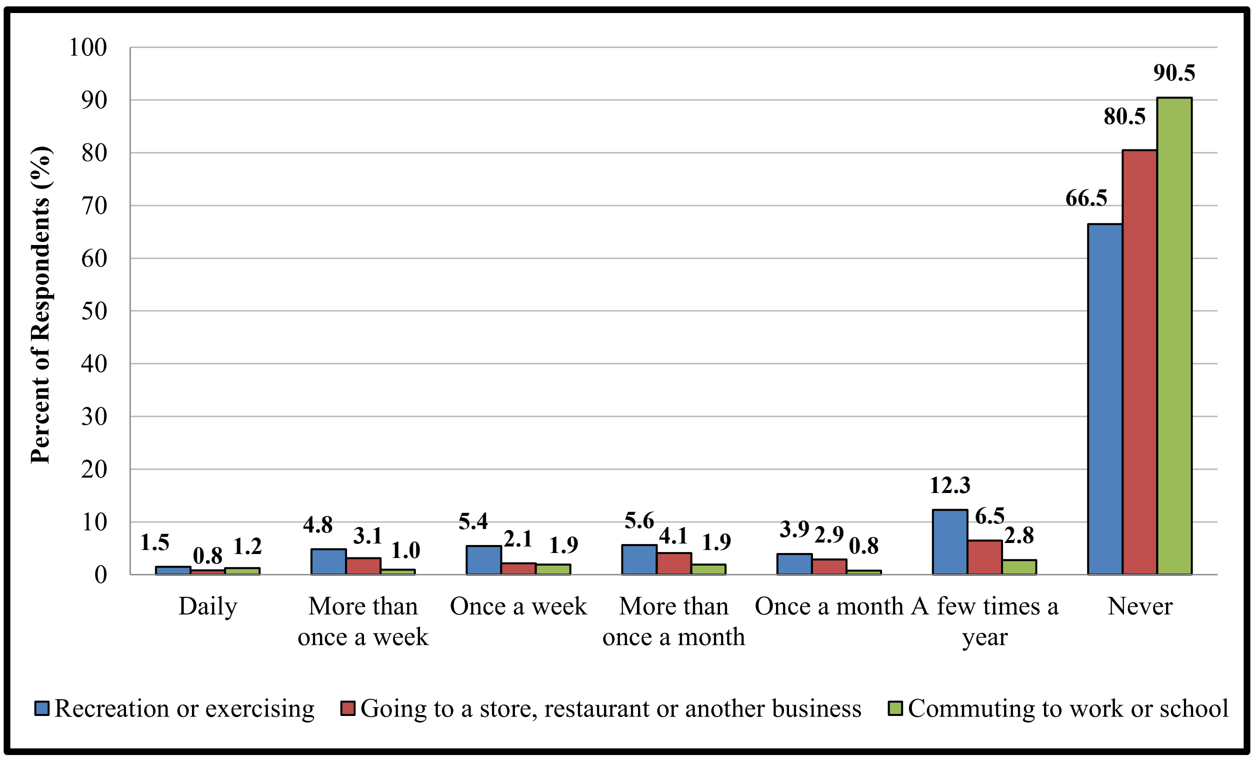


Figure 11. Frequency of Travel by Bicycle – Distribution of Responses

The frequency of travel on foot or by bicycle varied among respondents depending upon the trip purpose. Respondents tended walk or bicycle more often for recreation or exercising than for going to a business or commuting. Intuitively, residents tend to travel on foot for all trip purposes more often than by bicycle. Nearly half of respondents (48.2 percent) indicated that they walk for exercise or recreation at least once per week. Approximately 63 percent of residents travel on foot to a business at least a few times per year. The least common walking trip purpose was commuting, where approximately 75 percent of residents indicated that they never commute on foot. While approximately one third of Michigan residents noted that they travel by bicycle for recreation or exercise at least once a year, only approximately 20 percent responded that they travel by bicycle for trips to a business and only 10 percent for commuting trips. The results of the MNL models presented in **Appendix 5.3** suggest that a range of socio-economic factors potentially impact the general behavioral patterns for walking (**Table 14**) and bicycling (**Table 15**).

Table 14. Summary of Socio-Demographic Factors which Impact General Walking Behavior

Factor	Summary of Impact
Age	A one-year increase in age was associated with 2.3% and 4.0% increase in "almost never" walking for recreation and commuting, respectively.
Race	Whites or Caucasian respondents indicated they "almost never" walk to businesses more frequently than respondents who were African American.
Income	Respondents with household incomes under $30,000 were less likely to indicate that they "frequently" walk to businesses than those with household incomes above $59,999.
Education	Respondents whose education-level was "some college" were more likely to respond that they "almost never" walk for exercise or recreation compared to college graduates.

Table 15. Summary of Socio-Demographic Factors which Impact General Bicycling Behavior

Factor	Summary of Impact
Age	A one-year increase in age was associated with 2.0% and 4.7% increase in "almost never" bicycling for recreation and commuting, respectively.
Gender	Female residents were more likely to respond that they "almost never" bicycle for exercise or recreation compared to male residents.
Race	Whites or Caucasians were approximately 3.1 times more likely to respond that they "almost never" travel by bicycle to businesses compared to African Americans.
Marital Status	Married residents were less likely to respond that they "frequently" walk for exercise or recreation than single residents.
Children in the House	Those with no children in the house were approximately 1.9 times more likely to respond that they "almost never" bicycle for recreation.
Employment Status	Residents in the labor force were approximately 2.0 times more likely to respond that they bicycle "frequently" for recreation or exercise. They were also approximately 1.7 times more likely to "almost never" bicycle for recreation.

3.1.3 Satisfaction with Existing Pedestrian and Bicycle Facilities (Question 3)

Survey respondents were asked how satisfied they were with the current availability of pedestrian and bicycle facilities. These findings are summarized in **Figure 12**.

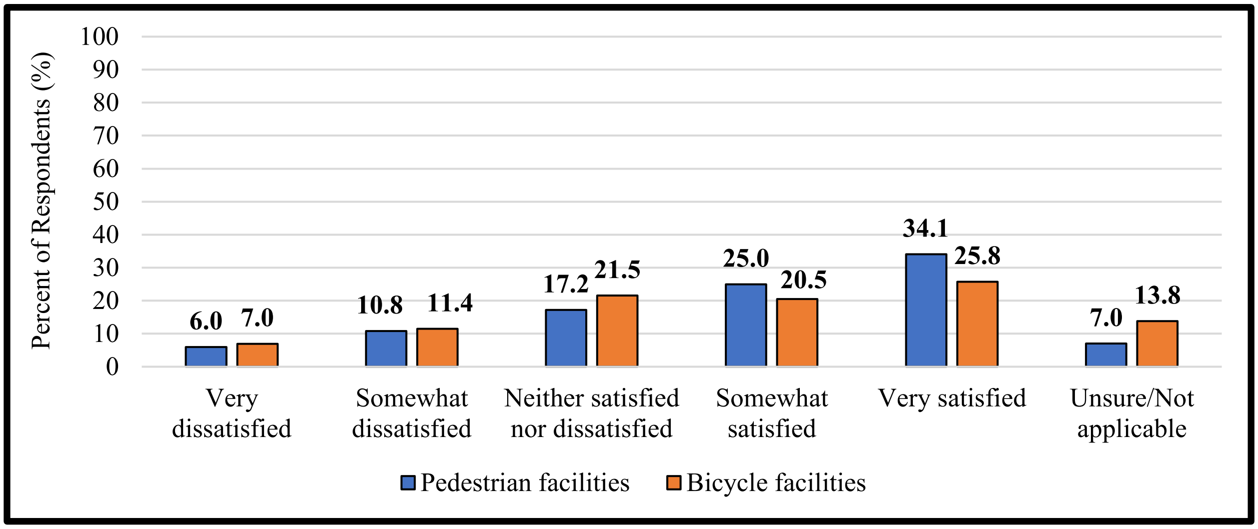


Figure 12. Satisfaction with Existing Pedestrian and Bicycle Facilities – Distribution of Responses

The level of satisfaction for both existing pedestrian and bicycle facilities was generally similar. A majority of residents (who did not answer unsure) responded that they were at least somewhat satisfied with the existing pedestrian and bicycle facilities. The results of the MNL models presented in **Appendix 5.3** suggest that a range of socio-economic factors potentially impact the satisfaction with existing facilities (**Table 16**).

Table 16. Summary of Socio-Demographic Factors which Impact Satisfaction with Existing Facilities

Factor	Summary of Impact
Age	Respondents were less likely to be dissatisfied with bicycle facilities as age increased.
Gender	Male residents tended to respond neither satisfied nor dissatisfied with pedestrian facilities more often than female residents.
Children in the House	Respondents without children in the house tended to be more dissatisfied with existing bicycling facilities.
Education	Respondents who did not attend college were less likely to express satisfaction with existing bicycle facilities than those with a college degree. They were also more likely to respond neither satisfied nor dissatisfied with pedestrian facilities
Recreation or Exercise	Respondents who frequently walk or bicycle for recreation tended to express more extreme opinions (both satisfied and dissatisfied) with respect to existing facilities.
Commuting Trips	Respondents who frequently commute by bicycle were less likely to express dissatisfaction with the existing bicycle facilities.

3.1.4 Safety Perception (Question 4)

Respondents were asked for their perception of safety while walking, bicycling, crossing the street on foot, and crossing the street on a bicycle. These findings are summarized in F**igure 13**.

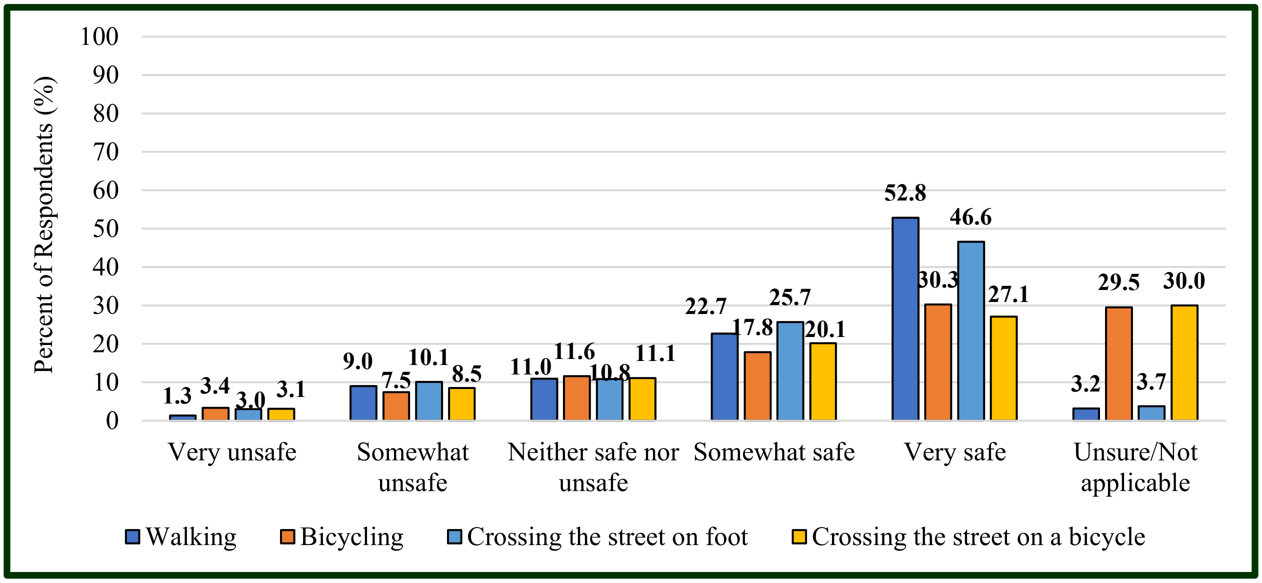


Figure 13. Current Safety Perception – Distribution of Responses

While most residents indicated that they felt at least somewhat safe while walking (75.5 percent), considerably fewer residents indicated that they felt at least somewhat safe while bicycling (48.1 percent). It is important to recognize that approximately 30 percent of residents responded either "Unsure" or "Not Applicable" to their perception of safety traveling by bicycle or crossing the street on a bicycle. The results of the MNL models presented in **Appendix 5.3** suggest that a range of socio-economic factors potentially impact the satisfaction with existing facilities (**Table 17**).

Table 17. Summary of Socio-Demographic Factors which Impact Current Safety Perception

Factor	Summary of Impact
Age	Residents were more likely to indicate that they felt safe walking or crossing the street on foot as age increased.
Race	Hispanic residents indicated that they felt less safe while walking compared to non-Hispanics.
Education	Residents who did not attend college tended to respond that they felt safe less often while bicycling or crossing the street (both by foot and by bicycle) than those with college degrees.
Place of Residence	Residents from rural and suburban communities tended to respond that they felt unsafe while walking or crossing the street less often than residents from urban communities.
Recreational Trips	Residents who walk or bicycle frequently for recreation or exercise were more likely to respond that they felt safe.
Service Trips	Residents who walk or bicycle at least occasionally to travel to a business tended to respond that they felt safe less often, particularly when crossing the street.
Commuting Trips	Residents who occasionally commute on foot tended to respond that they felt safe crossing the street more often than those who almost never commute.

3.1.5 Walking and Bicycling Intentions with Improved Conditions (Question 5)

Respondents were asked how their travel patterns would change if the pedestrian and bicycle facilities within their community were improved. These findings are summarized in **Figure 14**.

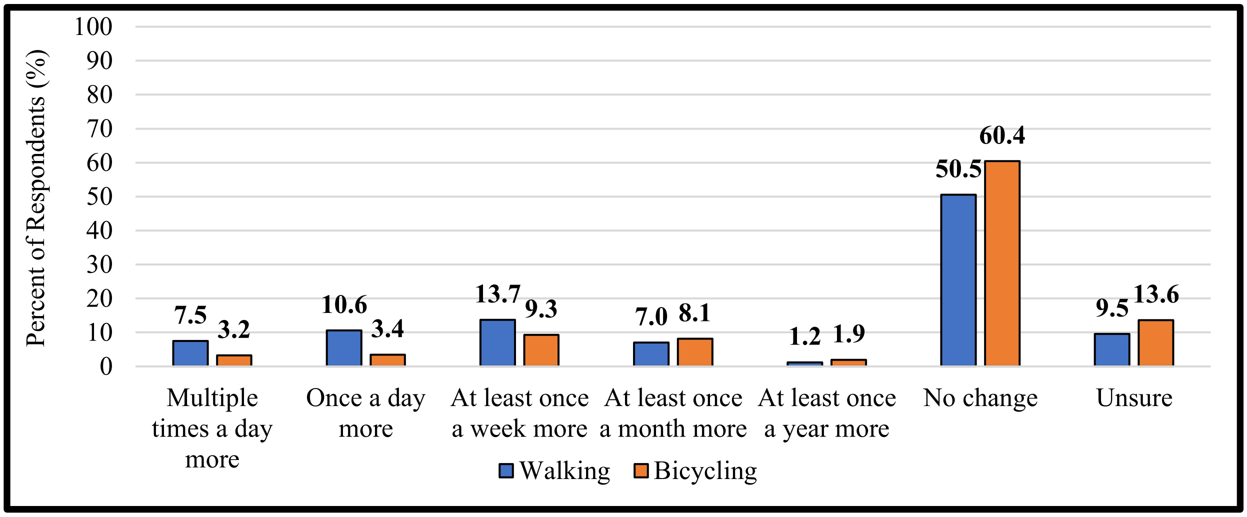


Figure 14. Walking and Bicycling Intentions with Improved Conditions – Distribution of Responses

While the majority of residents indicated that their travel patterns would not change if non-motorized facilities were improved, approximately 40 percent of respondents indicated they would walk more often, and 26 percent indicated they would bicycle more often. The results of the MNL models presented in **Appendix 5.3** suggest that a range of socio-economic factors potentially impact the travel intentions with improved conditions (**Table 18**).

Table 18. Summary of Socio-Demographic Factors which Impact Travel Intentions with Improved Conditions

Factor	Summary of Impact
Age	Residents were more likely to respond that they would not change their walking or bicycling behavior with improved facility conditions as their age increased.
Race	White or Caucasian residents were more likely to respond that they would not change their walking behavior with improved facility conditions than African American residents.
Place of Residence	Residents from small cities or towns were more likely to respond that they would increase bicycling trips with improved facility conditions than those from urban areas.
Recreational Trips	Residents who walk frequently for recreation were more likely to respond that they would increase walking trips with improved conditions than those who almost never walk. Residents who currently bicycle at least occasionally for recreation were less likely to indicate that they would not change their bicycling behavior.
Service Trips	Residents who bicycle frequently to businesses were much more likely to respond that they would increase bicycling trips with improved facility conditions than those who almost never travel by bicycle.
Commuting Trips	Residents who walk occasionally for commuting responded that they would not change the number of walking trips with improved facility conditions more often than those who almost never travel on foot.

3.1.6 Preferred Routes while Walking or Bicycling (Questions 6 and 7)

Survey respondents were asked when traveling on foot (Question 6) or by bicycle (Question 7) if they prefer a direct route compared to a longer route which is more safe or comfortable. These findings are summarized in **Figures 15 (walking) and 16 (bicycling)**.

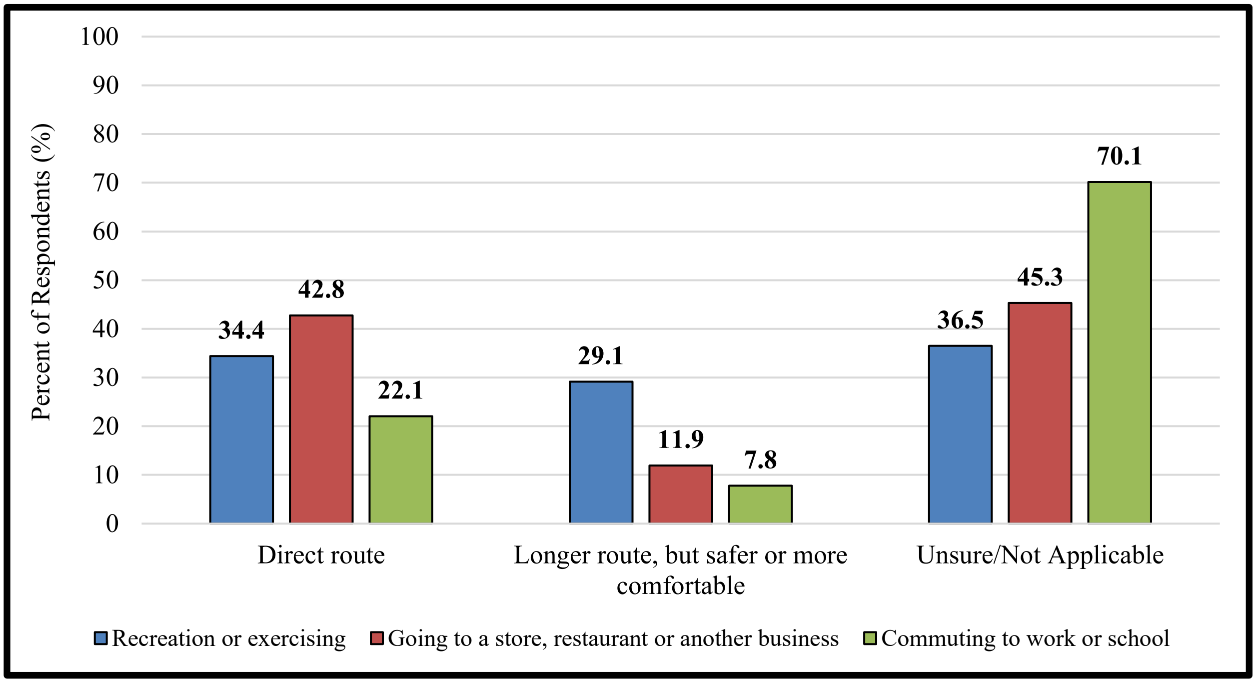


Figure 15. Preferred Routes on Foot – Distribution of Responses

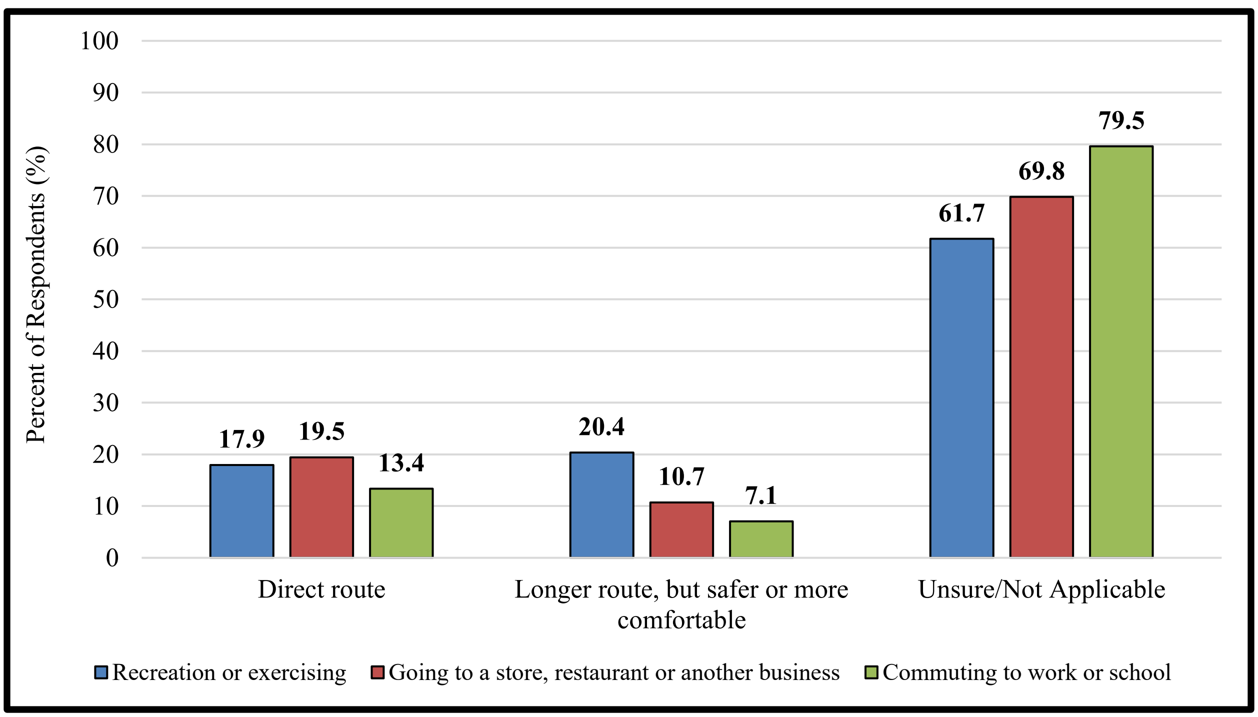


Figure 16. Preferred Routes by Bicycle – Distribution of Responses

While there a considerable number of unsure or not applicable responses to both the walking and bicycling questions, residents in Michigan generally prefer a more direct route when traveling on foot or by bicycle. Intuitively, a notable exception involves recreation or exercising by bicycle where more respondents indicated that they prefer a more comfortable route (20.4 percent) than a direct route (17.9 percent). The results of the MNL models presented in **Appendix 5.3** suggest that a range of socio-economic factors potentially impact route choice (**Table 19**).

Table 19. Summary of Socio-Demographic Factors which Impact Preferred Routes

Factor	Summary of Impact
Employment	Residents who are in the labor force responded more often that they prefer to take a direct route while commuting on foot. Similarly, residents who are in the labor force indicated that they prefer a more direct route while traveling to a business by bicycle.
Education	Residents without a college degree were more likely to respond that they prefer a direct route when traveling by bicycle for recreation.

3.1.7 Travel Behavior without Sidewalks (Questions 8)

Residents were asked where they typically position themselves when walking or bicycling along a route without sidewalks present. These findings are summarized in **Figure 17**.

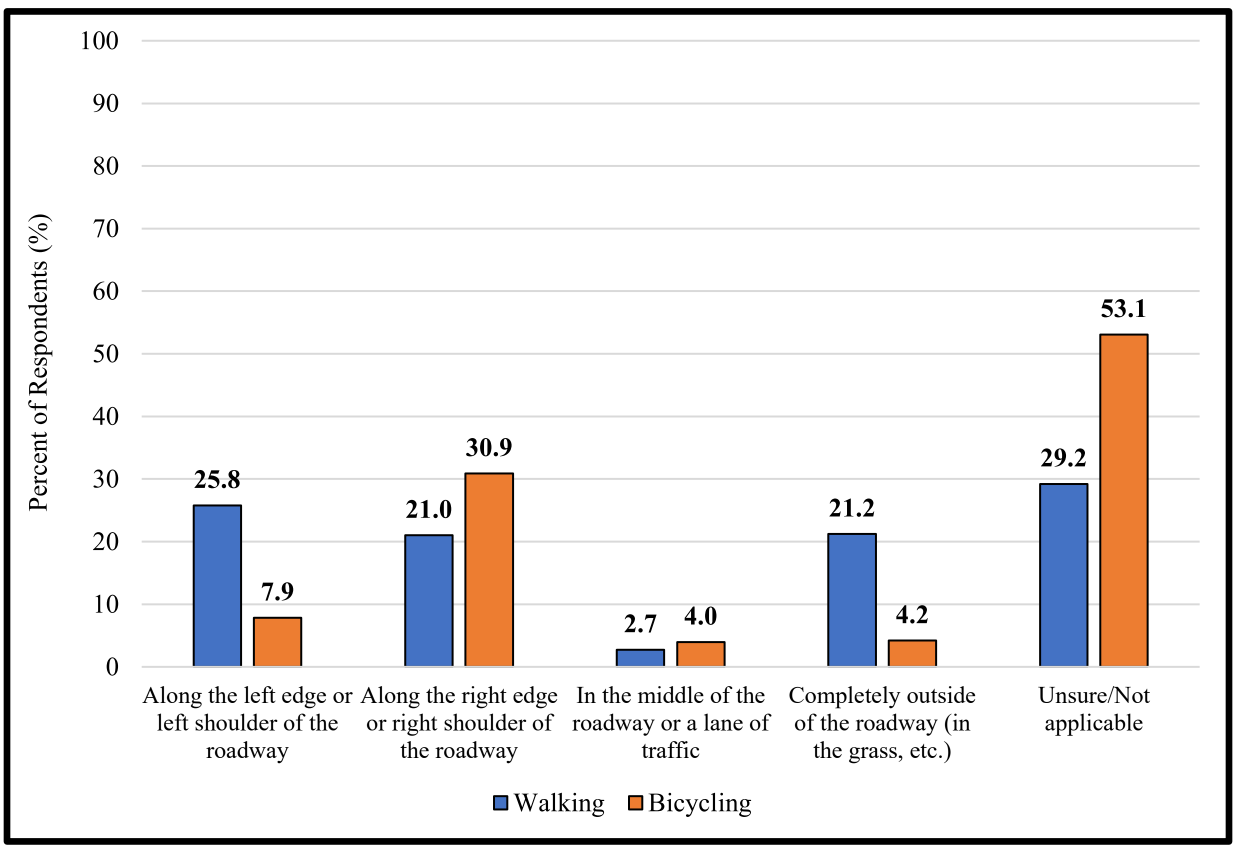


Figure 17. Positioning without Sidewalks – Distribution of Responses

Among respondents who did not answer "Unsure" or "Not Applicable", Michigan residents indicated that they most often travel along the left edge or left shoulder of the roadway when traveling along routes without sidewalks (25.8 percent), followed by completely outside the roadway (21.2 percent), and along the right edge or right shoulder (21.0 percent). Bicyclists tend to use the right edge or right shoulder of the roadway (30.9 percent). The results of the MNL models presented in **Appendix 5.3** suggest that a range of socio-economic factors potentially impact positioning without sidewalks (**Table 20**).

Table 20. Summary of Socio-Demographic Factors which Impact Positioning without Sidewalks

Factor	Summary of Impact
Age	Residents were more likely to respond that they would position themselves along the right side of the roadway while bicycling as their age increased.
Gender	Male residents were less likely to respond that they would walk completely outside of the roadway. Male residents were also more likely to respond that they would position themselves along the left side of the roadway while bicycling.
Education	Residents who have not attended college were less likely to indicate they would position themselves along the right side of the roadway while bicycling compared to residents with a college degree.
Place of Residence	Residents from small cities and towns were more likely to ride along the right side of the roadway or completely outside the roadway than residents from urban areas.
Recreational Trips	Residents who walk frequently for recreation were more likely to walk along the right side of the roadway or completely outside the roadway than those who almost never walk for recreation. Residents who occasionally travel by bicycle for recreation were more likely to ride completely outside the roadway than those who almost never travel by bicycle for recreation.
Commuting Trips	Residents who commute on foot or by bicycle were less likely to respond that they would ride in the center of the roadway.

3.1.8 COVID-19 Pandemic Impacts on Behavior (Questions 9 and 10)

Finally, two questions were provided to Michigan residents specific to the impacts of the COVID-19 pandemic on walking and bicycling travel behavior. Respondents were asked how often they had gone walking or bicycling during the COVID-19 pandemic compared to the same period last year. These findings are summarized in **Figure 18**.

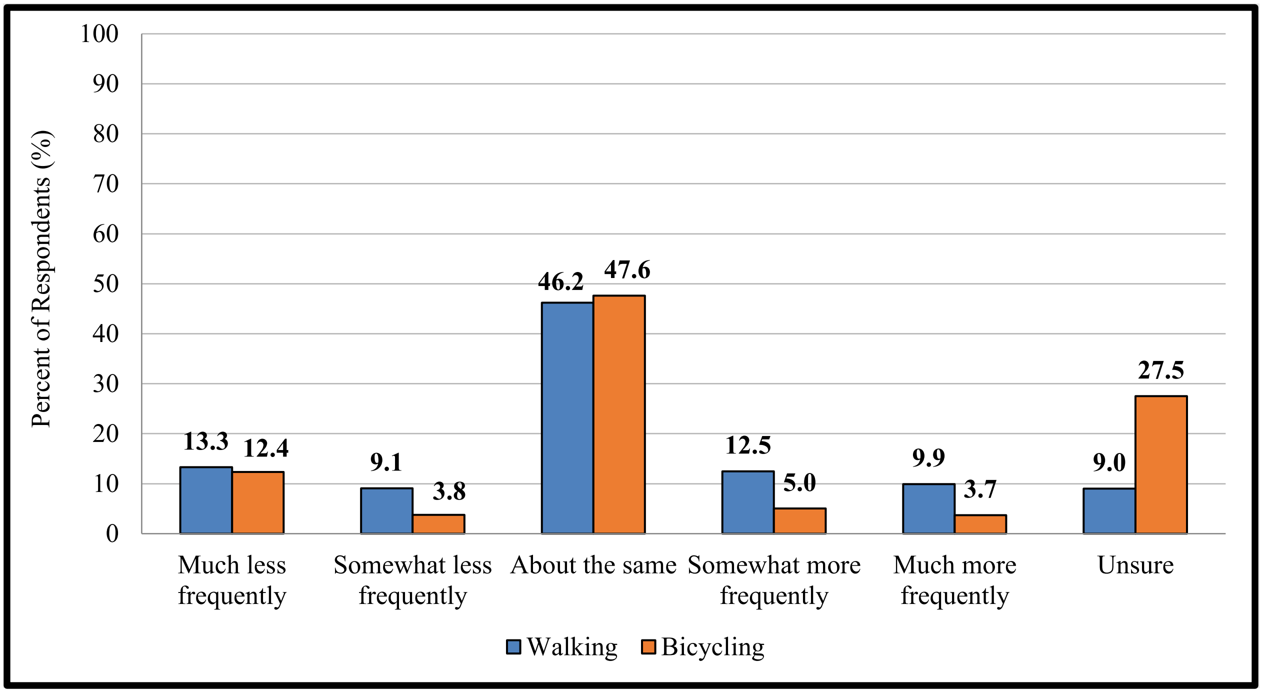


Figure 18. Travel Behavior COVID-19 Pandemic Compared to Year Prior – Distribution of Responses

Nearly half of Michigan residents indicated that they did not change their walking or bicycling behavior during the pandemic. The proportion of respondents who indicated that their walking trips were reduced (22.4 percent) was balanced with the proportion who indicated that their walking trips increased (22.4 percent). It is important to note that more respondents indicated that their bicycling trips decreased (16.2 percent) during the pandemic than increased (8.7). The results of the MNL models presented in **Appendix 5.3** suggest that a range of socio-economic factors potentially impact travel pattern changes related to the COVID-19 pandemic (**Table 21**).

Table 21. Summary of Socio-Demographic Factors which Impact

Factor	Summary of Impact
Age	Walking behavior tended to stay the same during the pandemic more often as the age of the respondent increased. Residents were less likely to indicate that their bicycling trips increased during pandemic as age increased.
Race	White or Caucasian residents were less likely to indicate that their bicycling behavior decreased during the pandemic than African American residents. Hispanic residents were more likely to indicate that their walking behavior increased or decreased compared to African American residents.
Income	Residents with income levels less than $60,000 were more likely to respond that their bicycling trips decreased during the pandemic than residents with incomes over $60,000.
Education	Residents who did not attend college were less likely to indicate that their walking trips increased during the pandemic compared to residents with a college degree.

Factor	Summary of Impact
Recreational Trips	Residents who walk frequently for recreation were more likely to respond that they increased walking during the pandemic than those who almost never walked. Residents who walk occasionally for recreation were less likely to respond that their behavior did not change during the pandemic compared to those who almost never walked. With respect to bicycling, residents who traveled frequently by bicycle for recreation were less likely to indicate that their behavior did not change during the pandemic than those who almost never bicycle for recreation. Residents who occasionally bicycle for recreation were more likely to indicate that they increased bicycling trips during the pandemic than those who almost never bicycle.
Service Trips	Residents who walk frequently to businesses were more likely to say that their walking trips decreased during the pandemic than those who almost never walk. Respondents who walked occasionally to businesses were more likely to say their walking trips increased during the pandemic compared to those who almost never walk. Respondents who bicycle frequently to services were less likely to indicate that their bicycling trips decreased during the pandemic than those who almost never travel by bicycle to businesses.
Commuting Trips	Respondents who frequently commute on foot were less likely to indicate that their bicycling trips increased compared to those who almost never commute on foot.

Respondents were then asked if they intended to change their walking and bicycling travel behavior in the future. These findings are summarized in **Figure 19**.

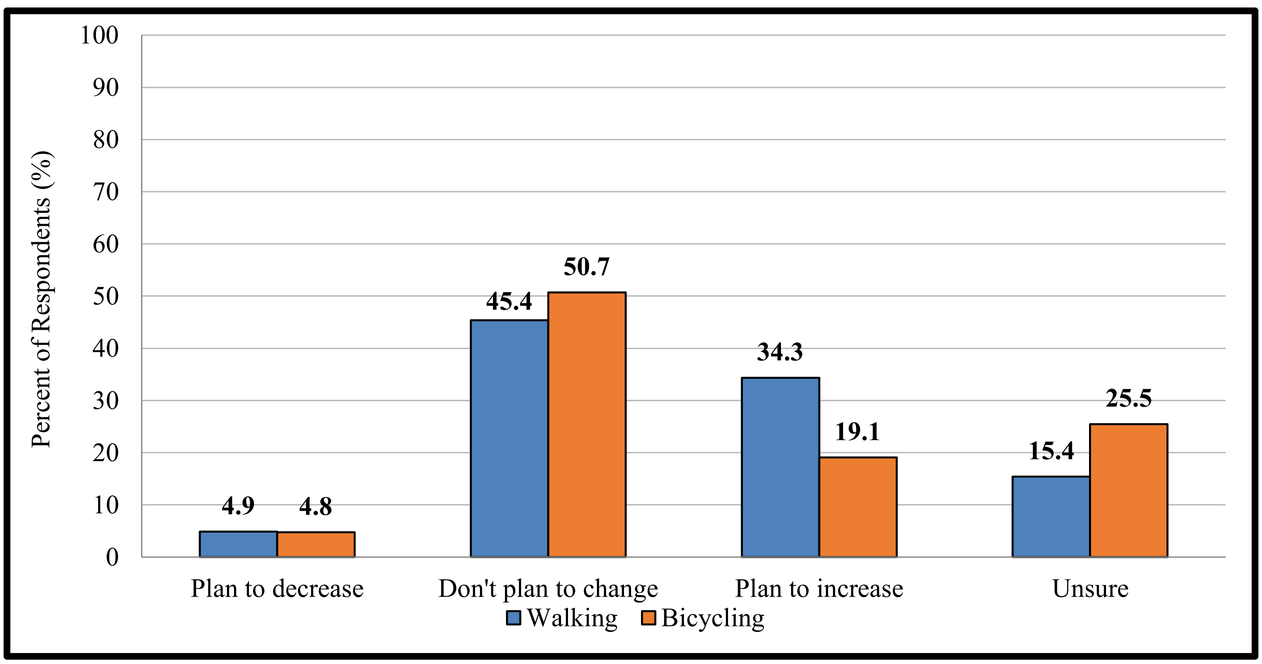


Figure 19. Intentions for Future Walking and Bicycling Behavior – Distribution of Responses

Approximately half of respondents indicated that they would not change their walking (45.4 percent) or bicycling (50.7 percent) behavior in the future. However, it is notable that considerably more residents indicated that they would increase their walking and bicycling trips in the future than those that plan to decrease trips. The results of the MNL models presented in **Appendix 5.3** suggest that a range of socio-economic factors potentially impact intentions for future walking and bicycling behavior (**Table 22**).

Table 22. Summary of Socio-Demographic Factors which Impact Intentions for Future Behavior

Factor	Summary of Impact
Age	As the age of residents increased, they were less likely to indicate that they planned to increase walking trips in the future. Additionally, respondents were less likely to indicate that their bicycling behavior would change in the future as age increased.
Education	Respondents who completed "some college" were less likely to indicate they planned to increase their walking trips in the future than those with a college degree. Respondents without a college degree were less likely to indicate that their bicycling trips would increase in the future.
COVID-19 Impacts	Respondents who noted that their walking trips decreased during the pandemic were less likely to indicate they planned to change their walking frequency in the future than those who increased walking trips during the pandemic. Respondents who did not change their walking behavior during the pandemic were less likely to indicate they intended to increase their walking trips in the future compared to those who increased walking trips during the pandemic. Residents who decreased their frequency of bicycling during the pandemic were more likely to indicate that their trips would increase in the future than those who indicated they increased their frequency of bicycling during the pandemic.

3.2 Focus Groups with Michigan Pedestrian and Bicycle Advocacy Groups

In May and June of 2021, the MSU research team conducted online Zoom focus groups targeting several key demographics of Michigan non-motorized road users. These included:

- Members of the American Association of Retired Persons (AARP) of Michigan
- Representatives from Disability Advocacy Groups of Michigan, and
- Representatives from Bicycling and Trails Advocacy Groups of Michigan.

3.2.1 Summary of AARP Focus Group

Members of the AARP were separated into two groups based on their preference for walking or bicycling. Ultimately, the focus group included five participants discussing walking-related issues and three participants discussing bicycle-related issues. Each of these groups were presented with visual examples of walking and biking infrastructure and asked to discuss their perceptions of each treatment. The MSU presenters provided images, accompanied with descriptions, of several physical pedestrian infrastructure treatments, and then engaged in open ended discussion with the members of the focus group. Participants were also asked for general comments and appropriate treatments for specific design scenarios. **Table 23** provides a summary of comments from focus group participants related to specific pedestrian treatments.

Table 23. Summary of AARP Focus Group Pedestrian Treatment Comments

Treatment	Summary of Comments
Crosswalk Markings	Participants preferred high-visibility crosswalk markings (such as continental or zebra designs) as opposed to conventional transverse designs. Some participants also preferred the zebra style markings over continental as they thought this design was more visible to drivers.
Curb Extensions	Curb extensions were seen as highly desirable as they enabled seniors to establish their presence within crossings, increasing confidence. Participants noted that other seniors within their community had noted an appreciation for curb extensions.
R1-6 Signs and Gateway Treatment	The response to in-street signs was generally positive among participants, noting that they felt it helps establish the crossing for both motorists and pedestrians. One participant noted that while this treatment wasn't present within their community, they have come across in-street signs in other communities and they were encouraged to slow down.
Pedestrian Refuge Islands	While several participants noted that they felt protected by refuge islands, one participant noted that they did not feel comfortable with the vertical protection offered by the curb.
Rectangular Rapid Flashing Beacons (RRFBs)	Participants felt that RRFBs were insufficient in stopping vehicle traffic at pedestrian crossings, preferring the nature of PHBs which were placed above the lane. Participants also noted that the flashing "wig-wag" pattern was jarring. However, it is worth noting that participants preferred the RRFB for a low-speed school crossing in combination with other treatments (such as curb extensions or in-street signs).
Pedestrian Hybrid Beacons (PHBs)	Participants expressed a preference for PHBs over RRFBs due to the nature of the device being located over the travel lane. Participants preferred PHBs for midblock crossings involving higher travel speeds.
Pedestrian Traffic Signal	Participants preferred a conventional traffic signal for midblock crossings located along high-volume routes.

Table 24 provides a summary of comments from focus group participants related to specific bicycle treatments. It is critical to note that only men with cycling experience participated in this focus group. The views expressed may not fully represent the general population, particularly women or inexperienced cyclists.

Table 24. Summary of AARP Focus Group Bicycle Treatment Comments

Treatment	Summary of Comments
Shared Lane Markings	While some participants noted that they might be comfortable with "sharrows" in relatively low speed environments (35 miles per hour or less), generally participants were uncomfortable with this treatment and expressed a preference for their own space within the roadway. Participants noted that the intent or messaging of this treatment was confusing as a driver.
Conventional Bicycle Lanes	While participants noted that they would be comfortable in a conventional bicycle lane, upkeep was noted as a potential concern (such as glass or other debris). Participants also noted concerns related to doors from parked cars.
Buffered Bicycle Lanes	Participants expressed an enthusiastic preference for buffered bicycle lanes over conventional bicycle lanes and would be comfortable within these facilities in a variety of environments (including higher speed trunkline highways). Participants noted an appreciation for bicycle design approaches from European cities such as Amsterdam.
Separated Bicycle Lanes	Participants noted that separated facilities are preferred where space permits. Additionally, participants expressed a preference for one-way facilities as opposed to two-way facilities.
Bicycle Boxes	While some participants noted being uncomfortable with vehicles being located behind them, others expressed positive feedback related to the treatment providing a designated space as well as helping to establish their right to be on the road.
Two-Stage Turn Boxes	Participants noted that the learning curve related to two-stage turn boxes could potentially be relatively steep. Participants expressed a desire for these devices to be included on driving exams. Participants felt that these treatments were most appropriate for downtown areas.
Green Intersection Crossing Markings	Participants expressed a preference for green pavement markings to remind all road users of the designated space for bicyclists.
Bicycle Signals	Participants felt that bicycle signals helped to establish to cyclists the appropriate time to cross intersections without ambiguity.

Treatment	Summary of Comments
Bicycle Wayfinding	Participants observed that they typically see wayfinding mostly around trails but would like to see additional wayfinding included elsewhere. Participants also noted that they would like to see the relative level of comfort signed along designated bicycle routes.

A variety of **general comments** were also recorded during the AARP focus group, including:

- A preference for non-motorized road users to receive additional priority in the planning and design process.
- Ensure that pavement markings are within their intended service life and can be easily seen by all road users.
- One participant noted concerns related to pedestrians crossing at roundabouts.
- Participants felt it was important to increase connectivity with trail heads, either via walking paths or public transit.
- Cyclists strongly supported any type of design (bicycle lanes, bicycle boxes, or two-stage turn boxes) that reinforced their "right to the road" by providing space clearly marked for bicycles.
- Cyclists noted that they would like to be able to have longer rides or rides between cities better accommodated by the bicycle network, such as Williamston to Lansing.
- Cyclists also noted that additional promotion and expansion of the bicycle network across the state would be beneficial, such as county-specific maps which identify priority routes.

3.2.2 Summary of Disability Advocacy Groups of Michigan Focus Group

Three members from disability advocacy groups participated in this focus group, including representatives from:

- Disability Network of Northern Michigan (Traverse City/ Alpena)
- Disability Network of Southwestern Michigan (Benton Harbor/Kalamazoo)
- Graham Rehabilitation Services (Greater Grand Rapids)

The focus group was structured as an open conversation with questions offered by the MSU presenters to stimulate the conversation. While participants in the group were members of organizations that represented a wide breadth of disabilities, the greatest concentration of discussion focused on those with hearing and sight impairments. Participants were asked open-ended questions about present challenges, positive and negative examples of current practices, and improvements they would like to see implemented. The following are the questions asked of the participants. Summarized responses, organized by topic, are provided.

What are some of the primary challenges faced by people with disabilities in Michigan?

In situations with **shared use paths or sidepaths**, participants noted that sharp corners with low visibility can create potential conflicts. Additionally, participants emphasized that environments shared by pedestrian and bicyclists include clear delineation as sight-impaired persons may find themselves in the wrong portion of the path. These environments also tend to lack braille on wayfinding signage.

In **downtown areas**, participants recognized a potential conflict between visually-impaired persons crossing at intersections with bicycle lanes as they may not realize the presence of the bicycle lane. Participants noted that audio signals may not be loud enough to be heard which potentially impacts road users with both hearing and sight difficulty. There was also a preference for high-visibility pavement markings which include transverse lines which track from one pedestrian signal to another. Participants also noted the importance of simple designs which minimize visual clutter, including landscaping around intersections.

Participants also noted a range of **challenging roadway settings** for those with accessibility needs, including:

- Separated bicycle lanes were recognized as a potential challenge given that they can pose difficulties for visually-impaired pedestrians at crossings unless they are properly delineated.
- Crossings which include pedestrian islands can also represent a potential concern for visually-impaired persons to err in their crossing by going into the parallel street as the nose of the island gets closer to the parallel street.
- Sidewalk gaps can result in pushing these users into the roadway.
- Roundabout designs often present potential challenges to users with accessibility needs.
- Scooters used as a part of micromobility systems are often left within the sidewalk or accessible ramps.

Participants mentioned several design considerations related to **accessible pedestrian pushbuttons**, including:

- It is important to ensure that the face plate of the button be positioned parallel with the walkway as touching the face plate can offer additional guidance.
    - Optimal designs use the orientation of the pushbutton to guide the pedestrian across the roadway.
- Accessible pushbuttons should be located within reach of the paved sidewalk.
- Audio output that adjusts to ambient noise can be a helpful inclusion.

Describe characteristics you are <u>most satisfied</u> with in terms of serving those with disabilities.

Participants discussed a variety of design characteristics related to **intersections with bicycle lanes** which they felt could help accommodate road users with accessibility needs, including:

- The of contrast (such as green pavement markings) represents a positive practice, although some concerns were stated related to the current green markings providing sufficient contrast for visually-impaired pedestrians.
- The vertical profile of the bicycle lane relative to the travel lane can also be used to provide additional guidance to visually-impaired pedestrians.
- Ultimately effective designs use color, profile, and tactile response to emphasize elements of the crossing to the pedestrian.

Participants identified **best practices for sidewalk maintenance** that they felt could help accommodate road users with accessibility needs, including:

- Ensuring that sidewalks are level and have not been misaligned by tree roots, drainage, or other issues.
- Conducting diligent winter maintenance to clear the entire pathway.
- Removing ice dams which are left by passing snowplows at crossings.

Participants discussed that **well-designed street furniture** provides for an accessible path that is clear for the length of the street. Participants noted that the design of street furniture can lack considerations for accessibility.

If you could choose one or <u>two improvements</u> that could be implemented throughout Michigan to better serve the needs of people with disabilities, what would those improvements be?

Participants noted a broad range of improvements which could help to accommodate users with accessibility needs, including:

- Ensuring that all paths within the transportation network are at least five feet wide.
- Ensuring that ramps are aligned at intersections and expanding corner radii to the extent possible so that crossings are perpendicular to the crossing ramps.
- Ensuring that pushbuttons are physically accessible from the pavement.
- Equipping pushbuttons to provide additional information if held down for an extended period, such as crossing design (e.g., the number of lanes) or wayfinding information.
- Ensuring design consistency throughout the transportation network.

How do your experiences with walking facilities outside of Michigan in general compare with those within Michigan in terms of meeting the needs of persons with disabilities?

Participants noted that bicycles in Europe are equipped with chimes to inform pedestrians that they are about to pass, helping to accommodate users with accessibility needs in shared environments. Participants also noted innovative designs employed in downtown areas outside of Michigan which separate various modes of transportation.

What are the additional barriers for people with disabilities? Any suggestions for removing these barriers and promoting bicycling for people with disabilities?

Finally, participants discussed a variety of additional barriers specific to road users with accessibility needs, including:

- Three-wheeled bicycles are difficult to operate along roadways without a dedicated bicycle facility given that sidewalks are often not wide enough to accommodate them.
- Shared environments for bicycles and pedestrians could include passing zones at regular intervals.
- ADA standards should be considered the minimum and designs that help to further accommodate those with accessibility needs can go beyond these standards.
- Participants noted “unmet demand” for bicycling in the disabled community and if accessibility were improved that trips would likely increase.
- Participants also noted that it is important to ensure that online trail information should include accessibility details.

3.2.3 Summary of Bicycle and Trails Advocacy Groups Focus Group

Five members from Bike and Trails Advocacy Groups participated in this focus group, including representatives from:

- Detroit Greenways Coalition
- Bike Friendly Kalamazoo
- Washtenaw Walking and Biking Coalition (two representatives)
- Iron Ore Heritage Recreation Area (Marquette)

The focus group was structured as an open conversation with questions offered by the MSU presenters to stimulate the conversation. The following are the questions asked of the participants. Summarized responses, organized by topic, are provided.

What are some of the primary challenges faced by bicyclists in Michigan?

Participants noted a wide range of potential challenges bicyclists face along the transportation network in Michigan, including:

- There is currently a lack of trails which accommodate bicyclists in the Upper Peninsula.
- The lack of paved shoulders in rural areas represents a potential barrier for bicyclists.
- Participants noted a lack of existing connectivity for bicyclists in urban and suburban areas of the state.
- Participants noted that while some local agencies pursue innovative designs which help to further accommodate bicyclists, other local agencies have had less buy-in.
- State speed limit laws have represented a constraint for local agencies to implement certain design treatments for bicyclists.
- Specific bicycle-focused treatments may cater towards more experienced cyclists and may not help to encourage cyclists of all levels to ride.
- Despite the prevalence of recreational trails across the state, participants noted that there is a lack of commuter trails which connect bicyclists to central business districts or other developed areas. Minneapolis, Minnesota and Madison, Wisconsin were provided as examples which have implemented comfortable routes for these purposes.

Describe the characteristics of bicycling infrastructure aspects or design characteristics that you are most satisfied with?

Participants identified bicycle infrastructure that is designed for all ages and abilities, not just experienced riders as a desirable characteristic. Participants also noted that designs developed using NACTO guidance documents possess characteristics which help to further accommodate bicyclists.

What one or two improvements would you implement throughout Michigan?

Participants noted a broad range of improvements which could help to accommodate cyclists, including:

- Paved shoulders along rural routes with a minimum width of five feet.
- Reductions in operating speeds and posted speed limits in urban areas, including appropriate traffic calming treatments.
- Further implementing road diets where five-lane designs are not necessary to accommodate vehicle level of service.
- The use of buffered or separated bicycle lanes where space permits.
- Minimum widths of ten feet for off-roadway paths and trails.

Participants also discussed a range of **high-level cultural or systemic concerns** which limit the expansion of bicycle-focused improvements to the transportation network, including:

- Advertisements for "powerful" or "fast" motor vehicles which helps to further a culture of motor vehicle dominance of the transportation network.
- Social media posts which support a negative perspective towards the cycling community.
- Existing speed limit laws and the culture within some agencies to increase the posted speed limit while others work to reduce speed to accommodate the use of specific bicycle-focused treatments.
- Bicycle planning across jurisdictional boundaries can be an issue when attempting to develop connections or pathways which span multiple communities.

Finally, participants discussed specific **bicycle-focused design treatments**, including:

- While participants noted that "sharrows" serve as an important communication tool to remind drivers that cyclists will be sharing the roadway, it is important to they do not increase potential conflicts between cyclists and parked vehicles opening doors.
- While participants expressed a favorable view of bicycle boxes, it was noted that it is important to ensure that these areas are large enough to comfortably accommodate bicyclists. Installations in Ferndale, Michigan were noted as an example of a successful implementation.
- Participants expressed a favorable view of intersection bicycle crossing markings.

4.0 IDENTIFICATION OF POTENTIAL UPDATES TO MDOT'S PLANNING AND DESIGN MATERIALS

Given the review of current practices in non-motorized planning and design (**Section 2.0**) as well as the additional context developed from collecting information from stakeholders in Michigan (**Section 3.0**), a series of potential updates to MDOT's materials were identified. This first included a review of similar work conducted as a part of MDOT's *Multi Modal Development and Delivery (M2D2) Work Plan* [*8*] (**Section 4.1**) as well as a comparison of generalized activities from the USDOT's *Pedestrian Safety Action Plan* [*32*] (**Section 4.2**). Ultimately, 12 documents from the list of 50 items included in **Appendix 2** were reviewed to identify elements which could be updated to reflect current practices with respect to non-motorized planning and design (**Section 4.3**).

4.1 2015 MDOT M2D2 Work Plan

In 2015, MDOT and Smart Growth America developed the *Multi Modal Development and Delivery (M2D2) Work Plan* [*8*]. A key purpose of M2D2 has been to provide education and training for state personnel and contractors on MDOT's existing policies on non-motorized transportation. Additionally, part of the scope of M2D2 was also to identify which processes or documents need to be revised or created. The *M2D2 Work Plan* first identified a list of materials which comprise MDOT's planning and design processes. The *Work Plan* also provides specific recommendations for 11 of these processes or documents, summarized in **Appendix 6.1**. It should be noted that most documents, although revised, did not fully integrate the recommended changes or introduced only partial changes. These findings were used to inform both the identification of relevant MDOT documents as well as the subsequent review of these documents.

4.2 Generalized Activities from USDOT *Pedestrian Safety Action Plan*

The USDOT published the *Pedestrian Safety Action Plan* in December 2020 which included an overview of pedestrian safety nationwide as well as stakeholder suggestions towards the goal of reducing pedestrian fatalities and serious injuries [*32*]. The plan ultimately provides a series of recently completed activities in addition to activities that are currently underway to achieve this goal. While many of these activities are specific to the national system, others could be generalized to consider at the state-level. Each activity from the action plan was reviewed to develop a list of generalized activities which could be considered at the state-level. These generalized activities are summarized in **Appendix 6.2**, including which activities are related to either MDOT documents or processes. A summary of the current status at the state-level is also provided, or a recommendation for potential implementation if the activity has not been previously considered.

4.3 Review of 12 Selected MDOT Documents

After the comprehensive list of MDOT documents for potential review was developed (summarized in **Appendix 2**), the MSU research team worked in consultation with the RAP to **select 12 MDOT documents** for detailed review. This involved reviewing each document in detail for elements which could be revised or added to help explicitly consider the needs of non-motorized road users within the agency's planning and design processes. This review was informed and supported by the findings obtained from several prior project tasks or other resources, including:

- Findings from the 2015 M2D2 *Work Plan* [*8*]
- The review of current non-motorized planning and design practices (**Section 2.0**)
- Information from obtained from non-motorized stakeholders in Michigan (**Section 3.0**)

For each element identified via the review process, the MSU team provided a comment to identify the concept of interest and a specific recommendation to improve the element. **Table 25** provides a summary of the review process for all 12 selected documents. Full details of each comment and recommendation for all 12 selected documents can be found in **Appendices 6.3-6.14.**

Table 25. Summary of the MSU Review of 12 Selected MDOT Documents

MDOT Document	Summary of Recommendations
Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways	MDOT's crosswalk guidance document was updated in 2020 as a part of an effort led by MDOT staff. The MSU research team provided a series of comments intended to offer additional contextual information to readers as well as update the technical content. The 2020 update can be found on MDOT's *Traffic and Safety/Standards and Special Details* webpage [*33*].
Best Design Practices for Walking and Bicycling in Michigan	The MSU team completed a comprehensive update to this document initially developed as a part of a prior research project conducted in 2012. The overall structure remains the same, however, the document has been updated to reflect new research and other publications since the development of the original iteration. There are also additional practices which have been added which were not widely used when the document was first developed. A copy of this document is provided in **Appendix 7** and is detailed further in **Section 5.1**.
Road Design Manual	The research team provided detailed comments and recommendations throughout the manual. In general, these recommendations are intended to provide an increased focus on the consideration of pedestrians and bicyclists as a part of the agency's design process. Additionally, recommendations are made to incorporate pedestrian- and bicycle-specific design treatments within the manual's guidance.
Bridge Design Manual	The research team has provided comments and recommendations to improve multimodal considerations within the manual. Given the context of the bridge manual which has a significant amount of content which is not related to pedestrian and bicycle design, there are comparatively fewer comments on this document than the others reviewed by the MSU research team.

MDOT Document	Summary of Recommendations
Project Scoping Manual	The research team provided detailed comments and recommendations throughout the manual. In general, these recommendations are intended to provide an increased focus on the consideration of pedestrians and bicyclists as a part of the agency's project development process.
Bus Stop and Shelter Guide	The research team has provided comments and recommendations to improve multimodal considerations within the guide. In general, the comments suggest expanding the document to provide additional coverage of key concepts.
Traffic and Safety Note 207C: *Guidelines for Pedestrian Push Button Use & Location*	The research team provided comments to improve multimodal considerations within the content, suggested additions to the expand the content related to the "use" of push buttons, as well as a recommendation to include the content in MDOT's *Electronic Traffic Control Device Guidelines*.
Local Agency Programs Guidelines for Geometrics on Local Agency Projects	The research team has provided comments and recommendations to improve multimodal considerations within the guide. In general, the comments suggest expanding the document to provide additional coverage of key concepts.
Roundabout Guidance Document	The research team has provided comments and recommendations to improve multimodal considerations within the guide. Given that this document was developed prior to the publication of the second edition of the national roundabout guide (NCHRP Report 672 [*34*]), many of the comments refer to updating the content to include pedestrian and bicycle concepts which were included in NCHRP Report 672 [*34*].
Guidelines for Traffic Safety Planning in School Areas	The research team has provided comments and recommendations to improve multimodal considerations within the guide. Given that this document was developed based upon ITE guidance from the 1980's, the comments focus on identifying opportunities to update the content. The research team also recommended combining this content with MDOT's *School Area Traffic Control Guidelines*.
School Area Traffic Control Guidelines	The research team has provided comments and recommendations to improve multimodal considerations within the guide. In general, the comments suggest expanding the document to provide additional coverage of key concepts. The research team also recommended combining this content with MDOT's *Guidelines for Traffic Safety Planning in School Areas*.
Sight Distance Guidelines	Given that this document does not currently include content specific to pedestrian and bicycle considerations, the comments identify general opportunities to incorporate new content specific to non-motorized road users. Specifically, there may be opportunities to include content from the American Association of State Highway and Transportation Officials' (AASHTO) pedestrian and bicycle guidance documents.

5.0 DEVELOPMENT OF MATERIALS TO PROMOTE PEDESTRIAN AND BICYCLE INNOVATIONS

Materials were also developed in consultation with the MDOT panel to help disseminate guidance to encourage the use of pedestrian and bicycle innovations. This included an update to MDOT's *Best Design Practices for Walking and Bicycling in Michigan* [*35*] (**Section 5.1**) and the development of a new document entitled *Tools for the Planning and Design of Pedestrian Crossing Enhancements* (**Section 5.2**).

5.1 Update of MDOT's *Best Design Practices for Walking and Bicycling in Michigan*

A comprehensive update of MDOT's *Best Design Practices for Walking and Bicycling in Michigan* [*35*] was completed to reflect new research and other publications since the development of the original iteration in 2012. There are also additional practices which have been added to the document which were not widely used when the document was first developed. A copy of the revised document is provided in **Appendix 7** and full details on elements modified by the MSU team are summarized in **Appendix 6.4**.

The document summarizes best design practices with respect to engineering improvements which can improve both safety and mobility for pedestrians and bicyclists. The guidance is intended to serve as a toolbox of potential treatments which can be considered by practitioners based upon MDOT's research, resources developed at the federal-level, as well as best practices identified from other state and local agencies. It is important to note that the guidance included in this resource is consistent with both the *Michigan Manual on Uniform Traffic Control Devices* (MMUTCD) [*36*] and relevant interim approvals published by the Federal Highway Administration (FHWA). Specific design practices may not be included in the MUTCD and require a request to experiment from the FHWA.

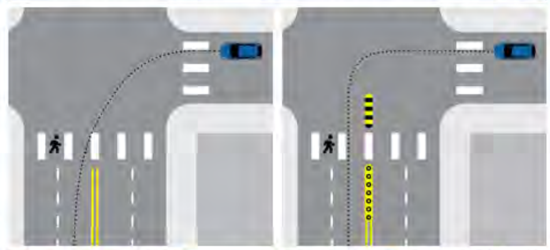
The best practices included in this guidance are categorized by treatments intended to improve (1) signalized intersections, (2) unsignalized crossings and (3) corridors. A summary matrix is provided for each category which details the potential impacts of each best practice with respect to safety performance and mobility. Potential safety performance impacts are characterized as "better" or "no difference" based upon prior research. Potential mobility impacts are characterized as "better", "no difference", or "worse" based upon the expected change in delay after a treatment is implemented. Distinct characterizations for safety performance and mobility impacts are provided for motor vehicles, pedestrians and bicyclists. A generalized cost estimate is also provided for implementing each best practice, characterized as "low" (less than $20,000), "medium" ($20,000 to $100,000), or "high" (greater than $100,000).

Each best practice is then detailed in a single-page format, including the "what", "where", "why", and "how" of implementing each treatment. Supporting photographs, figures or other visual aids are included for each best practice. Key references for each practice are included for more detailed information. An example specific to centerline hardening is provided in **Figure 20**.

Centerline Hardening

What	Centerline hardening, wedges, or other turn-related traffic calming treatments typically involving speed humps and bollards have been used which are intended to reduce conflicts between turning vehicles and non-motorized road users [1]. Several different configurations have been evaluated which alter vehicle paths to limit crossing over into crosswalks or bicycle facilities (shown right) [1, 2].
Where	Centerline hardening treatments should be considered at locations with historical conflicts between vehicles and non-motorized road users as well as where geometric characteristics exist which may lead to potential crossover concerns – particularly involving larger vehicles [2].
Why	Research has demonstrated that centerline hardening and similar turn-related traffic calming treatments have improved driver behavior [1, 2] and safety performance [2].
How	More information can be found on MDOT's Pavement Marking Standards [3], New York DOT's Left Turn Traffic Calming webpage [2], NACTO's Don't Give Up at the Intersection [4], and a study conducted by IIHS in 2020 [1].
Key References	1) The Effects of Left-Turn Traffic-Calming Treatments on Conflicts and Speeds in Washington, D.C. (Wen, H. and Cicchino, J. – 2020) 2) Left Turn Traffic Calming (NYDOT) 3) Pavement Markings (MDOT) 4) Don't Give Up at the Intersection (NACTO – 2019) 5) Simple Infrastructure Changes Make Left Turns Safer for Pedestrians (IIHS – 2020)

Centerline Hardening – Before and After [5]



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	Better	No Difference	Better	Better	Low

Best Design Practices for Walking and Bicycling in Michigan - 29

Figure 20. Example from *Best Design Practices for Walking and Bicycling in* Michigan: Centerline Hardening

5.2 Development of *Tools for the Planning and Design of Pedestrian Crossing Enhancements*

As a part of the FHWA's Safe Transportation for Every Pedestrian (STEP) initiative [*37*], the agency developed a document entitled *STEP Studio* which was intended to provide a "comprehensive compilation of resources, design guidance, research, and best practices for practitioners to identify appropriate countermeasures for improved pedestrian safety" [*38*]. While this document includes a variety of helpful tools to improve pedestrian crossing safety, many of the items included in the materials are not state-specific. The MDOT panel requested the MSU research team to develop a Michigan-specific version of *STEP Studio* as an activity under OR19-072. The MSU team subsequently developed a draft document which employed a similar structure as the national version with reduced content to fit Michigan's current design standards and guidance. The document is intended to serve as a "pocket guide" or reference for the design of pedestrian crossing enhancements that does not replace existing materials, such as MDOT's *Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways* [*39*]. A copy of this draft document, entitled *Tools for the Planning and Design of Pedestrian Crossing Enhancements*, can be found in **Appendix 8**. It should be noted that MDOT requested the MSU team to only complete a draft with appropriate content and the department would work to finalize the presentation of the materials for subsequent publication. An example from the draft document is shown in **Figure 21**, where a matrix is provided to identify one of four MDOT standard crossing treatments (labeled A-D).

Criteria for Selecting Crossing Treatments [18]

3 Treatment Selection

Roadway Configuration at the Location of the Crossing Treatment	Number of Lanes Crossed to Reach Refuge	Number of Multiple Threat Lanes*	Roadway ADT and Posted Speed Limit															
			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
Two-Lane (One-Way)	2	1	A	A	A	B	A	A	B	B	A	A	B	B	A	A	B	B
Two-Lane Two-Way Undivided	2	0	A	A	A	B	A	A	B	B	A	A	B	B	A	A	B	B
Three-Lane with Refuge Island <u>or</u> Two-Lane with Raised Median	1	0	A	A	A	B	A	A	B	B	A	A	B	B	A	B	B	B
Two-Lane with Center Left-Turn Lane	3	1	A	A	B	B	A	B	B	B	A	B	B	B	A	B	B	B
Four-Lane Two-Way Undivided	4	2	A	B	B	C	A	B	C	C	A	B	C	C	B	B	C	C
Five-Lane with Refuge Island <u>or</u> Four Lane with Raised Median	2	2	A	A	B	B	A	B	B	C	A	B	C	C	B	B	C	C
Five-Lane with Center Left-Turn Lane	5	2	A	B	C	C	B	B	C	C	C	C	C	D	C	C	C	C
Six-Lane (with or without Raised Median)	3 - 6	4	A	B	D	D	B	B	D	D	D	D	D	D	D	D	D	D

**Multiple threat lanes represent travel lanes where a pedestrian crossing in front of a stopped or slowed vehicle in an adjacent travel lane could step out in front of a moving vehicle in the same direction*

Tools for the Planning and Design of Pedestrian Crossing Enhancements - 11

Figure 21. Example from Draft *Tools for the Planning and Design of Pedestrian Crossing Enhancements* – Criteria for Selecting Crossing Treatments

6.0 SUMMARY AND CONCLUSIONS

In order to accelerate progress towards the state's *Towards Zero Death* vision [*6*, *12*], MDOT sponsored this research effort, *Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance, and Technology Innovations* (OR19-072). The primary goal of this project was to assess national best practices related to pedestrian and bicyclist planning and design, culminating in the development of recommendations to allow MDOT to explicitly consider the needs of such non-motorized users. A series of tasks were conducted towards this end by the MSU research team in consultation with the MDOT panel. This report summarizes these efforts as a comprehensive reference for implementing the research and recommendations developed as a part of the project. An overview of key findings identified as a part of this project include:

- Both MDOT and local roadway agencies in Michigan have either previously implemented or considered most the innovative non-motorized design treatments identified as a part of this effort to some extent. These practices are also included in the revised *Best Design Practices for Walking and Bicycling in Michigan* (**Appendix 7**). However, there remains a considerable opportunity to expand the use of many treatments identified within the review of current practices (**Section 2.0**) across the state.
- The information obtained from Michigan residents and advocacy groups (**Section 3.0**) offers additional context to the review of current practices and helps to provide a benchmark for public opinion specific to Michigan's non-motorized transportation network. The findings obtained from Michigan's stakeholders can help the department in future decision-making related to non-motorized planning and design.
- Despite MDOT's recent *Multi Modal Development and Delivery (M2D2)* efforts which have helped to further incorporate innovative treatments into the department's policies and procedures, there also remains a considerable opportunity to further expand and revise these key planning and design materials. This includes both the review conducted by the MSU team as a part of this effort (**Section 4.0**) as well as future efforts by MDOT.
- The materials developed to help disseminate guidance to encourage the use of pedestrian and bicycle innovations (**Section 5.0**) represent tools which can be employed by both MDOT and local roadway agencies in Michigan. This includes the update to MDOT's *Best Design Practices for Walking and Bicycling in Michigan* (**Appendix 7**) as well as the development of a new document entitled *Tools for the Planning and Design of Pedestrian Crossing Enhancements* (**Appendix 8**).

A series of project deliverables are provided within **Appendices 1-8** and key details of these materials were discussed in the preceding sections. **Table 26** provides a summary of major tasks associated with the project as well as specific recommendations for MDOT to consider in order to implement project deliverables into the department's processes.

Table 26. Summary of Recommendations to Implement OR19-072 Findings

Section	Recommendation for Implementation
2.1 - Comprehensive Literature Review	MDOT staff can refer to the literature review (**Appendix 1**) as a comprehensive resource for pedestrian and bicycle design information, including a detailed overview of specific practices as well as links to more than 400 key references.
2.2 - Identification of MDOT's Existing Relevant Materials	The list of MDOT materials included in **Appendix 2** represents a resource which defines the department's current guidance with respect to pedestrians and bicyclists. This list could be referenced by staff when examining the department's overall non-motorized program.
2.3 - Survey of State and Local Agency Non-Motorized Staff	The survey of non-motorized staff provides detailed information related to the use of specific design strategies, the use of national and jurisdiction-specific guidance documents, the availability of non-motorized master plans, non-motorized data resources, and micromobility considerations. These findings can be reviewed by the department to guide future decision-making related to these topics.
2.4 - Best Practices for Bicycle Signal Detection	The detailed review of best design practices for bicycle signal detection can be used by the department as a part of expanding the use of bicycle signals and detection systems in Michigan (**Appendix 4**).
3.1 - Statewide Survey of Michigan Residents	The survey of residents provides detailed information related to general behavioral patterns, satisfaction with existing facilities, safety perceptions, intentions with improvements, preferred routes, and the impact of COVID-19. This information can be reviewed by the department to guide future decision-making related to these topics.
3.2 - Focus Groups with Michigan Pedestrian and Bicycle Advocacy Groups	The information obtained from the focus groups supplement the findings of the survey of residents by targeting key demographics of non-motorized road users in Michigan. This included representation from the AARP of Michigan, disability advocacy groups, and bicycling and trails advocacy groups. This information can be reviewed by the department to guide future decision-making which impacts these key demographic groups.

Section	Recommendation for Implementation
4.2 - Generalized Activities from USDOT *Pedestrian Safety Action Plan*	The list of generalized activities which can be considered at the state-level, as well as the status of these activities in Michigan and associated recommendation for implementation, can be reviewed by the department to identify potential opportunities to improve non-motorized policies and procedures related to non-motorized planning and design (**Appendix 6.2**).
4.3 - Review of 12 Selected MDOT Documents	The elements within each of the 12 documents identified for potential revision and associated recommendations for improvement can be considered by the department to help explicitly consider the needs of non-motorized road users within the agency's planning and design processes (**Appendices 6.3-6.14**).
5.1 - Update of MDOT's *Best Design Practices for Walking and Bicycling in Michigan*	The comprehensive update of MDOT's *Best Design Practices for Walking and Bicycling in Michigan* to reflect new research and other publications can be used to help disseminate guidance to encourage the use of pedestrian and bicycle innovations. There are also additional practices which have been added to the document which were not widely used when the document was first developed (**Appendix 7**).
5.2 - Development of *Tools for the Planning and Design of Pedestrian Crossing Enhancements*	The draft Michigan-specific version of FHWA's *STEP Studio* entitled *Tools for the Planning and Design of Pedestrian Crossing Enhancements* can be used as a "pocket guide" or reference for the design of pedestrian crossing enhancements that does not replace existing materials. It should be noted that MDOT requested the MSU team to only complete a draft with appropriate content and the department would work to finalize the presentation of the materials for subsequent publication (**Appendix 8**).

REFERENCES

1. Towards Zero Deaths (2014). Towards Zero Deaths: A National Strategy on Highway Safety. Retrieved September 2021 from: https://www.towardzerodeaths.org/wp-content/uploads/2019/12/TZD_National_Strategy.pdf
2. National Highway Traffic Safety Administration. Traffic Safety Facts 2019. Retrieved September 2021 from: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813141
3. Michigan Office of Highway Safety Planning (2021). Michigan Traffic Crash Facts. The Regents of the University of Michigan. Retrieved September 2021 from: https://www.michigantrafficcrashfacts.org/
4. Federal Highway Administration. Michigan Highway Safety Improvement Program 2020 Annual Report. Retrieved September 2021 from: https://safety.fhwa.dot.gov/hsip/reports/pdf/2020/mi.pdf
5. Governor's Traffic Safety Advisory Commission (2019). Pedestrian and Bicycle Safety Action Team Action Plan Accomplishment Summary. Retrieved September 2021 from: https://www.michigan.gov/documents/msp/PBSAT_Accomplishments_2019_Updates_2_672332_7.pdf
6. Governor's Traffic Safety Advisory Commission (2019). 2019-2022 State of Michigan Strategic Highway Safety Plan. Retrieved October 2021 from: https://www.michigan.gov/documents/msp/SHSP_2019-2022_25_web_699817_7.pdf
7. Michigan Department of Transportation. MDOT Mission, Vison, Values. Retrieved October 2021 from: https://www.michigan.gov/mdot/0,4616,7-151-9623-65024--,00.html
8. Michigan Department of Transportation (2015). M2D2 – Multi Modal Development and Delivery Work Plan. Retrieved July 2021 from: https://www.michigan.gov/documents/mdot/M2D2_Michigan_DOT_Work_Plan_Final_012315_609171_7.pdf
9. LaPlante, J., R. Van Houten, S. Meekins, T. Gustafson, D. Cleveland, and S. Hoch (2012). Sharing the Road: Optimizing Pedestrian and Bicycle Safety and Vehicle Mobility. Michigan Department of Transportation.
10. Michigan Department of Transportation (2005). Context Sensitive Solutions Commission Policy. Retrieved October 2021 from: https://www.michigan.gov/documents/MDOT_CSS_Policy_159545_7.pdf
11. Michigan Department of Transportation. PROJECT: Developing a Consistent Data Driven Methodology to Multimodal, Performance Based, and Context Sensitive Design. Retrieved October 2021 from: https://trid.trb.org/View/1865581
12. Michigan Department of Transportation. Towards Zero Deaths. Retrieved September 2021 from: https://www.michigan.gov/mdot/0,4616,7-151-9615_11261_45350_66595---,00.html
13. American Association of State Highway and Transportation Officials (2012). Guide for the Development of Bicycle Facilities: Fourth Edition.
14. Federal Highway Administration (2016). Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts. Washington, D.C.
15. National Association of City Transportation Officials (2018). Urban Street Design Guide.
16. World Health Organization. Pedestrian Safety: A Road Safety Manual for Decision-Makers and Practitioners.
17. Federal Highway Administration (2016). Incorporating On-Road Bicycle Networks into Resurfacing Projects. Washington, D.C.
18. Federal Highway Administration (2016). Small Town and Rural Multimodal Networks. Washington, D.C.

19. Institute of Transportation Engineers (2010). Designing Walkable Urban Throughfares: A Context Sensitive Approach
20. Federal Highway Administration. Pedestrian Safety Guide and Countermeasures Selection System (PEDSAFE). Retrieved March 2021 from: http://www.pedbikesafe.org/pedsafe/
21. Thomas, L. (2013). Road Diet Conversions: A Synthesis of Safety Research. Federal Highway Administration.
22. Federal Highway Administration (2014). Road Diet Informational Guide.
23. National Cooperative Highway Research Program (2018). Assessing Interactions Between Access Management Treatments and Multimodal Users.
24. Michigan Department of Transportation (2019). M2D2 Guidebook.
25. Federal Highway Administration. Accommodating Pedestrians in Work Zones.
26. Federal Highway Administration (2018). Guidelines for Work Zone Designers: Pedestrian & Bicycle Accommodation.
27. Qualtrics (2021). Qualtrics XM Platform. Retrieved October 2021 from: https://www.qualtrics.com/platform/
28. Federal Highway Administration (2021). State Bicycle and Pedestrian Coordinator. Retrieved October 2021 from: https://www.fhwa.dot.gov/environment/bicycle_pedestrian/state_contacts.cfm
29. Smart Growth America (2019). The Best Complete Street Policies of 2018. Retrieved October 2021 from: https://smartgrowthamerica.org/resources/the-best-complete-streets-policies-of-2018/
30. Federal Highway Administration (2021). Highway Safety Improvement Program. Retrieved October 2021 from: https://safety.fhwa.dot.gov/hsip/
31. Urbanik, T., A. Tanaka, B. Lozner, E. Lindstrom, K. Lee, S. Quayle, S. Beaird, S. Tsoi, P. Ryus, D. Gettman, S. Sunkari, K. Balke, and D. Bullock (2015). NCHRP Report 812: Signal Timing Manual. Transportation Research Board, Washington, D.C.
32. United States Department of Transportation (2020). USDOT Pedestrian Safety Action Plan. Retrieved July 2021 from: https://highways.dot.gov/sites/fhwa.dot.gov/files/2020-11/FHWA_PedSafety_ActionPlan_Nov2020.pdf
33. Michigan Department of Transportation. Michigan Department of Transportation: Traffic and Safety/Standards and Special Details. Retrieved April 2021 from: https://mdotjboss.state.mi.us/TSSD/tssdHome.htm
34. National Cooperative Highway Research Program (2010). Roundabouts: An Informational Guide, 2nd Edition. Transportation Research Board, Washington, D.C.
35. Michigan Department of Transportation. Best Design Practices for Walking and Bicycling in Michigan. Retrieved July 2021 from: https://mdotjboss.state.mi.us/TSSD/getTSDocument.htm?docGuid=791bcb73-13b6-49aa-9830-fbc85b8bd663&fileName=mdot_research_report.pdf
36. Michigan Department of Transportation (2013). Michigan Manual on Uniform Traffic Control Devices.
37. Federal Highway Administration (2020). Safe Transportation for Every Pedestrian (STEP) – Resources. Retrieved July 2021 from: https://safety.fhwa.dot.gov/ped_bike/step/resources/
38. Federal Highway Administration. STEP Studio. Retrieved July 2021 from: https://safety.fhwa.dot.gov/ped_bike/step/resources/docs/step_studio.pdf
39. Michigan Department of Transportation (2020). Guidance for Installation of Pedestrian Crosswalks on Michigan state Trunkline Highways. Retrieved July 2021 from: https://mdotjboss.state.mi.us/TSSD/getTSDocument.htm?docGuid=29acdb28-6da4-46d6-9115-8890ca554bda&fileName=FINAL%20MDOT%20ped%20crosswalk%20guide%20March%202020.pdf

APPENDICES

Schedule of Appendices

Appendix	Description
1	Review of Best Practices in Pedestrian and Bicycle Design
2	Summary of Relevant MDOT Planning and Design Materials
3	Details of Survey of State and Local Agency Non-Motorized Staff
4	Review of Best Practices for Bicycle Signal Detection
5	Details of Statewide Survey of Michigan Residents
6	Details of Potential Updates to MDOT's Planning and Design Materials
7	MSU Update to *Best Design Practices for Walking and Bicycling in Michigan*
8	MSU Draft of *Tools for the Planning and Design of Pedestrian Crossing Enhancements*

Appendix 1:

Review of Best Practices in Pedestrian and Bicycle Design

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

As a part of the Michigan Department of Transportation's (MDOT) Towards Zero Death (TZD) vision, the agency sponsored a research project entitled "*Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance and Technology Innovations*" in order to accelerate progress towards the department's ultimate vision of zero fatalities and serious injuries on Michigan's roadways. Additionally, supporting mobility for all users of the transportation system is key MDOT's mission of "providing the highest quality integrated transportation services for economic benefit and improved quality of life" [*C.40*]. While MDOT has made several recent efforts towards improving multimodal design guidance following context sensitive principles [*C.40, C.43, C.50, C.111*], there may be opportunities to improve the agencies current guidance and design processes by examining best practices conducted both across the United States and abroad. This effort represents a comprehensive literature review to identify best practices in pedestrian and bicycle design and planning efforts. The existing literature was critically reviewed with a focus on the following:

- Best practices in Michigan, the United States, and abroad.
- Processes that have led to successful projects by other state and local agencies.
- Compliance with the Americans with Disabilities Act (ADA).

The review ultimately included a search of guidelines for pedestrian and bicycle design, project reports from agencies including the Federal Highway Administration (FHWA), United States Department of Transportation (USDOT), Transportation Research Board (TRB), State DOTs, and other governmental or quasi-governmental organizations in Michigan, the United States, and elsewhere, as well as a review of relevant articles from transportation engineering journals. The Transport Research International Documentation (TRID) bibliographical database and other relevant search engines were also utilized to identify relevant publications.

While a full list of the resources identified as a part of this literature review can be found in **Appendices A-D**, an examination of each topic is provided in subsequent sections. **Section 2.0** details best practices in the design and planning of pedestrian facilities. Similarly, **Section 3.0** details best practices in the design and planning of bicycle facilities. It should be noted that while the appendices represent the library of materials which support this review as well as future project tasks, for brevity each resource may not be referred to directly within **Sections 2.0 and 3.0**.

Additionally, while a discussion of each topic is provided, including coverage of foundational principles and concepts, it is not possible to cover all aspects of a specific element in this format. Instead, the cited resource(s) should be referenced for more detailed information. Further, a greater focus is provided for new or innovative treatments as opposed to fundamental elements.

1.1 Selected National Design Guides, Manuals and Other Resources

The research team identified resources developed at the federal-level or otherwise intended to provide guidance across the United States. This included design guides, manuals and other resources developed by the FHWA, the American Association of State Highway Transportation Officials (AASTHO), the National Association of City Transportation Officials (NACTO), the Institute of Transportation Engineers (ITE), among others. Each of these **155 resources** are provided in **Appendix A**, including a brief summary and a reference number which will be used to refer to each document.

1.2 Selected International Design Guides, Manuals and Other Resources

The research team collected resources which were developed in other countries in order to ensure that best practices in design, guidance and recent innovations employed outside of the United States were considered. Each of these **24 resources** are provided in **Appendix B**, including a brief summary and a reference number which will be used to refer to each document.

1.3 Selected State and Local Design Guides, Manuals and Other Resources

In addition to the national and international resources identified by the research team, it was also important to consider literature developed by state and local agencies which provide further insight into best practices, case study examples, or other experiences which may be helpful for MDOT. Each of these **113 resources** are provided in **Appendix C**, including a brief summary and a reference number which will be used to refer to each document.

1.4 Selected Journal Articles, Conference Proceedings and Other Literature

While the design guidance, manuals and other resources developed across the United States and internationally provide key details on a variety of best practices in multimodal planning and design, peer-reviewed journal articles, conference proceedings or other literature were also collected by the research team to identify the state-of-the-art specific to each best practice. Each of these **134 resources** are provided in **Appendix D**, including a reference number which will be used to refer to each document.

2.0 BEST PRACTICES IN PEDESTRIAN DESIGN AND PLANNING

Based upon the resources identified in **Appendices A-D**, the research team identified best practices in pedestrian design and planning. The subsections that follow include a discussion of each topic based upon the literature reviewed as a part of this effort.

2.1 Roadway Segment Planning and Design for Pedestrians

The planning and design of highway segments, from high-speed arterials to low-speed urban streets, plays a critical role in supporting the context-sensitive approach encouraged by USDOT [*A.16*]. This includes going beyond minimum design requirements to "proactively provide convenient, safe, and context-sensitive facilities that foster increased use by bicyclists and pedestrians of all ages and abilities" [*A.16*]. The AASHTO *Green Book* further clarifies this concept to state that "a highway has wide-ranging effects in addition to providing traffic service to users. It is essential that the highway be considered as an element of the total environment." [*A.44*]. Ultimately, the various elements that comprise streets, including sidewalks, travel lanes and transit stops, must all compete for space within a limited right-of-way [*A.13*]. The following subsections identify best practices with respect to roadway segment planning and design for pedestrians.

2.1.1 Lane Widths

While a certain amount of street width is necessary to support particular design elements, such as the lateral positioning of vehicles or on-street parking, relatively wide streets (or those greater than 60 feet) can result in barriers for pedestrians and higher vehicle speeds [*A.22*]. NACTO's *Urban Street Design Guide* notes that "Lane widths should be considered within the assemblage of a given street delineating space to serve all needs, including travel lanes, safety islands, bike lanes, and sidewalks." [*A.13*]. ITE recommends that lane widths should be selected based upon the target speed, design vehicle, right-of-way and the width of adjacent bicycle or parking lanes [*A.22*].

Given that the *Green Book* allows for considerable flexibility in selecting lane widths (ranging from 9 to 12 feet depending on a variety of design considerations) [*A.44*], implementing narrower lane widths can provide benefits to non-motorized road users while not significantly impacting safety performance in urban environments [*A.10, A.13*]. Narrower lanes may allow designers to implement bicycle-specific facilities, widen sidewalks, and reduce crossing distances [*A.10, B.5*].

Wider travel lanes have also been shown to be associated with higher travel speeds which may impact safety and comfort for non-motorized road users [*A.13*]. It should be noted that NACTO advocates for the use of 10-foot travel lanes in urban areas, with wider lanes (particularly the outside curb lane for multilane highways) depending on the traffic mix or other geometric considerations [*A.13*]. In fact, FHWA notes the idea that lane widths less than 11 feet are not allowed when federal funds are used among common misconceptions [*A.37*].

2.1.2 Paved Shoulders and Shoulder Widths

The inclusion of paved shoulders along a highway can provide a variety of benefits, including those related to non-motorized road users (such as providing space for travel, facilitating safer passing behaviors and increasing comfort) and unrelated to non-motorized road users (such as serving as a recovery area for errant vehicles, lengthening pavement lifespans and reducing maintenance costs) [*A.10*]. The *Green Book* notes that paved shoulders can provide a space for pedestrian and bicycle use and vary in width from 2 feet along minor rural highways to 12 feet along major roads [*A.44*]. The FHWA recommends that designers can consider reducing lane widths and provide more shoulder width during resurfacing projects [*A.10*]. It is also important to note that paved shoulders must meet ADA requirements to the maximum extent possible if a shoulder is intended as a pedestrian access route [*A.10*].

The FHWA suggests that while the *Green Book* does not specify paved shoulders along local and collector streets, designers should consider paved shoulders to help accommodate non-motorized road users in rural areas [*A.10, A.86*]. FHWA's *Small Town and Rural Multimodal Networks* guidance notes that while any amount of paved shoulder width can provide benefits for non-motorized road users, a 4-foot width minimum should be used and expanded to the recommended widths shown in **Figure 1** where feasible [*A.23*].

Functional classification	Volume (AADT)	Speed (Mi/h)	Recommended Minimum Paved Shoulder Width
Minor Collector	up to 1,100	35 (55 km/h)	5 ft (1.5 m)
Major Collector	up to 2,600	45 (70 km/h)	6.5 ft (2.0 m)
Minor Arterial	up to 6,000	55 (90 km/h)	7 ft (2.1 m)
Principal Arterial	up to 8,500	65 (100 km/h)	8 ft (2.4 m)

Figure 1. Recommended Minimum Paved Shoulder Widths by Roadway Conditions [*A.23*]

The guidance also notes that for shoulders which are intended for pedestrian and bicycle activity, the edge should be clearly delineated, including potential options beyond a normal white line such as a wider line (8 inches) or the inclusion of a buffer space with dual solid white lines [*A.23*]

Prior research has demonstrated that the installation of paved shoulders with a minimum of four feet in width have been associated with a 71 percent decrease in pedestrian crashes [*A.32*]. The FHWA aggregated case study examples from around the country specific to the use of paved shoulders in *State Best Practice Policy for Shoulders and Walkways* [*A.86*].

2.1.3 Sidewalks

Sidewalks are intended to provide a dedicated space for pedestrians that is safe, comfortable, accessible for all potential users [*A.23*]. Typically, sidewalks are physically separated from highways via curb and gutter (generally in urban environments) or an unpaved buffer space (generally in suburban or rural environments) [*A.23*]. Sidewalks serve a variety of key functions in cities, including providing access and mobility for pedestrians, enhancing connectivity and promoting walking [*A.13*]. It is also important to note that sidewalks should be included on all streets in urban areas to conform to ADA accessibility guidelines [*A.13*]. The typical sidewalk zones are shown in **Figure 2**, including the frontage zone, through zone and furnishing zone [*A.23*]. It should be noted that there may be an enhancement or buffer zone in urban areas [*A.13*].

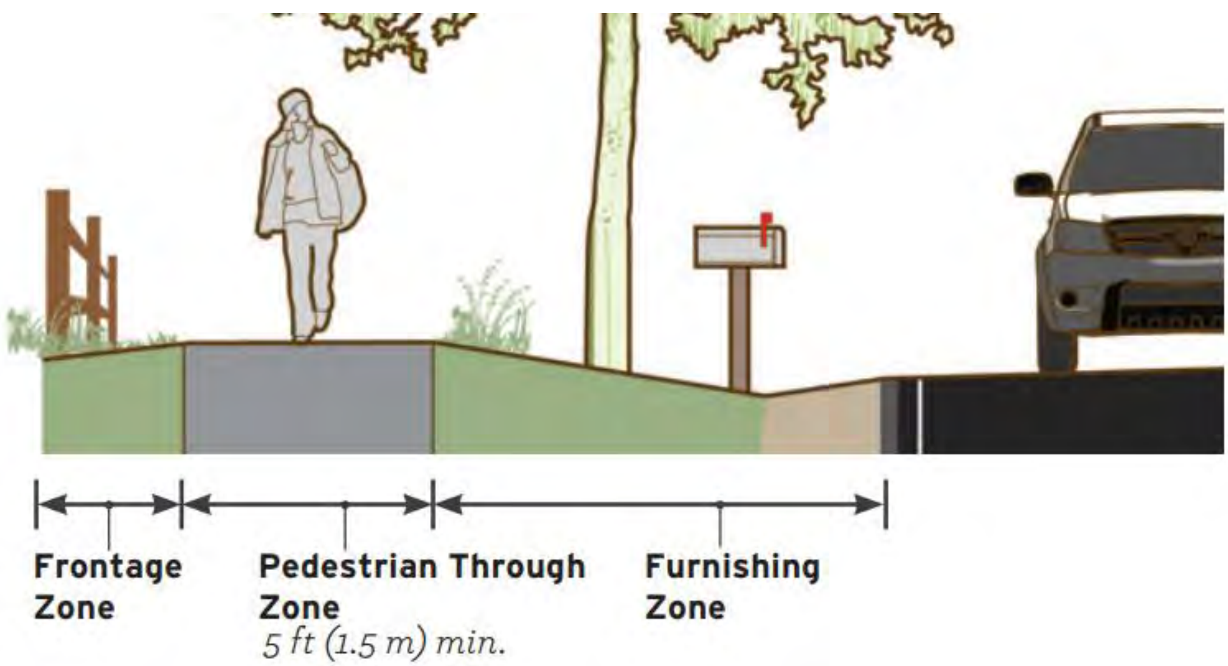


Figure 2. Typical Sidewalk Zones [*A.23*]

The constrained minimum and recommended minimum sidewalk widths per the FHWA are provided in **Figure 3**.

Volume And User Mix	Frontage Zone	Pedestrian Through Zone	Furnishing Zone	Total Width
Constrained Minimum	1 ft (0.3 m)	5 ft (1.2 m)	2 ft (0.6 m)	8 ft (2.4 m)
Recommended Minimum	2 ft (0.6 m)	6 ft (1.5 m)	4 ft (1.2 m)	12 ft (3.6 m)

Figure 3. Minimum Recommended Dimensions for Sidewalks [*A.23*]

The installation of sidewalks has been associated with an 88 percent decrease in pedestrian crashes which involved "walking along the roadway" [*A.32*]. More detailed information on the design and planning of sidewalks for a variety of roadway environments can be found in the references included in **Appendices A-D** [*A.1, A.10, A.13, A.14, A.20, A.22, A.23, C.99, D.39*].

2.1.4 On-Street Parking

While on on-street parking is key to serving the needs of certain land uses adjacent to urban streets, the presence of on-street parking can have both positive and negative impacts related to pedestrian safety [*A.22, A.41*]. Specifically, on-street parking can result in lower travel speeds, reduce the crossing width, and serve as a buffer between vehicles and pedestrians walking along a sidewalk [*A.22*, *A.41*]. On-street parking can also reduce walking distances to destinations for disabled persons [*A.22*]. However, the presence of on-street parking can create a visual barrier between drivers and crossing pedestrians and reduce the available width that could be used for other pedestrian-friendly design elements. [*A.22*, *A.41*].

One notable treatment specific to pedestrian safety and on-street parking is the elimination of parking spaces near intersections. Vehicles parked immediately adjacent to intersections may obscure the visibility of pedestrians and eliminating parking can improve sight lines, resulting in potentially safer crossings [*A.70*]. One study demonstrated a 30 percent reduction in pedestrian crashes by restricting parking near intersections [*A.32*]. Physical barriers should be used to eliminate the possibility of illegal parking [*A.70*].

More detailed information on the design and planning of on-street parking can be found in the references included in **Appendices A-D** [*A.22, A.41, C.11*].

2.1.5 Design Speed, the Posted Speed Limit and Traffic Calming Treatments

Design speed is one of the fundamental criteria used in establishing a variety of roadway design elements, including horizontal alignment, vertical alignment as well as cross sectional features [*A.10*]. In the context of designing pedestrian-friendly transportation facilities, higher design speeds can result in less comfortable environments for non-motorized road users [*A.10*]. Further, NACTO notes "there is a direct correlation between higher speeds, crash risk and the severity of injuries" [*A.13*]. Research has also shown that drivers visual field reduces at higher speeds, which combined with decreased available time to take corrective action, increases the risk of collisions between vehicles and non-motorized road users [*A.10, A.23*].

The *Green Book* provides important flexibility with respect to design speeds, noting that the selection of design speeds should be "a logical one with respect to the anticipated operating speed, topography, the adjacent land use, and the functional classification of the highway." [*A.44*]. The *Green Book* also notes that "every effort should be made to attain a desired combination of safety, mobility and efficiency within the constraints of environmental quality, economics, aesthetics, and social or political impacts." [*A.44*]. While posted speed limits are often set based upon the measured 85th percentile of observed speeds along a facility, the FHWA includes the idea that posted speed limits must be set based upon the 85th percentile methodology as a common misconception [*A.37*]. FHWA notes that are a several other approaches which can be used in setting appropriate speed limits for all road users [*A.37*].

Another important aspect is the relationship been the selected design speed of a facility and the posted speed limit. While it has been common practice among designers to select a design speed greater than the posted speed limit with the intent of improving safety performance, this can result in higher travel speeds which can reduce safety performance [*A.10*]. Both ITE and NACTO recommend selecting design speeds which are equal to the desired target speed [*A.13, A.22*]. Ultimately, designers should consider a variety of factors beyond just the posted speed limit when determining design speeds, including target speed, adjacent land use, the level of non-motorized activity, transit activity, as well as driveway density [*A.10*]. ITE also provides guidance related to the selection of target speeds, which is not an arbitrary decision, but instead is achieved by the consideration of a variety of design elements and decisions [*A.22*].

The selection of design speed, target speed and posted speed is a complex engineering process and more detailed information can be found in the references provided in **Appendices A-D** [*A.10, A.13, A.22, A.37, A.44, A.102, A.105, B.7, C.4, C.17, C.36, C.58, C.72, C.92, C.108, D.1, D.58, D.67]*.

Traffic Calming Treatments

Traffic calming refers a relatively broad group of treatments intended to address negative impacts of motor vehicle use, alter driver behavior and improve conditions for non-motorized road users [*A.10*]. Generally, traffic calming involves physical countermeasures to reduce travel speeds and encourage desired driver behavior to maximize non-motorized road user safety [*A.10*]. The NACTO *Urban Street Design Guide* provides a variety of example traffic calming tools intended to reduce traffic speeds, shown in **Figure 4** [*A.13*].

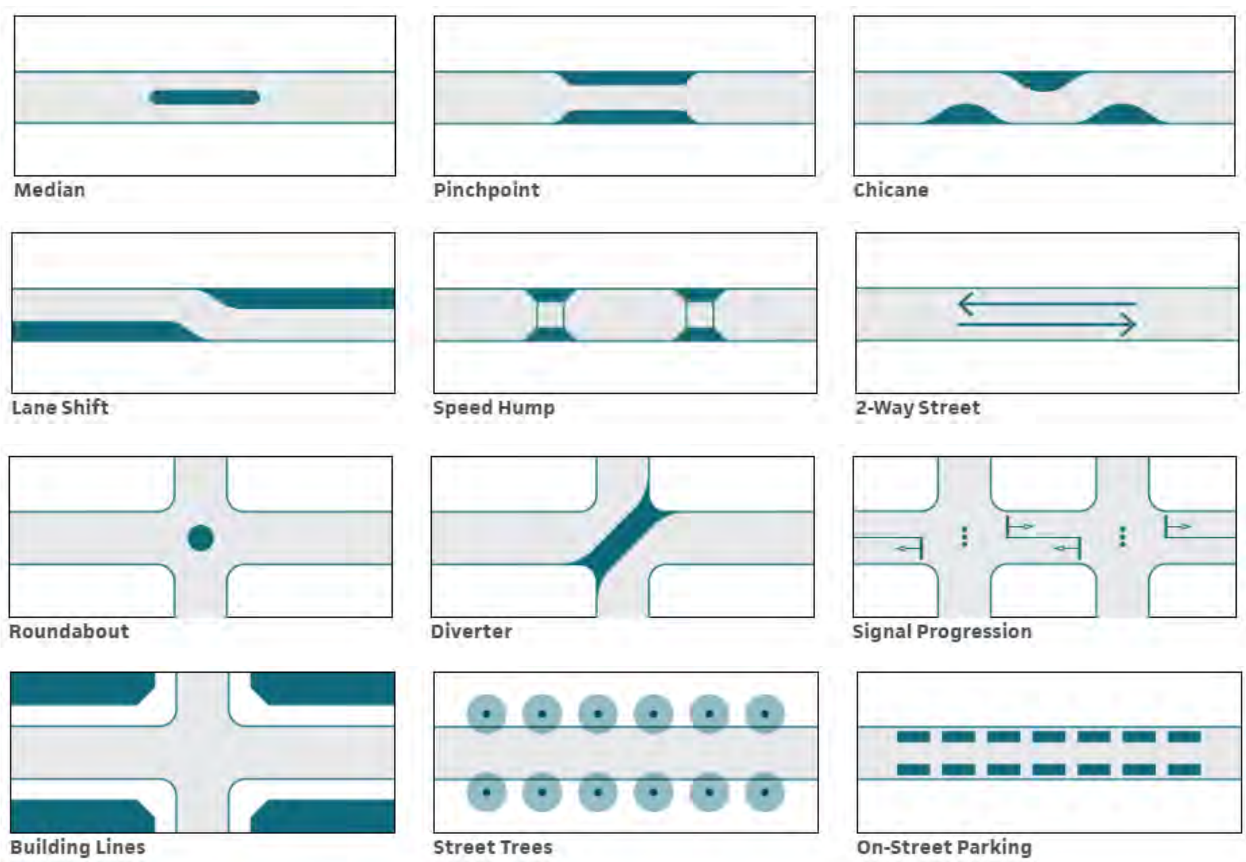


Figure 4. Traffic Calming Tools [*A.13*]

There is a wealth of available guidance specific to the planning, selection, and design of traffic calming treatments included in the resources aggregated in **Appendices A-D** for more detailed information [*A.10, A.13, A.22, A.23, A.41, A.106, C.25, C.26, C.38, C.72, C.82, D.39, D.68*].

Gateway Treatments and Transitions to Main Streets

One of the most important uses of traffic calming treatments involves the transition from roadway segments designed for higher speeds with less of an emphasis placed on pedestrian travel to lower-speed sections (often involving "main street" or downtown areas) that place a greater emphasis on pedestrian access and connectivity. These transitional areas often involve "gateway treatments" which generally include physical or geometric features that indicate a change in environment from a higher speed arterial or collector to a lower speed street with residential or commercial land use [*A.41*]. There are a variety of potential methods for marking such gateways in transitional areas, including the narrowing of streets, medians, signing, archways, roundabouts, curb extensions or other similar traffic calming measures [*A.13, A.41*]. An example of a gateway treatment implemented in Virginia along U.S. 50 is provided in **Figure 5**.

Figure 5. Example of Gateway Treatment in Virginia [*A.10*]

Additional information related to gateway treatment planning and design can be found in the resources in **Appendices A-D** [*A.10, A.13, A.22, A.41, A.106, C.42, C.47, D.51, D.53, D.55, D.59*].

2.1.6 Road Diets and Other Roadway Reconfigurations

Road diets have been defined as "the reallocation of road space through the reduction of the number of motorized traffic lanes" [*A.60*]. While there are a variety of potential roadway reconfigurations, the most common road diet involves the conversion of a four-lane undivided roadway to a two-lane roadway which includes a center two-way left-turn lane (**Figure 6**) [*A.66*].

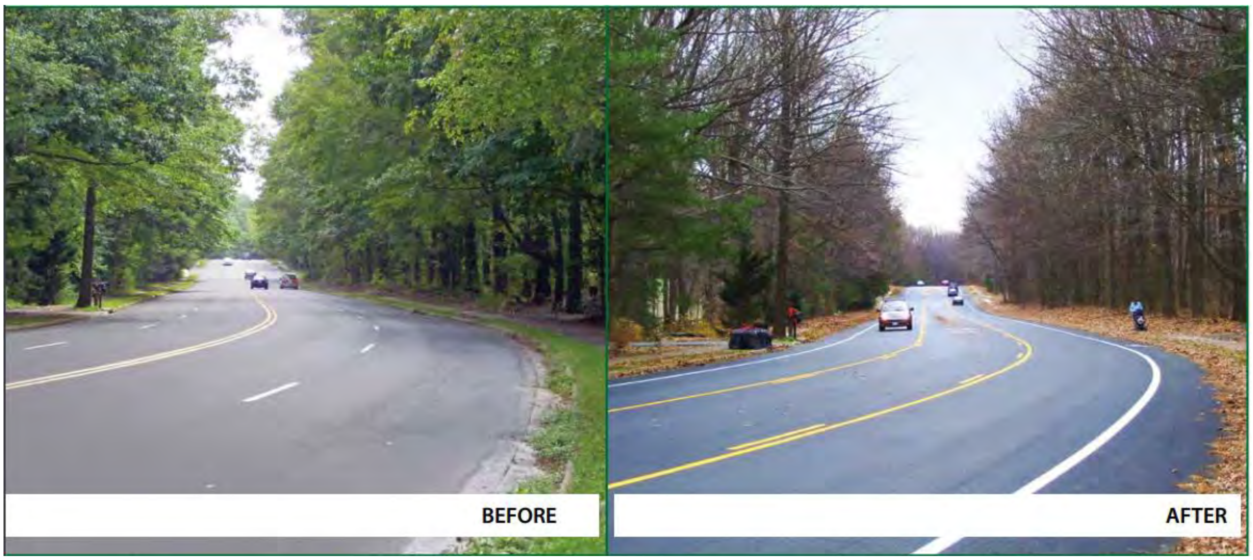


Figure 6. Example of Four-Lane to Three-Lane Road Diet [*A.66*]

Road diets can offer a variety of traffic safety benefits as four-lane undivided highways often suffer from relatively poor safety performance at higher traffic volumes due to conflicts between through traffic and left-turning vehicles [*A.66*]. The implementation of a road diet can also offer safety benefits specific to pedestrians as crossing widths are reduced and refuge islands can be introduced within the right-of-way [*A.66*]. Curb extensions and/or other treatments to improve the safety of uncontrolled midblock crossings have also been installed as a part of road diet reconfigurations [*A.60, A.66*].

However, there are a variety of factors which need to be considered in order to determine if a road diet is appropriate and feasible for a given corridor, including the surrounding land use, access point density, right-of-way considerations, traffic volumes and speed [*A.66*]. The FHWA also notes the idea that federal funds can't be used for road diets as a common misconception, promoting the concept of road diets as a part of the *Every Day Counts* initiative [*A.37*]. Additional information related to road diet planning and design can be found in the resources in **Appendices A-D** [*A.10, A.22, A.41*, *A.55, A.60, A.66, C.23, C.92*].

2.1.7 Yield Roadways

A yield roadway serves bidirectional vehicle traffic without lane markings, as well as non-motorized road users, within the same slow-speed travel area [*A.23*]. Generally intended for very low-volume local rural roads, yield roadways include a travel way width of 12 to 20 feet and infrequent space for parking or queuing of vehicles when the available width does not allow vehicles to pass within the traveled way [*A.23*]. Additionally, MUTCD-complaint signs should be considered to warn drivers that pedestrians are on the roadway (W11-2) and that the roadway serves two-way traffic (W6-3) [*A.23*]. An example diagram of a yield roadway in provided in **Figure 7**, along with the potential warning signs.

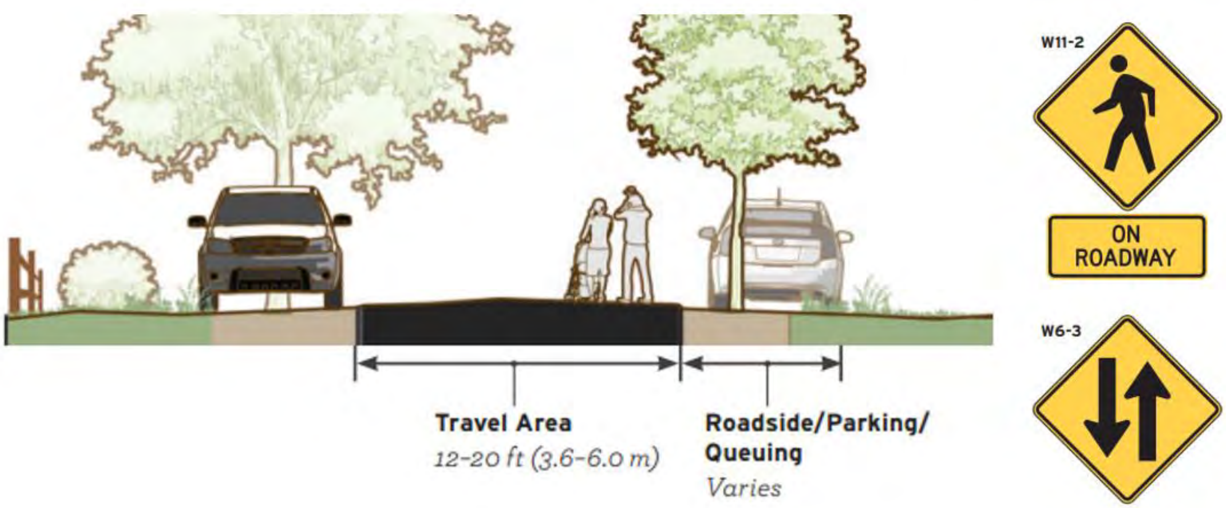


Figure 7. Example of a Yield Roadway and Warning Signage [*A.1, A.23*]

2.1.8 Pedestrian Lanes

Pedestrian lanes are intended for interim or temporary accommodation specific to roadway segments that do not include sidewalks [*A.23*]. It is important to note that pedestrian lanes should not be used as a replacement for sidewalks – instead they should be used to connect short gaps between appropriate long-term facilities along roadways with low to moderate speeds and traffic volumes [*A.23*]. Pedestrian lanes must meet ADA guidelines with a minimum width of 5 feet and a preferred width of 8 feet (**Figure 8**) [*A.23*].

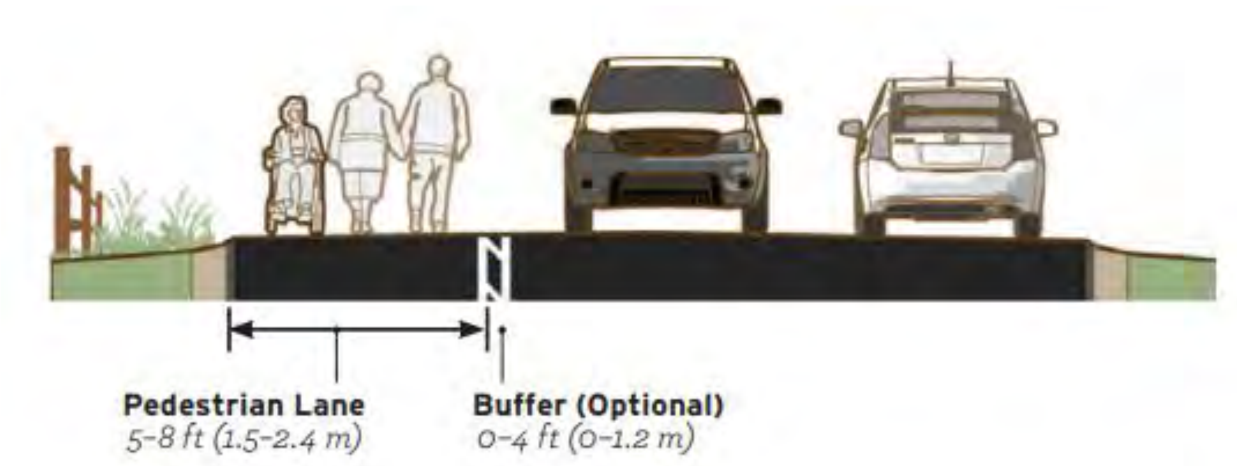


Figure 8. Example Diagram of a Pedestrian Lane [*A.23*]

2.1.9 Access Management Considerations

While safely accommodating all road users if a fundamental principle of the transportation system, it is also required to provide access connections to the roadway system [*A.138*]. Additionally, the location and design of these access points impact both safety and mobility for each road user [*A.138*]. There are a variety of potential driveway design characteristics which may have impacts specific to pedestrians, including wide or sloped driveways, relatively large turning radii, adjacent driveways, driveways which are not well-defined, as well as driveways which require driver attention to select an appropriate gap to complete turning movements [*A.41*]. NCHRP Research Report 900: *Guide for the Analysis of Multimodal Corridor Access Management* [*A.147*] includes a summary of more than 70 access management techniques across 19 groups which can be used to help mitigate these potential concerns, including:

- Restricting left-turn movements at access points
- Non-traversable medians
- Continuous two-way left-turn lanes
- Frontage and service roads
- Unsignalized median openings
- Traffic signal spacing
- Number and spacing of unsignalized access points
- Interchange areas
- Left-turn lanes

- Right-turn lanes
- Driveway channelization
- Alternative intersections and interchanges
- Parking and stopping restrictions
- Roundabouts
- Driveway sight distance
- One-way driveways
- Driveway width
- Driveway vertical geometry
- Driveway throat length

2.2 Intersection Design for Pedestrians

Highway intersections are a critical element of the transportation network but also can result in potentially serious conflicts between non-motorized road users and motor vehicles [*A.13*]. NACTO advocates for intersections that "facilitate visibility and predictability for all users, creating an environment in which complex movements feel safe, easy, and intuitive." [*A.13*]. ITE identifies several foundational principles for successful multimodal intersection design, including [*A.22*]:

- Minimizing conflicts between modes
- Accommodate all modes with the appropriate level of service
- Avoid elimination of any travel modes due to design
- Provide driver and non-motorized road user visibility with appropriate sight distance triangles
- Minimize pedestrian exposure to traffic and keep crossing distances as short as practical
- Design for slower speeds at potential pedestrian-vehicle conflict points
- Avoid extreme intersection angles or complex intersections
- Ensure intersections are accessible for users with disabilities

Ultimately, accommodating pedestrians at highway intersections is a complex topic which includes a variety of design aspects which need to be considered. It should be noted that the NCHRP has research underway to provide guidance specific to pedestrian and bicyclist safety at intersections [*A.126*]. Additional research is being performed to provide guidance for alternative intersection designs [*A.125*]. The following subsections identify best practices with respect to roadway intersection planning and design for pedestrians.

2.2.1 Intersection Geometric Design

The presence of intersections creates potential conflict points between vehicles and pedestrians, including 16 at four-legged intersections and 12 at three-legged intersections (**Figure 9**) [A.22].

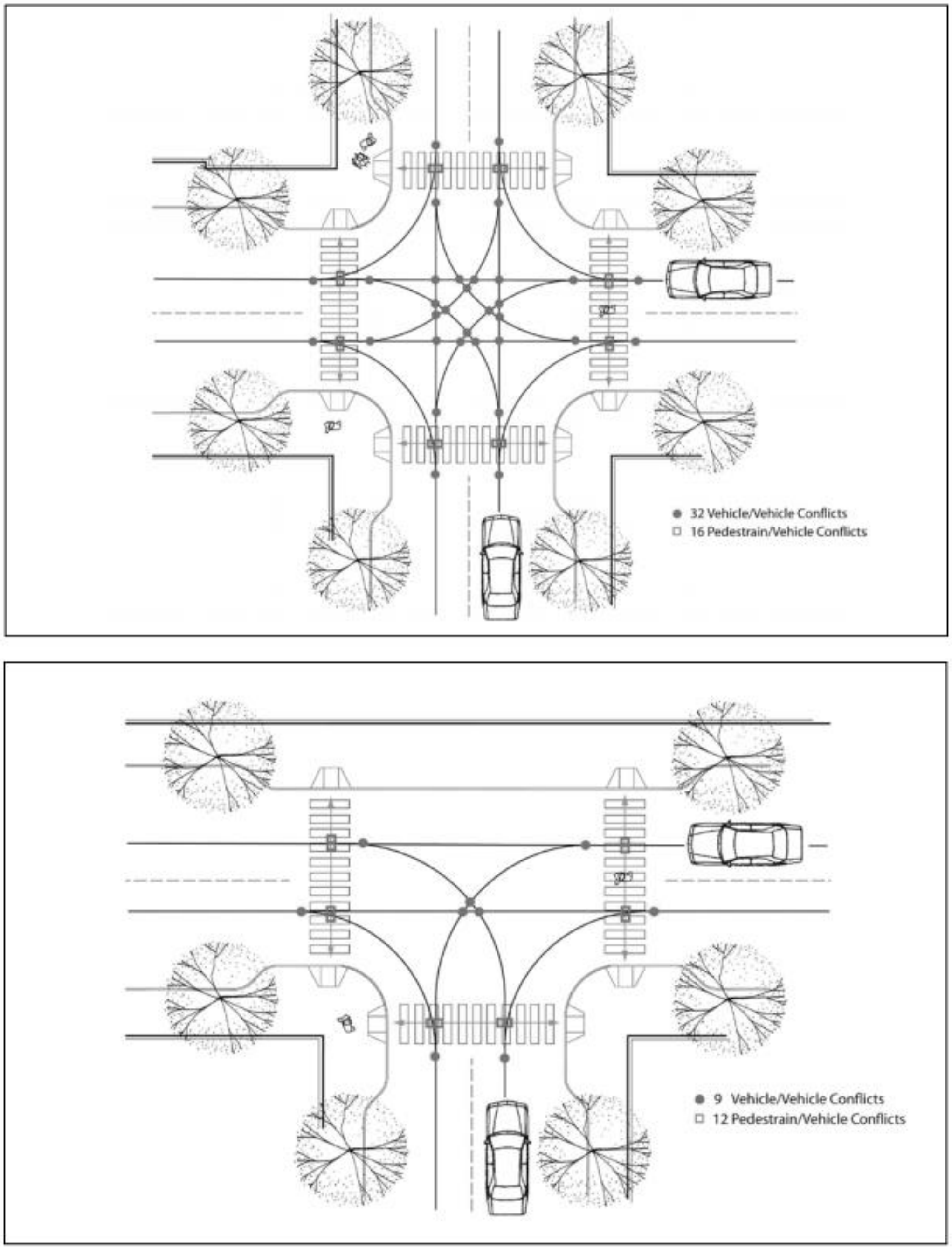


Figure 9. Vehicle and Pedestrian Conflict Points at Four and Three Leg Intersections [*A.22*]

The FHWA suggests that effective context-sensitive design "derives from key decisions made about intersection geometry" [*A.10*]. NACTO advocates for designing intersections for the most vulnerable street user as opposed to the largest possible vehicle [*A.13*]. With these concepts in mind, there are several treatments specific to intersection geometry that can help to improve pedestrian safety and mobility, including [*A.10, A.13, A.22, A.41*]:

- Ensure intersections meet at right angles to the extent possible
- Consider reduced lane widths in appropriate settings to reduce vehicle speeds and pedestrian crossing distances
- Consider turn restrictions when turning traffic volumes are low and pedestrian crossing volumes are high
- Use smaller curb radii and curb extensions when appropriate
- Consider mountable truck aprons to discourage vehicle encroachment into pedestrian areas but can also accommodate large vehicles (**Figure 10**)
- When implemented in appropriate settings, design channelized right-turns that are pedestrian-friendly (**Figure 11**)
- Crossings with four or more lanes of traffic should include pedestrian refuge in the form of a median or crossing island
- Consider raised intersections at appropriate locations to lower speed and encourage driver yielding compliance (**Figure 12**)
- Consider implementing mini roundabouts at uncontrolled intersections in appropriate areas to lower speeds at crossings

More detailed information specific to the design of intersection geometry for pedestrians can be found in the references aggregated in **Appendices A-D** [*A.10 A.13, A.22, A.67, A.79, A.82, A.125, A.126, A.134, C.8, C.71, D.18, D.70*].

MOUNTABLE TRUCK APRONS
PORTLAND, OR

The City of Portland installed mountable truck aprons at an existing intersection where large turning vehicles were relatively frequent. The character of the neighborhood has changed from an industrial area in recent years and large vehicles are now less frequent.

The mountable truck aprons allow drivers of large vehicles to turn without entering the pedestrian zone or encroaching on vehicle lanes. The height of the mountable section discourages smaller vehicles from making the same turn, which reduces their speed through the intersection.

Figure 10. Mountable Truck Aprons Case Study Example from Portland, OR [*A.10*]

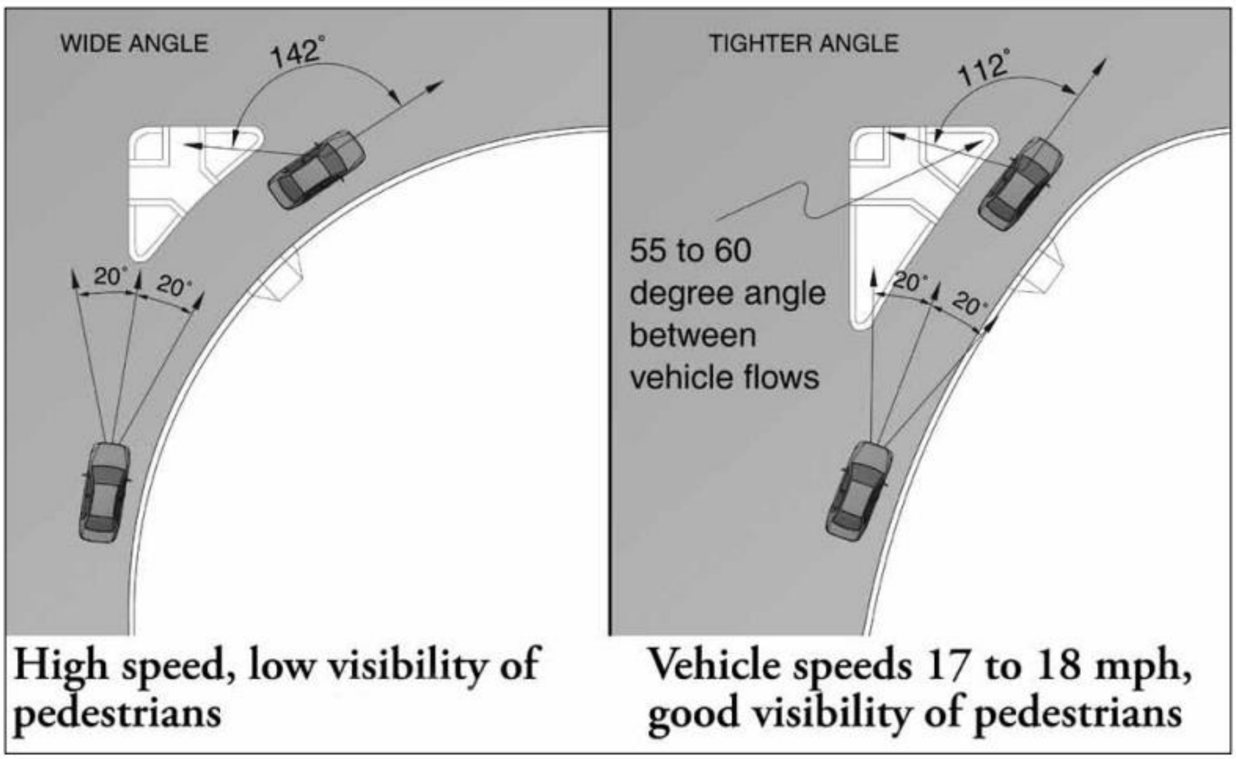


Figure 11. Wide Angle vs. Tighter Angle Channelized Right-Turns [*A.22*]

Figure 12. Raised Intersection Example from NACTO [*A.13*]

2.2.2 Pedestrian Design at Unsignalized Intersections

An important concept established by the MUTCD is that marked crosswalks should not be used indiscriminately, specifically noting that an engineering study should be performed at locations where approaches not controlled by a traffic signal, stop or yield sign [*A.1*]. However, there are a variety of recent design features, traffic control devices and other technologies which can be used to improve both the safety and comfort of pedestrian crossings at uncontrolled approaches [*A.56*]. NCHRP Report 562 *Improving Pedestrian Safety at Unsignalized Crossings* provides guidance specific to engineering treatments intended to improve safety at unsignalized high volume crossing locations [*A.56*]. While pedestrian crossing treatments will be discussed in greater detail in **Section 2.7**, prior work has documented several suggestions to improve pedestrian safety and mobility at unsignalized intersections, including [*A.22, A.56*]:

- Consider the use of high-visibility crosswalks when marked crossings are appropriate
- Consider the use of curb extensions (**Section 2.7.6**), median refuge islands (**Section 2.7.5**) and traffic calming treatments (**Section 2.1.5**)
- Consider including street and crosswalk lighting
- Consider advanced yield lines to improve pedestrian visibility and reduce multiple threat-type crashes
- Consider the installation of flashing beacons, additional signing or other advanced crossing treatments (**Section 2.7**)

- Effective crossing treatments should include a combination of several design treatments (such as implementing curb extensions to reduce crossing distances with additional signage) as opposed to simply installing a crossing alone

2.2.3 Pedestrian Design at Signalized Intersections

Traffic signals have the potential to reduce conflicts between vehicles and non-motorized road users by managing traffic flows [*A.10*]. The FHWA notes that traffic signal design should provide for a "safe and predictable environment for all users" [*A.10*]. Further, the MUTCD states that "The design and operation of traffic signals shall take into consideration the needs of pedestrian as well as vehicular traffic" [A.1]. This includes appropriate detection systems, cycle lengths and phasing, intervals, and related equipment [*A.10*]. ITE compiled a list of many design features specific to signalized intersections which are available to increase visibility, information and convenience for pedestrians (**Figure 13**).

Traffic Signals

Traffic signals can help to provide opportunities for pedestrians to cross the street at locations where crossings would either be difficult, impart excessive delay and result in potential safety concerns [*A.41*]. The MUTCD establishes standards, guidance, options and support specific to the use of traffic signals in the United States [*A.1*]. It is also important to note that an interim approval was published in 2017 which allows for the optional use of an alternative crash experience signal warrant in addition to the other warrants in the MUTCD which includes pedestrian crash frequency [*A.148*]. Pedestrian accommodations should be included at all signalized intersections regardless if there are irregular pedestrian crossings [*A.41*].

Pedestrian Signals

The MUTCD notes that "Pedestrian signal heads provide special types of traffic signal indications exclusively intended for controlling pedestrian traffic" [*A.1*]. This includes a WALKING PERSON (for WALK) and an UPRAISED HAND (for DON'T WALK) with or without pedestrian countdown displays (**Figure 14**) [*A.1*]. Prior research has demonstrated that the implementation of pedestrian countdown signal heads can reduce pedestrian-involved crash frequencies and should be included on new installations [*A.70*]. Detection for pedestrians can include pushbuttons or passive devices that do not require the pedestrian to use pushbuttons [*A.41, A.115*]. In general, the FHWA recommends ensuring that signals are visible to pedestrians, providing a walk interval for every cycle, providing supplemental non-visual guidance for disabled users, and installing marked crosswalks consistent with pedestrian signal heads [*A.41*]. The FHWA notes that in an ideal scenario, all signalized intersections would include pedestrian signal heads. [*A.41*]. The United Kingdom has experimented with several signalized pedestrian crossing devices, including the Pelican, Puffin and Toucan crossings [*A.151*].

Shorter and more visible crosswalks	• Crosswalks on all approaches; • Longitudinal markings (possible use of colored and/or textured paving); • Reduced overall street widths by reducing the number of travel and turn lanes, or narrowing travel lanes; • Curb extensions with pedestrian push buttons on extensions; and • Median refuges on wide streets (greater than 60 feet) with median push buttons.

Priority for pedestrians, bicyclists, and accessibility	• Shorter cycle lengths, meeting minimum pedestrian clearances (also improves transit travel times);
	• Longer pedestrian clearance times (based on 3.5 feet/sec. to set flashing (clearance) time and 3.0 feet/sec for total crossing time);
	• Reduced conflicts between pedestrians and turning vehicles achieved with:
	  ▪ Pedestrian lead phases;
	  ▪ Scramble phases in very high pedestrian volume locations;
	  ▪ Restricted right turns on red when pedestrians are present during specified hours; and
	  ▪ Allowing right turns during cross-street left turn phases reduces the number of right turn conflicts during pedestrian crossing phase.

Low speed channelized right turn lanes	• Adequate sized islands for pedestrian refuge; • Raised pedestrian crossing/speed table within channelized right turn lane; and • Signal control of channelized right turn in high pedestrian volume locations.
Improved pedestrian information	• Pedestrian countdown timers; and • "Look Before Crossing" markings or signs.
Bicycle features	• Bicycle lanes striped up to crosswalk (using "skip lines" if vehicular right turns are allowed); • Bicycle detectors on high volume routes, or bicyclist-accessible push buttons; • Adequate clearance interval for bicyclists; • Colored paving in bicycle/vehicle lanes in high-conflict areas; and • "Bike Boxes" (painted rectangle along right hand curb or behind crosswalk) to indicate potential high-conflict area between bicycles continuing through an intersection and right turning vehicles, and to allow bicyclists to proceed through intersection or turn in advance of vehicles.
High-priority transit thoroughfare elements	• Adaptive Transit Signal Priority (TSP) when transit detected: • Extended green phase on bus route (rapid transit signal priority); • Truncated green phase for cross street; • Re-order phasing to provide transit priority (transit priority not to be given in two successive cycles to avoid severe traffic impacts); • Other bus priority signal phasing (sequencing) • Queue jump lanes and associated signal phasing; and • Curb extension bus stops, bus bulbs.

Accessibility and space for pedestrians	• Properly placed pedestrian actuation buttons, with audible locator tones;
	• Detectable warnings;
	• Two curb ramps per corner depending on radius of curb return and presence of curb extensions;
	• Clear pedestrian paths (and shoulder clearances) ensuring utilities and appurtenances are located outside pedestrian paths;
	• Vertical and overhang clearance of street furnishings for the visually impaired;
	• Properly placed signal poles and cabinets:
	  ▪ Behind sidewalks (in landscaping or in building niches);
	  ▪ In planting strips (furnishings zone); and
	  ▪ In sidewalk or curb extensions, at least three feet from curb ramps.

Traffic operations for safe speeds and pedestrian convenience	• Target speeds between 25–35 mph; • Signal progression at target speeds; and • Fewer very long/very short cycle lengths.
Higher priority on aesthetics	• Textured and colored material within the streetside; • Colored material within crosswalks, but avoid coarse textures which provide rough surfaces for the disabled; • Attractive decorative signal hardware, or specialized hardware; and • Attention to landscaping and integration with green street stormwater management techniques.

Figure 13. Pedestrian and Bicycle Features at Signalized Intersections [*A.22*]

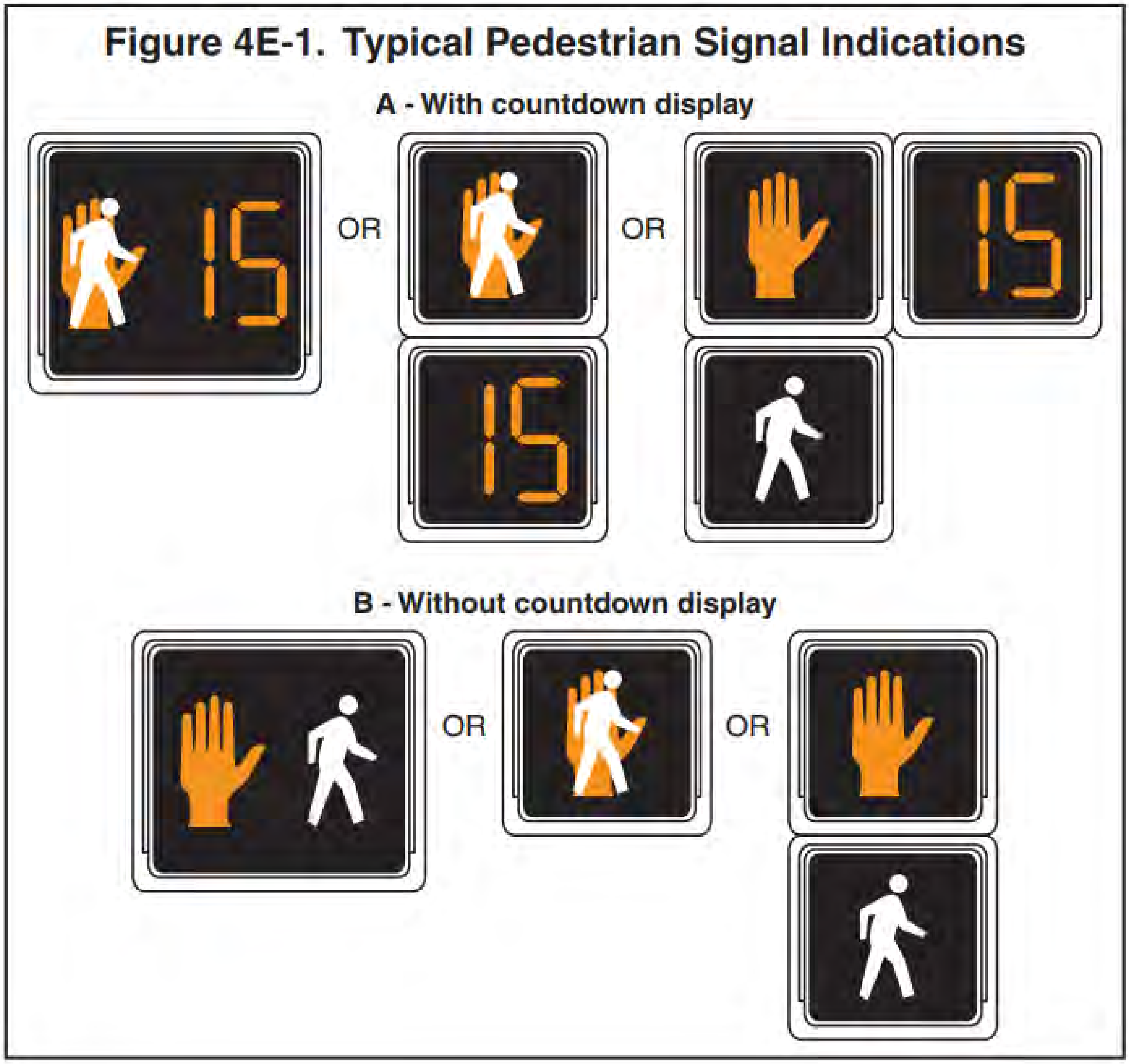


Figure 14. Typical Pedestrian Signal Indications (Figure 4E-1 from MUTCD) [*A.1*]

Accessible Pedestrian Signals

Accessible pedestrian signals are devices that communicate timing information via non-visual formats, such as audible tones, verbal messages and vibrating surfaces [*A.1, A.96, A.111*]. NCHRP's *Accessible Pedestrian Signals: A Guide to Best Practices* complies detailed design information, guidance, case studies and best practices with respect to the use accessible pedestrian signals, including the following general design principles:

- "Provide pedestrian signal information to those who cannot see the pedestrian signal head across the street

- Provide information to pedestrians about the presence and location of pushbuttons, if pressing a button is required to actuate pedestrian timing
- Provide unambiguous information about the WALK indication and which crossing is being signaled
- Use audible beaconing only where necessary
    - Put as little additional sound in the environment as possible
    - Avoid disturbance of neighbors
    - Allow pedestrians who are blind or visually impaired to hear the traffic sounds, as well as the APS" [*A.96*].

Signal Timing for Pedestrians

Pedestrian signal timing generally refers to the length of the WALK and related change intervals [*A.96*]. NCHRP's *Accessible Pedestrian Signals: A Guide to Best Practices* provides a detailed summary of the aspects related to signal timing for pedestrians [*A.96*]. It should be noted there is a NCHRP project currently under way to develop guidance specific to traffic signal design and non-motorized road users [*A.139*].

There are a variety of signal timing best practices, strategies and other considerations which have been recommended to improve safety and mobility for pedestrians, including [*A.10, A.13, A.41*]:

- Consider reducing cycle lengths (preferably from 60 to 90 seconds) to help reduce delays for non-motorized road users and increase crossing compliance rates
- Consider protected, exclusive and leading pedestrian phases when deemed appropriate by an engineering study to reduce conflicts between pedestrians and vehicles
- Consider prohibiting "Right Turn on Red" movements where pedestrian volumes are high or exclusive pedestrian phases are employed
- Consider synchronizing signals to encourage drivers to maintain travel speeds consistent with low target speeds
- Consider the impacts of fixed vs. actuated signalization and the number of overall signal phases on pedestrian crossings
- Pedestrian phases should be activated automatically, with actuation for pedestrians only where crossing activity is intermittent

Leading Pedestrian Intervals

Conventionally, pedestrian crossing signal phases are run concurrent with adjacent circular green vehicle phases [*A.130*]. As a result, a potential conflict can occur between turning vehicles and pedestrians completing crossing movements [*A.130*]. Leading pedestrian intervals (LPIs) involve beginning the pedestrian walk interval approximately three to seven seconds before the adjacent circular green in order to allow pedestrians to establish their presence within the marked crosswalk and be more visible to drivers [*A.10, A.13, A.130*]. **Figure 15** shows an example of an intersection with an LPI and **Figure 16** describes the movements associated with their use. It is important to note that the MUTCD notes as a part of "Frequently Asked Questions" that LPIs are specifically allowed per *Section 4E.06* [*A.1*].

Figure 15. Example of an Intersection with a Leading Pedestrian Interval [*A.130*]

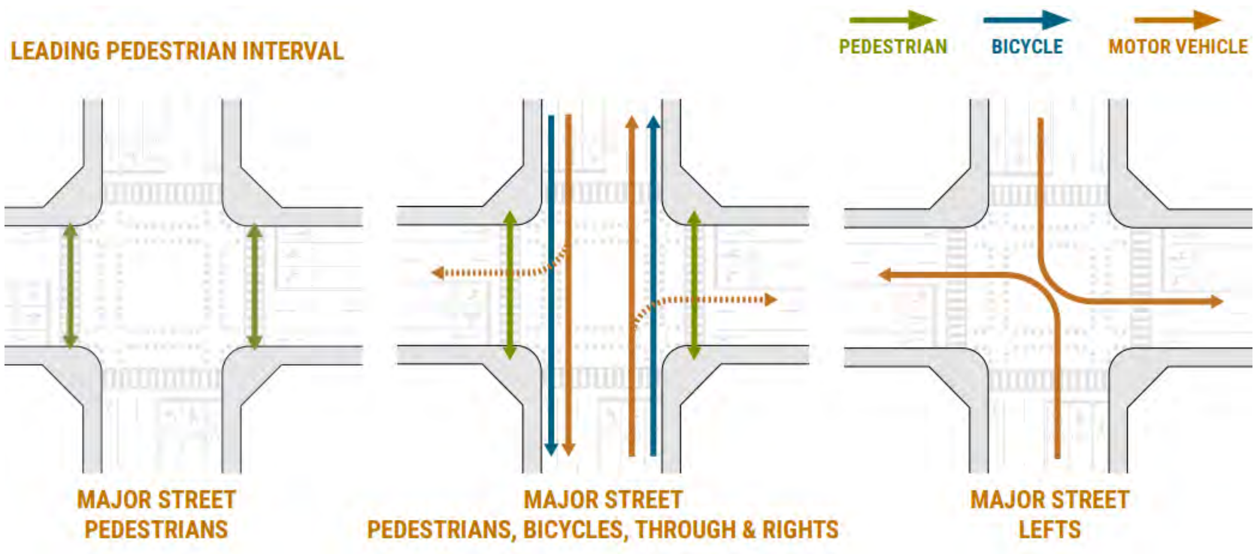
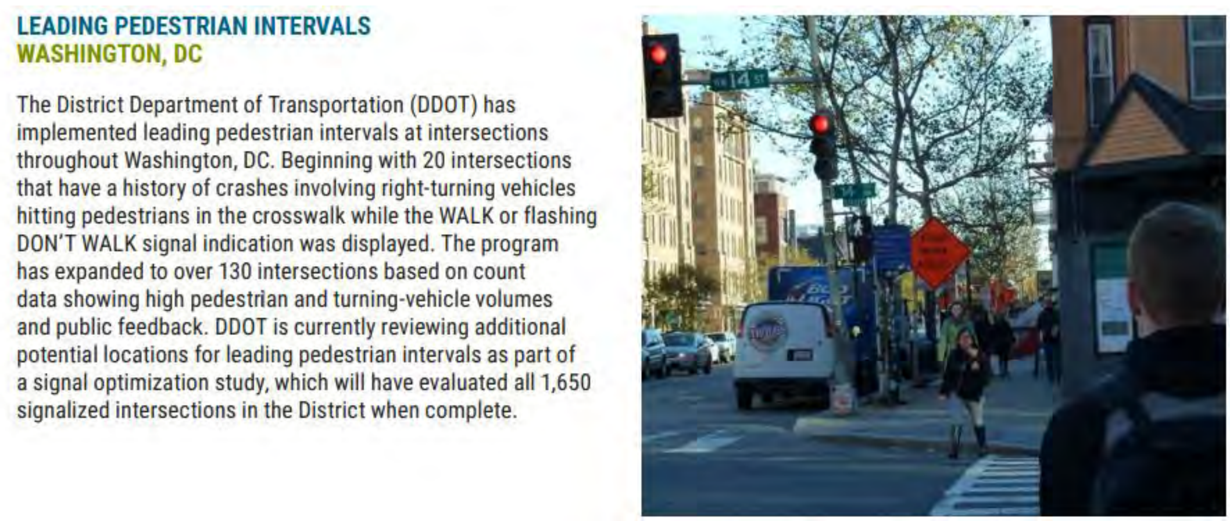


Figure 16. Movements Associated a Leading Pedestrian Interval [*A.10*]

Prior safety studies of LPIs demonstrated pedestrian-vehicle crash reductions ranging from 13 to nearly 60 percent [*A.130, D.61*]. Prior work has also identified several best practices, recommendations and other considerations with respect to LPIs, including [*A.10, A.13, A.96*]:

- Consider the potential impacts on visually impaired pedestrians who may be unaware of the presence of the LPI and wait to enter the crosswalk until they hear parallel traffic begin moving.
- Consider LPIs at intersections which involve frequent conflicts between pedestrians and turning vehicles – locations which would generally warrant the use of a dedicated interval for pedestrian crossing movements.
- Consider implementing LPIs in conjunction with curb extensions to reduce crossing distances at the intersection.

More information specific to the use of leading pedestrian intervals can be found within several resources aggregated in **Appendices A-D** [*A.10, A.13, A.41, A.96, A.130, D.8, D.61, D.82*]. A case study example of a program to implement leading pedestrian intervals in Washington, D.C. is provided in **Figure 17**.


LEADING PEDESTRIAN INTERVALS
WASHINGTON, DC

The District Department of Transportation (DDOT) has implemented leading pedestrian intervals at intersections throughout Washington, DC. Beginning with 20 intersections that have a history of crashes involving right-turning vehicles hitting pedestrians in the crosswalk while the WALK or flashing DON'T WALK signal indication was displayed. The program has expanded to over 130 intersections based on count data showing high pedestrian and turning-vehicle volumes and public feedback. DDOT is currently reviewing additional potential locations for leading pedestrian intervals as part of a signal optimization study, which will have evaluated all 1,650 signalized intersections in the District when complete.

Figure 17. Leading Pedestrian Intervals in Washington, D.C. [*A.10*]

Advance Stop or Yield Markings

Per AASHTO guidance, "Elements, such as crosswalk treatments, signal location, and signal timing, should account for pedestrians and other roadway users" [*A.24*]. One example of this concept is the placement of the vehicle stop bar or yield line at signalized intersections. Specifically, placing the stop bar back four feet from crosswalk can allow greater visibility of pedestrians and alleviate concerns related to vehicles crowding pedestrian crossings by stopping too close to the crosswalk [*A.41*]. The effectiveness of the treatment relies on drivers to comply with the pavement markings, in certain locations it may be more advantageous to use a wider crosswalk instead [*A.41*]. Prior research has shown that the treatment is associated with a reduction in pedestrian -vehicle conflicts as well as an increase in yielding compliance [*A.150*]. Recent NCHRP research developed a crash modification factor of 0.750 for pedestrian crashes specific to the implementation of advanced YIELD or STOP markings and signs, shown in **Figure 18** [*A.150*].

Figure 18. Example of Advanced STOP (left) and YIELD (right) Markings and Signs [*A.150*]

2.3 Pedestrian Design at Roundabouts

While modern roundabouts conversions from traditional signalized or unsignalized intersections have demonstrated potential improvements in safety and operational performance, as well potential benefits to aesthetics and urban design considerations, there are some concerns specific to the accommodation of non-motorized road users [*A.22*]. In particular, multilane roundabouts can present problems for pedestrians with visual impairments, as well as for bicyclists [*A.22*]. There are a variety of design considerations specific to accommodating pedestrians at roundabouts, including [*A.22, A.41*]:

- Locate roundabout pedestrian crossings at least 25 feet from entry points
- Consider providing midblock crossings away from multilane roundabouts
- Ensure that landscaping features in the center island are not attractive to pedestrians
- Consider channelizing islands at approaches to lower vehicle speeds and allow pedestrians to cross only one direction of travel at a time; include ADA-compliant at-grade pedestrian cut-throughs
- Accessible pedestrian signals should be considered at single lane roundabouts and are required at multilane roundabouts per accessibility guidance

More detailed information related to pedestrian accommodations for modern roundabouts can be found in the references aggregated in **Appendices A-D** [*A.22, A.41, A.89, A.104, C.42, C.108, D.22, D.130*].

2.4 Pedestrian Design at Interchanges and Alternative Intersections

Pedestrian facilities adjacent to interchange areas, particularly crossings near ramps, should involve design considerations similar to those related to highway intersections [*A.41*]. This includes keeping crossings as short as possible, using smaller turning radii and the implementation of raised median islands as needed [*A.41*]. ITE recently developed the *Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges* which provides key information towards improving safety and accessibility for non-motorized road users at interchanges [*A.45*]. It is also important to note that NCHRP has research underway to develop guidance specific to accommodating pedestrians and bicyclists alternative intersections (such as median u-turn and restricted crossing u-turn designs) and interchanges (such as diverging diamonds) [*A.125*].

2.5 Network-Wide Considerations for Pedestrians

The pedestrian transportation network is comprised of sidewalks, street crossings, shared streets, shared use paths, and paved shoulders which should be connected and consistent to reduce conflicts and encourage higher levels of activity [*A.10*]. The planning of pedestrian networks is conducted at a variety of scales, from region-wide systems to plans specific to a small area [*A.10*]. According to the FHWA, exemplary pedestrian and bicycle networks satisfy the principles shown in **Table 1**.

Table 1. Principles for Exemplary Pedestrian and Bicycle Networks [*A.18*]

Principle	Description
Cohesion	How connected is the network in terms of its concentration of destinations and routes?
Directness	Does the network provide direct and convenient access to destinations?
Accessibility	How well does the network accommodate travel for all users, regardless of age or ability?
Alternatives	Are there a number of different route choices available within the network?
Safety and Security	Does the network provide routes that minimize risk of injury, danger, and crime?
Comfort	Does the network appeal to a broad range of age and ability levels and is consideration given to user amenities?

Prior work has also identified several basic concepts specific to the design and planning of pedestrian networks, including [*A.10, A.23*]:

- Cul-de-sacs common to suburban street networks can force people towards higher-volume, higher-speed arterials rather than local streets. Keep block sizes small and connect cul-de-sac street works via shared use paths.

- Freeways, railroad tracks and other transportation network elements can create barriers for non-motorized road users, resulting in excessive crossing distances. Consider adding crossings (such as bridges or tunnels) to improve network connectivity. A case study from West Long Branch, New Jersey involved the construction of a pedestrian underpass to redirect pedestrians from a poorly performing at-grade crossing [***C.65***].
- Provide sidewalks on both sides of the street, particularly for higher-volume and higher-speed roadways
- Consider enhanced crossing treatments (**Section 2.7**) to improve connectivity
- Consider traffic calming elements and other geometric treatments to reduce crossing distances and reduce travel speeds (**Section 2.1.5**)
- While developing interconnected pedestrian networks in rural areas can be challenging, it remains important to think creatively to establish connected facilities in these areas
- Networks should provide a high degree of connectivity to that users can select the most direct routes for access
- Networks should provide for intermodal connectivity so that users can easily transfer between modes

2.5.1 Context Sensitive Solutions

Context sensitive solutions (CSS) is a broad concept with a variety of definitions in use by highway agencies [*A.22*] However, CSS generally involves an approach to the design and planning of transportation projects which balances the competing needs of stakeholders and also allows for the flexibility in design controls, guidelines and standards towards an ultimate project which works for all road users regardless of the mode of travel, with the following core principles [*A.22*]:

- Balancing safety, mobility, community and environmental goals
- Involve the public and shareholders throughout the entire planning and project development process, particularly early on
- Employ a multidisciplinary team specific to the project
- Consider all modes of travel and all types of road users
- Allows for flexibility in design standards
- Incorporates aesthetics and accessibility

2.5.2 Complete Streets Policies

Smart Growth America defines complete streets as roadways which are "designed and operated to enable safe access for all users, including pedestrians, bicyclists, motorists and transit riders of all ages and abilities" [*A.152*]. Communities across the United States have recently begun adopting complete streets policies, directing planners and engineers to "consistently design and construct the right-of-way to accommodate all anticipated users, including pedestrians, bicyclists, public transportation users, motorists, and freight vehicles" [*A.152*]. The prior literature includes a variety of resources which can be used to adopt and implement complete streets policies [*A.29, A.78, A.92, A.94, A.152, C.18, C.29, C.40, C.63, C.111, D.6, D.120*].

MDOT's Multi Modal Development and Delivery Initiative

Within the context of context sensitive solutions and complete streets, MDOT has recently partnered with Smart Growth America as a part of its *Multi Modal Development and Delivery* (M2D2) initiative [*C.111*]. The process initiated in 2013 as MDOT and Smart Growth America identified needs and expectations for Michigan's transportation system to balance the considerations for all modes of travel collectively [*C.111*], which culminated in the *M2D2 Work Plan* in 2015 [*C.40*]. Most recently, MDOT published their *M2D2 Guidebook* which is intended to serve as a collaboration tool for MDOT staff, staff from state and local agencies, non-profits, and other stakeholders [*C.111*]. The document includes best practices and examples "for planning and designing smart transportation networks that support sustainable and livable communities" [*C.111*]. The *M2D2 Guidebook* is comprised of benchmarking to measure existing readiness, data gathering for informed projects as well as an implementation framework [*C.111*].

2.5.3 Other Guidance and Initiatives

Recently, a private company is developing a web-based application which employs smart data with sidewalk and pathway network data in order to improve pedestrian accessibility and walkability [*A.153*]. The pathVu application provides information to its users about the accessibility of pedestrian routes towards their ultimate destination via a web interface (**Figure 19**) [*A.153*]. This includes a route accessibility index which considers the quality of the route based upon data collected by the company as well as from the application [*A.153*].

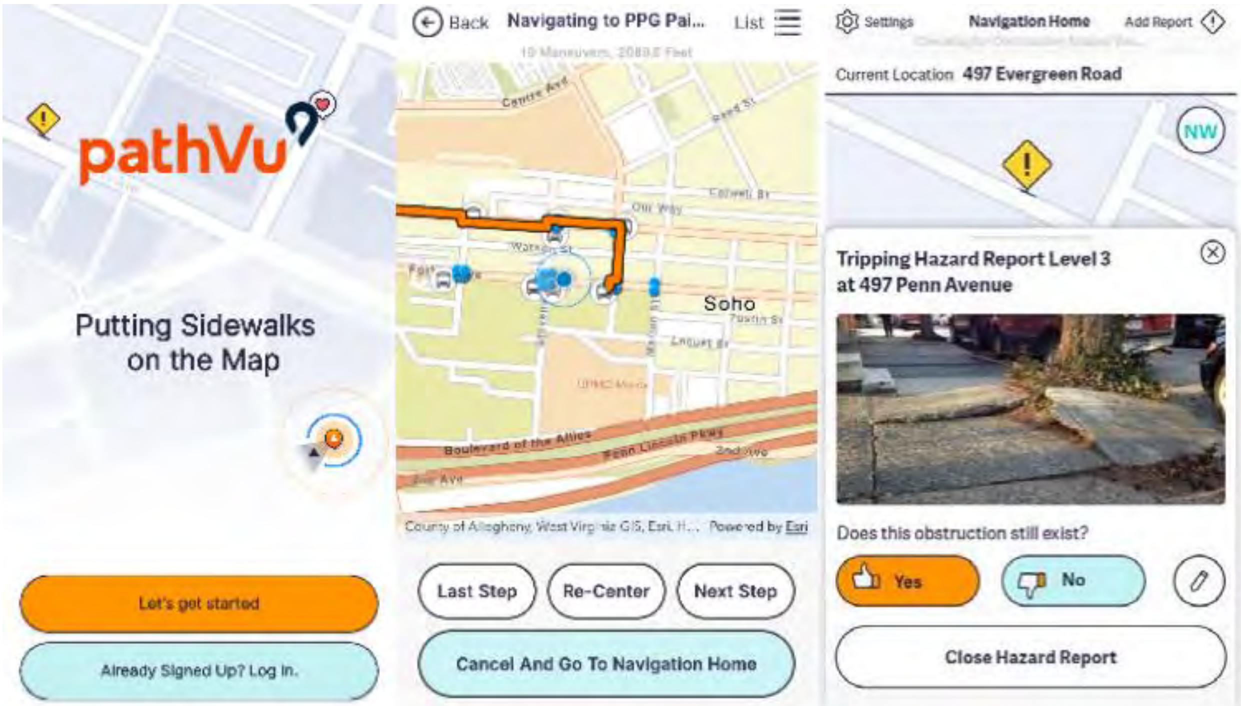


Figure 19. Screenshots from pathVu Application [A.153]

There is a wealth of prior guidance and case studies specific to pedestrian network planning, context sensitive solutions, complete streets policies and multi modal delivery and development; additional information on this topic can be found in the references aggregated in **Appendices A-D** [*A.10, A.18, A.22, A.23, A.27, A.29, A.42, A.78, A.92, A.94, A.145, A.152, C.18, C.29, C.50, C.63, C.111, D.6, D.120*].

2.6 Performance Measures and Other Data Considerations

While performance measures related to pedestrians and the transportation system is a complex topic which is outside the scope of this memorandum, it remains an important consideration as certain performance measures and other data are often required to objectively plan, prioritize and design potential pedestrian projects [*A.19*]. Performance measures can also be used to compare plan alternatives or measure the performance of a specific objective [*A.22*]. The FHWA published the *Guidebook for Developing Pedestrian and Bicycle Performance Measures* in 2016, which provides guidance on performance measures specific to pedestrian and bicycle planning which can be used for ongoing activities [*A.19*]. The guidebook identifies seven categories of community goals which are used as a framework for measuring performance, including [*A.19*]:

- Connectivity

- Economic
- Environment
- Equity
- Health
- Livability
- Safety

There are a variety of resources aggregated in **Appendices A-D** which provide greater detail specific to performance measures specific to pedestrian planning and design [*A.19, A.22, A.26, A.47, A.78, B.23*].

2.6.1 Pedestrian Volume Data Collection

One data element which is key to a variety of performance measures and other data-driven design and planning decisions is the availability of pedestrian volume data. The FHWA notes that "Clear and comprehensive information about pedestrian travel patterns is a critical component of multimodal transportation planning, programming, and management." [*A.101*]. Such data can be used for a variety of functions, including [*A.39, A.101*]:

- Tracking changes in non-motorized activity or travel patterns
- Evaluating the impacts of new facilities on non-motorized activity
- Prioritizing non-motorized infrastructure projects
- Travel demand modeling or volume estimation planning tasks
- Performing safety risk or exposure analyses
- Supporting economic development
- The design and operation of transportation facilities
- Other pedestrian-related traffic studies

Both FHWA's *Exploring Pedestrian Counting Procedures* [*A.101*] and NCHRP's *Guidebook on Pedestrian and Bicycle Volume Data Collection* [*A.39*] can be referred to for additional information specific to pedestrian volume data collection and related applications.

2.6.2 Pedestrian Safety, Risk and Traffic Crash Data

The evaluation of pedestrian safety performance and the identification of potential risks to pedestrians within the transportation system is an important concept that is outside the scope of this memorandum which includes a broad range of prior research, including work conducted by MDOT [*C.44, C.52, C.56*]. However, there are a variety of design and planning decisions which incorporate relative pedestrian safety performance, historical crash frequencies, and/or systemic risk. For example, this includes the alternative signal warrant which has interim approval that includes pedestrian crash frequency [*A.148*]. This concept is particularly relevant given FHWA encourages a data-driven approach to identifying and mitigating safety problems [*A.54*].

There is variety of prior published research and other guidance specific to the analysis of historical pedestrian crash data and other pedestrian-specific safety studies, including:

- FHWA's *Guidebook on Identification of High Pedestrian Crash Locations* [*A.54*]
- FHWA's *Pedestrian and Bicycle Crash Analysis Tool* [*A.149*]
- FHWA's *Pedestrian and Bicyclist Intersection Safety Indices: User Guide* [*A.82*]
- FHWA's *Pedestrian Safety on Rural Highways* [*A.107*]
- Florida DOT's *Comprehensive Study to Reduce Pedestrian Crashes in Florida* [*C.24*]
- Oregon DOT's *Risk Factors for Pedestrian and Bicycle Crashes* [*C.81*]
- Seattle DOT's *City of Seattle Bicycle and Pedestrian Safety Analysis* [*A.98*]
- *Pedestrian Crash Trends and Potential Countermeasures from Around the World* [*D.4*]

Systemic and Risk-Based Evaluation Methods

Generally, pedestrian safety risk has been defined as "a measure of the probability of a crash to occur given exposure to potential crash events." [*A.52*]. Exposure has also generally been defined as "a measure of the number of potential opportunities for a crash to occur." [*A.52*]. In addition to a traditional approach to pedestrian safety evaluation (e.g. using historical crash data to identify "hot spots"), there are also proactive risk-based approaches which employ predictive models (such as safety performance functions) which can be used to assess the potential risk for crashes to occur based upon site characteristics rather than a historical pattern of crashes alone [*A.52*]. This can also be extended to a systemic approach recommended by the FHWA which takes a broader view of risk across an entire roadway system [*A.52*]. A systemic approach recognizes that historical crash data alone can be insufficient to determine locations which may benefit from specific countermeasures, especially when crash densities are lower (e.g. in rural areas or crashes involving non-motorized users) [*A.52*].

FHWA's *Synthesis of Methods for Estimating Pedestrian and Bicyclist Exposure to Risk at Areawide Levels and on Specific Transportation Facilities* summarizes available methods to evaluate exposure to risk specific to pedestrians and bicyclists [*A.52*]. Additional guidance can be also found in FHWA's *Guide for Scalable Risk Assessment Methods for Pedestrians and Bicyclists* [*A.75*] and NCHRP's *Systemic Pedestrian Safety Analysis* [*A.53*]. It is important to note that NCHRP currently has a project underway to develop safety performance functions specific to pedestrians and bicyclists to be integrated into the next version of the AASHTO's *Highway Safety Manual* [*A.141*]. Guidance has also been developed by FHWA to assist in the safety assessment of traffic control devices for pedestrians and bicyclists [*A.88*].

Road Safety Audits

A road safety audit (RSA) is a formal safety examination of a future project or in-service facility that is conducted by an independent multidisciplinary team [*A.36*]. While RSAs in general should consider pedestrian safety – RSAs may be conducted in response to a previously identified pedestrian concern [*A.36*]. FHWA has developed guidance specific to pedestrian RSAs, including an existing knowledge base, a field manual as well as prompt lists [*A.36*]. FHWA has also recently conducted similar pedestrian and bicyclist safety assessments in every state as well as Puerto Rico and Washington, D.C. [*A.28*]. A summary report was subsequently published which highlights findings from the assessments which can be used in future endeavors [*A.28*]. A case study example from North Carolina included conducting pedestrian- and bicycle-specific RSAs at eight areas which were identified for potential study using historical crash data, road user surveys and other proactive methods [*C.79*].

2.7 Crossing Treatments

Pedestrian crossings, including both midblock and at intersections, "should provide safe and comfortable locations to cross the street." [*A.10*]. NACTO notes that in situations where a signalized or stop-controlled crossing is not warranted but potential crossing demand may exist, enhanced crossing treatments or actuated crossings should be considered [*A.13*]. An important concept specific to pedestrian crossing design is that pedestrians will often cross where necessary to conveniently access their destination, particularly in cases where the spacing of crossings is high or the desire line is directly across the street [*A.22*]. This can expose pedestrians to conflicts with vehicles in situations where drivers are not expecting them [*A.22*]. Midblock crossings represent an important consideration to respond to this potential pedestrian behavior, providing for crossing environments that both protect pedestrians and also warn drivers of the presence of potential pedestrians downstream [*A.22*].

There are several design considerations related to pedestrian crossing treatments identified in prior guidance, including [*A.10, A.13, A.22, A.41, A.44, A.68*]:

- Surrounding land use on each side of the street and walking distances with and without crossing treatments should be considered
- It is important to consider both existing and potential future crossing demand
- Frequent crossings can help to reinforce walkability of a corridor
- The presence of a crosswalk alone does not automatically result in a safe crossing environment, additional treatments should be considered depending on the context
- Simply not marking uncontrolled crossings is not a viable solution as this can encourage unsafe crossing behaviors
- Pedestrian crossings should be at-grade unless the crossing involves a limited access highway as overpasses/underpasses can be a security risk or not used in lieu of a more direct route
- Enhanced crossing treatments should be considered for unsignalized crossings adjacent to transit stops
- It is critical to consider stopping sight distance per the *Green Book*
- Midblock crossings should be able to be identified by pedestrians with vision impairments

While the subsections that follow cover specific crossing treatments in greater detail, there are several resources aggregated in **Appendices A-D** which provide guidance specific to the consideration of uncontrolled pedestrian crossing treatments [*A.10, A.13, A.22, A.41, A.56, A.68, A.70, A.121, A.144, A.150, C.17, C.45, C.95, D.13, D.20, D.50, D.58*]. A case study example is presented in **Figure 20** from Seattle, Washington which involved a comprehensive improvement plan for pedestrian crossings at uncontrolled locations.

IMPROVEMENT PLAN FOR UNCONTROLLED MARKED CROSSWALKS
SEATTLE, WA

In 2001, the City of Seattle completed a detailed inventory analysis of 622 marked crosswalks at uncontrolled locations. Crosswalks were rated based on traffic volume, number of lanes, and speed. In 2002, the City released a multi-year Improvement Plan for Uncontrolled Marked Crosswalks that addressed identified deficiencies. Rather than just decide "yes" or "no" on whether to mark a crosswalk, the improvement plan asks "what are the most effective measures that can be used to help pedestrians safely cross the street?" The plan was implemented over a period of six years. Deficiencies were addressed with signing, markings, crossing islands, road and lane diets, rectangular rapid flash beacons, pedestrian signals, and other ADA improvements.

Figure 20. Improvement Plan for Uncontrolled Marked Crosswalks from Seattle, WA [*A.10*]

2.7.1 Crosswalk Markings

An important consideration related to pedestrian crossings is the decision to mark crosswalks and provide enhanced crossing treatments [*A.10*]. The MUTCD states that "crosswalk lines should not be used indiscriminately" and an engineering study should be performed which considers the number of lanes, the spacing of signalized intersections, crossing and vehicular volumes as well as the speed of vehicles [*A.1, A.13*]. Enhanced crossing treatments should also be considered for locations that have higher traffic volumes and/or speeds, as well as longer crossing distances [*A.10, A.13, A.114*]. **Figure 21** presents Table 11 from FHWA's *Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations* which provides recommendations for marked crosswalks and other improvements based upon geometry, traffic volume and speed.

Table 11. Recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled locations.*

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT ≤ 9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT >12,000–15,000			Vehicle ADT > 15,000		
	Speed Limit**											
	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median***	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

* These guidelines include intersection and midblock locations with no traffic signals or stop signs on the approach to the crossing. They do not apply to school crossings. A two-way center turn lane is not considered a median. Crosswalks should not be installed at locations that could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, a substantial volume of heavy trucks, or other dangers, without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossings safer, nor will they necessarily result in more vehicles stopping for pedestrians. Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic-calming measures, curb extensions), as needed, to improve the safety of the crossing. These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.
** Where the speed limit exceeds 64.4 km/h (40 mi/h), marked crosswalks alone should not be used at unsignalized locations.
*** The raised median or crossing island must be at least 1.2 m (4 ft) wide and 1.8 m (6 ft) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and American Association of State Highway and Transportation Officials (AASHTO) guidelines.
C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more indepth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.
P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.
N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.

Figure 21. Recommendations for Installing Crosswalks and Pedestrian Improvements at Uncontrolled Locations [*A.114*]

There are several specific design considerations related to marked crosswalks identified in prior guidance, including [*A.13, A.70, A.114*]:

- All crossings at signalized intersections should be marked to reinforce yielding behavior for turning vehicles
- Crosswalks should be striped at least as wide as the walkway its connected to
- High-visibility markings (such as ladder, zebra or continental markings) are preferred to conventional crosswalk markings
- Additional consideration should be given to street lighting near crosswalks
- Accessible curb ramps are required at all crosswalks per ADA
- Crossings distances should be kept as short as possible
- Stop bars should be installed perpendicular to the travel lane as opposed to the crosswalk
- Additional consideration should be provided for crossings within school zones

Additional information and guidance specific to the decision to mark a crosswalk and related considerations can be found in the references aggregated in **Appendices A-D** [*A.10, A.13, A.22, A.41, A,68, A.70, A.80, A.90, A.102, A.109, A.112, A.114, C.33, C.46, C.48, C.88, D.62*].

2.7.2 In-Street Pedestrian Crossing Signs

There is a variety of signage specific to unsignalized pedestrian crossings covered in the MUTCD (**Figure 22**) [*A.1*]. However, a treatment which has been evaluated in recent research is the use of in-street R1-6 and R1-6a signs placed on the center line, lane line, or median island [*A.1*], such as the gateway configuration evaluated in Michigan (**Figure 23**) [*C.47*]. The intent of the devices is to indicate the optimal location for crossing while reinforcing the requirement for drivers to yield the right-of-way to pedestrians at crossing locations [*A.41*].

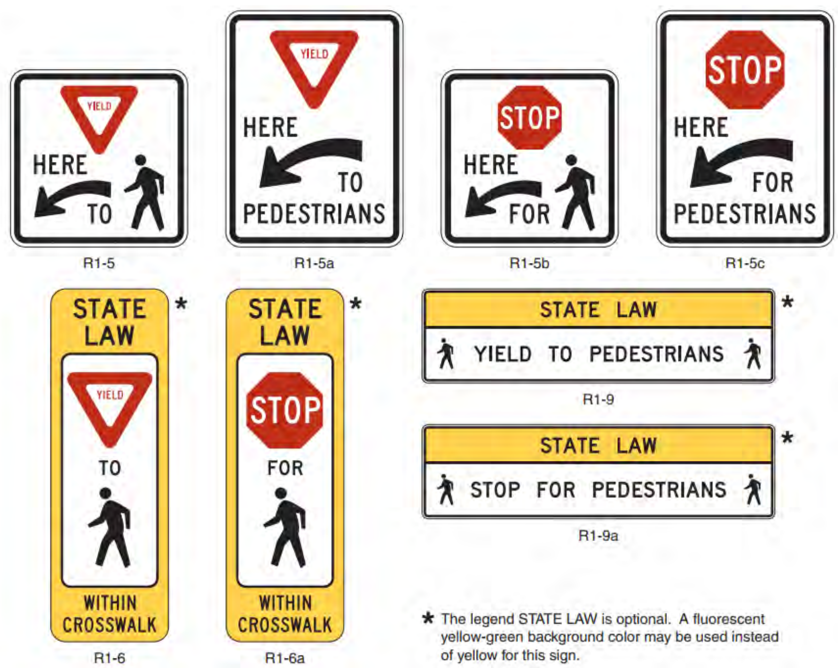


Figure 22. MUTCD Figure 2B-2 Unsignalized Pedestrian Crosswalk Signs [*A.1*]

Figure 23. Example of R1-6 Signs Used as a Gateway Treatment in Michigan [*C.47*]

The devices have been shown to potentially provide benefits related driver yielding compliance as well as traffic calming effects resulting in reduced vehicular speeds [*C.47*]. A recent study conducted in Michigan demonstrated yielding compliance rates of approximately 95 percent [*D.50*]. The treatment is not intended for signalization locations [*A.41*] and may need to be removed during the winter season for snow plowing [*A.41, C.47*]. More information specific to pedestrian crossing signage can be found in the references aggregated in **Appendices A-D** [*A.1, A.41, A.56, A.68, A.70, A.144, C.34, C.42, C.47, C.61, D.29, D.32, D.50, D.51, D.53, D.55, D.59, D.66*].

2.7.3 Pedestrian Hybrid Beacons

A pedestrian hybrid beacon (PHB), shown in **Figure 24**, "is a special type of hybrid beacon used to warn and control traffic at an unsignalized location to assist pedestrians in crossing a street or highway at a marked crosswalk." [*A.1*]. Previously referred to as "high-intensity activated crosswalk beacons" or HAWKs, PHBs incorporate heads which include two red lenses and a single yellow lens with pedestrian signal heads at each end of the crosswalk [*A.56*]. The beacons rest in dark until actuated by a pedestrian via pushbuttons [*A.56*]. PHBs are covered in Chapter 4F of the MUTCD, including the sequence of signal indications shown in **Figure 25** [*A.1*].

Figure 24. Example of a Pedestrian Hybrid Beacon [*A.144*]

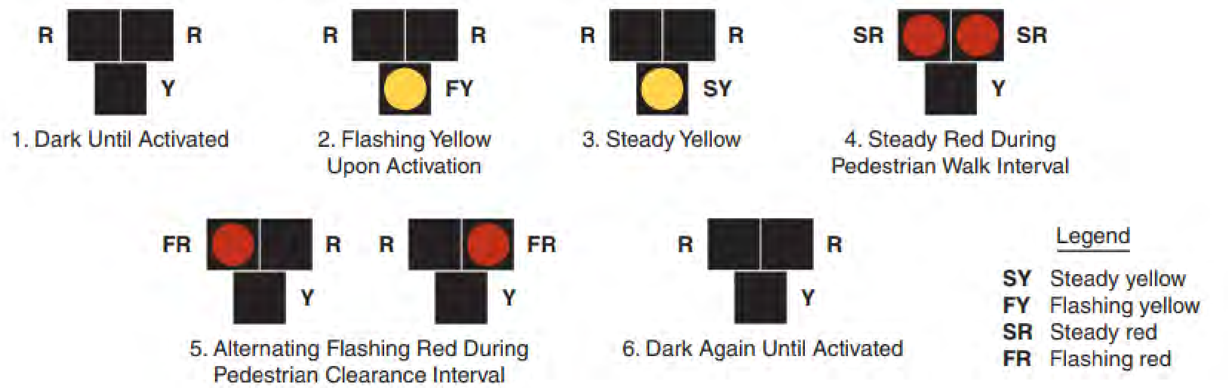


Figure 25. Sequence for a Pedestrian Hybrid Beacon (Figure 4F-3 from MUTCD) [*A.1*]

PHBs can be considered at locations where a demand for crossing exists across a roadway with relatively high traffic volume or speeds but the warrants for a traffic signal are not met [*A.1, A.41*]. While PHBs have been used at intersections under certain conditions (note that this contradicts recommendations in the MUTCD to locate PHBs at least 100 feet away from intersections), they are generally used midblock locations [*A.1, A.41, A.56*]. Prior research has shown pedestrian crash reductions of approximately 69 percent [*A.91*], and recent work conducted by NCHRP recommended pedestrian crash modification factors both with (0.432) and without (0.453) advance STOP or YIELD markings [*A.150*]. These safety benefits are driven by improvements in yielding compliance – prior studies have demonstrated driver yielding rates ranging from 77 to 98 percent, with the majority of studies exceeding 90 percent [*A.91, A.122, C.42, D.33, D.50*]. PHBs can also help reduce the risk of "multiple threat"-type pedestrian crashes [*A.41*]. There are several design requirements, guidance and other considerations specific to the use of PHBs noted in the literature, including [*A.41, A.56, A.63, A.144*]:

- May be a candidate treatment for roadways with three or more lanes and daily traffic volumes greater than 9,000 vehicles per day
- Should be strongly considered for locations with speed limits of 40 MPH or greater
- PHBs should only be installed at marked crosswalks
- Parking and other sight obstructions should be removed adjacent to the crosswalk
- Ensure to coordinate PHBs if within a signal system

More information specific to PHBs can be found in the references aggregated in **Appendices A-D** [*A.1, A.41, A.56, A.63, A.91, A.122, A.123, A.144, A.150, C.22, C.41, C.42, C.85 D.33, D.50*]. A case study example of a PHB from Portland, Oregon is shown in **Figure 26**.

Figure 26. Example of Pedestrian Hybrid Beacon in Portland, Oregon [*A.10*]

2.7.4 Rectangular-Rapid Flashing Beacons

Rectangular rapid-flashing beacons (RRFBs) are "pedestrian-actuated conspicuity enhancements used in combination with a pedestrian, school, or trail crossing warning sign to improve safety at uncontrolled, marked crosswalks" (**Figure 27**) [*A.41*]. "The RRFB uses rectangular-shaped high-intensity light-emitting-diode (LED)-based indications, flashes rapidly in a combination wig-wag and simultaneous flash pattern and may be mounted immediately adjacent to the crossing sign" (**Figure 28)** [*A.9*].

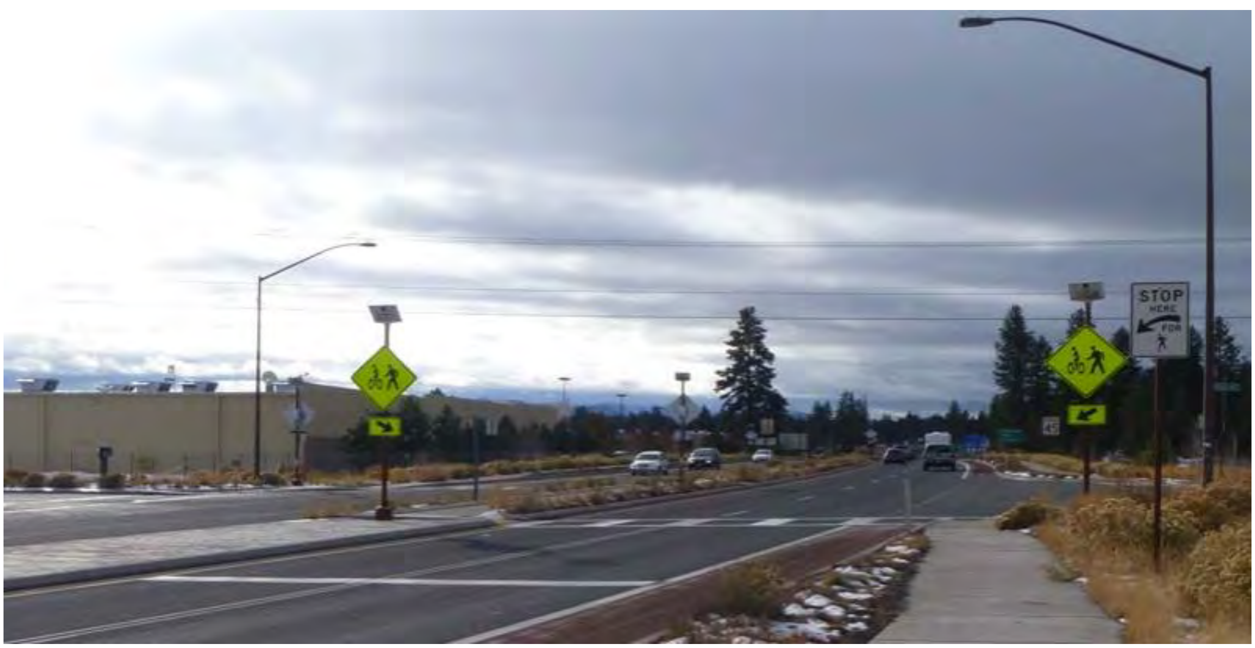


Figure 27. Example of a RRFB Installation in Oregon [*A.86*]

Figure 28. RRFB in Dark and Flashing Mode with W11-2 Sign and W16-7P Plaque [*A.9*]

It is important to note that RRFBs did not meet the standards specific to flashing warning beacons in the 2009 edition of the MUTCD and an interim approval (IA-11) was ultimately granted by the FHWA after reviewing the available research in 2008 [*A.9*]. However, due to concerns related to patenting issues, IA-11 was subsequently terminated by the FHWA in 2017 [*A.9*]. Recently, the FHWA issued IA-21 after the concept of RRFBs was established as a part of the public domain, allowing for the optional use of the devices to provide "enhanced pedestrian safety at uncontrolled marked crosswalks" [*A.9*]. RRFBs should be considered to supplement warning signs at marked crossing locations where signals or PHBs are "not warranted, cost prohibitive, or deemed unnecessary" [*A.10*].

There have been a variety of prior research efforts related to impacts of RRFBs on driver behavior, pedestrian behavior and ultimate safety performance. Recent work conducted by NCHRP suggested a pedestrian crash modification factor of 0.526 associated with the implementation of RRFBs [*A.150*]. Similar to PHBs, these crash reductions are largely driven by increases in yielding compliance, with prior studies demonstrating driver yielding rates of 19 to 100 percent – with the majority of studies near the high end of the range [*A.56, A.58, A.93, A.122, C.42, C.85, C.94, D.50*].

There are several design requirements, guidance and other considerations specific to the use of RRFBs noted in the literature, including [*A.41, A.70*]:

- Can be particularly effective for multilane crossings with speed limits less than 40 MPH

- RRFBs should be installed within the median for divided roadways
- Consider advanced yield or stop pavement markings to supplement RRFBs
- Can often be solar powered to eliminate connecting to a power source
- Should be used judiciously to avoid diminished effectiveness

More information specific to RRFBs can be found in the references aggregated in **Appendices A-D** [*A.9, A.41, A.56, A.58, A.70, A.93, A.122, A.150, C.45, C.62, C.85, C.86, C.94, D.50*].

2.7.5 Pedestrian Refuge Islands

A pedestrian refuge island, also referred to as a median island or a crossing island, provides a refuge area for pedestrians crossing two-way streets within a marked crosswalk (**Figure 29**) [*A.41, A.56, A.144*]. These refuge islands allow "pedestrians to focus on one direction of traffic at a time as they cross and provides space to wait for an adequate gap in oncoming traffic before finishing the second phase of a crossing" [*A.41*]. Pedestrian refuge islands can be considered at both uncontrolled midblock locations as well as at signalized intersections [*A.22, A.41*]. Additionally, they can be used to disaggregate complex crossings into shorter and simpler crossings for pedestrians [*A.22*].

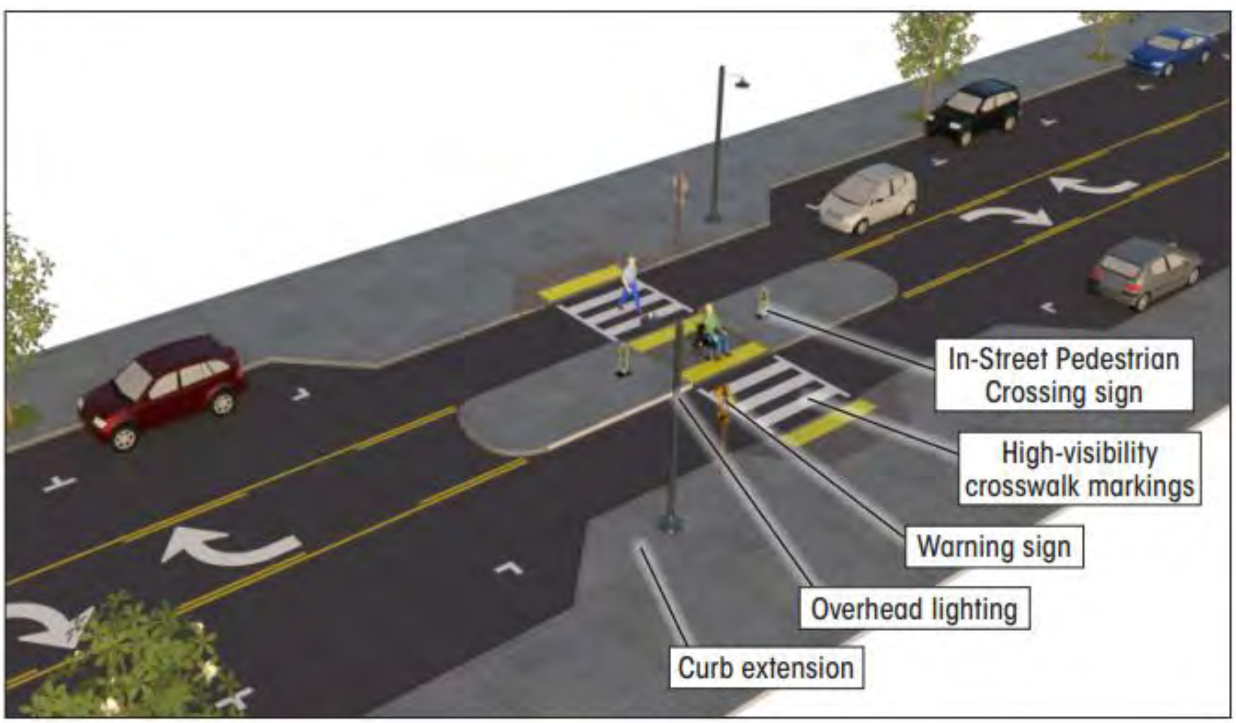


Figure 29. Example of Pedestrian Refuge Island [*A.144*]

Prior research has demonstrated crash reductions ranging between 23 and 73 percent, depending on the configuration and roadway scenario [*A.10, A.32, A.70, A.144*]. There are several design requirements, guidance and other considerations specific to the use of pedestrian refuge islands noted in the literature, including [*A.10, A.22, A.41*]:

- Should be considered for crossings greater than 60 feet or when signalized crossings will be frequently used by pedestrians who walk slower than 3.5 feet per second generally used in timing pedestrian intervals
- Islands should be at least 6 feet wide with an area of 120 square feet, and 10 feet is recommended where refuge islands are installed to improve crossings adjacent to shared use paths
- Islands must include appropriate ADA accommodations; including channels at street grade as well as audio and visual components at signalized intersections
- Highly desirable for midblock crossings of four or more lanes, particularly for roadways with speeds 35 MPH or greater and volumes 9,000 or higher
- Can also be considered for uncontrolled crossings of two and three lane highways with high speeds and/or volumes
- May impact left-turn access near intersections and driveways
- Consider illumination and curb extensions in conjunction with refuge islands

More information on pedestrian refuge islands can be found in the references aggregated in **Appendices A-D** [*A.1, A.,10, A.22, A.41, A.56, A.70, A.87, A.106, A.144, A.150, D.132*], including a case study example from Eureka, California [*C.8*].

2.7.6 Curb Extensions or Bulb Outs

Curb extensions "extend the sidewalk or curb line out into the parking lane and reduce the effective street width", shown in **Figures 30 and 31** [*A.41*]. Curb extensions can have a variety of benefits for pedestrians, including visually and physically narrowing the roadway; increasing the visibility for both pedestrians and motorists due to better positioning; encouraging smaller turning radii resulting in slower turning speeds, preventing parking near the intersection and reducing the overall crossing distance [*A.13, A.22, A.41*].

Figure 30. Drawing of Curb Extensions Implemented in Different Environments [*A.41*]

Figure 31. Example of Curb Extensions [*A.13*]

Curb extensions, also known as bulb-outs or neckdowns [*A.41*], have a variety of potential applications, including being implemented as midblock pinchpoints, as a part of a gateway treatment, as a chicane, and as a “bus bulb” at transit stops. [*A.13, A.41*]. Curb extensions can also provide additional space for street furniture, landscaping and curb ramps [*A.13, A.22, A.41*].

There are several design requirements, guidance and other considerations specific to the use of curb extensions noted in the literature, including [*A.13, A.22, A.41]:*

- Should not extend more than 6 feet from the curb
- Implemented when there is an on-street parking lane
- Turning radii for larger vehicles still need to be accommodated
- Ensure drainage is not significantly impacted
- May require moving existing fire hydrant locations to ensure curbside access
- Should not encroach on the path of travel for bicyclists

More information specific to the use of curb extensions or bulb outs can be found in the references included in **Appendices A-D** [*A.10, A.13, A.22, A.41, A.65, A.70, A.106, A.131, A.144*]. Several case studies are also included which incorporated curb extensions as a part of pedestrian safety treatments [*C.38, C.73, C.77, C.97*].

2.7.7 Raised Pedestrian Crossings

Raised pedestrian crossings are "are ramped speed tables spanning the entire width of the roadway or intersection" (**Figure 32**) with the intent of raising the pedestrian in a vehicles field of vision, reducing vehicular speeds and improving yielding compliance [*A.41*]. While the need for curb ramps are eliminated as the crosswalk can be provided at the same level as the sidewalk, detectable warnings are still included at the street edge [*A.41*]. Prior research has demonstrated pedestrian crash reductions of 45 percent after implantation [*A.41*].

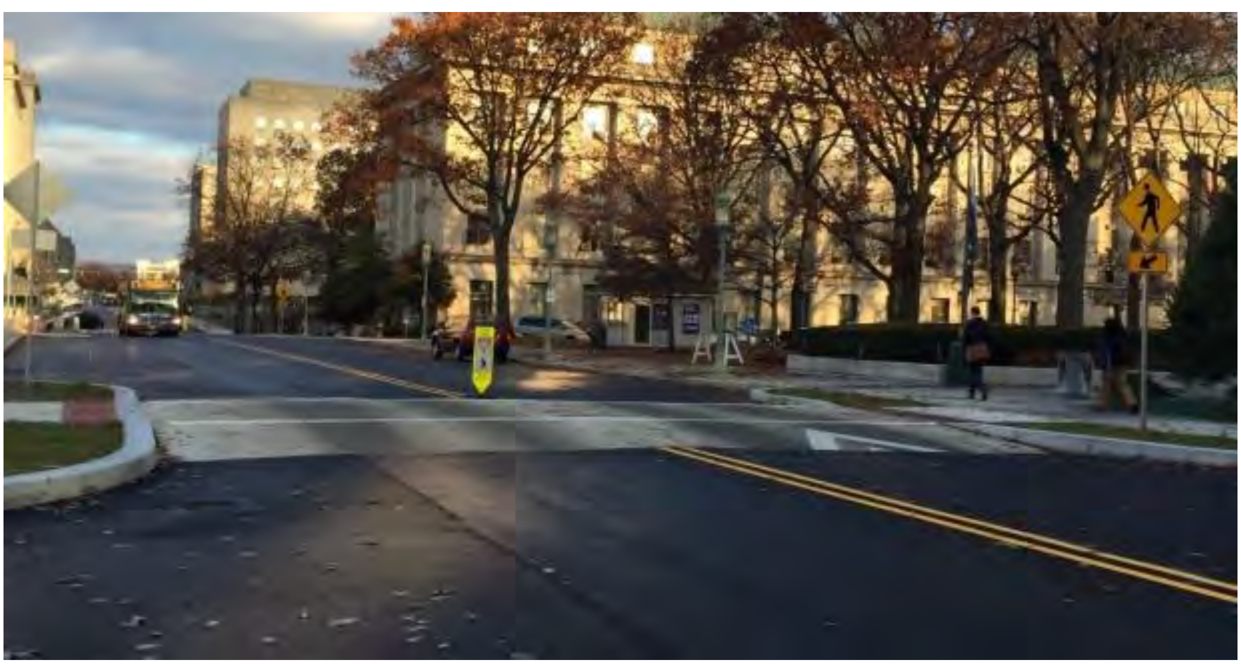


Figure 32. Example of Raised Pedestrian Crossing [*A.41*]

Raised pedestrian crossings should generally be considered for local or collector roadways with two or three lanes, speed limits of 30 MPH or less and daily traffic volumes below 9,000 vehicles per day [*A.41*]. The FHWA also notes that it is a myth that raised crosswalks can't be considered for arterial crossings, recommending that while high speed roadways may not be suitable – they can be used along arterials, particularly at intersections with slip lanes or intersecting side streets [*A.10*]. Raised crossings may not be appropriate for locations along bus transit routes, primary emergency vehicle routes, locations which include considerable curvature or grades, or locations where snowplowing may be a concern [*A.41*]

More information specific to the use of raised crossings can be found in the references included in **Appendices A-D** [*A.1, A.10, A.41, A.70, A.106, D.67*]. Several case studies are also included which incorporated raised crossings as a part of pedestrian safety treatments [*C.38, C.97*], including the example from West Palm Beach, Florida shown in **Figure 33**.

OLIVE AVENUE
WEST PALM BEACH, FL

In 1999, the City of West Palm Beach completed a traffic calming project on Olive Avenue, a State arterial roadway. The road had been one-way with approximately 12,000 vehicles per day and relatively high speeds. Beach Atlantic College, which occupies both sides of Olive Avenue, was considering building two pedestrian bridges to connect their severed campus. The City of West Palm Beach, the Florida Department of Transportation, and the College collaborated to improve the design. The new design narrowed travel lanes, added landscaping and street trees, and converted the arterial from one-way to two-way. The project incorporated raised crossings, designed with transitions suitable for emergency vehicles. The result provided comfortable at-grade crossings, increased property values, improved quality of life, and reduced traffic volumes.

Figure 33. Example of Raised Crossings Implemented as a part of Pedestrian Improvements [*A.10*]

2.8 Transit and Pedestrian Design

All transit trips must start and end with a walking or bicycling trip, making the consideration of pedestrians critical to transit design [*C.111*]. Further, bus stops are often located in urban areas adjacent to transportation centers or business districts which serve relatively high pedestrian volumes [*A.10*]. Bus stops may also be located in rural or suburban areas where they represent the only available transit service [*A.10*]. It is important to ensure bus stops are designed for local context, are safe and accessible for pedestrians and compliment the overall transportation network

[*A.10*]. There are several critical design guides developed at the national level, including NACTO's *Transit Street Design Guide* [*A.14*], FTA's *Manual on Pedestrian and Bicycle Connections to Transit* [*A.21*], FHWA's *Pedestrian Safety Guide for Transit Agencies* [*A.33*], and TCRP's *Guidelines for Providing Access to Public Transit Stations* [*A.85*]. ITE defined four types of public transit often incorporated along urban thoroughfares, shown in **Figure 34**.

Transit Type	Definition
Local Bus	Bus service operating at a fixed frequency that serves designated stops along a fixed route. Fares are collected onboard by the bus operator. Local bus service usually operates in mixed-flow lanes on urban thoroughfares. The typical average operating speed is low and is dependent on the operating speed of the urban thoroughfare.
Rapid Bus	Bus service similar to local bus serves designated stops along fixed route but with fewer stops than local service. This service is also known as commuter express. Fares are collected onboard by the bus operator. Rapid bus service usually operates along mixed-flow lanes on urban thoroughfares. Rapid buses may operate only during peak travel periods along peak directions. Some rapid bus systems use transit priority signal systems to improve headways, and queue jump lanes to bypass congestion at intersections.
Bus Rapid Transit (BRT)	Enhanced bus service that operates within its own right of way or designated lanes along the urban thoroughfares. BRT may utilize off-board fare collection to minimize boarding delays. BRT stops are typically spaced one mile apart and operate with high-frequency headways. The average speed of BRT is higher than that of rapid bus. BRT buses and stations are branded to distinguish them from local bus services. Stations frequently have more passenger amenities than typical bus stops. BRT systems use transit priority signal systems to improve headways, and queue jump lanes to bypass congestion at intersections.
Streetcar/Light Rail Transit (LRT)	Streetcars and LRT are fixed guideway transit systems. Streetcars (or trolleys) are electrically powered vehicles that may share the street with other modes of transportation and operate in mixed-flow lanes. LRT is typically electrical powered rail cars within exclusive rights of way in thoroughfare medians but may also operate in mixed-flow lanes. LRT is provided with traffic signal prioritization at intersections and requires special signal phasing to reduce conflicts. LRT utilizes off-board fare collection at transit stations. Transit stations, whether on the median or edges of thoroughfares, may require substantial right of way.

Figure 34. Types of Public Transportation Using Urban Thoroughfares [*A.22*]

There are several design requirements, guidance and other considerations specific to the planning and design of transit stops for pedestrians noted in the literature, including [*A.10, A.14, A.22, A.41, A.85]:*

- Transit stops should be connected to an accessible route via sidewalk, path or a shoulder
- Enhanced crossing treatments (**Section 2.7**) should be considered for both midblock and intersection pedestrian crossings near transit stops
- Clear zone considerations are an important component of bus stop design, and considerable flexibility is provided within federal guidance
- Driveways should be minimized and parking prohibited adjacent to transit stops

- Transit stops should be located with the minimum distance to the traveled way that is appropriate per clear zone considerations
- Vertical curbs should be included adjacent to bus stops along low-speed urban roadways
- Conflicts between transit and other modes of travel represent and important considerations which can addressed by clearly identifying the path for each mode and maximizing predictability
- Consider bus bulbs or other curb extension designs that align the transit stop with the parking lane, allowing buses to stop without making large lateral shifts and providing a waiting space for pedestrians
- Human-scale lighting should be provided for sidewalks

More information specific to pedestrian planning and design in relation to transit can be found in the references Aggregated in **Appendices A-D** [*A.1, A.10, A.14, A.21, A.22, A.33, A.41, A.84, A.85, A.95, A.98, A.120, A.138, A.143, A.147, C.27, D.131, A.146, A.154*]. There are also several case study examples [*C.11, C.106*], including the floating bus stop shown in **Figure 35**.

FLOATING BUS STOP
SEATTLE, WA

The City of Seattle has installed bus stop floating islands at a majority of bus stops along Dexter Avenue, a major bicycle commuting corridor that has peak bicycle volumes of over 300 bicyclists per hour. This 1.5-mile corridor carries buses at 10 minute headways during peak periods. The bus stop floating islands allow buses to stop in-lane, decreasing bus delay and allowing buses to easily re-enter traffic without waiting for a gap in passing motorists. The buffered bike lane is routed behind the bus stop, which prevents conflicts between bicyclists and stopped buses. The bus stop floating islands are accessible, with curb ramps and detectable warning surfaces. Some of the bus stops include railings across the back of the bus islands to encourage pedestrians to cross the bike lane at a designated point.

Figure 35. Example of Floating Bus Stop in Seattle, Washington [*A.10*]

2.8.1 Rail-Grade Crossing Treatments

Pedestrians will often need to cross railroads or light rail tracks, resulting in potentially dangerous conflicts between pedestrians and trains [*A.33*]. There are a variety of potential safety treatments that can be used specific to rail-grade crossings, including [*A.1, A.33, A.41, A.62, A.84, A.85, A.95, A.146, A.154, D.7, D.131*]:

- Traditional gates, flashers or bells
- Other active warning devices (such as automated gates, pedestrian signals, variable message signs or blank-out signs)
- Smart warning systems
- Additional gate skirting
- Additional signage
- Fencing, barriers or channelization to discourage crossing not at the intended area
- Grade-separated crossings (such as tunnels or overpasses)
- Additional surveillance, education or enforcement
- Pavement markings and texturing
- Ensuring flat area to cross tracks
- Ensuring that crossings intersect rail at 90-degree angles
- Audible warning devices

FHWA's *Engineering Design for Pedestrian Safety at High-Rail Grade Crossings*, published in 2016, summarizes the available treatments and provides recommendations and guidance for future improvement projects [*A.146*]. Additionally, TCHRP's *Guidebook on Pedestrian Crossings of Public Transit Rail Services* provides information specific to 34 pedestrian treatments which can be implemented at rail-grade crossings to improve pedestrian safety [*A.84*].

2.9 Bridge Treatments

While bridge crossings may represent a significant investment, accommodating crossings is critical as bridges without access can result in impractical trips for non-motorized road users [*A.10*]. Policy statements from USDOT encourage considering both existing and future demand for crossings when considering accommodations [*A.10*]. There are several design requirements, guidance and other considerations specific to pedestrian accommodations specific to bridges noted in the literature, including [*A.10, A.23]:*

- Both sides of the bridge should include accommodations
- Pedestrians and bicyclists can either be separated or combined via a shared use path
- Connections to existing pedestrian facilities should include appropriate accessibility considerations, including grades which may require switchbacks

- Appropriate wayfinding and markings should be provided to direct pedestrians to the bridge crossing access points
- Designs should include adequate clear and usable width for pedestrians

More information specific to accommodating pedestrians at bridges can be found in the references aggregated in **Appendices A-D** [*A.10, A.23, A.24, C.71]*, including the case study from Portland, Oregon shown in **Figure 36**.

BRIDGE ACCOMMODATION AND WIDTHS
PORTLAND, OR

In 2015, TriMet completed the Tilikum Crossing Bridge as part of a new light rail alignment in Portland, OR. The Tilikum Crossing is the first major bridge in the U.S. designed for transit vehicles (light rail and buses), pedestrians, and bicyclists but not cars, trucks, or motorcycles. The bridge has two 14-foot pedestrian and bicycle pathways on each side: each with more than 7 feet dedicated to one-way bicycle travel and 6 feet for two-way pedestrian travel. By completing key bicycle and pedestrian connections and expanding the City's bicycle and pedestrian network, the bridge's facilities helped build good will and excitement for the project in the community.

Figure 36. Example Bridge Pedestrian and Bicyclist Accommodation in Portland, OR [*A.10*]

2.10 School Zone Treatments

Families, staff and student trips to and from school facilities, including trips which occur school hours as well as during evening or weeks, result in multiple modes of travel interacting around the school zone as well as adjacent roadway facilities [*A.10*]. It is therefore critical for designers, planners and engineers to consider vehicle speeds, geometry, crossings and other non-motorized facilities along routes to schools [*A.10*]. An additional challenge that often arises is limited space available at older school facilities which "may limit the ability to provide separate space for all modes" [*A.10*]. There are several considerations specific to accommodating pedestrians adjacent to or within school zones, including [*A.10*]:

- Non-motorized routes should be continuous and lead directly to school entrances
- Separating bus stops, pick-up and drop-off locations from pedestrians as space allows

- Driveways should maintain the grade of intersecting non-motorized crossings and alter the grade of vehicular traffic
- Minimize turning radii at driveways to reduce vehicular speeds
- Consider enhanced crossing treatments (**Section 2.7**)
- Signal timings should consider the needs of children who may walk more slowly

ITE's *School Zone Planning, Design, and Transportation* provides guidance and information specific to improving the walkability, safety and efficiency of school facilities [*A.48*]. It is also important to recognize *Safe Routes to School* (SR2S) programs which work to improve the safety and convenience of walking and bicycling to school [*A.71*]. A variety of guidance and information is available specific to implementing SR2S projects [*A.71, A.72*]. More information specific to school zone treatments can be found in the references aggregated in **Appendices A-D** [*A.10, A.23, A.41, A.48, A.71, A.72, D.62*], including several case studies [*C.3, C.4, C.38, C.82, C.97, C.108*].

2.11 Work Zone Accommodations

Pedestrians in work zones can present "special safety and mobility concerns" and therefore it is critical to consider pedestrians during the planning, design and operation of work zones [*A.99*]. Work zone designs which do not follow standards or best practices "can sometimes provoke pedestrians and bicyclists to take risks that they would ordinarily avoid, resulting in preventable casualties" [*A.155*]. There are several considerations specific to accommodating pedestrians within highway work zones noted in prior guidance, including [*A.1, A.41, A.99, A.155*]:

- Avoid direct conflicts between pedestrians, vehicular traffic and work vehicles
- Temporary pedestrian facilities should include safe and accessible routes that replicate the characteristics existing facilities as much as is practical, including detectable curb ramps
- Covered walkways should be included where there is a risk of injury from falling objects
- Maintain pedestrian access during construction can help to reduce adverse economic impacts to local businesses
- Ensure advance warning to pedestrians is providing related to alternate routes

- While pedestrians are generally prohibited along limited access highways, work zones along these facilities may impact surrounding pedestrian facilities and appropriate accommodations should be provided

More information specific to accommodating pedestrians within work zones can be found within the references aggregated in **Appendices A-D** [*A.41, A.99, D.117*], including FHWA's *Guidelines for Work Zone Designers: Pedestrian and Bicycle Accommodation* [*A.155]*. Additionally, it is important to note that Chapter 6D of the MUTCD includes several provisions specific to accommodating non-motorized road users in highway work zones [*A.1*].

2.12 Lighting for Pedestrians

"Appropriate quality and placement of lighting can enhance an environment and increase comfort and safety" [*A.41*]. It is important to recognize that while pedestrians may believe that a vehicle's headlights are sufficient to be seen by drivers, it may actually be difficult to see pedestrians at night without sufficient lighting [*A.41*].While roadway lighting is intended to improve the safety of all road users, pedestrian-scale lighting improves "nighttime security and enhances commercial districts" [*A.41*]. Lighting is also particularly important at uncontrolled midblock crossings to ensure the visibility of pedestrians given the potential conflicts [*A.10*]. Lighting employed along shared use paths increases the utility, reduces the risk of falls or crashes, and increases the personal security of path users [*A.10*]. There are several considerations specific to lighting for pedestrians identified in prior research, including [*A.41*]:

- Lighting should be provided for both sides of wide streets or streets in commercial districts
- Uniform lighting levels should be implemented
- Lighting should be placed in advance of crossings on both sides to avoid creating silhouettes

More information specific to lighting for pedestrians can be found within the references aggregated in **Appendices A-D** [*A.10, A.22, A.41, B.21, C.14, D.40, D.65, D.134*], including FHWA's *Informational Report on Lighting Design for Midblock Crosswalks* [*A.97*]. It should also be noted that a project is currently underway in Illinois to investigate the effects of pedestrian lighting at both intersections and midblock crosswalks [*C.112*].

3.0 BEST PRACTICES IN BICYLE DESIGN AND PLANNING

Based upon the resources identified in **Appendices A-D**, the research team identified best practices in bicycle design and planning. The subsections that follow include a discussion of each topic based upon the literature reviewed as a part of this effort. For brevity, concepts which relate to both pedestrians and bicyclists which were covered as a part of **Section 2.0** will only be referred to as necessary in **Section 3.0**. Therefore, reference will be made to subsections within **Section 2.0** where more information can be found.

3.1 Road Segment Planning Design for Bicycles

The planning and design of highway segments, from high-speed arterials to low-speed urban streets, plays a critical role in supporting the context-sensitive approach encouraged by USDOT [*A.16*]. This includes going beyond minimum design requirements to "proactively provide convenient, safe, and context-sensitive facilities that foster increased use by bicyclists and pedestrians of all ages and abilities" [*A.16*]. The AASHTO *Green Book* further clarifies this concept to state that "a highway has wide-ranging effects in addition to providing traffic service to users. It is essential that the highway be considered as an element of the total environment." [*A.44*]. Ultimately, the various elements that comprise streets, including sidewalks, travel lanes and transit stops, must all compete for space within a limited right-of-way [*A.13*]. The following subsections identify best practices with respect to roadway segment planning and design for bicyclists.

3.1.1 Lane Widths

While many of the concepts related to lane width noted in **Section 2.1.1** apply to bicycles as well as pedestrians, there are additional considerations specific to bicyclists that are important to recognize. Much of the prior guidance notes that narrower lane widths may allow for implementing bicycle-specific facilities [*A.10, A.11, A.13, A.22, A.41, B.5*]. In fact, FHWA's *Incorporating On-Road Bicycle Networks into Resurfacing Projects* notes that reducing lane widths to create space for bicycle facilities "does not impact traffic capacity and is likely the least controversial option" [*A.17*]. However; lane widths of less than 12 feet should be considered with caution for scenarios without bicycle-specific facilities where considerable bicycle traffic is expected to share the road with vehicles [*A.17*]. Wider curb lanes have also been implemented in conjunction with enhanced shared lane markings where spatial limitations limited installation of a bicycle lane [*A.64*].

3.1.2 Paved Shoulders and Shoulder Widths

Similar to lane width, many of the concepts specific to paved shoulders and shoulder widths which apply to pedestrians (described in **Section 2.1.2**) also apply to bicyclists. Wide paved shoulders "can greatly improve bicyclist safety and comfort, particularly on higher-speed, higher-volume roadways" [*A.10*]. A continuous paved shoulder of four feet or greater should be provided to accommodate bicyclists, with at least five feet where roadside barriers are present [*A.10*]. AASHTO's *Guide for the Development of Bicycle Facilities* suggest that designers should consider wider shoulders for roadways with vehicular speeds greater than 50 MPH, as well as the use of the "Bicycle Level of Service" model which incorporates traffic speeds, volumes and lane widths to determine an appropriate shoulder width [*A.25*].

More information specific to the design of shoulder widths and paved shoulders for bicyclists can be found in the references aggregated in **Appendices A-D** [*A.10, A.17, A.23, A.25, A.41, A.86, A.87*], including the case study shown in **Figure 37**.

PAVED SHOULDERS AS BICYCLE ACCOMMODATIONS
ARIZONA

State departments of transportation pave shoulders based on well-documented benefits they produce for all modes, including the accommodation of bicyclists. For example, the Arizona Department of Transportation (ADOT) typically adds wider paved shoulders (6 feet or greater) to State highways that are part of major reconstruction projects, which is consistent with their bicycle policy. Additionally, on pavement preservation projects, ADOT maintains existing paved shoulders and, in some cases, widens paved shoulders. Sometimes this requires a change in scope for the project and an additional source of funding. ADOT has also revised its **Traffic Engineering Guidelines and Processes on Continuous Longitudinal Rumble Strips** to include a clear shoulder width of 4 feet in order to make shoulders usable for bicyclists.

Figure 37. Case Study Example of Paved Shoulders to Accommodate Bicycles in Arizona [*A.10*]

Advisory Shoulders

Advisory shoulders (or "dashed bicycle lanes") have been experimented with in some jurisdictions, which involves creating a useable shoulder for bicyclists along roadways that are otherwise too narrow [*A.23*]. The design includes a center two-way travel lane and drivers may only use the shoulder when no bicyclists are present (**Figure 38**) [*A.23*]. Note that advisory shoulders require an approved request to experiment with the FHWA and are generally intended for relatively low volume, low speed roadways in rural areas or small towns [*A.3, A.23*]. More details on advisory shoulders can be found in FHWA' *Small Town and Rural Multimodal Networks* [*A.23*] as well as FHWA's *Bicycle Facilities and the Manual on Uniform Traffic Control Devices* [*A.3*].

Figure 38. Example of Advisory Shoulder [*A.23*]

Rumble Strips

While rumble strips are a proven safety countermeasure according to the FHWA, it is important to ensure that rumble strips are implemented in a manner that accommodates bicyclists [*A.10*]. AASHTO recommends at least four feet of clear space between the rumble strip and the outside edge of a paved shoulder, as well as 12-foot minimum gaps spaced every 40 to 60 feet to allow the bicyclist to enter or exit the shoulder [*A.25*]. Ultimately, there is a considerable amount of prior research which has evaluated a variety of rumble strip designs intended to accommodate bicyclists. More information on implementing rumble strips in a manner which accommodate bicyclists can be found in the references aggregated in **Appendices A-D** [*A.10, A.17, A.23, A.25, A.41, C.67*, *C.110*].

3.1.3 Road Diets and Other Roadway Reconfigurations

As noted in **Section 2.1.6**, road diets can offer a variety of benefits to non-motorized road users. With respect to bicyclists, road diet conversions can allow for dedicated space to implement bicycle-specific facilities [*A.10*]. There are also scenarios where a road diet can be implemented where a bicycle lane already exists – allowing for an opportunity to add a buffer space or implement a protected lane [*A.66*]. Road diet conversions which include bicycle lanes may have additional advantages if it closes a gap in the overall bicycle network [*A.66*].

Additional information related to road diet planning and design specific to bicyclists can be found in the resources in **Appendices A-D** [*A.10, A.17, A.22, A.41*, *A.55, A.60, A.66, C.23, C.92*], including the case study shown in **Figure 39**.

STONE WAY NORTH
SEATTLE, WA

In 2007, the City of Seattle implemented a road diet on 1.2 miles of Stone Way North, converting four travel lanes to two travel lanes with a center turn lane and bicycle climbing lane. The Road Diet reduced travel speeds and collision rates while increasing bicycle volumes. The 85th percentile speed decreased and traffic volumes remained consistent with citywide trends without diversion onto adjacent streets. Based on crash data for two years before and two years after Road Diet implementation, total crashes declined by 14 percent and injury collisions declined by 33 percent. Bicycle volumes increased by 35 percent along the corridor.

Figure 39. Example of Road Diet Conversion in Seattle, Washington [*A.10*]

3.1.4 On-Street Parking

While many of the concepts discussed in **Section 2.1.4** related to pedestrians and on-street parking also can apply to bicyclists, there are a variety of distinct considerations that are specific to bicyclists. In fact, there are variety of design and planning concepts related to bicycle facilities which may be impacted by on-street parking, including [*A.11, A.25, A.133*]:

- Adjacent parallel parking results in a potential conflict between bicycles and vehicles suddenly opening doors which should be considered
- Traditional diagonal parking should generally not be used adjacent to bicycle lanes as drivers may have a hard time seeing bicycles while backing out
    - Back-in diagonal parking should be considered to mitigate risks
- In general, bicycle lanes should be placed between the parking lane and the travel lane
    - Placement between the curb may reduce visibility at intersections and driveways, increase conflicts with vehicle doors, complicate maintenance and results in more difficult left-turns for bicyclists
- On-street parking may serve as a separator between the roadway and separated bike lanes

- Space for on-street parking can often be repurposed to implement separated facilities for bicyclists
- Floating bicycle lanes have also been used which restricts on-street parking during peak hours for bicyclists and allows them to use the space

More information specific to bicyclists and on-street parking can be found in the references aggregated in **Appendices A-D** [*A.10, A.17, A.25, A.41, A.64, A.133, C.11, D.100, D.102, D.113*]., including Transport for London's *Cycling Design Standards* which includes strategies for rethinking parking and loading adjacent to bicycle routes (**Figure 40**) [*B.3*].

Separating cycling from kerbside activity at network level	Where integration of uses cannot be resolved on a given street, it may be possible to rationalise parking and loading across an area to focus it on particular streets, leaving others free of most kerbside activity. This is likely to require rethinking cycle route options at the route assessment stage.
Mechanisms for area-wide management of parking and loading	In **Urban clearways** there is no stopping on the carriageway for parking or loading (including for cyclists). They can be time-limited, with hours of operation provided on signs. **Controlled parking zones** (CPZs) prohibit waiting throughout a defined area. Signs at entry-points to the CPZ show times of operation and can include 'no loading'. **Restricted parking zones** avoid the need for painted lines at the kerbside by allowing parking and loading subject to restrictions shown by signs.
Relocation of parking and loading locally	Certain types of loading activity are more amenable to being moved than others, while the extent to which parking can be relocated depends on consultation with businesses and residents whose needs are served by that parking.
Floating parking and loading	Where segregated or light segregated cycle lanes/tracks are used, parking and loading could be included in bays 'floated' away from the cycle track. Allowance needs to be made for the 'dooring zone' and the kerb height and profiles, all of which of which may reduce the effective width for cycling. (See section 4.2.6)
On-carriageway loading/ parking bays	Kerbside activity may be rationalised by creating dedicated bays rather than allowing parking and loading generally on a street. This allows kerbside activity to be focused at particular locations and for cycling infrastructure to be designed around it.
Inset loading/parking bays	Although likely to require a more extensive redesign of the highway, this is a good option for cycling, provided that on-carriageway cycling facilities are appropriately marked so as to deter riding in the dooring zone. It can invite a more flexible use of space, with inset bays effectively forming part of the footway when not in use, depending on the materials used. However, they may not be suitable for all types of delivery.

Figure 40. Summary of Interventions for Parking and Loading on Bicycle Routes [*B.3*]

3.1.5 Design Speed, Posted Speed Limit and Traffic Calming Treatments

As outlined in **Section 2.1.5**, the design speed, posted speed limit and related traffic calming treatments are an important consideration in the planning and design of roadways for non-motorized users. Additionally, vehicular traffic speed has been recognized as a potential stressor for bicyclists – according to NACTO "most people are not comfortable riding a bicycle immediately next to motor vehicles driving at speeds over 25 MPH" [*A.12*]. More information related to design speed, the posted speed limit and traffic calming treatments specific to bicyclists can be found in the references aggregated in **Appendices A-D** [*A.10, A.12, A.13, A.23, A.25, A.37,* *A.41, A.64, A.105, A.140, B.4, B.7, B.12, C.35, D.99*], including Transport for London's *Cycling Design Standards* which includes strategies for traffic calming specific to bicyclists (**Figure 41**) [*B.3*].

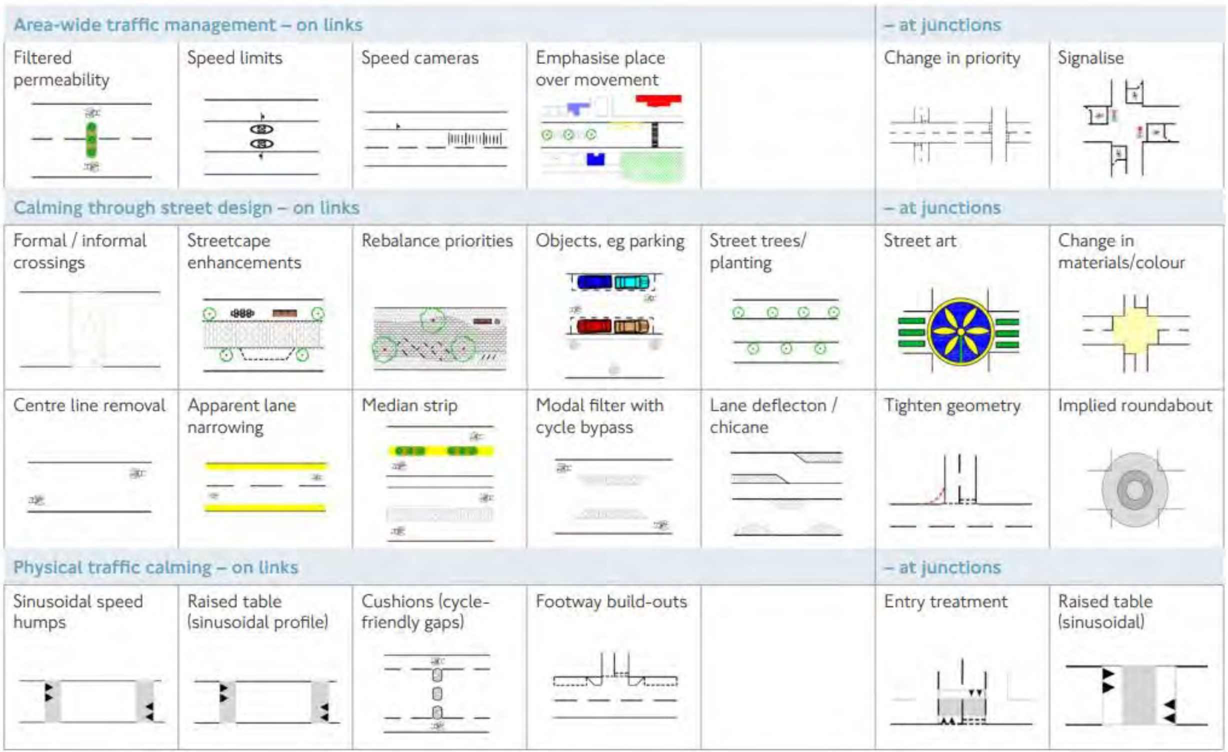


Figure 41. Traffic Calming Techniques from London Cycling Design Standards [*B.3*]

3.1.6 Bicycling on Freeways

While bicycling on freeways is generally prohibited, there are some circumstances where operation is allowed on freeway shoulders [*A.25*]. This typically involves circumstances where alternative routes are either unavailable or less suitable than the freeway shoulder [*A.25*]. Design and planning considerations include the wind blast effect of high-speed vehicles, the frequency of entrance/exit ramps, and heavy traffic at specific ramps [*A.25*].

3.1.7 Access Management Considerations

See **Section 2.1.9** for a discussion of the impacts of access management specific to non-motorized road users. Refer to either NCHRP's *Assessing Interactions Between Access Management Treatments and Multimodal Users* [*A.138*] or NCHRP Research Report 900: *Guide for the Analysis of Multimodal Corridor Access Management* [*A.147*] for more information on techniques to improve multimodal safety related to driveways and access management.

3.2 Intersection Design for Bicycles

Highway intersections are a critical element of the transportation network but also can result in potentially serious conflicts between non-motorized road users and motor vehicles [*A.13*]. NACTO advocates for intersections that "facilitate visibility and predictability for all users, creating an environment in which complex movements feel safe, easy, and intuitive." [*A.13*]. AASHTO notes that "good intersection design clearly indicates to bicyclists and motorists how they should traverse the intersection" [*A.25*]. NACTO's *Urban Bikeway Design Guide* recommends that intersection designs which include bicycle facilities "should reduce conflict between bicyclists (and other vulnerable road users) and vehicles by heightening the level of visibility, denoting a clear right-of-way, and facilitating eye contact and awareness with competing modes." [*A.12*].

Ultimately, accommodating bicyclists at highway intersections is a complex topic which includes a variety of design aspects which need to be considered, including several traffic control devices which are either subject to experimentation, available through interim approval or have interpretations as a part of the MUTCD [*A.3*]. NACTO recently published *Don't Give Up at the Intersection* [*A.15*], which expands upon the *Urban Bikeway Design Guide* [*A.12*] to provide additional detail specific to intersection treatments that reduce conflicts between non-motorized road users and vehicles. It should be noted that the NCHRP has research underway to provide guidance specific to pedestrian and bicyclist safety at intersections [*A.126*]. Additional research is being performed to provide guidance for alternative intersection designs [*A.125*]. The following subsections identify best practices with respect to roadway intersection planning and design for bicyclists.

3.2.1 Intersection Geometric Design

While many of the concepts identified in **Section 2.2.1** related to intersection geometry for pedestrians may also apply to bicyclists, there are several design and planning considerations which are specific to bicyclists. NACTO recognizes that geometric treatments to reduce vehicle turning speeds, making bicycles more visible, and giving bicyclists the right of way when possible as ways to reduce conflicts at intersections [*A.15*]. Intersection geometry is an important consideration in the planning and design of bicycle-specific facilities – more information can be found in NACTO's *Don't Give Up at the Intersection* [*A.15*] and FHWA's *Separated Bike Lane Planning and Design Guide* [*A.11*]. It is also important to note that NCHRP currently has a project underway to develop design guidance related to reducing conflicts between turning vehicles and bicyclists at highway intersections [*A.128*]. More information on geometric design for intersections specific to bicyclists can be found in the references aggregated in **Appendices A-D** [*A.10, A.11, A.12, A.13, A.15, A.41, B.2, B.3*].

3.2.2 Intersection Pavement Markings for Bicyclists

There are a variety of intersection pavement markings specific to bicyclists available, such as the intersection crossing markings shown in **Figure 42**. Intersection crossing markings are intended to indicate the intended bicycle path through the intersection, raising awareness for both bicyclists and drivers of potential conflicts within the intersection [*A.11*]. The markings can be particularly helpful at wide or complex intersections, especially in situations where vehicle movements may frequently encroach upon the intended bicycle space [*A.11*].

Figure 42. Example of Intersection Crossing Markings in Chicago, Illinois [*A.11*]

Additional examples and guidance related to pavement markings for highway intersections intended to improve safety for bicyclists can be found in the references aggregated in **Appendices A-D** [*A.1, A.3, A.11, A.12, A.15, A.41, C16*].

3.2.3 Centerline Hardening

Centerline hardening is an intersection safety treatment implemented to reduce the risk of vehicles "corner cutting" and encroaching on the bikeway [*A.15*]. This typically involves modular curbs with or without vertical delineator along the centerline [*A.15*], shown with red dots in **Figure 43**.

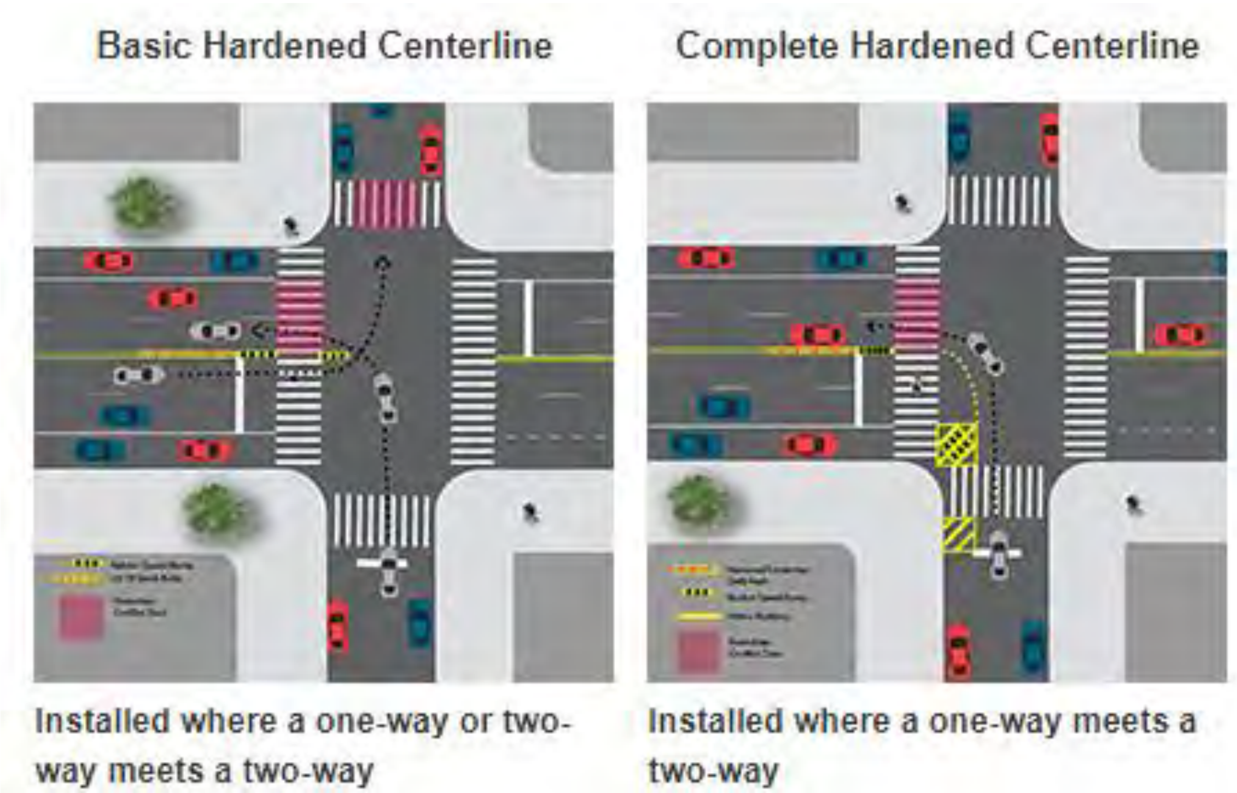


Figure 43. Drawing of Hardened Centerlines as Employed by New York City [*A.113*]

3.2.4 Protected Intersections

Protected intersections keep bicycles and vehicles separate up until the intersection in order to provide increased comfort and safety for riders [*A.15*]. Protected intersections can reduce vehicular turning speeds, increase the visibility of bicyclists and reduce bicyclists exposure to conflicts with vehicles [*A.15*]. Generally, protected intersections involve providing a dedicated path for bicyclists as well as the right of way over vehicles completing turning movements [*A.15*]. This is completed by implementing a setback between the travel lane and bikeway, allowing for a bicycle queuing area as well as a waiting zone for turning vehicles [*A.15*]. A diagram which shows how protected intersections place bicyclists in a more visible area of the intersection is shown in **Figure 44**.

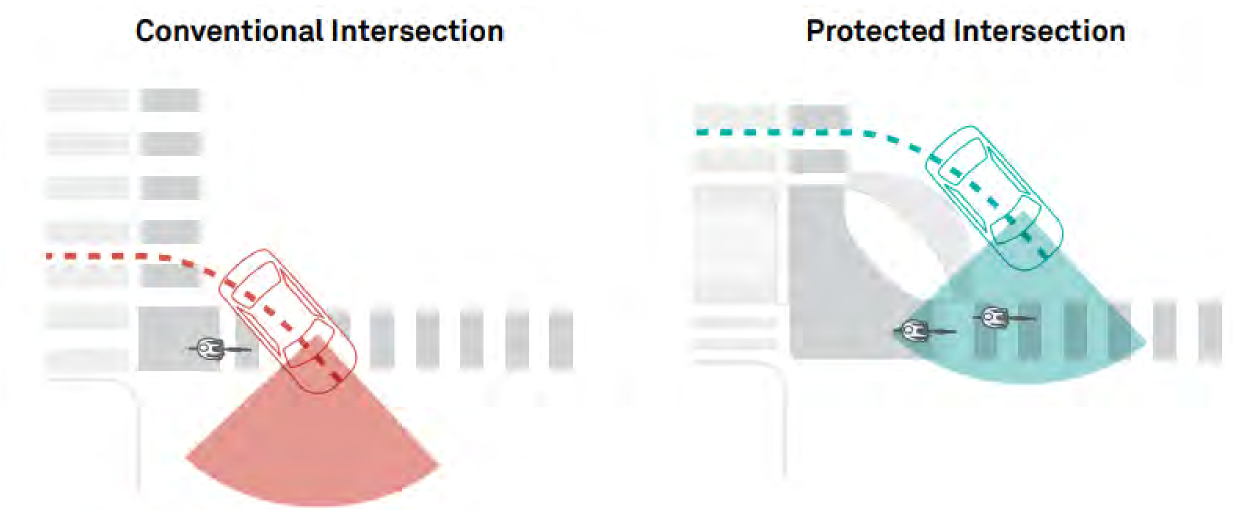


Figure 44. Conventional vs. Protected Intersections [*A.15*]

More details on protected intersections for bicyclists can be found in the references aggregated in **Appendices A-D** [*A.10, A.11, A.12, A.41, A.134*], including NACTO's *Don't Give Up at the Intersection* which provides detailed guidance on implementing protected intersections as well as several different design variations [*A.15*]. A case study example from Davis, California is also provided in **Figure 45**.

Figure 45. Protected Intersection Example from Davis, California [*A.10*]

3.2.5 Dedicated Intersections

In situations where there is not enough space to provide a full setback for bicyclists to create a protected intersection (**Section 3.2.4**), a dedicated intersection can be implemented which includes corner wedges, speed bumps or crosswalk separators to discourage vehicles from encroaching on the bikeway, reduce turning speeds and improve driver yielding (**Figure 46**) [*A.15*]. Centerline hardening treatments (**Section 3.2.3**) can also be included [*A.15*]. NACTO's *Don't Give Up at the Intersection* which provides detailed guidance on implementing dedicated intersections as well as several different design variations [*A.15*].

Figure 46. Example of Dedicated Bicycle Intersection from San Jose, California [*A.15*]

3.2.6 Minor Street Crossings

Minor street crossings represent a transition zone between a moderate speed environment and a low-speed side street – NACTO notes that effective minor street crossing designs provide a clear indication to all road users that non-motorized road users have the priority while crossing the minor street [*A.15*]. This can include the use of a combination of treatments, including compact corners, raised crossings, centerline hardening, turn wedges, raised islands and additional pavement markings [*A.15*]. An example of a bicycle lane in Cambridge, Massachusetts which incorporated raised crossings at minor street intersections is shown in **Figure 47**.

Figure 47. Example of Separated Bicycle Lane Installation with Raised Crossings at Minor Street Intersections [*A.10*]

3.2.7 Bicyclists and Signalized Intersections

Signal Timing for Bicyclists

Due to the fact that bicycles have different operational characteristics than vehicles, adjustments to various signal parameters (including minimum green times, clearance intervals and extension times) are needed to accommodate bicycle traffic [*A.10, A.25*]. Locations which have higher traffic speeds or long crossing distances are more likely to need additional consideration with respect to bicyclists [*A.10*]. AASHTO's *Guide for the Development of Bicycle Facilities* provides detailed information on accommodating bicyclists at signalized intersections [*A.25*]. Additionally, more information specific to signal timing for separated bicycle facilities can be found in FHWA's *Separated Bike Lane Planning and Design Guide* [*A.11*]. It is also important to consider detection for bicyclists at actuated signals to ensure bicyclists are able to call a green phase [*A.25*].

Bicycle Signals

While generally bicyclists should follow the same traffic signals at vehicles, bicycle signals should be considered at intersections where bicyclists either can't see signal heads or where bicyclists have separate movements [*A.10*]. Bicycle signals can be more suitable over the use of pedestrian signal heads to control bicyclist movements due to the differences in operational characteristics between the two modes [*A.10*]. Recent guidance published by NACTO details signal phasing strategies, including the use of protected-permissive signals, protected signals, leading bicyclist intervals, and bicycle scrambles [*A.12, A.15*].

While the MUTCD initially included provisions to provide circular signal indications to control bikeways or bicycle movements, no provisions were included for signal faces that include bicycle symbols [*A.6*]. FHWA's *Interim Approval for Optional Use of a Bicycle Signal Face* (IA-16) allows for the optional use of bicycle signal faces, shown in **Figure 48** [*A.6*]. IA-16 includes that conditions that "Steady and flashing RED BICYCLE, YELLOW BICYCLE, and GREEN BICYCLE signal indications shall have the same meanings as described in Paragraph 3 of Section 4D.04 for steady and flashing CIRCULAR RED, CIRCULAR YELLOW, and CIRCULAR GREEN signal indications for motor vehicles, respectively, except that the bicycle signal indications shall only be applicable to bicyclists." [*A.6*]. I-16 also provides conditions for the use of bicycle signal phases, including the design and operation of such devices [*A.6*].

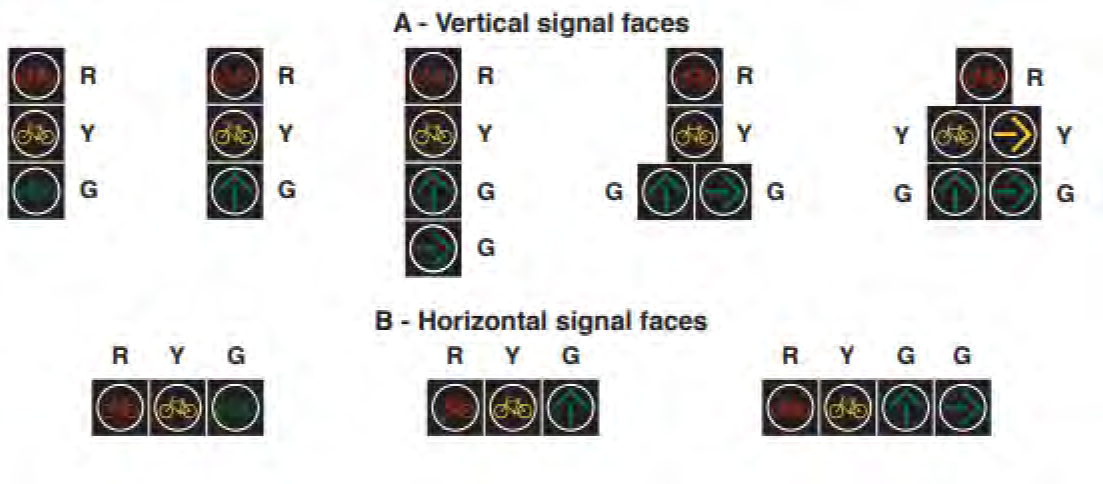


Figure 48. Typical Arrangements of Signal Sections in Bicycle Signal Faces [*A.6*]

More information and signal timing for bicycles and bicycle signals can be found in the references aggregated in **Appendices A-D** [*A.1, A.6, A.10, A.11, A.12, A.15 A.25, A.41, B.3, B.23, B.24, C.84, C.105, D.45, D.109, D.119*]. It is also important to note that NCHRP currently has a research project underway to develop guidance specific to traffic signal design and non-motorized road users [*A.139*]. A recent case study example from Tucson, Arizona explored the use of a pedestrian hybrid beacon for bicyclists [*C.2*].

3.2.8 Bicycle Boxes

Bicycle boxes are a designated space located at signalized intersections which are intended for bicyclists to queue in front of vehicles at red lights [*A.11*]. The box is placed between the stop line and crosswalk with the intent of allowing bicyclists to enter the intersection before vehicles when a green indication is received – increasing the visibility of queued bicyclists (**Figure 49**) [*A.11*]. Bicycle boxes also allow bicyclists to get into position to complete left turn movements, extending all the way to the left turn lane along multilane streets [*A.11*].

Figure 49. Example of Bicyclist Approaching Bicycle Box in Washington, D.C. [*A.11*]

FHWA's *Interim Approval for Optional Use of an Intersection Bicycle Box* (IA-18) allows for the optional use of bicycle boxes [*A.7*]. The treatment, shown in **Figure 50**, can also mitigate the risk of "right-hook" conflicts with turning vehicles [*A.7*]. Green colored pavement may also be used within the bicycle box and approach lane [*A.7*]. For multilane approaches, countdown pedestrian signals should be included on the approach where the box is located [*A.7*].

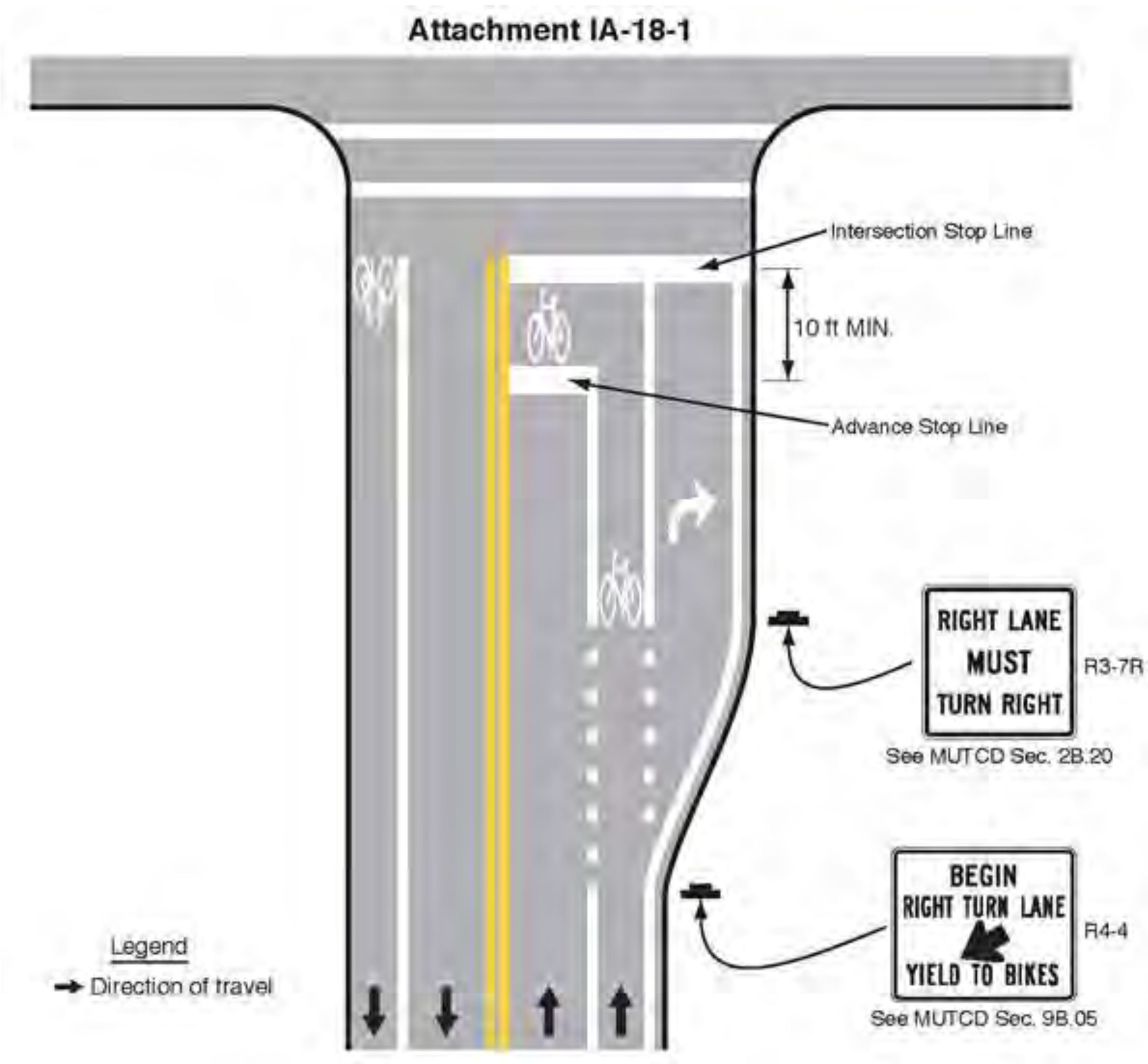


Figure 50. Example of Optional Bicycle Box from IA-18 [*A.7*]

Two-Stage Bicycle Turn Boxes

Two-stage turn queue boxes have also been used which allow bicyclists to complete left-turn movements at multilane intersections from either a right-side separated bicycle lane or a right-turn from a left-side separated bicycle lane [*A.11*]. While there are a variety of potential configurations, including applications at unsignalized intersections, two-stage turn boxes are generally implemented at signalized intersections and provide bicyclists an area outside the traveled path of vehicles and other bicyclists (**Figure 51**) [*A.8*]. Bicyclists are intended to proceed on the green signal to the two-stage turn box on the right-hand side of the travel lanes, turn left within the box, and then complete the movement across the perpendicular street once the appropriate signal indication is provided [*A.8*].

Figure 51. Example of Left-Turn Queue Box in San Francisco, California [*A.11*]

FHWA's *Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes* (IA-20) allows for the optional use of two-stage bicycle turn boxes [*A.8*]. **Figure 52** shows an example of a two-stage bicycle turn box where use is optional per IA-20 [*A.8*]. IA-20 also includes a design specific to scenarios where use of the turn box is mandatory which should be limited to locations where "physical or operational conditions make it impracticable or unsafe for a bicyclist to merge and make the appropriate turn as would any other vehicle." [*A.8*].

More information specific to bicycle boxes and two-stage turn boxes can be found in the references aggregated in **Appendices A-D** [*A.7, A.8, A.10, A.11, A.12, A.15, A.64, B.2, C.105, D.24, D.37, D.89*].

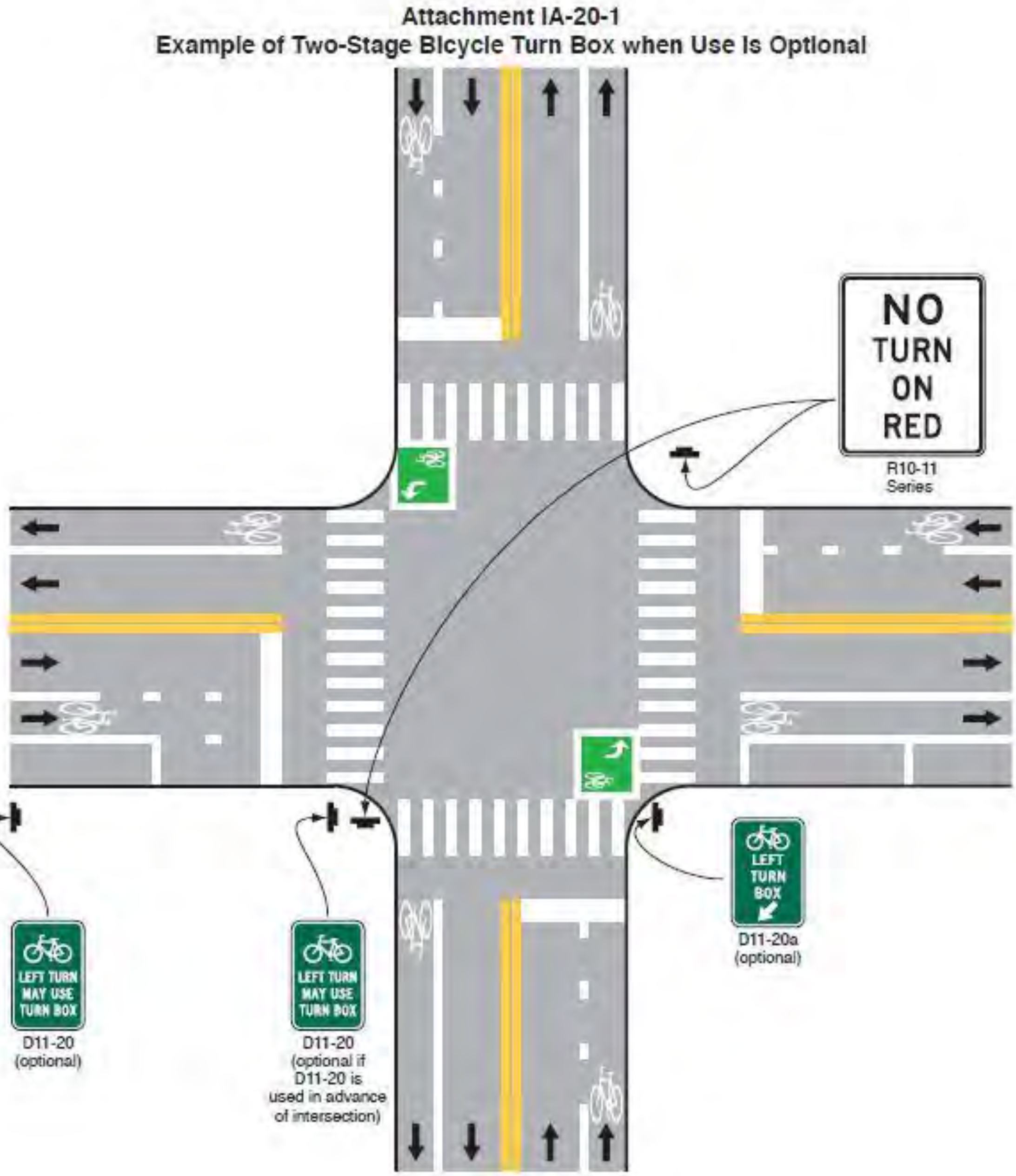


Figure 52. Example of Two-Stage Bicycle Turn Box when Use is Optional [*A.8*]

3.2.9 Accommodating Turning Movements at Intersections

According to AASHTO, "Most conflicts between bicyclists and motor vehicles occur at intersections and driveways" [*A.25*]. AASHTO also notes that crossing-path conflicts are increased because drivers are generally focused on the main traffic paths while bicyclists ride along the periphery [*A.25*]. AASHTO's *Guide for the Development of Bicycle Facilities* [*A.25*] provides detailed information specific to accommodating bicycle facilities at intersections, including considerations specific to exclusive right-turn lanes. In general, the correct placement of a bicycle lane is to the left of exclusive right-turn lanes (**Figure 53**) [*A.25*]. This allows for merging movements to occur upstream of the intersection – avoiding conflicts at the intersection [*A.25*].

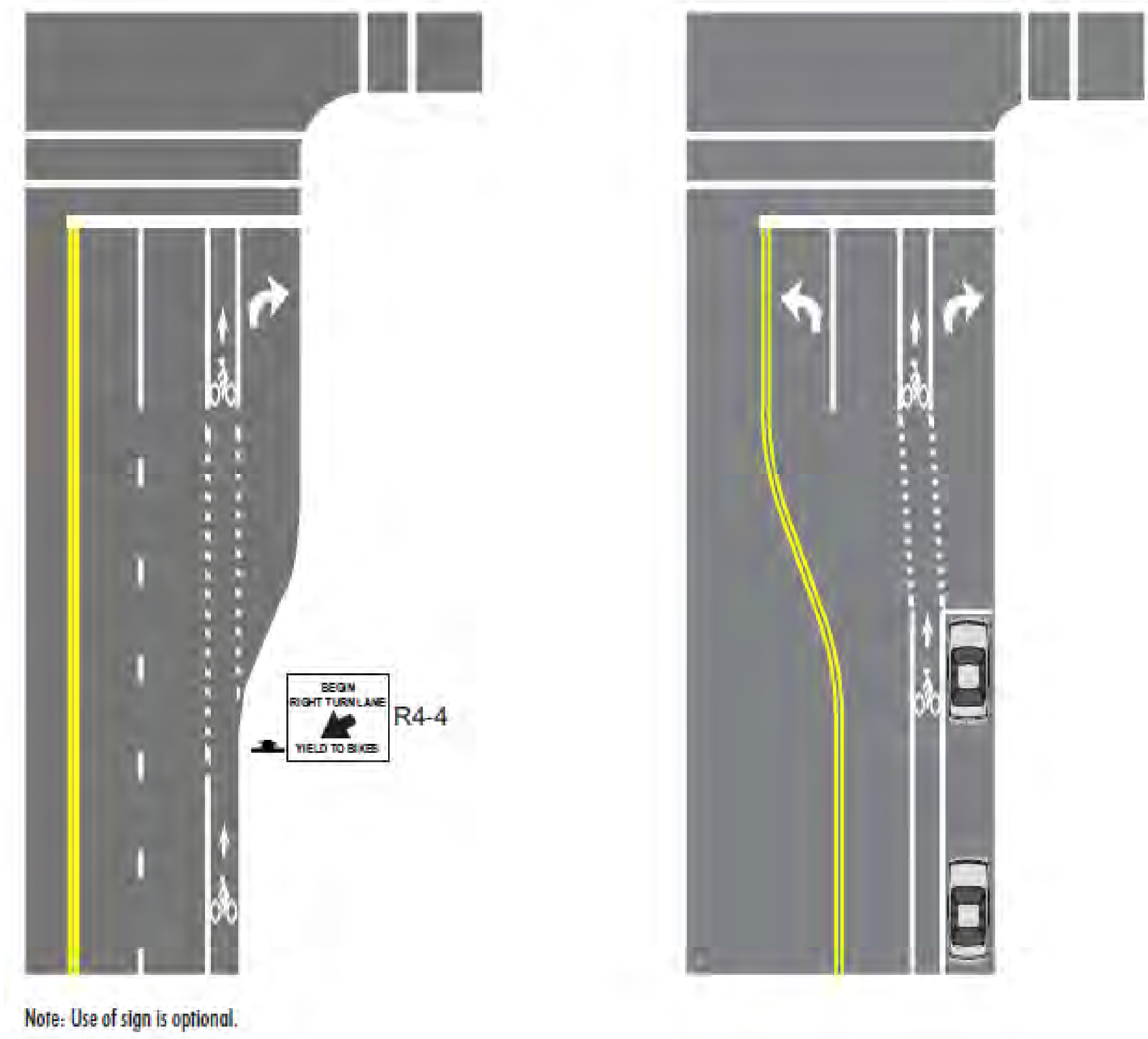


Figure 53. Example of Bike Lane Approaching Right-Turn Only Lanes (With and Without Parking) [*A.25*]

It is important to note that in more recent guidance, there are a variety of designs to accommodate turning movements and bicycle facilities at intersections for both conventional and separated bicycle lanes – including lateral shifts, combined bicycle and turn lanes, mixing zones as well as bend-ins/outs [*A.11, A.12*]. Additionally, green pavement markings can be used in combination with these treatments per FHWA's *Interim Approval for Optional Use of Green Colored Pavement* *for Bike Lanes* (IA-14) [*A.4, A.11*]. While an example is shown in **Figure 54**, there are a variety of designs employed by roadway agencies across the United States [*A.11*].

Figure 54. Example of Green Pavement Markings Across a Mixing Zone in Washington, D.C. [*A.11*]

More information specific to accommodating bicycle facilities at intersections can be found in the references aggregated in **Appendices A-D** [*A.10, A.15, A.25, A.64, A.117, C.30, C.31, D.123*].

3.3 Bicyclist Design at Roundabouts

Section 2.3 provides details on accommodating non-motorized road users as a part of roundabout conversions. AASHTO recognizes that some bicyclists will choose to travel on the roadway while others will often choose to travel on the sidewalk [*A.25*]. Additionally, AASHTO notes that "Single-lane roundabouts are much simpler for bicyclists than multilane roundabouts, since bicyclists do not need to change lanes, and motorists are less likely to cut off bicyclists when they exit the roundabout." [*A.25*]. Ultimately, AASHTO states that "bicyclists who have the skills to ride in urban traffic can manage single-lane roundabouts with little difficulty." [*A.25*]. More detailed information specific to bicyclists accommodations for modern roundabouts can be found in AASHTO's *Guide for the Development of Bicycle Facilities* [*A.25*], as well as the references aggregated in **Appendices A-D** [*A.10, A.25, A.41. A.64, B.3, D.104, D.107*].

3.4 Bicyclist Design at Interchanges and Alternative Intersections

Poorly designed interchanges can represent a potential barrier to bicycle traffic – especially travel along crossroads adjacent to complex interchanges for younger bicyclists [*A.25*]. Interchanges often involve high travel speeds and can result in "conflicts typically associated with the free-flow and yield-controlled conditions" at these locations [*A.41*]. AASHTO's *Guide for the Development of Bicyclist Facilities* provides detailed guidance specific to accommodating bicyclists at highway interchanges [*A.25*]. ITE recently developed the *Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges* which provides key information towards improving safety and accessibility for non-motorized road users at interchanges [*A.45*]. It is also important to note that NCHRP has research underway to develop guidance specific to accommodating pedestrians and bicyclists alternative intersections (such as median u-turn and restricted crossing u-turn designs) and interchanges (such as diverging diamonds) [*A.125*].

3.5 Network-Wide Considerations for Bicyclists

Section 2.5 covers concepts related to non-motorized networks, context sensitive solutions and complete streets policies. However, there are variety of design and planning considerations specific to bicycle networks and routes.

3.5.1 Bicycle Networks

The FHWA has defined bicycle networks as the "connected system made up of facilities such as separated bike lanes, bike lanes, bike boulevards, low-volume, streets, shared use paths, and paved shoulders" [*A.10*]. Additionally, the FHWA has also recognized that "a well-connected bicycle network can encourage people to bike to key area destinations" [*A.10*]. There are several design and planning considerations specific to creating well-connected bicycle networks according to the FHWA, including [A.10]:

- Provide separated facilities along high-volume/high-speed roadways
- Provide bicycle lanes where feasible to incorporate a designed space for bicyclists
- Consider bicycle boulevards along low-volume/low-speed roadways
- Include paved shoulders along rural roadways
- Consider bicycle signals or other advanced treatments (such as RRFBs or PHBs) to improve uncontrolled crossings

Ultimately, the planning and design of bicycle networks is a complex topic and more information can be found in the references aggregated in **Appendices A-D** [*A.10, A.12, A.17, A.18, A.23, A.27, A.76, A.77, A.145, B.22, B.23,C.57*], including two key references:

- FHWA's *Separated Bike Lane Planning and Design Guide* provides details as to how separated facilities can be used as a part of a well-connected bicycle network [*A.11*]
- FHWA's *Bike Network Mapping Idea Book* includes a variety of example mapping applications by highway agencies which can be used as a resource to identify, plan and improve bicycle networks, such as the example shown in **Figure 55** [*A.30*]

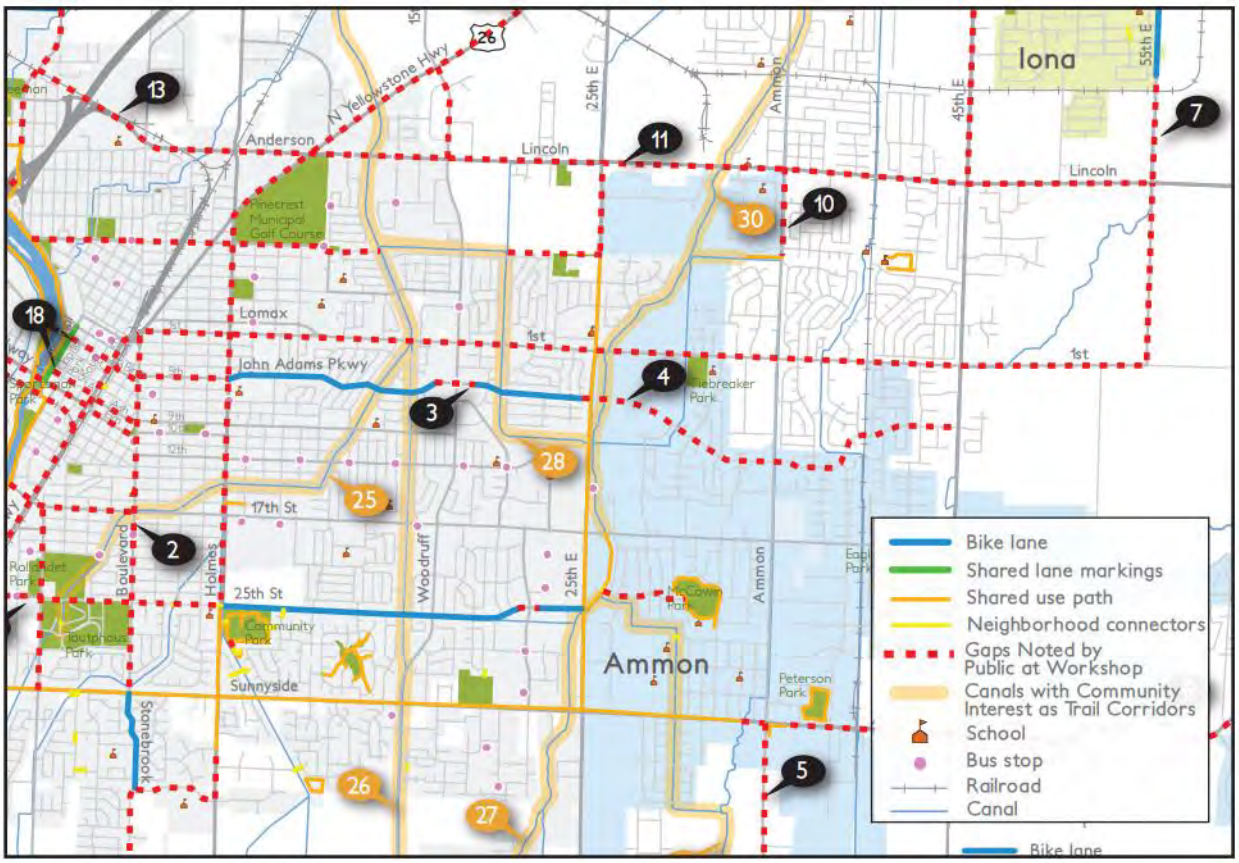


Figure 55. Example Bicycle Network Map from Idaho Falls, Idaho [*A.30*]

3.5.2 Bicycle Route Wayfinding

Bicycle wayfinding systems incorporate "comprehensive signing and/or pavement markings to guide bicyclists to their destinations along preferred bicycle routes." [*A.12*]. Signs are generally provided at decision points along the route, including intersections and other key locations and are often categorized into three types [*A.12*]:

- Confirmation signs intended to indicate to bicyclists they are on a designated bikeway
- Turn signs which indicate when the bikeway is turning from one street to another
- Decision signs that mark the junction of two or more bikeways

It should also be noted that pavement markings can also be used to assist in reinforcing routes and directional signage [*A.12*]. Effective wayfinding systems require clear user information and navigational instructions, requiring planners and designers to determine which routes bicyclists actually prefer – in addition to routes which include good conditions for bicycling [*A.25*]. While common signs from the MUTCD are shown in **Figure 56**, it is important to note that FHWA's *Interim Approval for the Optional Use of an Alternative Design for the U.S. Bicycle Route (M1-9) Sign* (IA-15) also allows for the optional use of an alternative design developed in Michigan [A.5]

Figure 56. Typical Bicycle Wayfinding Signs [*A.1, A.25*]

3.6 Performance Measures and Other Data Considerations

Performance measures and other data considerations related to non-motorized road users are discussed in **Section 2.6**, including volume collection, safety performance analyses, systemic considerations and road safety audits. In addition, there are several bicycle-specific references aggregated in **Appendices A-D** [A.25*, B.10, B.12, C.6, D.101, D.108, D.115, D.118*], including FHWA's *Bicycle Road Safety Audit Guidelines and Prompt Lists* [*A.35*]. It is also important to note that NCHRP currently has research underway to develop bicycle-specific safety performance functions for use with AASHTO's *Highway Safety Manual* [*A.141*]

3.7 Bicycle Facilities

As noted by AASHTO, all roadway facilities in the United States "should be designed and constructed under the assumption they will be used by bicyclists." [*A.25*]. As a result, transportation agencies should consider bicyclists during the planning, design, construction, maintenance and operations phases of transportation projects [*A.25*]. AASHTO defines bicycle facilities as "a general term denoting improvements and provisions to accommodate or encourage bicycling, including parking and storage facilities, and shared roadways not specifically defined for bicycle use." [*A.25*]. Part 9 of the MUTCD "covers signs, pavement markings, and highway traffic signals specifically related to bicycle operation on both roadways and shared-use paths." [*A.1*]. Additionally, the FHWA also maintains a webpage dedicated to traffic control devices which are permitted by the MUTCD, including devices that are subject to experimentation, available through interim approval, as well as interpretations [*A.3*]. The following subsections provide detail the prior work specific to the planning and design of bicycle facilities.

3.7.1 Selection of Bicycle Facilities

There are several prior resources that have been developed to assist in the selection of the appropriate bicycle facilities [*A.10, A.11, A.13, A.15, A.17, A.23, A1.35, A.136, A.137, B.3*], including several key resources which provide guidance specific to various aspects of bicycle facilities:

- NACTO's *Urban Bikeway Design Guide* [*A.12*]
- AASHTO's *Guide for the Development of Bicycle Facilities* [*A.25*]
- FHWA's *BIKESAFE Countermeasure Selection System* [*A.41*]
- NACTO's *Designing for All Ages & Abilities* [*A.140*]
- FHWA's *Bikeway Selection Guide* [*A.49*]

3.7.2 Shared Environments

Bicycles may operate on all roadways except where prohibited by either statute or regulation – in most instances [*A.25*]. Therefore, in most cases, bicyclists share the same travel lanes as traffic [*A.25*]. AASHTO's *Guide for the Development of Bicycle Facilities* notes that while shared lanes don’t necessarily involve bicycle-specific designs or dimensions, a variety of design features can be implemented which improve safety and comfort for bicyclists, including [*A.25*]:

- High quality pavement
- Adequate side distances
- Designs that encourage lower vehicular speeds
- Bicycle-compatible drainage gates, bridge expansion joints and railroad crossings

There are also several signs, pavement markings and other traffic control devices detailed in the MUTCD which can be used to supplement shared environments (**Figure 57**) [*A.1, A.25*].

Figure 57. Example of Bicycle-Specific Signs and Pavement Markings [*A.1, A.25*]

Specifically, shared lane markings or sharrows (**Figure 58**) are intended to indicate a shared environment for bicycles and traffic, providing several potential benefits, including [*A.12*]:

- Alerts and reinforces the legitimacy of bicycle traffic on the roadway for drivers
- Recommends proper positioning for bicyclists and informs drivers of this positioning
- Provides wayfinding or other directional guidance
- Encourages safe passing behaviors for vehicles overtaking bicyclists
- Reduces sidewalk riding and wrong-way riding by bicyclists
- Increases the distance between bicyclists and parked cars, reducing risk of “dooring” crashes

Figure 58. Example of Shared Lane Markings in Austin, Texas [*A.12*]

NACTO recommends that shared lane markings "should not be considered a substitute for bike lanes, cycle tracks, or other separation treatments where these types of facilities are otherwise warranted or space permits." [*A.12]*. More information specific to shared environments and related treatments can be found in the references aggregated in **Appendices A-D** [*A.1, A.12, A.25, A.41, A.123, C.31, C.32, C.70, D.92*], including FHWA's *Evaluation of Shared Lane Markings* [*A.124*].

Bicycle Boulevards, Priority Streets and Greenways

MDOT has previously defined bicycle boulevards as "a segment of street, or series of contiguous street segments, that has been modified to accommodate through-bicycle traffic and minimize through-motor traffic." [*C.39*]. Also referred to as priority streets or greenways, bicycle boulevards generally involve the use of signs, pavement markings and other speed or volume management treatments to provide an environment that's safe and comfortable for bicyclists [*A.12*]. The FHWA's *Small Town and Rural Multimodal Networks* provides details for the use of bicycle boulevards in rural or small town areas (**Figure 59**) [*A.23*]. An example of a bicycle boulevard application in Minnesota is shown in **Figure 60** and more information can be found in **Appendices A-D** [*A.12, A.23, A.25, C.12, C.74, C.78, D.124*].

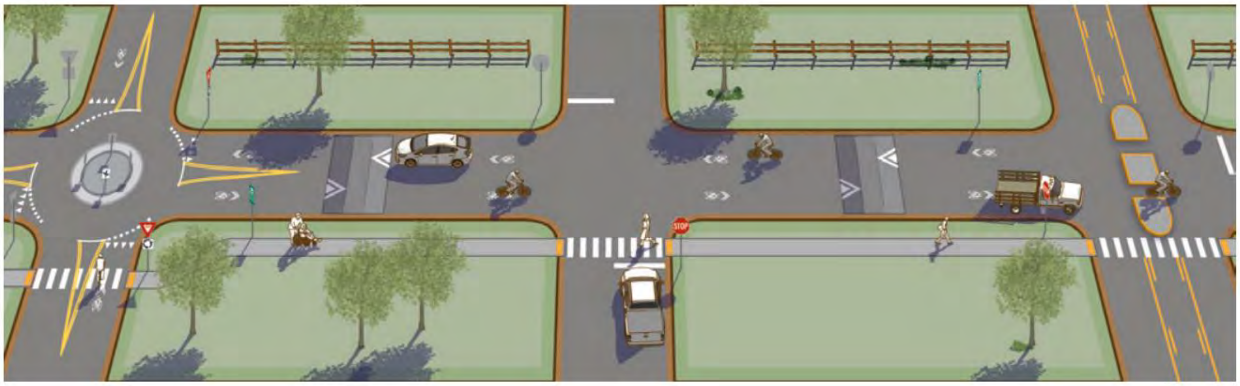


Figure 59. Example of Bicycle Boulevard in Rural Setting [*A.23*]

Figure 60. Example of Bicycle Boulevard in Minneapolis, Minnesota [*A.10*]

3.7.3 Conventional Bicycle Lanes

Bicycle lanes have been defined by NACTO as "a portion of the roadway that has been designated by striping, signage, and pavement markings for the preferential or exclusive use of bicyclists." [*A.12*]. The intent of bicycle lanes is to enable riders to operate "at their preferred speed without interference from prevailing traffic conditions and facilitate predictable behavior and movements between bicyclists and motorists" [*A.12*]. Conventional bicycle lanes "designate an exclusive space for bicyclists through the use of pavement markings and signage" (**Figure 61**) [*A.12*].

Figure 61. Conceptual Drawing of Conventional Bicycle Lane [*A.12*]

While the MUTCD does include provisions for conventional bicycle lanes [*A.1*], it is important to note FHWA's *Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes* (IA-14) allows for the optional use of green colored pavement in both marked bicycle lanes as well as extensions through intersections and other conflict areas [*A.4*]. The planning and design of conventional bicycle lanes is a complex topic with a considerable amount of prior guidance – more information can be found in the references aggregated in **Appendices A-D** [*A.3, A.17, A.23, A.25, A.41, A.119, B.3, B.12, C.35, D.38, D.43, D.91, D.96, D.111, D.112, D.118, D.122, D.123*], including NACTO's *Urban Bikeway Design Guide* [*A.12*].

3.7.4 Buffered Bicycle Lanes

Buffered bicycle lanes are similar to conventional bicycle lanes except that a designated buffer space is included to separate the bicycle lane from travel or parking lanes (**Figure 62**) [*A.12*]. The FHWA has recognized that buffered bicycle lanes are allowable per the 2009 MUTCD [*A.3*]. Buffered bicycle lanes offer a variety of benefits per NACTO guidance, including [*A.12*]:

- Provides greater shy distances between vehicles and bicyclists
- Provides space for bicyclists to overtake other bicyclists
- Encourages bicyclists to not ride in the "door zone"

- Will be used by wide cross section of bicyclists
- Encourages perception of safety for local bicyclists

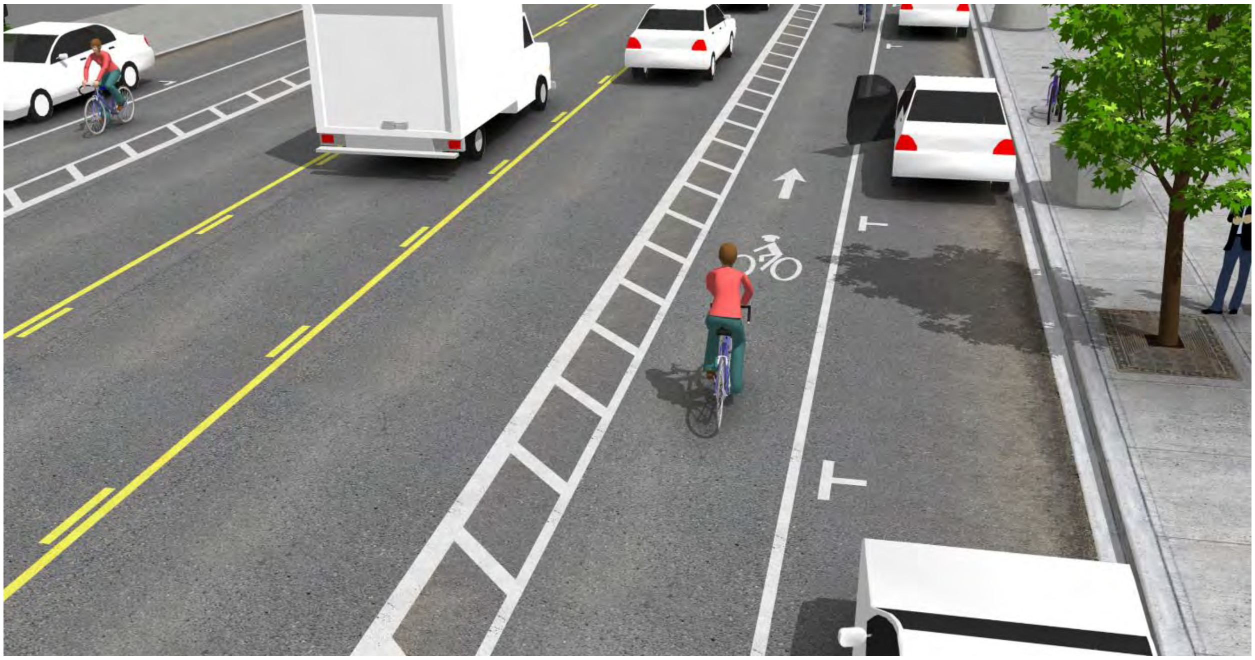


Figure 62. Conceptual Drawing of Buffered Bicycle Lane [*A.12*]

More information specific to buffered bicycle lanes can be found in the references aggregated in **Appendices A-D** [*A.12, A.17, A.23, A.41, C.35, C.74, C.105, D.54, D.87*].

3.7.5 Contra-Flow Bicycle Lanes

Contra-flow bicycle lanes are generally used to convert a one-way traffic street into a two-way street for bicyclists by including a bicycle lane adjacent to the opposite direction of travel separated by yellow center lane striping (**Figure 63**) [*A.12*]. The FHWA has recognized that contra-flow bicycle lanes are allowable per the 2009 MUTCD [*A.3*]. Contra-flow bicycle lanes have also been used to combine both directions of bicycle travel on one side of the street as a part of separated bicycle lane designs [*A.12*].

Figure 63. Conceptual Drawing of Contra-Flow Bicycle Lane [*A.12*]

Contra-flow bicycle lanes have a variety of applications in targeted settings, including the following situations per NACTO guidance [*A.12*]:

- Streets where bicyclists are already consistently riding the wrong way
- Corridors where alternate routes would require excessive travel in the wrong direction or involve travel along unsafe or comfortable streets
- Corridors where the contra-flow bicycle lane would provide direct access to key destinations or where two-way connections are otherwise needed

More information specific to contra-flow bicycle lanes can be found in the references aggregated in **Appendices A-D** [*A.12, A.41, C.105*].

3.7.6 Left-Side Bicycle Lanes

Left-side bicycle lanes generally involve the placement of a conventional bicycle lane on the left side of either one-way streets or two-way streets divided by a median (**Figure 64**) [*A.12*]. The FHWA has recognized that left-side bicycle lanes are allowable per the 2009 MUTCD [*A.3*]. Left-side bicycle lanes have a variety of potential applications, including [*A.12*]:

- Streets with considerable delivery or transit traffic
- Frequent parking turn over or other potential conflicts
- Locations where right-side travel lanes are involve parking restrictions or flexible uses
- Streets with high right-turn traffic volumes or left-turning bicycle volumes
- Situations where traffic enters into an add lane along the right side of the road (such as at connections with freeway ramps)
- Allows for favorable alignment with another bicycle facility

Figure 64. Conceptual Drawing of Left-Side Bicycle Lane [*A.12*]

3.7.7 Separated Bike Lanes

Separated bicycle lanes, also called cycle tracks or protected bicycle lanes, are exclusive facilities for bicyclists located either within or directly adjacent to highways and separated by a vertical element (**Figure 65**) [*A.11*]. The vertical element represents the fundamental difference between conventional and buffered bicycle lanes and can include one or more of the following [*A.11*]:

- Delineator posts
- Bollards
- Concrete barriers

- Raised medians
- Raised lanes
- Planters
- Parking stops
- Parked cars

Figure 65. Example of Separated Bicycle Lane with Raised Curb Island in New York City [*A.11*]

Separated bicycle lanes can offer safety benefits for all road users – particularly when implemented in conjunction with road diets or traffic calming projects [*A.11*]. The FHWA notes that separated bicycle lanes implemented as a part of a well-connected bicycle network can have the following benefits [*A.11*]:

- Providing a more comfortable experience for less-skilled riders
- Improve access
- Enhance access to public transit
- Improve access to employment
- Provide connectivity between regional trail systems

While separated bicycle lanes were installed in the United States as early as the 1970s, they have only recently gained widespread popularity among highway agencies [*A.11*]. As a result, it is important to note that the FHWA recognizes that "the practice of designing separated bike lanes is still evolving and until various configurations have been implemented and thoroughly evaluated on a consistent basis, design flexibility will remain a priority." [*A.11*]. The FHWA also notes the idea that separated bicycle lanes can't be built with federal funds as a common misconception [*A.37*]. More information related to separated bicycle lanes can be found in the references aggregated in **Appendices A-D** [*A.10, A.12, A.23, A.41, A.50, C.16, D.87, D.88, D.97, D.100, D.104, D.118*], including FHWA's *Separating Bike Lane Planning and Design Guide* [*A.11*]. A case study example from Portland, Oregon is included in **Figure 66**. There is also an upcoming NCHRP research project to quantify the safety characteristics of separated bicycle facilities [*A.127*].

Figure 66. Example of Separated Bicycle Lane from Portland, Oregon [A.10]

3.7.8 Shared Use Paths

Shared use paths provide a travel area away from traffic for non-motorized road users, resulting in a low stress environment for a variety of modes – including bicyclists, pedestrians, skaters, wheelchair users, joggers and other forms of non-motorized travel (**Figure 67**) [*A.23*]. Shared use paths have a variety of applications, but are often included adjacent to parks, rivers, beaches, greenbelts or utility corridors [*A.23*].

Figure 67. Example of Shared Use Path in Yacolt, Washington [*A.23*]

Generally, FHWA recommends a ten foot minimum width with a two foot shoulder (**Figure 68**) [*A.23*]. Wider paths can also be useful to accommodate maintenance vehicles [*A.23*].

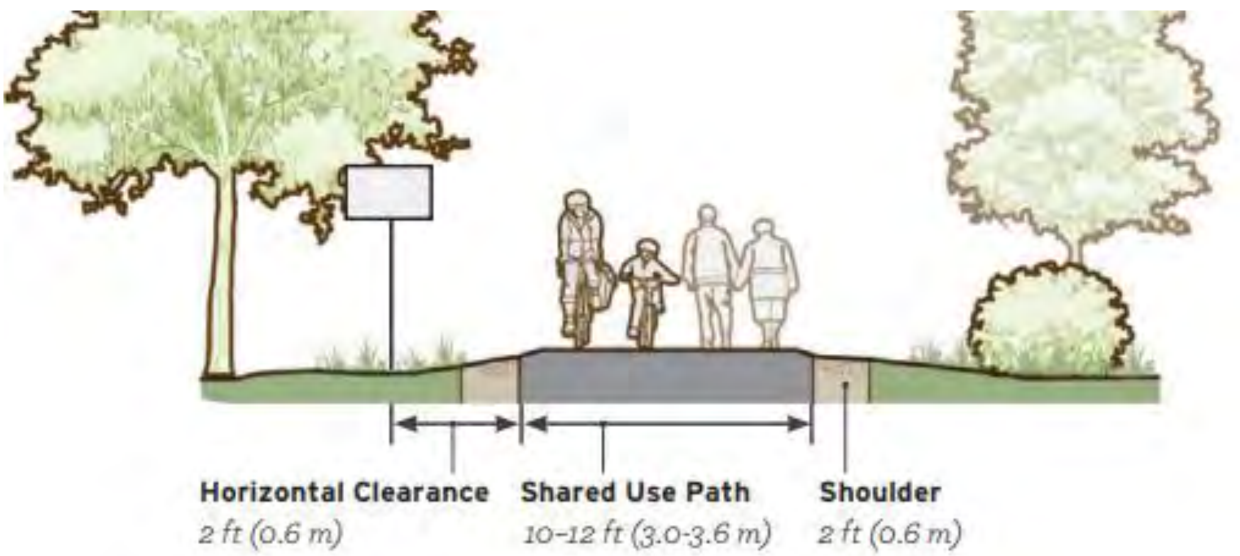


Figure 68. Example of Shared Use Path with Dimensions [*A.23*]

Sidepaths

Sidepaths are shared use paths which are located immediately adjacent and parallel to a highway, providing a low stress experience for non-motorized road users (**Figure 69**) [*A.23, A.25*].

Figure 69. Example of a Sidepath in South Lake Tahoe, California [*A.23*]

While the dimensions and other design details of sidepaths vary based upon the application, minimum widths of 8-12 feet with 5 feet in separation are recommended (**Figure 70**) [*A.23*].

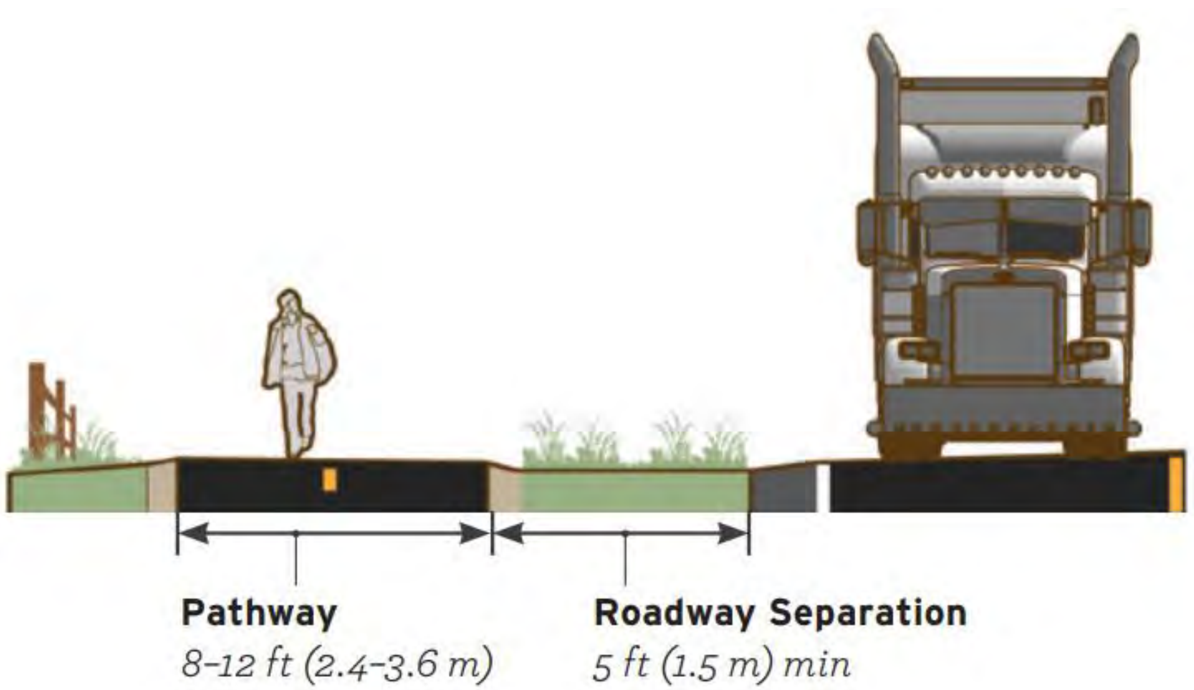


Figure 70. Example of Sidepath with Dimensions [*A.23*]

More information specific to both shared use paths and sidepaths can be found in the references aggregated in **Appendices A-D** [*A.10, A.23, A.41, A,108, B.11, C.51, C.76, C.78, C.101*], including

FHWA's *Guide for the Development of Bicycle Facilities* which provides detailed design guidance [*A.25*].

3.7.9 Bicycle Parking

AASHTO notes that "providing bicycle parking facilities is an essential element in a multi-modal transportation system." [*A.25*]. Bicycle parking is critical as bicycles do not include the anti-theft devices of vehicles and are relatively light – resulting in theft being a concern [*A.25*]. More information specific to bicycle parking facilities can be found in the references aggregated in **Appendices A-D** [*A.10*], including FHWA's *Guide for the Development of Bicycle Facilities* [*A.25*] and the Association of Pedestrian and Bicycle Professionals' *Bicycle Parking Guidelines* [*A.51*].

3.8 Transit and Bicycle Design

Section 2.8 provides details on integrating non-motorized road users and transit facilities. More information specific to bicyclists can be found in the references aggregated in **Appendices A-D** [*A.10, A.14, A.21, A.25*].

3.8.1 Rail-Grade Crossing Treatments

While more information specific to accommodating non-motorized road users at rail-grade crossings can be found in **Section 2.8.1**, it is important to note that bicyclists may suffer from steering difficulties when railroad tracks meet roadways or shared use paths on a diagonal [*A.25*]. More information specific to accommodating bicyclists at rail-grade crossings can be found in the references aggregated in **Appendices A-D** [*A.10, A.41, D.106*], including FHWA's *Guide for the Development of Bicyclist Facilities* [*A.25*].

3.9 Bridge Treatments

Information related to accommodating non-motorized road users at bridges can be found in **Section 2.9**. See FHWA's *Guide for the Development of Bicyclist Facilities* for more information specific to bicyclists [*A.25*].

3.10 School Zone Treatments

Information related to the planning and design of non-motorized facilities adjacent to schools can be found in **Section 2.10**. See FHWA's *Guide for the Development of Bicyclist Facilities* for more information specific to bicyclists [*A.25*].

3.11 Work Zone Treatments

Information related to accommodating non-motorized road users as a part of work zones can be found in **Section 2.11**. See FHWA's *Guide for the Development of Bicyclist Facilities* for more information specific to bicyclists [*A.25*].

3.12 Lighting for Bicyclists

Information related to accommodating non-motorized road users as a part of work zones can be found in **Section 2.12**. See FHWA's *Guide for the Development of Bicyclist Facilities* for more information specific to bicyclists [*A.25*].

APPENDICES

- **Appendix A – Selected National Design Guides, Manuals and Other Resources**

- **Appendix B – Selected International Design Guides, Manuals and Other Resources**

- **Appendix C – Selected State and Local Design Guides, Manuals and Other Resources**

- **Appendix D – Selected Journal Articles, Conference Proceedings and Other Literature**

Appendix A – Selected National Design Guides, Manuals and Other Resources

No.	Reference	Summary
A.1	Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways – FHWA (2009)	Defines the standards used by agencies to install and maintain traffic control on all public streets, highways, bikeways and private roadways open to public travel in the United States. Published by the FHWA under 23 Code of Federal Regulations (CFR), Part 655, Subpart F.
A.2	Strategic Agenda for Pedestrian and Bicycle Transportation – FHWA (2016)	The agenda is a framework to guide FHWA's pedestrian and bicycle initiatives and investments for the upcoming five-year period from FY 2016-17 to FY 2020-21. The agenda is intended to establish a strategic and collaborative approach for making walking and bicycling viable transportation options for all road users.
A.3	Bicycle Facilities and the Manual on Uniform Traffic Control Devices - FHWA	Webpage maintained by the FHWA which provides guidance as to which traffic control devices are permitted per the MUTCD. This includes devices which are subject to experimentation, available through interim approval, as well as interpretations.
A.4	Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes (IA-14) – FHWA (2011)	Interim approval memorandum by the FHWA which allows for the optional use of green colored pavement in marked bicycle lanes.
A.5	Interim Approval for the Optional Use of an Alternative Design for the U.S. Bicycle Route (M1-9) Sign (IA-15) – FHWA (2012)	Interim approval memorandum by the FHA which allows for the optional use of an alternative design for the U.S. Bicycle Route (M1-9) sign.

No.	Reference	Summary
A.6	Interim Approval for Optional Use of a Bicycle Signal Face (IA-16) – FHWA (2013)	Interim approval memorandum by the FHWA which allows for the optional use of bicycle signal faces.
A.7	Interim Approval for Optional Use of an Intersection Bicycle Box (IA-18) – FHWA (2016)	Interim approval memorandum by the FHWA which allows for the optional use of intersection bicycle boxes.
A.8	Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes (IA-20) – FHWA (2017)	Interim approval memorandum by the FHWA which allows for the optional use of two-sage bicycle turn boxes.
A.9	Interim Approval for Optional Use of Pedestrian-Actuated Rectangular Rapid-Flashing Beacons at Uncontrolled Marked Crosswalks (IA-21) – FHWA (2018)	Interim approval memorandum by the FHWA which allows for the optional use of rectangular rapid-flashing beacons.
A.10	Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts – FHWA (2016)	The document is intended to be a resource for practitioners in building multimodal transportation networks, including the identification of ways planners and designers can apply design flexibility included in current national design guidance.
A.11	Separated Bike Lane Planning and Design Guide – FHWA (2015)	The document outlines planning considerations for separated bike lanes and provides options for designs in both one-way and two-way scenarios.
A.12	Urban Bikeway Design Guide – NACTO (2018)	The guide is intended to provide practitioners with state-of-the-practice solutions that can help agencies develop complete streets which are safe and enjoyable for bicyclists. The design guide is based upon best practice experiences in cities throughout the world.

No.	Reference	Summary
A.13	Urban Street Design Guide – NACTO (2018)	The design guide is intended to provide a toolbox of the tactics cities have used to make streets safer, more livable and economically vibrant. The document includes principles and practices for engineers, planners and designers of cities.
A.14	Transit Street Design Guide – NACTO (2018)	The document provides design guidance for agencies to develop transit facilities along city streets. The guidance is based upon case studies, best practices and research of designs which have been employed in North America.
A.15	Don't Give Up at the Intersection – NACTO (2019)	The document expands upon the NACTO Urban Bikeway Design Guide to provide details on intersection design treatments intended to reduce vehicle-bike and vehicle-pedestrian conflicts. This includes guidance on protected bike intersections, dedicated bike intersections, minor street crossings as well as signalization strategies.
A.16	Bicycle and Pedestrian Facility Design Flexibility Memorandum – FHWA (2013)	Memorandum distributed by the FHWA which establishes support for a flexible approach in pedestrian and bicycle design. The memo notes design guides developed by AASHTO, NACTO and ITE which should be used to help communities implement safe and convenient facilities.

No.	Reference	Summary
A.17	Incorporating On-Road Bicycle Networks into Resurfacing Projects – FHWA (2015)	The document provides recommendations for highway agencies to implement bicycle facilities as a part of their resurfacing program. Also included are methods for retrofitting bicycle facilities onto existing roadways, including costs and case studies.
A.18	Case Studies in Delivering Safety, Comfortable and Connected Pedestrian and Bicycle Networks: Volumes I & II – FHWA (2015/2016)	The document includes an overview of pedestrian and bicycle network principles and also highlights examples from across the United States. A complete listing of projects examined as a part of developing the report is included in the appendices.
A.19	Guidebook for Developing Pedestrian and Bicycle Performance Measures – FHWA (2016)	The document provides guidance on performance measures specific to pedestrian and bicycle planning which can be used for ongoing activities. A broad range of ways in which pedestrian- and bicyclist-related investments can be measured and compared to the goals outlined in a community's planning process.
A.20	Accessible Shared Streets: Notable Practices and Considerations for Accommodating Pedestrians with Vision Disabilities – FHWA (2017)	The document includes notable practices and other considerations for accommodating pedestrians with vision disabilities on shared streets. Specifically, the guidance is focused on streets where multiple modes of travel are intended to mix in the same space.

No.	Reference	Summary
A.21	Manual on Pedestrian and Bicycle Connections to Transit – FHWA (2017)	The manual is intended to include a compendium of best practice to support agencies in improving pedestrian and bicycle safety and their access to transit. The document includes key information as to evaluating, planning and implementing specific improvements.
A.22	Designing Walkable Urban Thoroughfares: A Context Sensitive Approach – ITE (2010)	The report is intended to provide concepts and principles to assist in the design and planning processes of developing walkable urban thoroughfares. Specifically, the report focuses on context sensitive solutions for urban arterials and collectors.
A.23	Small Town and Rural Multimodal Networks – FHWA (2016)	The report is intended to serve as a resource to help small towns and rural communities in supporting safe, accessible, comfortable and active travel for all road users. The report attempts to bridge existing guidance on pedestrian and bicycle design with rural practice, encouraging innovation and providing examples from peer communities.
A.24	Guide for the Planning, Design, And Operation of Pedestrian Facilities – AASTHO (2004)	The document provides guidance specific to the planning, design and operation of pedestrian facilities along both streets and highways. A specific focus is placed on identifying effective measures for accommodating pedestrians within the public right-of-way.

No.	Reference	Summary
A.25	Guide for the Development of Bicycle Facilities – AASHTO (2012)	The document includes guidance on how to accommodate bicycle travel and operations in most riding environments. This guidance is intended to provide facilities which meet the needs of both bicyclists and other road users.
A.26	Pedestrians First: Tools for a Walkable City – Institute for Transportation Development and Policy (2018)	A tool that was developed to facilitate the understanding of walkability in urban environments. The tool was designed for worldwide use and can be applied in both lower-income and higher-income communities.
A.27	Guidebook for Measuring Multimodal Network Connectivity – FHWA (2018)	The document contains guidance for planners and analysts to apply methods and measures to support multimodal transportation planning and programming decisions. It includes a five-step process and other methods to support planning decisions, as well as examples of current practices.
A.28	Pedestrian and Bicyclist Road Safety Assessments – FHWA (2015)	The document summarizes pedestrian and bicyclist assessments conducted by US DOT, including highlighting methods used to conduct the assessments. It provides examples of both infrastructure and non-infrastructure barriers and how communities used the assessments to support safe and convenient walking and bicycling.

No.	Reference	Summary
A.29	The Best Complete Street Policies of 2018 – Smart Growth America (2019)	The document summarizes the best complete streets policies within the United States, including ten communities that worked towards the framework for complete streets developed by the National Complete Streets Coalition.
A.30	Bike Network Mapping Idea Book – FHWA (2016)	The document highlights several communities that have mapped their respective existing and proposed bicycle networks. Example are provided of maps at different scales as well as differing strategies, techniques and approaches.
A.31	Pursing Equity in Pedestrian and Bicycle Planning – FHWA (2016)	The report is intended to define transportation equity for pedestrians and bicyclists, synthesize recent research and share strategies or practices which have been used to address bicycle and pedestrian planning.
A.32	Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes – FHWA (2013)	Technical brief which documents crash reductions that can be expected specific to countermeasures intended to address pedestrian crashes. Estimates are provided in the form of crash reduction factors.
A.33	Pedestrian Safety Guide for Transit Agencies – FHWA (2008)	The report provides transit agency personnel with a resource for improving pedestrian safety, including a variety of approaches to address pedestrian safety issues near transit stations.

No.	Reference	Summary
A.34	Guide for Maintaining Pedestrian Facilities for Enhanced Safety – FHWA (2013)	The document provides guidance for agencies to maintain pedestrian facilities which increase safety and mobility. This includes guidance which addresses the need for pedestrian facility maintenance, common issues, inspection, accessibility and other related issues.
A.35	Bicycle Road Safety Audit Guidelines and Prompt Lists – FHWA (2012)	The document includes guidance and prompt lists which can be integrated into road safety audits to provide teams with a better understanding of bicycle-related safety issues.
A.36	Pedestrian Road Safety Audit Guidelines and Prompt Lists – FHWA (2007)	The document includes guidance and prompt lists which can be integrated into road safety audits to provide teams with a better understanding of pedestrian-related safety issues.
A.37	Bicycle and Pedestrian Funding, Design, and Environmental Review: Addressing Common Misconceptions – FHWA (2015)	The document published by the FHWA addresses common misconceptions regarding federal standards as well as state and local practices involving nonmotorized road user safety issues. The document focuses on funding, design and environmental reviews.

No.	Reference	Summary
A.38	Transportation Alternatives Program Performance Management Guidebook – FHWA (2016)	The document provides guidance to ensure that program managers for the Transportation Alternatives Program implement a performance-based approach. The guide also includes an overview of performance-based planning and management, an introduction to FHWA's performance-based planning framework, how to implement performance management with limited resources, and a roadmap for creating a performance-based planning and programing approach.
A.39	Guidebook on Pedestrian and Bicycle Volume Data Collection – NCHRP (2014)	The document provides guidance for practitioners involved in the collection of non-motorized count data. This includes methods and technologies, the development of a count program, suggestions on selecting methods and technologies, as well as examples implemented by other agencies.
A.40	Practical Approaches for Involving Traditionally Underserved Populations in Transportation Decision Making – NCHRP (2012)	The document provides highway agencies with tools and techniques to identify and connect populations which have traditional been underserved into agency decision making.
A.41	PEDSAFE and BIKESAFE - FHWA	Webpages maintained by FHWA which provide practitioners with the latest information towards improving the safety and mobility of non-motorized road users. The tools include engineering, education and enforcement treatments.

No.	Reference	Summary
A.42	Statewide Pedestrian and Bicycle Planning Handbook – FHWA (2014)	The document provides guidance for state DOTs to develop or update statewide pedestrian and bicycle plans. The guidance incorporates recent experiences and noteworthy practices from state DOTs across the country.
A.43	Roadside Design Guide – AASHTO (2011)	The document serves as a reference for highway agencies by providing a synthesis of practices and current information related to roadside safety. The guidance focuses on safety treatments that can be used to minimize the risk of serious injuries when a vehicle leaves the roadway.
A.44	A Policy on Geometric Design of Highways and Streets – AASHTO (2018)	The document, commonly known as the "green book", provides current design research and practices for the geometric design of highways and streets. The most recent edition provides an updated framework for design which has a greater focus on flexible and multimodal design.
A.45	Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges: An ITE Proposed Recommended Practice – ITE (2014)	The report is intended to provide guidance to engineers and designers to better accommodate both pedestrians and bicyclists at highway interchanges. Only design alternatives which are compliant with the MUTCD were included in the guidance.

No.	Reference	Summary
A.46	A Resident's Guide for Creating Safety Communities for Walking and Biking – FHWA (2015)	The document is intended to assist residents, parents, community association members and other citizens towards getting involved in making communities safer for non-motorized road users. A variety of resources are provided which can help residents learn about common traffic problems that impact both pedestrians and bicyclists.
A.47	Highway Capacity Manual – TRB (2010)	The manual provides methods of quantifying highway capacity and serves as the fundamental reference for concepts, performance measures and analysis for evaluating the multimodal operation of transportation facilities.
A.48	School Site Planning, Design, and Transportation – ITE (2013)	The document is intended to assist school stakeholders in creating walkable and community-based schools with an emphasis on the design of new schools for walkability, safety and efficiency. The document also contains information on the issues related to the improvement of existing schools.

No.	Reference	Summary
A.49	Bikeway Selection Guide – FHWA (2019)	The report is intended to be a reference for highway agencies to select appropriate bikeway types, including linkages between the bikeway selection and planning processes. The guidance focuses on available research and emphasizes engineering judgement, design flexibility and experimentation.
A.50	Separated Bikeways – ITE (2013)	The report developed by ITE's Pedestrian and Bicycle Council is intended to provide information specific to separated bikeways, consider the utility of separated bikeways and promote future research. The document identifies locations and designs of existing separated bikeways, summarizes safety studies and identifies needs for future research.
A.51	Bicycle Parking Guidelines – Association of Pedestrian & Bicycle Professionals (2010)	The document provides a set of recommendations specific to bicycle parking, including general principles and definitions, short-term and long-term parking, elements of lockers, maintenance best practices, sample plans, sample quantity requirements, and a worksheet to program parking.

No.	Reference	Summary
A.52	Synthesis of Methods for Estimating Pedestrian and Bicyclist Exposure to Risk at Areawide Levels and on Specific Transportation Facilities – FHWA (2017)	The document summarizes methods to evaluate pedestrian and bicycle safety risks. The report includes examples of exposure estimation methods as well as other non-motorized road user risk factors.
A.53	Systemic Pedestrian Safety Analysis – NCHRP (2018)	The report provides safety analysis methods which can be used to identify sites for potential safety improvements based on specific systemic risk factors for pedestrians. The guidebook is intended for highway agency personnel responsible for safety improvement programs, planning and prioritization of projects related to pedestrians.
A.54	Guidebook on Identification of High Pedestrian Crash Locations – FHWA (2018)	The report provides methods and examples which can be used to identify and prioritize high pedestrian crash locations. The guidance is intended to assist state and local highway agency staff in identifying high pedestrian crash intersections, segments, facilities and areas.
A.55	Road Diet Case Studies – FHWA (2015)	The document summarizes examples of prior road diets from across the country to provide highway agencies with information that can be used towards planning and implementing future road diets within their jurisdictions.
A.56	Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations – FHWA (2018)	The document is intended to provide guidance to highway agencies towards the installation of countermeasures which improve safety for pedestrians at uncontrolled crossing locations.

No.	Reference	Summary
A.57	A Right to the Road: Understanding & Addressing Bicyclist Safety – Governors Highway Safety Association	The document summarizes 30 recommendations to improve bicyclist safety spanning engineering, education and enforcement activities. Recommendations address planning, resource allocation, education and training, public outreach, policy and technology.
A.58	Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks – FHWA (2010)	The report summaries a study conducted to evaluate the effectiveness of RRFBs implemented at multilane uncontrolled crosswalks. Also included are comparisons with traditional overhead and side-mounted beacons.
A.59	Evaluating Pedestrian Safety Countermeasures – FHWA (2011)	Summary of pilot studies conducted by FHWA in three cities in the United States known as the "Pedestrian Safety Countermeasure Deployment Project". Each city identified problem locations, installed countermeasures, and evaluated impacts on safety performance.
A.60	Road Diet Conversions: A Synthesis of Safety Research – FHWA (2013)	The document summarizes the available research into prior road diet conversions, including six studies published since 2002.
A.61	Costs for Pedestrian and Bicyclist Infrastructure Improvements – University of North Carolina Highway Safety Research Center (2013)	The document summarizes data which can be used to develop estimates of infrastructure costs specific to pedestrian and bicycle treatments.
A.62	Effect of Gate Skirts on Pedestrian Behavior at Highway-Rail Grade Crossings – Federal Railroad Administration (2013)	The document summarizes a study of pedestrian behavior in response to a prototype gate skirt at a rail-grade crossing in New Jersey.

No.	Reference	Summary
A.63	Pedestrian Hybrid Beacon Guide: Recommendations and Case Study - FHWA	Document which summarizes guidance and other recommendations specific to the use of pedestrian hybrid beacons.
A.64	Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research – FHWA (2014)	The document summarizes available research specific to bicycle safety countermeasures, primarily serving as a companion document to the BIKESAFE guidance.
A.65	Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research – FHWA (2014)	The document summarizes available research specific to pedestrian safety countermeasures, primarily serving as a companion document to the PEDSAFE guidance.
A.66	Road Diet Informational Guide – FHWA (2014)	Guidance document which summarizes the safety, operational and quality of life considerations associated with road diets. The report includes design guidance and also is intended to help agencies determine if a road diet is appropriate for corridors under consideration.
A.67	Understanding Interactions between Drivers and Pedestrian Features at Signalized Intersections – University of South Florida and Florida DOT (2015)	Summary of a study intended to determine the relationship between drivers and specific pedestrian features at signalized intersections.
A.68	Improving Pedestrian Safety at Unsignalized Crossings – NCHRP (2006)	Report intended for highway agency staff which includes guidance and other information specific to pedestrian safety at unsignalized crossings.

No.	Reference	Summary
A.69	Advancing Pedestrian and Bicyclist Safety: A Primer for Highway Safety Professionals – NHTSA (2016)	Report intended for highway agency staff intended to serve as a reference for promising infrastructure treatments and behavioral programs specific to pedestrians and bicyclists. The report also includes examples of prior state and local projects.
A.70	Application of Pedestrian Crossing Treatments for Streets and Highways - NCHRP (2016)	Synthesis report which summarizes pedestrian crossing treatments used across the United States. The report includes information obtained from surveying highway agency staff, identifying effective practices and policies, as well as a comprehensive literature review.
A.71	Safety-based prioritization of schools for Safe Routes to School infrastructure projects: A process for transportation professionals – National Center for Safe Routes to School	Document which explains a process which can be used to identify schools which may benefit from pedestrian-specific safety infrastructure improvements. Guidance is also provided to conduct field reviews for the prioritized school facilities.
A.72	Safe Routes to School Briefing Sheets - ITE	Set of briefing sheets which serves as a reference for professionals involved in the Safe Routes to Schools program. Specifically, the document is intended to assist staff in addressing infrastructure as a part of Safe Routes to Schools.
A.73	Handbook for Designing Roadways for the Aging Population – FHWA (2014)	Reference document which provides information and research findings which can be used to improve a transportation system's level of safety for the aging population.

No.	Reference	Summary
A.74	Strategies for Accelerating Multimodal Project Delivery – FHWA (2018)	The document is intended to be a workbook to assist transportation agencies in identifying strategies which can be used to accelerate the delivery of multimodal projects. Thirteen key strategies are identified within the document, including case study examples for each strategy.
A.75	Guide for Scalable Risk Assessment Methods for Pedestrians and Bicyclists – FHWA (2018)	The report provides guidance to determine risk using scalable methods for pedestrians and bicyclists. Eight sequential steps are included which can be used to develop risk values at several geographic scales.
A.76	Defining Connected Bike Networks – Pedestrian and Bicycle Information Center (2017)	The information brief includes information which can be used to define a connected bicycle network, including how to measure connectivity.
A.77	Using Connectivity Measures to Evaluate and Build Connected Bicycle Networks – Pedestrian and Bicycle Information Center (2019)	The document provides an overview of existing approaches for measuring bicycle network quality focusing on a specific case study.
A.78	Evaluating Complete Streets Projects: A guide for practitioners – Smart Growth America (2015)	The document represents a toolkit designed to help practitioners towards identifying and establishing performance measures specific to complete streets projects.
A.79	Design Guidance for Channelized Right-Turn Lanes – NCHRP (2014)	The report provides guidance related to the design of channelized right-turn lanes. This included the results of observational field studies, simulation modeling, and an evaluation of traffic crash data.

No.	Reference	Summary
A.80	An Overview and Recommendations of High-Visibility Crosswalk Marking Styles – FHWA (2013)	The document provides an overview of research completed specific to crosswalk marking design and suggests the optimal patterns for various traffic and roadway conditions.
A.81	Pedestrian Safety Engineering and Intelligent Transportation System-Based Countermeasures Program For Reducing Pedestrian Fatalities, Injuries, Conflicts, and Other Surrogate Measures – FHWA (2008)	The report summarizes findings of the evaluation of fifteen pedestrian-focused countermeasures, including treatments which have intelligent transportation system components.
A.82	Pedestrian and Bicycle Intersection Safety Indices – FHWA (2007)	The report summarizes a study which developed safety indices which can be used to prioritize crosswalks and intersection approaches for pedestrian and bicycle safety.
A.83	Review of Studies on Pedestrian and Bicycle Safety, 1991-2007 – NHTSA (2012)	The report provides a brief summary of the existing pedestrian and bicycle safety-related research that was published from 1991 to 2007.
A.84	Guidebook on Pedestrian Crossings of Public Transit Rail Services – Transit Cooperative Research Program (2015)	The document includes guidance specific to engineering treatments which can be implemented to improve pedestrian safety associated with public transit rail services.
A.85	Guidelines for Providing Access to Public Transportation Stations – Transit Cooperative Research Program (2015)	The report includes a process and related spreadsheet tool for planning access to transit stations. The effectiveness of transit-oriented development to increase ridership is also included.

No.	Reference	Summary
A.86	State Best Practice Policy for Shoulders and Walkways - FHWA	The document summarizes best practices and policies from three state DOTs specific to shoulders and walkways.
A.87	Pedestrian Countermeasure Policy Best Practice Report - FHWA	The document summarizes best practices specific to raised medians and the use of walkways or paved shoulders.
A.88	Pedestrian and Bicyclist Traffic Control Device Evaluation Methods – FHWA (2011)	The document summarizes methods for evaluating traffic control devices specific to pedestrians and bicyclists.
A.89	Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities – NCHRP (2011)	The report provides practitioners with guidance related to crossings at roundabouts and channelized turn lanes for pedestrians with vision disabilities. While the document is not intended to inform agencies on when to install countermeasures, it does provide information on how improved crossing environments may be beneficial.
A.90	Crosswalk Marking Field Visibility Study – FHWA (2010)	The document summarizes the findings from a study which evaluated both daytime and nighttime visibility of three crosswalk marking patterns – including transverse, continental and bar pairs.
A.91	Safety Effectiveness of the HAWK Pedestrian Crossing Treatment – FHWA (2010)	The report documents a study of the HAWK pedestrian crossing treatment. A before and after study of the safety performance of the HAWK treatment was performed and evaluated using the empirical Bayes method.

No.	Reference	Summary
A.92	Complete Streets: Best Policy and Implementation Practices – American Planning Association	The document summarizes complete streets policy and implementation practices from around the United States, including case study examples.
A.93	Investigating Improvements to Pedestrian Crossings with an Emphasis on the Rectangular Rapid-Flashing Beacon – FHWA (2015)	The document identifies methods used to highlight the presence of pedestrian crossings, such as supplementing signing with beacons or LEDs. The report includes a specific focus on RRFBs, incorporating the results of field studies conducted in five states.
A.94	Planning Complete Streets for An Aging America – American Association of Retired Persons (2009)	The document expands upon the concept of complete streets to specifically address the needs of older drivers and pedestrians.
A.95	Compilation of Pedestrian Safety Devices in Use at Grade Crossings – Federal Railroad Administration (2008)	The document summarizes information on signs, signals, pavement markings and others devices to enhance pedestrian safety at rail-grade crossings.
A.96	Accessible Pedestrian Signals: A Guide to Best Practices – NCHRP (2011)	The report provides a summary of best practices specific to accessible pedestrian signals, including guidance related to features, installation, design as well as operations and maintenance. Additionally, case study examples are provided.
A.97	Informational Report on Lighting Design for Midblock Crosswalks – FHWA (2008)	The report summarizes the parameters and design criteria specific to installing lighting for midblock crosswalks. The guidance was developed based upon field studies which evaluated driver performance relating to the detection of pedestrians within crosswalks.

No.	Reference	Summary
A.98	Guidebook for Mitigating Fixed-Route Bus and Pedestrian Collisions – TCRP (2008)	The document is intended to provide transit agencies with guidance related to bus-and-pedestrian collisions as well as strategies to reduce their frequency.
A.99	Accommodating Pedestrians in Work Zones – FHWA	Brief informational document which provides strategies for safely accommodating pedestrians in work zones.
A.100	Pedestrian Safety Handbook – American Council for the Blind	Webpage maintained by the American Council for the Blind which provides information on a variety of contemporary approaches for assuring safe paths of travel for pedestrians with visual disabilities.
A.101	Exploring Pedestrian Counting Procedures – FHWA (2016)	The document provides guidance and best practices for strategies to measure pedestrian travel. Several recommendations are included to support the identification of pedestrian travel patterns for multimodal transportation planning, programming and management.
A.102	The Effect of Crosswalk Markings on Vehicle Speeds in Maryland, Virginia and Arizona – FHWA (2000)	The document summarizes a before and after evaluation of pedestrian crosswalk markings in three states. The study demonstrated that crosswalk markings resulted in drivers being more aware of pedestrians on relatively low-speed arterials.
A.103	Pedestrian and Bicyclist Standards and Innovations in Large Central Cities – Rudin Center for Transportation Policy and Management (2006)	The report reviews pedestrian and bicyclist standards and innovations in large central cities. The document also includes the results of a peer-to-peer session with representatives from ten cities.

No.	Reference	Summary
A.104	Pedestrian Access to Roundabouts: Assessment of Motorists' Yielding to Visually Impaired Pedestrians and Potential Treatments to Improve Access – FHWA (2006)	The report summarizes studies conducted to address double-lane roundabout accessibility concerns related to visually impaired pedestrians. This included a study on a closed course to evaluate a pavement treatment designed to alert bind pedestrians when vehicles have yielded, and a second study which examined driver behavior of the treatment in the field.
A.105	Design Speed, Operating Speed, and Posted Speed Practices – NCHRP (2003)	The report evaluates the relationship between design speed and operating speed via a survey of practice and analysis of geometric, traffic and speed conditions. It should be noted the document also summarizes the basis for recent changes to the "green book" and MUTCD.
A.106	The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior – FHWA (2001)	The report summarizes a study to evaluate traffic calming treatments at both intersections and midblock locations specific to driver and pedestrian behavior. This included before and after studies of bulb outs, raised intersections, refuge islands and raised crosswalks.
A.107	Pedestrian Safety on Rural Highways – FHWA (2004)	The document summarizes research conducted to identify the characteristics of rural pedestrian fatalities in ten states with above average rural pedestrian fatality rates.
A.108	Evaluation of Safety, Design, and Operation of Shared-Use Paths – FHWA (2006)	The report provides details of a level of service estimate method that was developed for shared-use paths, as well as the development of flow theory.

No.	Reference	Summary
A.109	Pedestrian Crosswalk Case Studies – FHWA (2001)	The report summarizes research conducted in four cities to evaluate the effect of crosswalk markings on driver and pedestrian behavior at unsignalized intersections.
A.110	Design and Safety of Pedestrian Facilities – ITE (1998)	The document provides recommended practices and guidelines for the design of safe and efficient pedestrian facilities.
A.111	Accessible Pedestrian Signals: Synthesis and Guide to Best Practice – NCHRP (2003)	The document includes information related to pedestrians with vision disabilities and how accessible pedestrian signals can assist in helping these vulnerable users cross streets.
A.112	An Evaluation of High-Visibility Crosswalk Treatment – FHWA (2001)	The document summarizes a study conducted to evaluate an overhead illuminated crosswalk sign and high-visibility ladder style crosswalk treatment in Florida.
A.113	The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments – FHWA (2000)	The document summarizes field studies conducted of three devices to improve pedestrian safety at unsignalized locations, including an overhead crosswalk sign, pedestrian safety cones and overhead pedestrian in crosswalk signs.
A.114	Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations – FHWA (2005)	The report provides details of a study of five years of pedestrian crash data at 1,000 marked and 1,000 unmarked crosswalks at uncontrolled locations.

No.	Reference	Summary
A.115	Evaluation of Automated Pedestrian Detection at Signalized Intersections – FHWA (2001)	The report summarizes a field evaluation of automated pedestrian detectors at signalized intersections. While the results demonstrated reductions in vehicle-pedestrian conflicts and pedestrians crossing during the Don't Walk signal, additional fine tuning of the detection zone was still required.
A.116	An Evaluation of Illuminated Pedestrian Push Buttons in Windsor, Ohio – FHWA (2001)	The report summarizes a study of illuminated pedestrian push buttons intended to inform the pedestrian if the push button had been previously pressed or was functional in general. The results demonstrated that there was not a statistically significant effect after treatment.
A.117	Evaluation of a Combined Bicycle Lane/Right Turn Lane in Eugene, Oregon – FHWA (2000)	The document summarizes a study of a combined bicycle lane/right-turn lane to be used when there is limited right-of-way. While the treatment was effective at two locations, the authors recommend further evaluation at additional locations.
A.118	A Review of Pedestrian Safety Research in the United States and Abroad – FHWA (2004)	The report summarizes pedestrian related research, including research conducted abroad. This includes research on safety statistics, treatments, educational programs and other concepts.
A.119	Recommended Bicycle Lane Widths for Various Roadway Characteristics – NCHRP (2014)	The report provides design guidance specific to the width of bicycle lanes for a variety of traffic, geometric and other scenarios.

No.	Reference	Summary
A.120	City of Richmond Bicycle and Pedestrian Network Improvement Study – FHWA (2017)	The report summarizes details of infrastructure improvements designed to increase access to seven bus rapid transit stations in the City of Richmond, Virginia.
A.121	Alternative Treatments for At-Grade Pedestrian Crossings – ITE (2001)	The document compiles guidance related to pedestrian crossing treatments for a variety of highway scenarios. The report compiled by the ITE Pedestrian and Bicycle task force includes information on more than 70 specific treatments.
A.122	Evaluation of Pedestrian Hybrid Beacons and Rapid Flashing Beacons – FHWA (2016)	The report summarizes studies of both pedestrian hybrid beacons as well as RRFBs which were intended to provide more information and refine guidance related to their use. This included both closed course and field studies of each treatment.
A.123	Evaluation of Pedestrian and Bicycle Engineering Countermeasures: Rectangular Rapid-Flashing Beacons, HAWKs, Sharrows, Crosswalk Markings, and the Development of an Evaluation Methods Report – FHWA (2011)	The document summarizes recent evaluations into four treatments specific to pedestrian and bicycle safey, including RRFBs, PHBs, sharrows and crosswalk markings. The document also details the development of an evaluation methods report specific to pedestrian and bicycle treatments.
A.124	Evaluation of Shared Lane Markings – FHWA (2010)	The report summarizes a study of shared lane markings, specifically sharrows, on the operational and safety effects for both drivers and bicyclists. The authors recommended additional study be performed in a variety of locations to expand guidance related to their use.

No.	Reference	Summary
A.125	PROJECT: Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges – NCHRP	The objective of the project is to develop design guidance to assist practitioners in implementing treatments for pedestrians and bicyclists specific to alternative intersections and interchanges (such as diverging diamonds, median u-turns, or restricted crossing u-turns).
A.126	PROJECT: Guidance to Improve Pedestrian and Bicycle Safety at Intersections - NCHRP	The objective of the project is to develop design guidance to assist practitioners in implementing treatments for pedestrians and bicyclists specific to highway intersections.
A.127	PROJECT: Safety Evaluation of On-Street Bikeway Designs - NCHRP	The objective of the project is to evaluate the safety performance of separated bikeways and bike lanes, provide additional guidance and identify future research needs.
A.128	PROJECT: Design Options to Reduce Turning Motor Vehicle–Bicycle Conflicts at Intersections - NCHRP	The objective of the project is to provide additional design guidance related to options to reduce conflicts between during vehicles and bicycles for a variety of bicycle facility types.
A.129	PROJECT: Development of a MASH Barrier to Shield Pedestrians, Bicyclists, and Other Vulnerable Users from Motor Vehicles	The objective of the project is to develop a nonproprietary barrier design to be used in separating nonmotorized road users from vehicular traffic.

No.	Reference	Summary
A.130	Safety Evaluation of Protected Left-Turn Phasing and Leading Pedestrian Intervals on Pedestrian Safety – FHWA (2018)	The report summarizes a before and after study of both protected left-turn phasing and leading pedestrian intervals on pedestrian safety using empirical Bayes methodology. The results demonstrated that there was not a statistically significant impact on pedestrian crash frequency with implementation of protected left-turn phasing, while leading pedestrian intervals did provide safety benefits for pedestrians.
A.131	Pedestrian Safety Impacts of Curb Extensions: A Case Study – Oregon State University (2005)	The report summarizes a study at a single location of curb extensions and the impact on driver behavior.
A.132	Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way – United States Access Board (2011)	The document represents accessibility guidelines for the design, construction and alteration of pedestrian facilities within the public right-of-way.
A.133	Floating Bicycle Lanes – Alta Planning (2016)	The document briefly describes the concept of a floating bicycle lane which prohibits parking during peak hours to accommodate peak hour bicycle traffic.
A.134	Dissecting the Safety Benefits of Protected Intersection Design Features – UMass Amherst (2019)	The report summarizes a driver simulation study of design features specific to protected intersections for complete streets.
A.135	Rethinking Streets for Bikes: An Evidence-Based Guidebook – National Institute for Transportation and Communities (2019)	The report summarizes efforts from cities around the country to retrofit streets to better accommodate bicyclists.
A.136	Rethinking Streets for Bikes: An Evidence-Based Guide to 25 Bike-Focused Street Transformations - National Institute for Transportation and Communities (2019)	The report summarizes recent examples from cities around the country to retrofit streets to better accommodate bicyclists.

No.	Reference	Summary
A.137	Literature Review: Resource Guide for Separating Bicyclists from Traffic – FHWA (2018)	The report summarizes research and prior guidance for separating bicyclists from traffic. The report also provides guidance and examples for selecting the appropriate bikeway treatment on public roadways.
A.138	Assessing Interactions Between Access Management Treatments and Multimodal Users – NCHRP (2018)	The report presents the results of a study of the safety and operational effects of access management techniques with a specific focus on pedestrians, bicyclists, transit and truck travel modes. This included a literature review, a practitioner survey as well as field and simulation data.
A.139	PROJECT: Traffic Signal Design and Operations Strategies for Non-Motorized Users – NCHRP	The objective of the project is to identify practices related to signal design and operations for non-motorized road users, identify gaps, develop guidance and suggest opportunities for future research.
A.140	Designing for All Ages & Abilities: Contextual Guidance for High-Comfort Bicycle Facilities – NACTO (2017)	The document builds upon the *Urban Bikeway Design Guide* to include best practices in bicycle facility design and network implementation. The guidance is intended to be used for a variety of urban street times considering contextual factors such as vehicular speeds, volumes, uses and sources of bicycle stress.
A.141	PROJECT: Pedestrian and Bicycle Safety Performance Functions for the Highway Safety Manual - NCHRP	The objective of the project is to develop both pedestrian and bicycle safety performance functions which can be integrated into the *Highway Safety Manual*.

No.	Reference	Summary
A.142	Development and Evaluation of Infrastructure Strategies for Safer Cycling – UMass Amherst (2017)	The report summarizes a driver simulation study and related survey designed to identify driver behavior when approaching unfamiliar bicycle intersection treatments.
A.143	Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists – Federal Transit Administration (2015)	The document summarizes a study to evaluate three commercially available pedestrian turn warning systems specific to transit buses. A unique crosswalk warning sign was also tested.
A.144	Field Guide for Selecting Countermeasures at Uncontrolled Pedestrian Crossing Locations – FHWA (2018)	The document represents a guide to select pedestrian countermeasures at uncontrolled crossing locations, as well as a form that agencies can use to document potential safety concerns.
A.145	Noteworthy Local Policies that Support Safe and complete Pedestrian and Bicycle Networks – FHWA (2016)	The document includes tools for highway agencies to support the development of safe and complete bicycle and pedestrian networks, including case study examples from across the country.
A.146	Engineering Design for Pedestrian Safety at Highway-Rail Grade Crossings – Federal Railroad Administration (2016)	The report includes an assessment of innovative and practical treatments for pedestrian grade crossing treatments related to highway-rail grade crossings. Future research is also suggested for treatments which have not been adequately studied.
A.147	Guide for the Analysis of Multimodal Corridor Access Management – NCHRP (2018)	The report summarizes the operational and safety relationships between specific access management techniques and multimodal road users, including vehicles, pedestrians, bicyclists, public transit and trucks.

No.	Reference	Summary
A.148	Interim Approval for Optional Use of an Alternative Signal Warrant 7 – Crash Experience (IA-19) – FHWA (2017)	Interim approval memorandum from the FHWA which allows for the optional use an alternative signal warrant for crash experience, including pedestrians.
A.149	PBCAT – Pedestrian and Bicycle Crash Analysis Tool Version 2.0 - FHWA	Software application intended to assist planners, engineers and other stakeholders with a tool to address pedestrian and bicyclist crash problems. The software also users to analyze historical crash data, develop reports and select countermeasures to addressed identified problems.
A.150	Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments – NCHRP (2017)	NCHRP Report #841 summarizes a study conducted to evaluate the safety benefits of RRFBs, PHBs, pedestrian refuge islands and advanced YIELD or STOP markings. A crash modification factor is identified for each treatment.
A.151	Research, Development, and Implementation of Pedestrian Safety Facilities in the United Kingdom – FHWA (1999)	Publication from FHWA which summaries various signalized pedestrian crossing devices used in the United Kingdom, including Pelican crossings, Puffin crossings and Toucan crossings.
A.152	Smart Growth America	Website maintained by Smart Growth America which details programs and technical assistance designed to support complete streets in the United States
A.153	Development of pathNav: A Pedestrian Navigation Tool that Utilizes Smart Data for Improved Accessibility and Walkability – Pathway Accessibility Solutions (2019)	Web application which employs smart data along with sidewalk and pathing data to improve pedestrian accessibility and walkability.

No.	Reference	Summary
A.154	Rail-Highway Grade Crossing Handbook (Revised Second Edition) – FHWA (2007)	Document is intended to serve as single reference for best practices and standards specific to highway-rail grade crossings in the United States.
A.155	Guidelines for Work Zone Designers: Pedestrian & Bicycle Accommodation – FHWA (2018)	Document which is intended to provide guidance specific to safely accommodating pedestrians and bicyclists in work zones. The material was developed from existing state manuals, best practices and published research.

Appendix B – Selected International Design Guides, Manuals and Other Resources

No.	Reference	Countries	Summary
B.1	Design Manual for Bicycle Traffic – CROW (2016)	Netherlands	The manual includes the necessary steps to develop a cycle-friendly infrastructure, including polices to promote implementation.
B.2	Focus on Cycling: Copenhagen Guidelines for the Design of Road Projects – City of Copenhagen (2013)	Denmark	The document provides guidance to ensure that road projects consider bicycle traffic to the greatest extent possible, consistent with the city's political aspirations.
B.3	London Cycling Design Standards – Transport for London (2014)	United Kingdom	The standards describe the requirements and guidance for cycle network planning and design which apply to all streets in London.
B.4	Making Space for Cycling: A guide for new developments and street renewals – Cambridge Cycling Campaign (2014)	United Kingdom	The guide is intended to assist designers in providing safe and efficient speed for bicycles for new developments and redesigned streets.
B.5	Pedestrian Safety: A Road Safety Manual for Decision-Makers and Practitioners – World Health Organization (2013)	Global	The manual covers pedestrian safety using a holistic approach, including safety statistics, countermeasures and planning, and evaluating treatments. The report is intended for a diverse audience, including engineers, planners, police and public health professionals.
B.6	Walkability and Pedestrian Facilities in Asian Cities – Asian Development Bank (2011)	Asia	The report is intended to provide information specific to pedestrian infrastructure in Asian cities, including field walkability surveys, interviews with pedestrians and an assessment of current policies.
B.7	Managing Speed – World Health Organization (2017)	Global	The document highlights how excessive speeds represent a key safety risk and includes approaches to managing speed.

No.	Reference	Countries	Summary
B.8	Pedestrian planning and design guide – New Zealand Transport Agency (2009)	New Zealand	The document includes guidance to improve walkability in New Zealand, including a process to determine the countermeasures that should be considered as well as design standards.
B.9	Road Safety Toolkit (Pedestrians) – International Road Assessment Programme	Global	The toolkit is a web-based guide which includes information on making roads and vehicles safer for pedestrians, as well as information for enforcement and education.
B.10	Road Safety Toolkit (Bicyclists) – International Road Assessment Programme	Global	The toolkit is a web-based guide which includes information on making roads and vehicles safer for bicyclists, as well as information for enforcement and education.
B.11	Shared Use Routes for Pedestrians and Bicyclists – United Kingdom Department for Transport (2012)	United Kingdom	The document represents a local transport note for design in the United Kingdom, providing guidance on the application of shared use routes in urban areas.
B.12	Cycle Safety: Reducing the Crash Risk – New Zealand Transport Agency (2009)	New Zealand	The technical note summarizes the results of a study which employed the empirical Bayes method to determine the safety benefits of several bicycle-specific safety treatments, including reducing traffic volumes and speeds, implementing bicycle lanes and off-road cycle paths.
B.13	Geometric Design Practices for European Roads – International Technology Exchange Program (2001)	Europe	The report aggregates European practices and policies specific to geometric and context-sensitive design, including the integration of bicyclists and pedestrians.
B.14	Pedestrian and Bicyclist Safety and Mobility in Europe – FHWA (2010)	Europe	The document includes a public policy review of five countries in Europe specific to pedestrian and bicyclist safety and mobility.

No.	Reference	Countries	Summary
B.15	Active Transportation in Canada: A Resource and Planning Guide – Transport Canada (2011)	Canada	The document is intended to be a resource for planners and engineers in Canada to accommodate and support active transportation. Tools, case studies and links to other resources are also provided.
B.16	Share the Road: Design Guidelines for Non-Motorised Transport in Africa – United Nations Environment Programme (2004)	Africa	The document provides guidelines which include a menu of potential interventions specific to the planning, design and realization of non-motorized road user facilities. The guidance was developed such that the recommendations are appropriate for the African continent.
B.17	Collisions involving pedal cyclists on Britain's roads: establishing the causes – Transport Research Laboratory (2009)	United Kingdom	The document includes an assessment of the risk factors associated with bicycling in Great Britain. The analysis is intended to support the Department for Transport's efforts to reduce fatalities for all road users.
B.18	Sight Line: Designing Better Streets for People with Low Vision – Commission for Architecture and the Built Environment (2011)	United Kingdom	The document represents a study intended to identify methods to better design streets for pedestrians with low vision. The recommendations are based upon a review of how eight blind or partially sighted persons navigate streets.
B.19	Better streets, better cities – Institute for Transportation & Development Policy (2011)	India	The document is intended to be a manual for planners, urban designers, landscape architects, engineers and other government officials to improve the urban design of streets in India.
B.20	Guide Information for Pedestrian Facilities – Austroads (2013)	Australia	The document represents a review of research and emerging practices specific to pedestrian facilities which can be integrated into Austroads guidance.

No.	Reference	Countries	Summary
B.21	Public lighting for safe and attractive pedestrian areas – Opus Central Laboratories (2010)	New Zealand	The document is intended to add to the understanding of public lighting specific to pedestrian areas. The guidance is based upon a literature review as well as information collected from the lighting industry.
B.22	Bicycle Network Planning & Facility Design Approaches in the Netherlands and the United States – FHWA	Netherlands	The report compares bicycle network planning and facility design in the Netherlands and the United States. The report identifies four specific areas of practice that are employed in Holland that could be used in the United States.
B.23	Delivering Safe, Comfortable, and Connected Pedestrian and Bicycle Networks: A Review of International Practices – FHWA (2015)	Global	The report identifies treatments and practices from 11 countries which have the potential to improve pedestrian and bicyclist safety and accessibility in the United States. The document covers six areas, including network infrastructure, areas limited to automobile traffic, signalization and ITS, policies, prioritization methods as well as goals and performance measures.
B.24	Cycle Gates: Understanding bicycle movements at traffic light controlled cycle gates – Transport for London (2018)	United Kingdom	The report summarizes a study specific to bicycle gates which have been installed in London that are intended to separate bicycles and vehicles at signalized intersections. The study was based upon road user behavior at two locations where bicycle gates had been installed along cycle superhighways.

Appendix C – Selected State and Local Design Guides, Manuals and Other Resources

No.	Reference	State	Summary
C.1	PUFFIN Crossing – Pedestrian and Bicycle Information Center	Arizona	Case study example in Tucson, Arizona of a unique crossing treatment called the Pedestrian-User-Friendly Intelligent Intersection known as a PUFFIN crossing.
C.2	BikeHAWK: Adapting the pedestrian hybrid beacon to aid bicyclists crossing busy streets – City of Tucson	Arizona	Case study example in Tucson, Arizona of a pedestrian hybrid beacon specifically designed to accommodate bicyclists known as a "BikeHAWK".
C.3	Staggered Median – Pedestrian and Bicycle Information Center	Arizona	Case study example in Tucson, Arizona of the implementation of a staggered median with split crosswalks to improve crossing conditions along a multilane highway adjacent to a high school.
C.4	Sunnyslope High School Pedestrian Demonstration Project - Pedestrian and Bicycle Information Center	Arizona	Case study example in Phoenix, Arizona of pedestrian treatments adjacent to a high school which included the implementation of speed feedback monitors, staggered crosswalks and "SCHOOL" pavement markings.
C.5	Third Street Promenade - Pedestrian and Bicycle Information Center	California	Case study example from Santa Monica, California which involved removing vehicular traffic from a three-block segment adjacent to a commercial area to develop a protected pedestrian space.
C.6	A Technical Guide for Conducting Bicycle Safety Assessments for California Communities – University of California Berkeley (2014)	California	The document summarizes California's bicycle safety assessment process and provides guidelines to conduct the assessments based upon best practices and research on bicycling safety.

No.	Reference	State	Summary
C.7	Exclusive Pedestrian Phasing – Pedestrian and Bicyclist Information Center	California	Case study example from Beverly Hills, California which included the implementation of exclusive pedestrian phases at eight intersections to reduce conflicts between pedestrians and vehicles which was creating safety and operational concerns.
C.8	Crossing Islands – Pedestrian and Bicycle Information Center	California	Case study example from Eureka, California which included the installation of a median island for pedestrian refuge which prohibited vehicular traffic from completing left-turn movements within an intersection with awkward geometry.
C.9	Model For Living Streets Design Manual – Los Angeles County (2011)	California	The manual provides guidance to achieve balanced street designs that accommodate all road users safely and comfortable. The guidance is intended for municipalities that lack the resources to complete major revisions of their design manuals but want to adopt the latest information in street design.
C.10	Across the Arterial: Mid-block Shared-Use Path Crossings of Multilane Roadways in California – Rails to Trails Conservancy (2011)	California	The report provides a summary of treatments used at approximately 50 at-grade crossings of shared-use paths which can be implemented to reduce the risk of collisions and provide users with a comfortable experience.

No.	Reference	State	Summary
C.11	Improving Pedestrian Conditions on a High Traffic Arterial - Pedestrian and Bicycle Information Center	California	Case study example from San Francisco, California which involved a comprehensive study of pedestrian conditions along a six-lane urban arterial which also incorporates public transit and on-street parking. A variety of pedestrian focused safety treatments were ultimately implemented to refocus the arterial as a multimodal corridor.
C.12	Bicycle Boulevards – Pedestrian and Bicycle Information Center	California	Case study example from Emeryville, California which included the implementation of a bicycle boulevard along a new street built to support the growth of the developing community.
C.13	Pedestrian and Bicycle Facilities in California – California DOT (2005)	California	The document is intended to serve as a reference for Caltrans staff specific to non-motorized transportation. The document is a technology transfer intended to provide guidance for department staff to accommodate pedestrian and bicycle traffic along state highways in California.
C.14	Campus-Wide Networked Adaptive LED Lighting – University of California, Davis (2014)	California	Case study example from the University of California-Davis which included the installation of more than 1,500 LED street lights to support the universities smart lighting initiative.
C.15	Market Street Raised Bikeway Demonstration Project: Findings Report – San Francisco Municipal	California	The memorandum summarizes the of an evaluation of four different raised bikeway designs in San Francisco. Recommendations were made based upon the findings of the study.

No.	Reference	State	Summary
	Transportation Agency (2017)		
C.16	Comprehensive Design Guidance for Cycle Tracks – Caltrans (2015)	California	The document provides guidance for Caltrans staff specific to design standards for cycle tracks, including geometry, signage, pavement markings, intersection treatments, accessibility and maintenance.
C.17	Finding Strategies to Improve Pedestrian Safety in Rural Areas – University of Connecticut/University of Maine (2001)	Connecticut	The report summarizes a study conducted to determine the safety performance of pedestrian crossings in rural areas. Several factors were considered, including population density, type of crossing, traffic control, land use, facility type, travel speeds, and volume.
C.18	Complete Streets Implementation Plan – Florida DOT (2015)	Florida	The plan provides a five-part implementation framework and process for implementing Florida's complete streets policy developed in 2014.
C.19	Context Classification – Florida DOT (2017)	Florida	The document details Florida's context classification system adopted as a part of complete streets, including the measures used to determine the class of each roadway.
C.20	Design Manual – Florida DOT (2019)	Florida	Florida's design manual updated in 2019.
C.21	Plans Preparation Manual – Florida DOT (2017)	Florida	Florida's plan preparation manual which specifies geometric and other design criteria as well as procedures for FDOT projects.

No.	Reference	State	Summary
C.22	Marketing Campaign and PHBs Improve Safety for Pedestrians in Tampa - FHWA	Florida	The document provides details of a marking campaign for pedestrian hybrid beacons in Tampa, Florida.
C.23	Nebraska Avenue Road Diet - Pedestrian and Bicycle Information Center	Florida	Case study example from Tampa, Florida involving a four to three lane road diet along a roadway with a history of pedestrian and bicycle collisions.
C.24	Comprehensive Study to Reduce Pedestrian Crashes in Florida – Florida International University (2015)	Florida	The report summarizes a study conducted to identify crash patterns and contributing factors specific to pedestrian crashes in Florida. The intent of the study was to propose potential countermeasures to improve pedestrian safety based upon these findings.
C.25	Traffic Calming Program – Pedestrian and Bicycle Information Center	Florida	Case study example from Sarasota, Florida which documents a traffic calming program which considered input from the public.
C.26	Seventh Avenue Traffic Calming – Pedestrian and Bicycle Information Center	Florida	Case study example from Naples, Florida which involved the implementation of several traffic calming treatments to address concerns related to cut through traffic on a residential street.
C.27	Pedestrian- and Transit-Friendly Design: A Primer for Smart Growth – Smart Growth Network	Florida	The report represents a manual intended to assist designers in implementing pedestrian facilities which are transit-friendly in Florida. The study is based upon a literature review, other design manuals and empirical studies.

No.	Reference	State	Summary
C.28	The Effects of NO TURN ON RED / YEILD TO PEDS Variable Message Signs on Motorist and Pedestrian Behavior – University of North Carolina (2000)	Florida	The report summarizes a study of variable message signs designed to improve pedestrian safety at signalized intersections which display "NO TURN ON RED" or "YIELD TO PEDS" based upon the current signal phase.
C.29	Central Florida Complete Streets Report – Smart Growth America (2017)	Florida	The document summarizes the results of three complete streets implementation workshops which included national experts and staff from municipalities in central Florida. The goal of the workshops was to share national best practices and identify barriers to complete streets in the region.
C.30	Evaluation of a Green Bike Lane Weaving Area in St. Petersburg, Florida – University of North Carolina (2008)	Florida	The report summarizes a study of green pavement and related signing specific to bicycle weaving areas for bicycle lanes adjacent to intersections. A field study was conducted which examined driver and bicyclist behavior before and after implementation of the treatment.
C.31	Evaluation of Shared Lane Markings in Miami Beach, Florida – University of North Carolina (2012)	Florida	The report summarizes a study of shared lane markings in Florida which were placed in the center of the outside lane. A field study was conducted which examined driver and bicyclist behavior before and after implementation of the treatment.

No.	Reference	State	Summary
C.32	Operational Analysis of Shared Lane Markings and Green Bike Lanes on Roadways with Speeds Greater than 35 MPH – University of North Florida (2014)	Florida	The report summarizes a study of sharrows, wide curb lanes, standard and buffered bike lanes and green bike lanes with respect to the operational performance of bicycle-specific facilities. Driver and bicyclist behavior were observed specific to each of the treatments evaluated within the study.
C.33	Crosswalk signing and marking effects on conflicts and pedestrian safety in UIUC campus – University of Illinois at Urbana-Champaign (2007)	Illinois	The report summarizes a study of pedestrian and vehicle interactions at 24 crosswalks within a campus area with a specific focus on several types of crosswalk markings and signing treatments.
C.34	In-Street Yield to Pedestrian Sign Application in Cedar Rapids, Iowa – Iowa State University (2003)	Iowa	The report summarizes the results of a small-scale study intended to evaluate an in-street sign which displays “State Law – Yield to Pedestrians in Crosswalk”.
C.35	Safe Accommodation of Bicyclists on High-Speed Roadways in Maryland – University of Maryland (2016)	Maryland	The report summarizes a study to investigate design options for bicycle infrastructure specific to high-speed roadways. This included the concept of a “rumble-buffered” bicycle lane which was proposed for several sample sites.

No.	Reference	State	Summary
C.36	Leland Street Redesign in Bethesda – Pedestrian and Bicycle Information Center	Maryland	Case study example from Montgomery County, Maryland which involved geometric treatments to reduce speeds along an arterial which travels through a residential suburban area.
C.37	Winthrop Street Shared Street - Pedestrian and Bicycle Information Center	Massachusetts	Case study example from Cambridge, Massachusetts which involved implementing a shared-street along a previously low-volume street which was in disrepair.
C.38	Granite Street Traffic Calming – Pedestrian and Bicycle Information Center	Massachusetts	Case study example from Cambridge, Massachusetts which involved the implementation of traffic calming measures, including curb extensions and a raised crosswalk, along a collector road which was adjacent to a school and a park.
C.39	Bicycle and Pedestrian Terminology – MDOT (2014)	Michigan	The document briefly summarizes key pedestrian and bicycle terminology specific to both on- and off-road facilities.

No.	Reference	State	Summary
C.40	Multimodal Development and Delivery Work Plan – Michigan DOT (2015)	Michigan	The document summarizes a work plan to update standards and policies for the planning, design, construction maintenance and operation of trunkline facilities for all modes of travel. The report is based upon workshops including MDOT department leadership and a project stakeholder group.
C.41	Livernois Avenue Corridor Project – Pedestrian and Bicycle Information Center	Michigan	Case study example from Detroit, Michigan which included the implementation of several pedestrian-focused treatments along a wide urban arterial. This included the installation of a median, a pedestrian hybrid beacon and a two-stage crossing.
C.42	Evaluating Pedestrian Safety Improvements: Final Report – MDOT (2012)	Michigan	The report summarizes a study of a variety of pedestrian safety countermeasures, including pedestrian hybrid beacons, RRFBs, in-street signs and gateway treatments. This also included the use of RRFBs and PHBs at roundabouts.

No.	Reference	State	Summary
C.43	Sharing the Road: Optimizing Pedestrian and Bicycle Safety and Vehicle Mobility – MDOT (2012)	Michigan	The report aggregates findings from five reports intended to provide recommendations to improve the multimodal components of MDOT's transportation network. This included an analysis of crashes involving pedestrians and bicyclists, a review of improvements summarized by FHWA, a case study analysis of five treatments in Michigan, a review of design treatments from NACTO as well as a summary report of best practices for Michigan.
C.44	Characteristics of Pedestrian Risk in Darkness – University of Michigan (2001)	Michigan	The report summarizes a study of pedestrian crash risk in dark conditions, including how risk is impacted by specific roadway features.
C.45	Best Design Practices for Walking and Bicycling in Michigan - MDOT	Michigan	The document is intended to serve as a toolbox of pedestrian and bicycle related treatments for planners and designers specific to signalized intersections, unsignalized crossings and corridor improvements.

No.	Reference	State	Summary
C.46	Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways – MDOT (2014)	Michigan	The document is intended to establish a step-by-step procedure to evaluate several potential crossing treatments on trunkline routes. The guidance is based upon recent research, other crosswalk guidelines, the MUTCD and state statutes.
C.47	User Guide for R1-6 Gateway Treatment for Pedestrian Crossings – MDOT (2018)	Michigan	The document serves as a reference for the use of in-street R1-6 signs applied as a gateway treatment for pedestrian crossings.
C.48	Intersection, Stop Bar & Crosswalk Markings – MDOT (2017)	Michigan	Design standards for intersection, stop bar and crosswalk markings per MDOT.
C.49	Road Design Manual – MDOT	Michigan	MDOT's Road Design Manual.
C.50	Context Sensitive Solutions – MDOT (2005)	Michigan	Commission policy statement which states that MDOT will "pursue a proactive, consistent and Context Sensitive Solutions" process".
C.51	Sidepath Application Criteria Development for Bicycle Use – MDOT (2018)	Michigan	The report summarizes a project which was designed to provide guidance for sidepaths in Michigan. This included an evaluation of crash data, a resident survey and the development of a practitioner guide.

No.	Reference	State	Summary
C.52	Pedestrian and Bicycle Crash Data Analysis: 2005-2010 – MDOT (2012)	Michigan	The report summarizes an evaluation of traffic crash data involving pedestrians and bicyclists in Michigan from 2005 to 2010. The intent of the study was to determine crash trends which are specific to the state.
C.53	Crash Countermeasure and Mobility Effects – MDOT (2012)	Michigan	The report reviews MDOT's current polices and design standards which impact potential roadway improvements. The document also includes an analysis of best practices from around the United States.
C.54	Case Study Report – MDOT (2012)	Michigan	The document includes a review of recently completed roadway projects and their impacts on pedestrian and bicyclist safety performance.
C.55	Review of National Association of Transportation Officials (NACTO) Bicycle Facilities – MDOT (2012)	Michigan	The document summarizes bicycle facilities which are recommended within NACTO's *Urban Bikeway Design Guide*.
C.56	Developing Michigan Pedestrian and Bicycle Safety Models – MDOT (2018)	Michigan	The report summarizes the development of a pedestrian and bicycle risk score based upon historical crash data and other risk characteristics for a defined area or network in Michigan.

No.	Reference	State	Summary
C.57	How to Better Visualize Southeast Michigan's Bicycle and Pedestrian Mobility Network – Southeast Michigan Council of Governments (2019)	Michigan	Web-based mapping tool that can be used to view the bicycle and pedestrian network in Southeast Michigan.
C.58	Methods to Reduce Traffic Speed in High Pedestrian Areas – Iowa State University (2002)	Minnesota	The report summarizes a study to evaluate the effectiveness treatments intended to reduce travel speeds in high pedestrian areas.
C.59	Minnesota's Best Practices for Pedestrian/Bicycle Safety – Minnesota DOT (2013)	Minnesota	The document represents a best practices guide for agencies to safety accommodate pedestrian and bicyclists on roadway networks in Minnesota
C.60	Traffic Impacts of Bicycle Facilities – University of Minnesota (2017)	Minnesota	The report represents the combination of a review of design guidelines and field observations to estimate the traffic impacts of bicycle-specific facilities.
C.61	Safety Evaluation of Yield-to-Pedestrian Channelizing Devices – Montana State University (2006)	Montana	The report summarizes the results of a field study to evaluate both driver and pedestrian behavior in response to the implementation of yield-to-pedestrian channelizing devices.

No.	Reference	State	Summary
C.62	Rectangular Rapid Flash Beacons Near a NJ Rail Station: Elmwood Park and Fairlawn Boroughs - Pedestrian and Bicycle Information Center	New Jersey	Case study example from Elmwood Park, New Jersey which involved the installation of a RRFB along a four-lane highway near an uncontrolled crossing between a commuter parking lot and a train station.
C.63	2017 State of New Jersey Complete Streets Design Guide – New Jersey DOT (2017)	New Jersey	The document includes tools and methodologies for designing complete streets in a variety of potential settings. The guidance is intended for both state and local staff, design professionals, private developers, and other stakeholders towards the planning and design of streets in New Jersey.
C.64	Daylighting – Pedestrian and Bicycle Information Center	New Jersey	Case study example from Hoboken, New Jersey which involved the installation of vertical delineators to prevent vehicles from being parked to close to intersections.
C.65	Route 71 Pedestrian Tunnel at Monmouth University – Pedestrian and Bicycle Information Center	New Jersey	Case study example from West Long Branch, New Jersey which involved the installation of a pedestrian tunnel to provide an alternative to the at-grade pedestrian crossing which was causing both operational and safety concerns despite the presence of a flashing beacon.

No.	Reference	State	Summary
C.66	Pedestrian Crosswalk Safety: Evaluating In-Pavement, Flashing Warning Lights – Rensselaer Polytechnic Institute (2002)	New Jersey	The report summarizes an evaluation of in-pavement flashing warning lights compared to conventional striping. Recommendations are also provided for the future application of similar treatments.
C.67	Shoulder Rumble Strips and Bicyclists – New Jersey Institute of Technology (2007)	New Jersey	The report provides a review of the existing research specific to shoulder rumble strips and their impact on bicycle-related safety performance. The research is used to develop guidelines for the design and placement of shoulder rumble strips in New Jersey.
C.68	New York City DOT: Pedestrians – New York DOT	New York	The webpage provides a variety of information and resources specific to pedestrian safety for New York City.
C.69	Don't Cut Corners: Left Turn Pedestrian & Bicyclist Crash Study – New York City DOT (2016)	New York	The document summarizes a study specific to traffic crashes involving non-motorized road users and vehicles completing left-turns in New York City.
C.70	Shared Lane Marking (SLM) Policy – New York DOT (2013)	New York	The document describes NYSDOT's policy on the use of sharrows on state highways.

No.	Reference	State	Summary
C.71	Pedestrian Improvements at Jackson Avenue and the Pulaski Bridge - Pedestrian and Bicycle Information Center	New York	Case study example from Queens, New York which involved the modification of geometry at an intersection which had concerns related to the existing pedestrian crossings.
C.72	Slow Zones – Pedestrian and Bicycle Information Center	New York	Case study example from New York City which involved the implementation of a "Slow Zone Program" that involves the installation traffic calming measures to limit speeds to 20 MPH along identified corridors.
C.73	Curb Extensions in Rural Village – Pedestrian and Bicycle Information Center	New York	Case study example from Fort Plain, New York which involved the implementation of curb extensions in the downtown area of a rural village where two state highways observed heavy truck volumes.
C.74	Allen and Pike Streets Corridor Improvements - Pedestrian and Bicycle Information Center	New York	Case study example from New York City which involved a reduction in travel lanes, a prohibition of left-turn movements and an implementation of a buffered bicycle lane along a corridor which connected the Lower East Side with a waterfront greenway.
C.75	Active Design: Shaping the Sidewalk Experience – New York City (2013)	New York	The document is intended to serve as a toolkit for communities to transform the built environment to encourage physical activity.

No.	Reference	State	Summary
C.76	Evaluating the Economic Impact of Shared Use Paths in North Carolina – Institute for Transportation Research and Education (2018)	North Carolina	The report summarizes a project completed to develop a methodology for estimating the economic impacts of shared use paths in North Carolina, including a comprehensive framework specific to a variety of impacts.
C.77	Main Street Redesign – Pedestrian and Bicycle Information Center	North Carolina	Case study example from Hendersonville, North Carolina which involved a redesign of the downtown Main Street to be more pedestrian friendly, including the reduction of lane widths and installing curb extensions.
C.78	Greensboro's Downtown Greenway: Successful Revitalization through Active Transportation - Pedestrian and Bicycle Information Center	North Carolina	Case study example from Greensboro, North Carolina which involved the installation of a shared use path greenway that circles approximately four miles around downtown.

No.	Reference	State	Summary
C.79	Identifying Locations for Pedestrian and Bicyclist Safety Improvements in Chapel Hill and Carrboro – University of North Carolina (2009)	North Carolina	The report summarizes an effort conducted to identify areas which represent potential hazards for pedestrians and bicycles to prioritize safety improvements. This included a review of crash data, surveys, road safety audits and other proactive methods of identifying areas with elevated risks.
C.80	Pedestrian and Bicycle Accommodations on Superstreets – North Carolina DOT (2014)	North Carolina	The report summarizes research conducted to identify challenges specific to pedestrians and bicyclists crossing “superstreet’ intersections and recommend alternatives.
C.81	Risk Factors for Pedestrian and Bicycle Crashes – ODOT (2017)	Oregon	The report summarizes research conducted to develop a tool for ODOT to identify and prioritize locations which have demonstrated an increased risk for pedestrian and bicycle crashes.
C.82	School Zone Traffic Calming – Pedestrian and Bicycle Information Center	Oregon	Case study example from Portland, Oregon which involved a variety of treatments to improve pedestrian safety along two arterials within a school zone.

No.	Reference	State	Summary
C.83	Bikeway Facility Design: Survey of Best Practices – City of Portland (2010)	Oregon	The document provides a review of best practices from other cities where innovative bicycle-related treatments have proven to be effective. The intent is to provide guidance for practitioners specific to proven bicycle facility design.
C.84	Towards Effective Design Treatment for Right Turns at Intersections with Bicycle Traffic – Portland State University (2015)	Oregon	The report summarizes research conducted to quantify the safety performance of alternative traffic control strategies to reduce the risk of bicycle-related crashes at signalized intersections in Oregon.
C.85	Evaluation of Alternative Pedestrian Traffic Control Devices – Oregon DOT (2012)	Oregon	The report summarizes a study of both RRFBs and pedestrian hybrid beacon installations in Oregon, including both a literature review and field studies.
C.86	Assessment of Driver Yield Rates Pre- and Post-RRRB Installation – Oregon DOT (2011)	Oregon	The report summarizes a study of two RRFBs installed at crosswalks in Oregon. The yielding rates of drivers was evaluated pre- and post-implementation.

No.	Reference	State	Summary
C.87	Pedestrian and Bicyclist Friendly Policies, Practices and Ordinances – Delaware Valley Regional Planning Commission (2011)	Pennsylvania / New Jersey	The document is intended to a serve as a handbook for the region specific to practices, policies and ordinances that have been used around the country to improve non-motorized road user safety.
C.88	Double-Ladder Crosswalks – Pedestrian and Bicycle Information Center	Utah	Case study example from Salt Lake City, Utah which involved implementing crosswalks where the middle third of the markings are eliminated to improve traction when the road surface is wet or icy.
C.89	Measuring Systemic Impacts of Bike Infrastructure Projects – Utah DOT (2018)	Utah	The report summarizes a study of the impacts of bicycle infrastructure on all road users, including safety operations and route selection. The research includes an evaluation of treatments along road segments as well as at intersections.
C.90	Vermont Pedestrian and Bicycle Facility Planning and Design Manual – National Center for Bicycling and Walking (2002)	Vermont	The document represents the VTrans design manual for pedestrian and bicycle transportation facilities in Vermont.

No.	Reference	State	Summary
C.91	Revising the Vermont State Standards M2D2 Work Plan – VTrans (2015)	Vermont	The document represents a work plan to update VTrans standards to accommodate all users of the transportation network based upon the state of the practice. The work plan is based upon the results of workshops conducted between VTrans staff and national experts.
C.92	Publicly-Support Road Diet Reduces Speeds in Alexandria - FHWA	Virginia	Case study example from Alexandria, Virginia which documents a successful road diet implementation.
C.93	Development of Guidelines for In-Roadway Warning Lights – Virginia Transportation Research Council (2004)	Virginia	The document summarizes the development of guidelines for the use of in-roadway warning lights in Virginia. Guidance for both the planning and design of devices is provided.
C.94	Evaluation of a Rectangular Rapid Flashing Beacon System at the Belmont Ridge Road and W&OD Trail Mid-Block Crosswalk – Virginia Center for Transportation Innovation & Research (2015)	Virginia	The report summarizes the evaluation of a RRFB installed in Virginia, including a study of driver and pedestrian behavior after implementation.
C.95	Action Plan for Implementing Pedestrian Crossing Countermeasures at Uncontrolled Locations – Washington DOT (2018)	Washington	The plan provides guidance to help WSDOT determine where pedestrian crossing needs exist, how to prioritize funding for countermeasures and which treatments will be most effective.
C.96	Terry Avenue North Shared Street - Pedestrian and Bicycle Information Center	Washington	Case study example from Seattle, Washington which involved the development of design guidelines which considered future adjacent land uses and potential desire lines.

No.	Reference	State	Summary
C.97	Elementary School Crosswalk Enhancement Project – Pedestrian and Bicycle Information Center	Washington	Case study example from Bellevue, Washington which involved the installation of raised crosswalks and curb extensions along residential streets adjacent to school facilities.
C.98	City of Seattle Bicycle and Pedestrian Safety Analysis – Seattle DOT (2016)	Washington	The report summarizes a study of historical pedestrian and bicyclist traffic crash data from 2007 to 2014 in order to identify trends which can be used to better design the cities street network.
C.99	Improved Sidewalk Access: Aurora Avenue Corridor Project - Pedestrian and Bicycle Information Center	Washington	Case study example from Shoreline, Washington which involved upgrades along an arterial corridor which did not have continuous sidewalks or other pedestrian-specific traffic control devices. Corridor improvements included the installation of sidewalks, a center median as opposed to a two-way left-turn lane as well as signalized crossings.
C.100	Nickerson Street Rechannelization – Seattle DOT	Washington	Case study example from Seattle, Washington which included reducing travel lanes and installing a center two-way left-turn lane with marked crosswalks.
C.101	Shared Use Paths Design Guidance – Washington DOT (2012)	Washington	Excerpt from WSDOT's design manual specific to shared use paths.
C.102	Pedestrian Facilities Design Guidance – Washington DOT (2018)	Washington	Excerpt from WSDOT's design manual specific to pedestrian facilities.

No.	Reference	State	Summary
C.103	Bicycle Facilities Design Manual Guidelines for the City of Redmond – City of Redmond (2012)	Washington	The document provides design guidance for bicycle facility design in the City of Redmond over and above the minimums specified by WSDOT and AASHTO.
C.104	Evaluation of HAWK Signal at Georgia Avenue and Hemlock Street – Howard University (2010)	Washington, D.C.	The document summarizes a study of a HAWK signal installed in Washington, D.C., including the results of a field study which evaluated driver and pedestrian behavior.
C.105	District Department of Transportation Bicycle Facility Evaluation – District DOT (2012)	Washington, D.C.	The document summarizes a study of three locations where innovative bicycle facilities were installed, including bicycle boxes, bicycle signals, bicycle contra-flow lanes, buffered bicycle lanes and a two-way cycle track.
C.106	Metrorail Bicycle and Pedestrian Access Improvements Study – Washington Metro Area Transit Authority (2010)	Washington, D.C.	The document summarizes a plan to enhance non-motorized road user access and connectivity to Metrorail stations in Washington, D.C. The plan includes a variety of recommendations, including infrastructure improvements.
C.107	Bicycle Facility Design Guide – District DOT (2006)	Washington, D.C.	The design guide is based upon the MUTCD as well as AASHTO guidance and represents the specifications for bicycle-related facilities in the District of Columbia.
C.108	School Zone Roundabout - Pedestrian and Bicycle Information Center	Wisconsin	Case study example from Green Bay, Wisconsin which involved the implementation of roundabouts near a school zone to reduce travel speeds.

No.	Reference	State	Summary
C.109	Wisconsin Guide to Pedestrian Best Practices – Wisconsin DOT (2010)	Wisconsin	Excerpt from Wisconsin Guide to Pedestrian Best Practices which covers the design of pedestrian facilities.
C.110	Developing an Effective Shoulder and Centerline Rumble Strips/Stripes Policy to Accommodate All Road Users – University of Wyoming (2015)	Wyoming	The report summarizes a study to assist Wyoming DOT in developing an effective rumble strip policy which is effective for all road users.
C.111	M2D2 Guidebook – Michigan DOT (2019)	Michigan	The document is intended to provide information specific to both existing and future transportation modes, data collection opportunities as well as develop a framework for context sensitive solutions for Michigan's transportation system.
C.112	PROJECT: Roadway Lighting's Effect on Pedestrian Safety at Intersection and Midblock Crosswalks	Illinois	Project currently underway in Illinois to investigate the effects of crosswalk lighting design on pedestrian safety at both midblock and intersection locations.
C.113	Left Turn Traffic Calming – New York City DOT	New York	Website which details a citywide program to reduce left turn speeds and enforce safe turning behavior.

Appendix D – Selected Journal Articles, Conference Proceedings and Other Literature

No.	Reference	Authors	Year
D.1	Lowering the speed limit from 30 mph to 25 mph in Boston: Effects on vehicle speeds	Hu, W. and Cicchino, J.	2019
D.2	Safer Cycling Through Improved Infrastructure	Buehler, R., and Pucher, J.	2016
D.3	Trends in Walking and Cycling Safety: Recent Evidence from High-Income Countries, With a Focus on the United States and Germany	Buehler, R., and Pucher, J.	2017
D.4	Pedestrian Crash Trends and Potential Countermeasures from Around the World	Zegeer, C. and Bushell, M.	2010
D.5	Sense and nonsense about Shared Space: For an objective view of a popular planning concept	Gerlach, J., Methorst, R., Boenke, D. and Leven, J.	2007
D.6	Development of Low-Cost Methodology for Evaluating Pedestrian Safety in Support of Complete Streets Policy Implementation	Tolford, T., Renne, J. and Fields, B.	2014
D.7	Pedestrian/Bicyclist Warning Devices and Signs at Highway-Rail and Pathway-Rail Grade Crossings	Metaxatos, P. and Sriraj, P.S.	2013
D.8	Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections	Van Houten, R., Retting, R., Farmer, C. and Van Houten, J.	2000
D.9	Advance Yield Markings: Reducing Motor Vehicle-Pedestrian Conflicts at Multilane Crosswalks with Uncontrolled Approach	Van Houten, R., Malenfant, J. and McCusker, D.	2001
D.10	Efficacy of Rectangular-shaped Rapid Flash LED Beacons	Van Houten, R. and Malenfant, J.	2008
D.11	Safety Effects of In-Roadway Warning Lights or "Flashing Crosswalk" Treatment: A Review and Synthesis of Research	Thomas, L.	2012
D.12	Evaluation of Innovative Bicycle Facilities	Monsere, C., McNeil, N. and Dill, J.	2011
D.13	Innovative Treatments at Unsignalized Pedestrian Crossing Locations	Huang, H., Zegeer, C. and Nassi, R.	2000

No.	Reference	Authors	Year
D.14	Evaluation of Pedestrian Countdown Signals in Montgomery County, Maryland	Eccles, K., Tao, R. and Mangum, B.	2004
D.15	Recommended Walking Speeds for Pedestrian Clearance Timing Based on Pedestrian Characteristics	Gates, T., Noyce, D., Bill, A. and Van Ee, N.	2005
D.16	Pedestrian Volume Modeling for Traffic Safety Exposure Analysis: The Case of Boston, Massachusetts	Raford, N. and Ragland, D.	2005
D.17	Motorist Yielding to Pedestrians at Unsignalized Intersections: Findings from a National Study on Improving Pedestrian Safety	Turner, S., Fitzpatrick, K., Brewer, M., and Park, E.S.	2006
D.18	Index for Assessing Pedestrian Safety at Intersections	Zegeer, C., Carter, D., Hunter, W., Stewart, J.R., Huang, H., Do, A. and Laura, S.	2006
D.19	Accessible Pedestrian Signals: Effect on Safety and Independence of Pedestrians Who Are Blind	Barlow, J., Bentzen, B., Bond, T. and Gubbe, D.	2006
D.20	Access and Mobility Design Policy for Disabled Pedestrians at Road Crossings: Exploration of Issues	Schoon, J. and Hounsell, N.	2006
D.21	Characteristics Related to Midblock Pedestrian–Vehicle Crashes and Potential Treatments	Sandt, L. and Zegeer, C.	2006
D.22	The Effects of Roundabouts on Pedestrian Safety	Stone, J., Chae, K. and Pillalamarri, S.	2002
D.23	A Review of ITS-Based Pedestrian Injury Countermeasures	Bechtel, A., Geyer, J., Ragland, D.,	2003
D.24	Evaluation of Innovative Bike-Box Application in Eugene, Oregon	Hunter, W.	2000
D.25	Development of Bicycle Compatibility Index for Rural Roads in Nebraska	Jones, E. and Carlson, T.	2003

No.	Reference	Authors	Year
D.26	Advance yield markings and drivers' performance in response to multiple-threat scenarios at mid-block crosswalks	Fisher, D. and Garay-Vega, L.	2010
D.27	An Evaluation of Effectiveness of Traffic Signs to Enhance Pedestrian Safety	Pulugurtha, S., Nambisan, N., Dangeti, M., Vasudevan, V.,	2010
D.28	Comparative Evaluation of Flashing Beacon Devices in Santa Monica	Morrissey, S. and Wienberger, S.	2012
D.29	Evaluation of Countermeasures: A Study on the Effect of Impactable Yield Signs Installed at Intersections in San Francisco	Banerjee, I. and Ragland, D.	2007
D.30	Evaluation of Rectangular Rapid Flash Beacon at Pinellas Trail Crossing in Saint Petersburg, Florida	Hunter, W., Srinivasan, R. and Martell, C.	2012
D.31	Event-Based Modeling of Driver Yielding Behavior at Unsignalized Crosswalks	Schroeder, B. and Rouphail, N.	2011
D.32	Spillover effects of yield-to-pedestrian channelizing devices	Strong, C. and Ye, Z.	2010
D.33	Effectiveness of a Pedestrian Hybrid Beacon at Mid-Block Pedestrian Crossings in Decreasing Unnecessary Delay to Drivers and a Comparison to Other Systems	Godavarthy, R.	2010
D.34	The safety or urban cycle tracks: A review of the literature	Thomas, B and DeRobertis, M.	2012
D.35	Measuring the Safety Effect of Raised Bicycle Crossings Using a New Research Methodology	Garder, P., Leden, L. and Pulkkinen, U.	1998
D.36	Risk of injury for bicycling on cycle tracks versus in the street	Lusk, A., Furth, P., Morency, P., Miranda-Morena, L., Willet, W. an dDennerlein, J.	2011
D.37	Evaluation of bike boxes at signalized intersections	Dill, J., Monsere, C. and McNeil, N.	2012

No.	Reference	Authors	Year
D.38	Evaluation of Blue Bike-Lane Treatment in Portland, Oregon	Hunter, W., Harkey, D., Stewart, J. and Birk, M.	2000
D.39	Optimal traffic calming: A mixed-integer bi-level programming model for locating sidewalks and crosswalks in a multimodal transportation network to maximize pedestrians' safety and network usability	Rashidi, E., Parsafard, M., Medal, H. and Li, X.	2016
D.40	Effects of road lighting: An analysis based on Dutch accident statistics 1987-2006	Wanvik, P.	2008
D.41	Optimization of pedestrian phase patterns and signal timings for isolated intersection	Ma, W., Liao, D., Liu, Y. and Lo, H.	2014
D.42	Safety effects of blue cycle crossings: A before-after study	Jensen, S.	2008
D.43	Evaluating the effectiveness of on-street bicycle lane and assessing risk to bicyclists in Charlotte, North Carolina	Pulugurtha, S. and Thakur, V.	2015
D.44	Safety impacts of bicycle infrastructure: A critical review	DigGioia, J., Watkins, K., Xu, Y., Rodgers, M. and Guensler, R.	2017
D.45	Bicycle-Specific Traffic Signals: Results from a State-of-the-Practice Review	Thompson, S., Monsere, C. and Figliozzi, M.	2013
D.46	Designing for the Safety of Pedestrians, Cyclists, and Motorists in Urban Environments	Dumbaugh, E. and Li, W.	2011
D.47	Evaluating the quality of inter-urban cycleways	McCarthy, O., Caulfeld, B. and Deenihan, G.	2016
D.48	Pedestrian and Bicycle Planning: A Guide to Best Practices	Litman, T., Blair, R., Demopoulos, B. and Eddy, N.	2002
D.49	The value of dedicated cyclist and pedestrian infrastructure on rural roads	Laird, J., Page, M. and Shen, S.	2013
D.50	Factors Affecting Driver Yielding Compliance at Uncontrolled Midblock Crosswalks on Low-Speed Roadways	Stapleton, S., Kirsch, T., Gates, T. and Savolainen, P.	2017

No.	Reference	Authors	Year
D.51	Variables Influencing Efficacy of Gateway In-Street Sign Configuration on Yielding at Crosswalks	Bennet, M. and Van Houten, R.	2016
D.52	Before-and-After Study of the Effectiveness of Rectangular Rapid-Flashing Beacons Used with School Sign in Garland, Texas	Brewer, M. and Fitzpatrick, K.	2012
D.53	Influence of Advanced Placement of the In-Street Sign Gateway on Distance of Yielding from the Crosswalk	Hochmuth, J. and Van Houten, R.	2018
D.54	The Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists	McNeil, N., Monsere, C. and Dill, J.	2015
D.55	An Examination of the Effects of the Gateway R1-6 Treatment on Drivers' Yielding Right-of-Way to Pedestrians, Speed at Crosswalk, and Sign Durability Over Time	Van Houten, R., Hochmuth, J. and Dixon, D.	2018
D.56	A comparison of safety benefits of pedestrian countdown signals with and without pushbuttons in Michigan	Boateng, R., Kwigizile, V. and Oh, J.	2017
D.57	Exploring the impact of walk–bike infrastructure, safety perception, and built-environment on active transportation mode choice: a random parameter model using New York City commuter data	Abdul Aziz, H., Nagle, N, Morton, A., Hillard, M., White, D., and Stewart, R.	2017
D.58	Effects of safety measures on driver's speed behavior at pedestrian crossings	Bella, F. and Silvestri, M.	2015
D.59	A comparison of gateway in-street sign configuration to other driver prompts to increase yielding to pedestrians at crosswalks	Bennet, M., Manal, H. and Van Houten, R.	2014
D.60	The impact of pedestrian countdown signals on single and two vehicle motor vehicle collisions: a quasi-experimental study	Escott, B., Richmond, S., Willan, A, Ravi, B. and Howard, A.	2016

No.	Reference	Authors	Year
D.61	Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before–After Study with Comparison Groups	Fayish, A. and Gross, F.	2010
D.62	Empirical Bayesian Evaluation of Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco, California	Feldmen, M. Manzi, J. and Mitman, M.	2010
D.63	Comparison of Above-Sign and Below-Sign Placement of Rectangular Rapid-Flashing Beacons	Fitzpatrick, K., Avelar, R., Lindheimer, T. and Brewer, M.	2016
D.64	Comparison of Rectangular and Circular Rapid-Flashing Beacons in an Open-Road Setting	Fitzpatrick, K., Potts, I., Brewer, M. and Avelar, R.	2019
D.65	Road lighting and pedestrian reassurance after dark: A review	Fotios, S., Unwin, J. and Farrall, S.	2014
D.66	Impacts of Alternative Yield Sign Placement on Pedestrian Safety	Gedafa, D., Kaemingk, B., Mager, B., Pape, J., Tupa, M. and Bohan, T.	2014
D.67	Changes in road-user behaviors following the installation of raised pedestrian crosswalks combined with preceding speed humps, on urban arterials	Gitelman, V., Carmel, R., Pesahov, F. and Chen, S.	2017
D.68	Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior	Huang, H. and Cynecki, M.	2000
D.69	A study of pedestrian compliance with traffic signals for exclusive and concurrent phasing	Ivan, J., McKernan, K., Zhang, Y., Ravishanker, N. and Mamun, S.	2017
D.70	Identifying street design elements associated with vehicle-to-pedestrian collision reduction at intersections in New York City	Kang, B.	2019
D.71	Motorist Actions at a Crosswalk with an In-Pavement Flashing Light System	Karkee, G., Mabisan, S. and Pulugurtha, S.	2010

No.	Reference	Authors	Year
D.72	Using Crash Modification Factors to Appraise the Safety Effects of Pedestrian Countdown Signals for Drivers	Kitali, A., Sando, T., Castro, A. and Kobelo, D.	2018
D.73	Use of Video for Automated Pedestrian Detection and Signal-Timing Extension: Results from a Pilot Installation in San Francisco, California	Lovejoy, K., Markowitz, F. and Montufar, J.	2012
D.74	Comparing the Operational Efficiency of Signalized Intersections with Exclusive and Concurrent Pedestrian Phase Operations Considering Pedestrian Non-Compliance	Mahmud, Md Shakir and Magalotti, M.	2018
D.78	Pedestrian Countdown Signals: Experience with an Extensive Pilot Installation	Markowitz, F., Sciotino, S. Fleck, J. and Yee, B.	2006
D.79	Factors associated with compliance rate at pedestrian crosswalks with Rectangular Rapid Flashing Beacon	Moshanhedi, N., Kattan, L. and Tay, R.	2018
D.80	Pedestrian compliance and cross walking speed adaptation due to countdown timer installations: A self report study	Paschadlidis, E., Politis, I., Basbas, S., and Lambranidou, P.	2016
D.81	Evaluating Effectiveness of Infrastructure-Based Countermeasures for Pedestrian Safety	Pulugurtha, S., Vasudevan, V. and Nambisan, S.	2012
D.82	Leading Pedestrian Interval: Assessment and Implementation Guidelines	Saneinejad, S. and Lo, J.	2019
D.83	The Effects of Pedestrian Countdown Timers on Safety and Efficiency of Operations at Signalized Intersections	Schmitz, J.	2011
D.84	Evaluation of in-pavement flashing warning lights on pedestrian crosswalk safety	Van Derlofske, J., Boyce, P. and Gilson, C.	2003
D.85	Advance Yield Markings and Fluorescent Yellow-Green RA 4 Signs at Crosswalks with Uncontrolled Approaches	Van Houten, R., McCusker, D., Huybers, S., Malenfant, J. and Rice-Smith, D.	2002

No.	Reference	Authors	Year
D.86	Evaluation of Innovative Bicycle Facilities in Washington, D.C.: Pennsylvania Avenue Median Lanes and 15th Street Cycle Track	Goodno, M., McNeil, N., Parks, J. and Dock, S.	2013
D.87	Bicycle Tracks and Lanes: A Before-and-After Study	Jensen, S.	2008
D.88	Lessons from the Green Lanes: Evaluating Protected Bike Lanes in the U.S.	Monsere, C., Dill, J., McNeil, N., Clifton, K. and Foster, N.	2014
D.89	Effects of Bicycle Boxes on Bicyclist and Motorist Behavior at Intersections in Austin, Texas	Loskorn, J., Mills, A., Brady, J. and Duthie, J.	2013
D.90	Operational and Safety Implications of Three Experimental Bicycle Safety Devices in Austin, Texas	Brady, J., Loskorn, J., Mills, A., Duthie, J. and Machemehl, R.	2011
D.91	Evaluating the Safety and Behavioral Impacts of Green Bike Lanes in Suburban Communities	LaMondia, J., McGhee, J., Fisher, M. and Cordero, F.	2019
D.92	Operational Analysis of "Sharrows" on Roadways with Narrow Lane Widths	Sando, T., Angel, M., Hunter, W., Chimba, D. and Kwigizile, V.	2013
D.93	Driver behavior during bicycle passing maneuvers in response to a Share the Road sign treatment	Kay, J., Savolainen, P., Gates, T. and Datta, T.	2014
D.94	Operational Impacts of Protected-Permitted Right-Turn Phasing and Pavement Markings on Bicyclist Performance during Conflicts with Right-Turning Vehicles	Ghodrat, A. and Hurwitz, D.	2019
D.95	Characterization of bicycle following and overtaking maneuvers on cycling paths	Mohammed, H., Bigazzi, A. and Sayed, T.	2019
D.96	Operational Evaluation of Advisory Bike Lane Treatment on Road User Behavior in Ottawa, Canada	Kassim, A., Culley, A. and McGuire, S.	2019

No.	Reference	Authors	Year
D.97	Perceived Safety and Separated Bike Lanes in the Midwest: Results from a Roadway Design Survey in Michigan	Sanders, R. and Judelman, B.	2018
D.98	Street Intersection Characteristics and Their Impacts on Perceived Bicycling Safety	Wang, K. and Akar, G.	2018
D.99	Design and Evaluation of K-Pass: A Bicycle-Friendly Modification of Speed Bumps	Vasudevan, V., Rajukar, A., Soni, R. and Tiwari, A.	2018
D.100	Bike lanes next to on-street parallel parking	Schimek, P.	2018
D.101	Towards a comprehensive safety evaluation of cycling infrastructure including objective and subjective measures	Gotschi, T., Castro, A., Deforth, M., Miranda-Moreno, L. and Zangenehpour, S.	2018
D.102	Evaluating bicycle–vehicle conflicts and delays on urban streets with bike lane and on-street parking	Chen, J., Li, Z., Wang, W. and Jiang, H.	2018
D.103	Evaluating Countermeasures to Improve Pedestrian and Bicycle Safety	Alsghan, I., Santiago, K., Chitturi, M., Bill, A. and Noyce, D.	2018
D.104	Operations and Safety of Separated Bicycle Facilities at Single-Lane Roundabouts	Stanek, D.	2018
D.105	A Comparative Safety Analysis of Bicycle Infrastructure Treatments at Intersections	Fournier, N., Deliali, A., Christofa, E. and Knodler, M.	2018
D.106	Factors Influencing Single-Bicycle Crashes at Skewed Railroad Grade Crossings	Ling, Z., Cherry, C. and Dhakal, N.	2017
D.107	Safe roundabouts for cyclists	Jensen, S.	2017
D.108	A simulator-based analysis of engineering treatments for right-hook bicycle crashes at signalized intersections	Warner, J., Hurwitz, D., Monsesre, C. and Fleskes, K.	2017
D.109	Comparison of five bicycle facility designs in signalized intersections using traffic conflict studies	Kidholm, T., Madsen, O. and Lahrmann, H.	2017

No.	Reference	Authors	Year
D.110	Sharing Is (S)caring? Interactions between Buses and Bicyclists on Bus Lanes Shared with Bicyclists	De Ceunynck, T., Dorleman, B., Daniels, S., LAureshyn, A., Brijs, T., Hermans, E. and Wets, G.	2017
D.111	How to Build the Best Bike Lane in America	Trinh, P.	2017
D.112	Friction and Surface Texture Evaluation of Green-Colored Bike Lanes	Offei, E., Wang, G., Holzschuher, C., Choubane, B. and Carver, D.	2017
D.113	Bicycle Facilities Adjacent to On-Street Parking: A Review of Crash Data, Design Standards, and Bicyclist Positioning	Schimek, P.	2017
D.114	Investigating the Correlation Between Sidewalk Gaps and Pedestrian Safety	Abou-Senna, H., Radwan, E. and Mohammed, A.	2016
D.115	Separated Bike Lane Crash Analysis	Rothenberg, H., Goodman, D. and Sunstrom, C.	
D.116	Shared-Use Path Intersection Control Compliance	Silber, H., Burdett, B., Bill, A. and Noyce, D.	2016
D.117	Bicyclist and Pedestrian Safety in Work Zones: Recent Advances and Future Directions	Shaw, J., Chitturi, M., Han, Y., Bremer, W. and Noyce, D.	2016
D.118	Developing crash modification functions to assess safety effects of adding bike lanes for urban arterials with different roadway and socio-economic characteristics	Park, J., Abdel-Aty, M., Lee, J. and Lee, C.	2015
D.119	Delay Estimation and Signal Timing Design Techniques for Multi-Stage Pedestrian Crossings and Two-Stage Bicycle Left Turns	Furth, P. and Wang, Y.	2015
D.120	Comprehensive Complete Streets Planning Approach	Kala, B. and Martin, P.	2015
D.121	Pedestrian and Bicyclist Accommodations and Crossings on Superstreets	Holzem, A., Hummer, J., Cunningham, C., O'Brien, S., Schroeder, B. and Salamati, K.	2015

No.	Reference	Authors	Year
D.122	Design Guidance for Bicycle Lane Widths	Fees, C., Torbic, D., Bauer, K., Van Houten, R., Roseberry, N. and LaPlante, J.	2015
D.123	User Behavior and Perceptions at Intersections with Turning and Mixing Zones on Protected Bike Lanes	Monsere, C., Foster, N., Dill, J., McNeil, N.	2015
D.124	A review of design and maintenance guidelines for greenways	Manton, R. and Clifford, E.	2015
D.125	Analysis of alternative treatments for left turn bicycles at tandem intersections	Zhao, J., Yan, J. and Wang, J.	2019
D.126	Analysis of Pedestrian-Crossing Speed Characteristics at Traffic Intersections	Zhu, H., and Yang, X.	2019
D.127	Midblock Pedestrian Crash Predictions in a Systemic, Risk-Based Pedestrian Safety Process	Kumfer, W., Thomas, L., Sandt, L. and Lan, B.	2019
D.128	A New Type of Road for North America: Solving the Challenge of Non-Motorized Infrastructure with Advisory Bike Lanes	Williams, M.	2018
D.129	A full Bayesian approach to appraise the safety effects of pedestrian countdown signals to drivers	Kitali, A. and Sando, T.	2017
D.130	Evaluation of Pedestrian Crosswalk Spacing at Roundabouts Based on Shockwave Theory	Ong, B., Mladenovic, M. and LeBlanc, S.	2017
D.131	Understanding Pedestrian Needs at Light Rail Transit Grade Crossings	Fitzpatrick, K., Sperry, B., Warner, J., Bentzen, B. and Brewer, M.	2017
D.132	Effects of Refuge Island Settings on Pedestrian Safety Perception and Signal Violation at Signalized Intersections	Cao, Y., Ni, Y. and Li, K.	2017
D.133	Safe and Efficient Pedestrian Accommodation at Coordinated Signalized Intersections	Tian, Z. and Gholami, A.	2016
D.134	Developing and testing a LED system to improve pedestrian safety in Nevada	Teng, H., Hu, B. and Kutela, B.	2018

Appendix 2:

Summary of Relevant MDOT Planning and Design Materials

Appendix 2: Summary of Relevant MDOT Planning and Design Materials

Document, Form, or Process	Summary of Pedestrian and Bicycle Impacts
Road Design Manual	MDOT's *Road Design Manual* includes a variety of design guidance and other information which both directly and indirectly impacts the planning and design pedestrian and bicycle facilities.
Bridge Design Manual	While MDOT's *Bridge Design Manual* contains only a limited amount of guidance which impacts the design of pedestrian and bicycle facilities, there are still a variety of elements which represent important considerations for non-motorized users.
Local Agency Projects Guidelines for Geometrics	The geometric guidelines for local projects incorporates a variety of design guidance and other information which can have a direct impact on the needs of non-motorized road users.
Local Agency Project Application	The project application includes fields which directly includes non-motorized considerations as well as fields which may indirectly impact non-motorized users.
Local Agency Program Project Planning Guide	The local agency project planning guide specifies policies and procedures which can impact pedestrian and bicycle considerations during the project development process.
Local Agency Federal Eligibility Guideline	The guidelines provide information on eligible and ineligible project elements which directly impact design for non-motorized users.
Project Scoping Manual	The scoping manual includes a range of policies and procedures which have direct and indirect impacts on non-motorized considerations in the project development process.
Call for Projects Memo and Instructions	MDOT's trunkline call for projects memorandum represents a core component of the department's project development process and therefore has a significant impact on non-motorized users.
MDOT/FHWA Stewardship and Oversight Agreement	The agreement represents a core component of the department's project development process and therefore has a significant impact on non-motorized users.
Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways	The guidance document represents the department's resource for designing pedestrian crosswalks on trunkline highways.
Bus Stop and Shelter Guide	The draft document details guidance information related to transit stops which has a direct impact on non-motorized design.
Michigan MUTCD	Michigan's manual includes design information related to traffic control devices which both directly and indirectly impact non-motorized users.
Geometric Design Guidance	The department maintains a variety of geometric design guidance on its Traffic and Safety/Standards and Special Details page which impact non-motorized users.
Road/Bridge Standard Plans and Specifications	The departments standard plans and specifications include a range of design information which impact non-motorized users.

Document, Form, or Process	Summary of Pedestrian and Bicycle Impacts
Work Zone Audit Report Form	The department maintains a variety of forms related to the project development process which potentially impact non-motorized users.
Road and Bridge Forms 0593 and 0594	
Design Exception Form	
Design Variance Form	
Scope Verification Form	
Regional Non-Motorized Plans	Each region within Michigan has developed a plan intended to help coordinate future investment in the non-motorized transportation system.
Local Road Safety Plans	Regional planning organizations partnered with MDOT in order to develop traffic safety plans intended to guide future investments.
Right-of-Way Construction Permit Manual and Documents	The permitting process includes a variety of policies and procedures which impact non-motorized users.
Michigan Strategic Highway Safety Plan (SHSP)	The state's strategic highway safety plan places a specific focus on non-motorized users within the at-risk road users emphasis area.
Work Zone Safety and Mobility Manual	The department's work zone manual includes a variety of policies and procedures which impact non-motorized users.
Maintenance Work Zone Traffic Control Guidelines	The document provides guidance for traffic signing in maintenance work zones which may impact non-motorized users.
Michigan Intersection Guide	The document provides guidance for various intersection types which can have a direct impact on design for non-motorized users.
Michigan Roundabout Guidance Document	The document provides guidance for roundabouts in Michigan which has a direct impact on design for non-motorized users.
Traffic Sign Design, Placement, and Application Guidelines	The document provides additional guidance for traffic signing along freeways and non-freeways beyond other relevant guidance materials (such as the MMUTCD) and has a direct impact on non-motorized users.
Best Design Practices for Walking and Bicycling in Michigan	The document identifies best practices in non-motorized design which was updated as a part of OR19-072.
School Area Traffic Control Guidelines	The departments guidance for school zone design includes information which directly impacts non-motorized users.
Guidelines for Traffic Safety Planning in School Areas	
Pavement Marking Standards	The departments pavement marking standards includes a range of design information which impacts non-motorized users.
Guidelines for Traffic Regulations and Traffic	The departments guidelines for traffic control orders has a direct impact on non-motorized users.

Document, Form, or Process	Summary of Pedestrian and Bicycle Impacts
Control Orders (speed studies/control)	
Sight Distance Guidelines	The department's guidelines on sight distance design have a direct impact on non-motorized users.
Design Advisories	The department's design advisories provide guidance on specific topics to promote uniformity in design and directly impact non-motorized users.
Diagonal Parking Review Process for Local Agency Projects	The process for implementing diagonal parking includes a variety of policies and procedures which impact non-motorized users.
Safe Routes to School Application	The Safe Routes to School (SRTS) process is a core component of the state's non-motorized program.
Guidelines for Signing on State Trunkline Highways	The document provides guidance for traffic signing along trunklines and has a direct impact on non-motorized users.
Guidelines for Highway Railroad Crossings	The department's guidelines for rail crossings includes design information which directly impacts non-motorized users.
Electronic Traffic Control Device Guidelines	The department's guidelines for electronic traffic control devices includes a variety of policies and procedures which impact non-motorized users.
LAP Guidance for Local Projects Having Rail Crossings	The guidance for local agency projects with rail crossings includes policies and procedures which impact non-motorized users.
M2D2 Work Plan	The M2D2 process is intended to help improve MDOT's capacity to accommodate multiple travel modes within the transportation system.
M2D2 Report	
Guidance for Truckline Main Streets	The department's guidance for mainline streets includes information which directly impacts non-motorized users.
ITS Strategic Plan	The strategic plan includes a range of information which directly and indirectly impacts non-motorized users.
Connected and Automated Vehicle Program Strategic Plan	The strategic plan includes a range of information which directly and indirectly impacts non-motorized users.
VISSIM Protocol Manual	The manual includes procedures for microsimulation which have a direct impact on the design of facilities for non-motorized users.
User Guide for R1-6 Gateway Treatment for Pedestrian Crossings	The use of R1-6 signs and gateway treatments represents an innovative design practice which can help to improve conditions for non-motorized road users.
Road Safety Audit Guidance	MDOT's road safety audit guidance includes policies and procedures which can impact non-motorized users.
Traffic and Safety Note 207C: Guidelines for Pedestrian Push Button Use & Location	The planning and design of pedestrian pushbuttons represents a critical element of pedestrian design guidance in Michigan.

Appendix 3:

Details of Survey of State and Local Agency Non-Motorized Staff

Appendix 3: Details of Survey of State and Local Agency Non-Motorized Staff

Appendix 3.1 Copy of Survey Instrument

(Note that only the state agency survey is provided for brevity and questions specific to local agencies are provided where the surveys varied)

MICHIGAN STATE UNIVERSITY

On behalf of the Michigan Department of Transportation (MDOT), Michigan State University (MSU) is inquiring about pedestrian and bicyclist practices, policies, and guidelines utilized within your state. Your responses will contribute to future transportation planning and design efforts in the State of Michigan.

INSTRUCTIONS:
This survey is comprised of seven topics, each with a question or short series of related questions. Please respond as you are comfortable and able. Your responses are automatically saved when you proceed to a new page. If you must close out of the survey, clicking on the link sent to your email will re-open the survey where you left off. Any relevant documents may be emailed to any of the contacts listed below.

If there are other persons, inside or outside of your agency, who may provide valuable responses regarding any of the survey topics, please share their contact information in the space provided at the end of the survey. We are hoping to gather a broad base of responses, so anyone you can direct us to is helpful.

Your Preferred Contact Information

Please enter your preferred contact information for any follow-up questions we may have. We will only contact you if further clarification is necessary for any response.

Name

Title

Division

Agency

Phone

Email

Please indicate the frequency of use of the following **BICYCLE** treatments at **SEGMENTS OR CORRIDORS** in your state.

Clicking on the name of the treatment will open a new window with more information about that treatment.

	Never	Rarely	Sometimes	Frequently	Unsure
Shared Lane Markings (e.g., Sharrows)	○	○	○	○	○
Bicycle Wayfinding Signs/ Markings	○	○	○	○	○
Paved Shoulders	○	○	○	○	○
Standard Bicycle Lanes	○	○	○	○	○
Buffered Bicycle Lanes	○	○	○	○	○
Back-in Angle Parking	○	○	○	○	○
Protected/Separated Bicycle Lanes	○	○	○	○	○
Contra-Flow Bicycle Lanes	○	○	○	○	○
Left-Side Bicycle Lanes on One-Way Streets	○	○	○	○	○
Shared Use Paths	○	○	○	○	○
Sidepaths	○	○	○	○	○
Other ____	○	○	○	○	○
Other ____	○	○	○	○	○

Please comment on any **successful** treatments, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance.

Please comment on any treatments that have experienced **failures or mixed results**, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance. This includes treatments that have been **discontinued.**

Please indicate the frequency of use of the following **BICYCLE** treatments at **INTERSECTIONS** in your state.

Clicking on the name of the treatment will open a new window with more information about that treatment.

	Never	Rarely	Sometimes	Frequently	Unsure
Bicycle Signals	○	○	○	○	○
Signal Detection for Bicycles	○	○	○	○	○
Bicycle Boxes	○	○	○	○	○
Two-Stage Turn Queue Boxes	○	○	○	○	○
Green Pavement Markings for Bicycle Lanes	○	○	○	○	○
Protected/Dedicated Intersection	○	○	○	○	○
Other	○	○	○	○	○
Other	○	○	○	○	○

Please comment on any **successful** treatments, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance.

Please comment on any treatments that have experienced **failures or mixed results**, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance. This includes treatments that have been **discontinued.**

Please indicate the frequency of use of the following **PEDESTRIAN** treatments at **CROSSWALKS OR MIDBLOCK AREAS** in your state.

Clicking on the name of the treatment will open a new window with more information about that treatment.

	Never	Rarely	Sometimes	Frequently	Unsure
R1-6 Signs	○	○	○	○	○
Pedestrian Refuge Islands	○	○	○	○	○
Raised Crosswalks	○	○	○	○	○
Curb Extensions (e.g., Bump/Bulb Out)	○	○	○	○	○
Rectangular Rapid Flashing Beacons (RRFB)	○	○	○	○	○
Pedestrian Hybrid Beacons (PHB)	○	○	○	○	○
Midblock Traffic Signals	○	○	○	○	○
Pedestrian Grade Separation	○	○	○	○	○
Advance Yield Markings	○	○	○	○	○
Other ________	○	○	○	○	○
Other ________	○	○	○	○	○

Please comment on any **successful** treatments, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance.

Please comment on any treatments that have experienced **failures or mixed results**, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance. This includes treatments that have been **discontinued.**

Please indicate the frequency of use of the following **PEDESTRIAN** treatments at **TRAFFIC SIGNALS** in your state.

Clicking on the name of the treatment will open a new window with more information about that treatment.

	Never	Rarely	Sometimes	Frequently	Unsure
Pedestrian Push-Buttons	○	○	○	○	○
Accessible Pedestrian Signals	○	○	○	○	○
Leading Pedestrian Intervals	○	○	○	○	○
Centerline Hardening	○	○	○	○	○
Exclusive Pedestrian Phase (e.g., "Barnes Dance")	○	○	○	○	○
Right Turn on Red Prohibitions	○	○	○	○	○
Advance Stop Markings	○	○	○	○	○
Other ________	○	○	○	○	○
Other ________	○	○	○	○	○

Please comment on any **successful** treatments, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance.

Please comment on any treatments that have experienced **failures or mixed results**, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance. This includes treatments that have been **discontinued.**

Please indicate the frequency of use of the following **TRAFFIC CALMING MEASURES** in your state.

Clicking on the name of the treatment will open a new window with more information about that treatment.

	Never	Rarely	Sometimes	Frequently	Unsure
Road Diets	○	○	○	○	○
Lane Narrowing/Pinchpoints	○	○	○	○	○
Lane Shifts/Chicanes	○	○	○	○	○
Diverters	○	○	○	○	○
Roundabouts	○	○	○	○	○
Mini Roundabouts/ Neighborhood Traffic Circles	○	○	○	○	○
Vertical Speed Control Elements (e.g., Speed Humps/Tables)	○	○	○	○	○
Reducing Speed Limits	○	○	○	○	○
Other ______	○	○	○	○	○
Other ______	○	○	○	○	○

Please comment on any **successful** treatments, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance.

Please comment on any treatments that have experienced **failures or mixed results**, in terms of crash reduction, driver behavior, public acceptance, weather issues, and/or maintenance. This includes treatments that have been **discontinued.**

How frequently do you or persons with whom you work reference the following **NATIONAL GUIDELINES** in the design of ped/bike facilities?

	Never	Rarely	Sometimes	Frequently	Always	Unsure
AASHTO Guide for the Development of Bicycle Facilties	○	○	○	○	○	○
AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities	○	○	○	○	○	○
NACTO Urban Bikeway Design Guide	○	○	○	○	○	○
NACTO Urban Street Design Guide	○	○	○	○	○	○
FHWA Achieving Multimodal Networks	○	○	○	○	○	○
FHWA Separated Bike Lane Planning and Design Guide	○	○	○	○	○	○
FHWA Small Town and Rural Multimodal Networks	○	○	○	○	○	○
ITE Designing Walkable Urban Thoroughfares	○	○	○	○	○	○
NCHRP or TCRP Reports ______	○	○	○	○	○	○
Other Guides ______	○	○	○	○	○	○
Other Guides ______	○	○	○	○	○	○

Does your **STATE** maintain any of the following **GUIDELINES, STANDARDS, OR POLICIES** related to the design or implementation of pedestrian or bicycle facilities?

	Yes	No	Unsure
Pedestrian Design Guide	○	○	○
Bicycle Design Guide	○	○	○
Transit Facility Design Guide	○	○	○
Complete Streets Policy/Guide	○	○	○
Context Sensitive Design Policy/Guide	○	○	○
Other ______	○	○	○

Has your agency reviewed its internal transportation practices, standards, guidance documents or other manuals (such as a road design manual or project scoping guidance) to identify content that can be modified to better address the needs of non-motorized road users? Please describe and provide links to any relevant documentation.

Does your agency maintain a master plan for non-motorized travel?

- Yes
- No

How often is this master plan evaluated and updated?

- Less than 5 years
- 5 years
- 6 - 9 years
- 10 years
- More than 10 years

Please provide a link to this plan, if available.

What types of data collection/monitoring systems (including crowd sourcing data systems) are utilized to better understand pedestrian and bicyclist activity in your state?

Does your agency maintain an inventory of pedestrian and/or bicycle infrastructure (such as sidewalks, bicycle lanes, enhanced crossings, etc.)?

Micromobility (such as bike-share and e-scooter share) use has been popular for the past several years.

As Micromobility users share the same facilities with pedestrians and cyclists, please describe any considerations or accommodations regarding infrastructure design to minimize conflicts between modes and improve safety.

Is there anyone else within your agency that you would recommend we also contact? Please provide contact info.

Are there any local agencies (i.e., cities, townships, counties, or MPOs) within your state or other out-of-state agencies that employ innovative bike and pedestrian practices that you would recommend we contact? Please provide contact info.

(Local Agencies Only):

What funding sources does your agency utilize, primarily, for major ped/bike improvement projects?

(Local Agencies in Michigan Only):

Are there aspects of Michigan specific design manuals, guidance documents or policies that have caused your local agency to be unable to deliver the multi modal projects/designs you were seeking to implement? If so please share your experiences with us.

Appendix 3.2 Shared Lane Marking/Sharrow Respondent Comments

Agency	Comment
Massachusetts	Sharrows are the least successful treatments as they offer no protection and act only as a reminder for motorists to be on the lookout for cyclists.
Utah	We typically only apply sharrows in right hand turn pockets where we mix the bicycle lane. It is very rare to see a UDOT facility with sharrows since many of our speed limits are above the recommended 35MPH or less for their application.
Louisiana	We do not typically recommend use of sharrows and signage as an acceptable treatment for bicyclists. These are not sufficient for improving safety and drivers may not respond positively to them in some cases.
Burlington, VT	Shared lane markings and bike wayfinding markings have had mixed results from bicyclists and drivers, respectively.
Chittenden CO, VT	public prefers protection which sharrows don't provide, but those can provide wayfinding and alert motorists to other roadway users.
Rochester NY	bike lanes, sharrows are not useful for crash reduction.

Appendix 3.3 Paved Shoulder Respondent Comments

Agency	Comment
Louisiana	On state routes shoulders are considered as a suitable bicycle facility. If a bike/ped/complete streets plan has been adopted that includes a specific recommendation within design guidelines (beyond shoulders) and a suitable alternative route does not exist, DOTD will consider the recommended bicycle improvement on the route.
Pennsylvania	Using paved shoulders can be challenging when the shoulder is inappropriately treated with rumble strips or used for a bypass travel lane for motor vehicles going around vehicle stopped for a left turn. Similarly, shoulders that become a 'free right' turn at intersections are challenging - we are trying to move the cyclists into the travel lane or shared space earlier but this is not an all-ages / all abilities treatment. And as local governments are completely responsible for the paint and signs associated with these treatments and they resist any additional costs (and also the suggested improvements). Overall paved shoulders are very appropriate in rural area but more consideration needs to be given to the above issues. Share the Road signs are being strongly discouraged in most situations due to documented lack-of-effect on driver behavior.
Fairbanks, AK	Fairbanks, Alaska, has long winters with snow cover from September to April. Bike Lanes are unfeasible because of the maintenance commitment to keep them maintained (snow free) all winter long. Typically the road shoulders are piled with rows of snow.
Chittenden County, VT	in our rural areas paved shoulders provide additional space for walking/biking but don't offer a level of protection from vehicles.
Washtenaw CO, MI	Wider shoulders have helped and driver expectation has helped with bikers riding on roadways on a routine basis.
Traverse City, MI	Striped shoulders are also popular due to traffic calming and still allowing parking.

Appendix 3.4 Standard Bicycle Lane Respondent Comments

Agency	Comment
Pennsylvania	Standard bike lanes or buffered bike lanes tend to be clogged with parked cars and delivery vehicles. Physical separation with flexible delineator posts at 8 feet seems to help.
Burlington, VT	Buffered and standard bike lanes have been successful for routine winter maintenance and public acceptance.
Chittenden County VT	our suburban towns are adding conventional bike lanes as well as sidepaths and shared use paths.
Rochester NY	bike lanes, sharrows are not useful for crash reduction.

Agency	Comment
Milwaukee WI	It is clear in Milwaukee, that standard bike lanes do not provide adequate separation or safety for people of all ages and abilities to feel comfortable bicycling. Projects that include standard bike lanes are increasingly viewed by advocates and residents as unsuccessful and do not sufficiently satisfy the City's Complete Streets policy.
Corvallis, OR	About 98% of arterial and collector streets in Corvallis have bike lanes and although they are dated in terms of best practices for cycling infrastructure, they are still the backbone of our bicycle network. We have MUPs, buffered bike lanes, shared streets, etc. but the workhorse of our system continues to be bike lanes. As we develop more advanced infrastructure, this likely will change but they serve a great purpose, are easily maintained and they have great public acceptance.
Kalamazoo CO, MI	Bike lanes, shared lanes, and bike route signage are difficult to maintain and coordinate with the townships. They are also more of a concern in rural areas where vehicle speeds are higher and motorists do not expect to see bicycles.
Lansing, MI	As far as maintenance, standard bike lanes seem to be the easiest to sweep and plow because they are just an extension of the roadway. Areas where bike lanes were installed by grinding and restriping have been a challenge since it's not possible to completely remove the original markings. Lane drops on a 4 to 3 lane conversion are also a challenge since there is a half lane shift as the bike lane develops, so the lane that drops has about the same shift as the one that doesn't which leads to some confusion.

Appendix 3.5 Buffered Bicycle Lane Respondent Comments

Agency	Comment
Vermont	Buffered bike lanes have resulted in increased levels of bicycling. Must be regularly maintained to continue effectiveness.
Burlington, VT	Buffered and standard bike lanes have been successful for routine winter maintenance and public acceptance.
Milwaukee, WI	We've also implemented several road diets (with buffered/protected bike lanes) in recent years and while it is too early to tell whether they have significantly reduced crashes, we can say that they have reduced speed.
Kalamazoo CO, MI	Buffered and protected bike lanes are a maintenance concern for the agency.

Appendix 3.6 Separated or Protected Bicycle Lane Respondent Comments

Agency	Comment
Ohio	Separated two-way bike lanes (cycletrack) in Columbus led to increased biking and reduced crashes overtime. Increased crashes occurred at first but was improved the longer the facility was in use. Additionally, the eventual installation of bike signals reduced the conflict of left-turns and bikes.
Massachusetts	The most successful treatments involve separated facilities. In terms of crash reduction separation is key, while driver behavior improves due to better awareness of facilities, public acceptance is universal, weather issues, and/or maintenance have both been addressed by utilizing smaller sweepers and plows to fit within these new lanes.
New Mexico	Separated bike lanes have maintenance issues because of sand or debris and a lack of appropriately sized cleaning equipment (street sweepers).
New York	Use of Separated Bicycle Lanes Successful
Washington DC	Pennsylvania Ave. NW has an interesting history – it’s a center running cycle track but it’s first iteration was also a road diet, removing a lane. That seemed to be confusing to drivers (and not politically popular) so it was revised to only use the median as the cycletrack. Parking blocks had to be installed eventually to prevent mid-block u-turning drivers.

Agency	Comment
	See some post construction analysis here of 2 cycle tracks and a road diet: https://comp.ddot.dc.gov/Documents/Post-Construction%20Analysis_FINAL_14August2015.pdf
Burlington, VT	Protected lanes have been successful at keeping drivers out of bike lanes (but have other significant challenges). Protected lanes have had mixed results for sweeping in warm-weather months and snow removal in winter, and for drivers unsure of options when an emergency vehicle needs to pass (all contributing to mixed public acceptance).
Chittenden CO, VT	feedback from the public is for more protected bike lanes for their safety, and they tend to slow down traffic. Our snowy winters can be an issue but sidewalk plows fit the PBL. non-cycling public doesn't like protected bike lanes (or road diets to create bike lanes)
Rochester, NY	off street cycletracks have been successful, but intersections have caused problems as the designs haven't always carried through.
Seattle, WA	Separated bicycle lanes, elevated bike lanes next to sidewalks, and two way bike lanes at sidewalk level have been installed with good results in ridership increase, reduction in collisions, and positive public feedback. Cost and project impact during construction have been concerns from elected official and the public. Separated bicycle lanes with level bus island crossing on one facility has been a source of conflict. This may be due to downhill grade of the street that have riders travelling at higher speed and unable to react pedestrians.
Milwaukee, WI	There is significant popular demand for protected bike lanes by both residents and advocates.
New York, NY	Protected bike lanes show great crash reductions not just for cyclists, but also for pedestrians.
Kalamazoo Co, MI	Buffered and protected bike lanes are a maintenance concern for the agency.

Appendix 3.7 Contra-Flow Bicycle Lane Respondent Comments

Agency	Comment
Traverse City, MI	The contraflow bike lane and traditional bike lanes have been generally accepted, but, particularly in areas where parking was removed to accommodate bike lanes, there has been some public push-back. Winter maintenance for these facilities, and the striped shoulders, can be a challenge due to snow storage and blocked storm sewers during the spring melt. None of our bike facilities have been removed due to failures, but many have been improved by widening the facility or replacing it with a more protected facility (such as the bike lanes on Eighth St being replaced by cycle tracks).

Appendix 3.8 Shared Use Path and Sidepath Respondent Comments

Agency	Comment
Alaska	Separated pathways are popular among public and designers. Shared sidewalks are not ideal though maintenance likes them because they reduce maintenance needs. signing and striping is mixed and confusion for users and drivers. inconsistent applications for bike lanes and shared use.
New Mexico	We have a new multiuse trail in one community and the trail needs to have bollards installed because vehicles are using it as a frontage road/ cutoff.
Pennsylvania	Trail crossings (shared use paths) have challenges with cyclists entering the roadway without yielding to oncoming traffic. Current practice is to include a STOP sign on the trail legs for cyclists but the issue is more of an education issue then a design issue
Arizona	Shared use paths installed along washes and rail ROW are extremely popular with the public and are extremely safe. Sidepaths (shared use areas that run alongside roadway rights-of-way) are associated with high crash rates at intersections and driveways because they essentially function as a sidewalk which are rarely suitable for bicycle travel.

Agency	Comment
Fairbanks, AK	Grooming snow on separated asphalt paths (instead of plowing) for people to ski and fat-tire bike on during the winter months.
Chittenden County, VT	our suburban towns are adding conventional bike lanes as well as sidepaths and shared use paths.
Traverse City, MI	The shared use paths and side paths are our most successful treatments--heavily used, safe, and well maintained.
Kalamazoo Co, MI	The KVRT is a well organized trail that is managed by the County Parks. It is well received by the public and follows an old rail line.
Lansing, MI	The public seems to like shared use paths best as they feel safest separated from traffic.

Appendix 3.9 Bicycle Signal Respondent Comments

Agency	Comment
Massachusetts	Bike signals also very helpful in giving cyclists adequate lead time in busy intersections.

Appendix 3.10 Bicycle Signal Detection Respondent Comments

Agency	Comment
Utah	We have provided signal detection and in some instances detection confirmation and bicycle specific signals. These have improved safety for people on bicycles by reducing left turn conflicts/movements. Additionally, reducing the instances of bicycles running red lights. Our intersection radar detection is deployed at 90+% of the states signals, however it cannot differentiate between vehicles/bikes. We are looking at various technologies to fully detect bicycles/pedestrians and their directional movements.
Seattle, WA	Bicycle signals with phase separation have provided good safety results in our high volume downtown bicycle lanes. There is now an expectation from the public that we install bicycle signals in our separated bicycle lane projects.
Corvallis, OR	So far we are having mixed results with a blue light detection pilot program. The light has been problematic in detecting either not detecting or staying on without anyone triggering it. We have it fixed for now but so far, the public is not impressed.
Traverse City, MI	Bicycle detection and signals are new this year in the City, however, they do seem to draw attention to cyclists and minimize right turn conflicts.
Kalamazoo Co, MI	RCKC uses Iteris Video Detection which comes with standard bike detection.
Lansing, MI	Other than camera detection at intersections, we haven't done much in the way of intersection treatments, so I can't comment on the success or failure

Appendix 3.11 Bicycle Box Respondent Comments

Agency	Comment
New York	Use of bike boxes successful
Pennsylvania	Bike boxes and Two Stage Queue Boxes are only being used in Philadelphia and Pittsburgh but results indicate they are effective.
Burlington, VT	Bike boxes have mixed results for driver compliance and concerns from some people biking when faced with a green light and a bike box. Bike box materials have been challenging to find a durable, affordable material that is slip-resistant. Bike boxes are still new in our area but more are being installed.
Kalamazoo Co, MI	Bike boxes, green pavement markings, and bike signals represent a large financial investment. Given the rural character of the county and the decreased bicycle traffic volumes, such treatments are not used at this time.

Appendix 3.12 Two-Stage Turn Queue Box Respondent Comments

Agency	Comment
Ohio	Some case studies have been done for the two stage turn boxes added in downtown Columbus several years ago related to improved visibility and driver behavior.
Utah	Two stage turn boxes have been installed on a variety of UDOT intersections (SPUI, CFI, traditional). We are using thermoplastics to address maintenance concerns especially as they relate to snow removal. We use radar detection for bicycles and have put in pavement markers to indicate where bicycles should wait for detection (behind the pavement
Pennsylvania	Bike boxes and Two Stage Queue Boxes are only being used in Philadelphia and Pittsburgh but results indicate they are effective.
New York, NY	Mixing zones for left turning vehicles through bike lanes, especially protected bike lanes, can cause confusion for both cyclists and vehicle drivers alike. I'm not sure of crash reductions here, but it is generally disliked by drivers and cyclists. At the same time, split phases are widely viewed as annoying by cyclists.

Appendix 3.13 Green Pavement Marking Respondent Comments

Agency	Comment
Vermont	Anecdotally, green pavement markings are noticed by drivers. Must be maintained to continue to be effective. One challenge is that we initially install with durable markings like MMA. Then, they are maintained with waterborne paint and the interaction of the two materials is somewhat an unknown.
Pennsylvania	We've used green paint for a bike lane successfully and while expensive, it holds up well in an urban environment.
New Mexico	One city that has deployed green bike lanes is now opposed to any new green paint because of claims it is slippery for the bikes. In the same city parking buffered bike lanes were installed, but a politically influential resident called for their removal.
Burlington, VT	Green pavement markings at intersections have had good public acceptance.
Chittenden Co, VT	green paint makes bike facilities more visible to all users. green paint fades in our snowy northeast climate and isn't always maintained.
Corvallis, OR	The most significant treatment we have found that reduces near-misses, crashes and is supported by both the bicycle community and motorists is green paint treatments within areas where bikes and vehicles mix, such as the crossover a vehicle must make to enter into a channelized right turn. Providing green paint (by "paint", I mean a durable product like thermoplastic) in areas like this is low-cost, long-term solution that is effective and visible in all weather conditions that nobody using the road system seems to have a problem with.
Washtenaw Co, MI	We have grown accustom to and have expanded our use of the green pavement markings.
Traverse City, MI	The bike markings at driveways have greatly reduced frequency of vehicles not looking for cyclists at driveways (entering and exiting), as well as helps discourage motorists from inching out into the bike facility before existing driveways. Green paint is bright and does a good job of drawing attention to cyclists in the intersection. However, the green paint wears off quickly, is expensive, and has been noted as "a waste of money" by some of the public.

Appendix 3.14 Other Bicycle-Related Respondent Comments

Agency	Comment
Massachusetts	Space will always be the biggest issue through intersections...advisory and dashed lanes help improve safety and flow through visual cues
New Jersey	Most treatments, aside from shared-use paths, are used in downtowns and by local governments with great success. There is resistance to using many bicycle treatments - aside from paved shoulders - on state highways.

Agency	Comment
Seattle, WA	Mixing zones at intersections and ending bicycle lane at intersections have not been well received by riders.
Los Angeles, CA	Many successful bicycle facilities including road diets. One large project was installed and subsequently removed due to public backlash.

Appendix 3.15 R1-6 Sign Respondent Comments

Agency	Comment
Pennsylvania	The R1-6 signs were in high demand by our local partners; however, having invested over ½ million dollars in them over more then a ten year period, we haven't really seen an impact on our pedestrian numbers. Additionally, the local governments were deploying them in a data driven manner nor were they being used how they were intended to be used.
Chittenden CO, VT	R1-6 signs tend to slow traffic.

Appendix 3.16 Pedestrian Refuge Island Respondent Comments

Agency	Comment
New Mexico	Refuge islands are gaining wider acceptance and inclusion in project on roadways large and small. When coupled with high visibility markings vehicle compliance is high.
Massachusetts	Curb extensions and pedestrian refuge islands have made the biggest safety impact
New York, NY	Pedestrian islands have been very popular with the public and show good crash reductions, though these are always installed with other treatments, like lane reduction, and often protected bike lanes, so it's hard to isolate ped islands in our crash analyses.

Appendix 3.17 Raised Crosswalk Respondent Comments

Agency	Comment
Utah	I am really trying to push UDOT away from apex ped ramps whenever possible, they introduce skew to crossings and in some cases extend the crossing distance, which increases ped/signal time and has negative vehicle mobility impacts.
Pennsylvania	Raised crosswalks have proven very effective at increasing the yield rate. Public responses to a survey indicated strong support and increased feeling of safety crossing the street. We also noted lower speeds of vehicles where these were used as part of midblock crossings. There were NO issues with buses or fire trucks clearing the installed design and snow plowing was unaffected.
Cambridge, MA	Raised crosswalks, especially for side street crossings, have shown to be very helpful in decreasing vehicle speeds and improving yielding behavior.
Burlington, VT	Raised crosswalks have been largely discontinued (or redesigned) due to failures with maintenance and limited measurable success in driver / pedestrian interactions.
Seattle, WA	RRFB, refuge island, curb extension, and some raised crosswalks. Raised crosswalks have received some concerns from transit and fire department due to vertical deflection and impact.
New York, NY	The few raised crosswalks we have been able to install have been received positively by the public, but it's too early to tell for crash reductions. So far, there have been no weather issues, but careful site selection to avoid weather issues has led to very few raised crosswalks being installed.

Appendix 3.18 Curb Extension Respondent Comments

Agency	Comment
Pennsylvania	Similarly, curb extensions are effective in traffic calming but we did have some issues with snow plows striking them in deep snow.

Agency	Comment
Massachusetts	Curb extensions and pedestrian refuge islands have made the biggest safety impact
Burlington VT	Curb extensions have been successful to improve visibility of pedestrians.
Fairbanks, AK	Bulb-outs have been controversial with maintenance managers due to snow removal issues.

Appendix 3.19 Rectangular Rapid Flashing Beacon Respondent Comments

Agency	Comment
Vermont	RRFBs are noticed by drivers.
New York	Use of RRFB successful
Massachusetts	Motorists response to PHB and RRFB has been mixed depending on roadway speeds and volumes
Cambridge MA	RRFBs have shown to be very effective (verified with internal studies) at increasing yielding.
Burlington VT	RRFBs and PHBs have been successful to increase driver yielding rates.
Fairbanks, AK	We have installed RRFBs with pedestrian refuges at our hospitals, libraries, senior centers, and university campus with great reception from the public and overall reduction in crashes. At higher speed and traffic volumes streets we are installing HAWKs.
Chittenden, County VT	RRFBs have been successful in creating safer crossings and alert drivers to pedestrian presence. RRFBs have become more common and preferred treatment.
Corvallis, OR	Wig-wag pedestrian crossing lights have proven to have inefficiencies and have failed us in the past. We have since moved to RRFBs with much greater compliance and consistent performance.

Appendix 3.20 Pedestrian Hybrid Beacon Respondent Comments

Agency	Comment
New Mexico	Drivers seem to comply with PHBs, though it takes a bit of a learning curve and education. There are at least 3 in the state.
New York	Use of PHB successful
Vermont	PHB is a very expensive treatment and must be used only where really needed. Lots of learning curve for drivers.
Massachusetts	Motorists response to PHB and RRFB has been mixed depending on roadway speeds and volumes
Utah	TOUCAN/yellow flashing crossings have lower compliance, so we more frequently push for HAWK signals.
Cambridge MA	Pedestrian Hybrid Beacons have proven to be confusing for a lot of users in a dense urban area. They are likely more appropriate for suburban areas with higher vehicle speeds and lower pedestrian volumes. Drivers tend to yield to pedestrians waiting at the signal during the dark phase creating confusion.
Burlington VT	RRFBs and PHBs have been successful to increase driver yielding rates.
Chittenden CO, VT	there are a couple of ped hybrid beacons but they are expensive and not all peds will activate them
Seattle WA	We don't use hybrid beacons. The display is similar to rail crossing and not an easily understood device for the travelling public. Traffic signal is used when warranted.

Appendix 3.21 Pedestrian Pushbutton Respondent Comments

Agency	Comment
Lansing, MI	Ped push buttons are generally successful, depending on the prevailing user population. Outside Lansing (MSU campus and along Grand River Ave in downtown East Lansing), the ped buttons do not seem to be used by the signal (are in ped recall) defeating the purpose of the buttons. APS are installed based on request and after evaluation by a mobility specialist. The requesting user has been satisfied once they were installed. Ever changing guidance on ped push button placement, ADA ramps, etc. makes their proper implementation difficult. In addition, the more poles that are installed to separate the buttons, have them the appropriate distance from the street, etc. the bigger maintenance challenge they present (being run over by large vehicles, snow clearing of the ramps, etc.)
Kalamazoo CO, MI	Audible pushbuttons are often ignored, misused, or misunderstood by the public. They are more often in need of upgrade or repair and costlier to maintain and replace. We try to avoid them when possible.

Appendix 3.22 Accessible Pedestrian Signals Respondent Comments

Agency	Comment
Washtenaw CO, MI	Accessible buttons have been successful
Kalamazoo CO, MI	Countdown pedestrian signals are standard as is installation of non-audible pedestrian pushbuttons. This makes maintenance and operations of the system extremely efficient when such standards are implemented. Locations of pedestrian signals are based upon township planning efforts. Signals are installed only at locations identified in the plans.

Appendix 3.23 Leading Pedestrian Interval and Exclusive Pedestrian Phase Respondent Comments

Agency	Comment
Massachusetts	LPI has had positive effect on reducing crashes
New Mexico	Our LPI installations are often not coupled with right on read prohibitions, making them less effective.
Utah	We have not found places to install LPIs. When looking at our radar/crash data, there are very few places that would benefit from this - instead we have opted into no-right on red or doing exclusive/protected left turns and separated the ped phases.
Cambridge, MA	We have found concurrent pedestrian phases with lead pedestrian intervals to be the most successful form of phasing at most intersections.
Burlington, VT	LPIs and exclusive ped phases are widely accepted by the public.
New York, NY	We have install more and more LPIs every year, and they are quite popular with the public, and an easy, low-cost treatment that offers generally good crash reductions, though we have only really installed these in large numbers in the last 3 years, so we're still working on studying the outcomes. There was a bit of a learning curve for pedestrians for LPIs, and drivers often will creep forward into the intersection when the ped signal changes. There is still confusion as to whether cyclists may use the ped signal to advance and legislation is in the works.
Corvallis, OR	LPIs in Corvallis are used on nearly every signalized intersection where a pedestrian button exists. This is such low-cost, low hanging fruit that makes a huge difference for driver compliance and getting people safely across the street.

Appendix 3.24 Right-Turn on Red Prohibition Respondent Comments

Agency	Comment
Cambridge, MA	Right turn on red is prohibited at most locations due to high pedestrian volumes.
Burlington VT	Dynamic (LED) No Right Turn on Red signs have been more successful than static signs.
New York, NY	We have widespread advanced stop markings and a citywide ban on right on reds.
Washtenaw CO, MI	Mixed results with right turn on red prohibitions.
Traverse City, MI	All treatments currently used in the City have been successful. The right turn on red prohibition, although not always adhered to, has greatly reduced the number of crashes with cyclists and pedestrians. Although the right turn on red prohibition at many of our intersections has increased pedestrian and cyclist safety, compliance is sometimes an issue. We have been addressing this by adding additional signage, as well as flags for pedestrians/cyclists (graciously maintained by our local advocacy groups) to increase safety.

Appendix 3.25 Advance Stop Marking Respondent Comments

Agency	Comment
Corvallis, OR	We have had mixed results and occasional negative public feedback on advanced stop markers in certain locations where bus stops exist. Pedestrians are difficult to see when bars are next to each other so in some areas, we have tried staggered bars. The jury is still out on effectiveness.

Appendix 3.26 Road Diet Respondent Comments

Agency	Comment
Vermont	Road diets are effective, but difficult to implement due to in house and public buy-in.
Utah	In Utah we have very large/wide roadways. Typically when we do a lane re-striping or road diet we have plenty of ROW to incorporate bicycle facilities, change parking configurations or adding park strip/landscaping where were are modifying curb/gutter.
Milwaukee, WI	We've also implemented several road diets (with buffered/protected bike lanes) in recent years and while it is too early to tell whether they have significantly reduced crashes, we can say that they have reduced speed.
Burlington, VT	Road diets have had measurable success in crash reduction. Road diets have had mixed success in slowing vehicle speeds.
Chittenden CO, VT	road diets have resulted in slower vehicle speeds and crash reduction. resistance to changes fades over time. creating new bike facility through pavement reallocation helps create a more connected bike network.
Seattle, WA	Road diets have been used extensively for many years in Seattle.
New York, NY	We see crash reductions with road diets and lane narrowing, but again, these are often used in conjunction with many other treatments, so it's hard to determine what is most effective.
Washtenaw CO, MI	We have a very successful traffic calming program
Traverse City, MI	Road diets, traffic circles, and on-street parking have resulted in the greatest speed reduction and safety improvements. Public acceptance has been mixed for all treatments upon initial implementation, but tend to be widely accepted once they have been in place for a while. Road diets, speed humps, and traffic circles are typically met with some public resistance due primarily to the slowing of traffic (which is the intent).
Lansing, MI	We've had success with road diets and speed humps. Neither have caused public opposition and maintenance issues have been minimal

Appendix 3.27 Lane Shift/Chicane Respondent Comments

Agency	Comment
New York, NY	We are doing a pilot with chicanes and so far they seem to be having positive safety results. The chicanes are seen pretty skeptically, especially when installed with temporary treatments.

Appendix 3.28 Diverters Respondent Comments

Agency	Comment
Traverse City, MI	Diverters, traffic circles, and speed humps cause winter maintenance issues, which we have been addressing with reflectors to help plow operators navigate the treatment.

Appendix 3.29 Roundabout Respondent Comments

Agency	Comment
Vermont	I wouldn't call a roundabout a traffic calming device. It is a type of intersection control. It works well and keeps speeds down.
New Jersey	Roundabouts have been very successful in reducing crashes. While the public has been resistant at first, they warm to them quickly after installation in most cases.
Massachusetts	Roundabout implementation has lowered crash rate in many locations
Fairbanks, AK	We have also installed a number of large roundabouts are major intersections throughout town that has effectively reduced the serious injury and fatality rates at these intersections to ZERO.
Chittenden CO, VT	roundabouts are preferred alternative in some projects due to safety improvements and reduced traffic speeds, but cost and ROW space can be prohibitive. Public sentiment is mixed based on limited roundabout experience and poor local examples of "not really roundabouts."
Seattle, WA	Roundabouts designed and funded for construction was pulled by elected officials due to the concerns about accessibility for pedestrians.
Traverse City, MI	Traffic circles are also deemed by some as "too confusing". Road diets, traffic circles, and on-street parking have resulted in the greatest speed reduction and safety improvements. Public acceptance has been mixed for all treatments upon initial implementation but tend to be widely accepted once they have been in place for a while.

Appendix 3.30 Mini-Roundabout Respondent Comments

Agency	Comment
Corvallis, OR	This year, we have our first Neighborhood Bikeway in development which will have many elements listed above and specifically, two mini traffic circles. Fingers crossed this is a successful initiative! Check back in with me in 2022.
Washtenaw CO, MI	Unsuccessful - mini roundabouts smaller than 100ft in diameter
Kalamazoo CO, MI	We are seeking our first installation of a mini roundabout and see benefit from those done in Washtenaw County.

Appendix 3.31 Vertical Element Respondent Comments

Agency	Comment
Vermont	I have my doubts about the effectiveness of vertical traffic calming. I think that narrower streets with lots of side "friction" like bike lanes or on-street parking are a better approach.
New Mexico	Some neighborhoods really like speed tables, but they can cause maintenance issues.
Utah	UDOT rarely implements vertical changes to our roadways (volume and speed is a reason). However, local communities and towns will deploy vertical profile changes on roadways where they want motorist to slow down or to give preference to pedestrians/bicyclists.
Massachusetts	Speed humps/table not generally used on roadways under MassDOT jurisdiction
Burlington, VT	Vertical speed control is generally accepted by the public (these are neighborhood-initiated) as effectively slowing travel on their street.
Milwaukee, WI	DPW also manages a Neighborhood Traffic Management Program where residents can request traffic calming treatments, most commonly speed humps. Public perception is that they're generally effective at reducing speed.
New York, NY	Speed humps have mixed results, but are very popular with the public, they have a strong perception of safety, but we don't see very good crash reductions.
Kalamazoo CO, MI	Speed humps, road undulations, features in the road to divert or narrow the road (chicanes, bump outs) are a major concern for winter maintenance and cost of the installation.
Lansing, MI	We've had success with road diets and speed humps. Neither have caused public opposition and maintenance issues have been minimal

Appendix 3.32 Reducing Speed Limit Respondent Comments

Agency	Comment
New Mexico	in some communities, bike boulevards have been established and are coupled with an 18MPH speed limit. These low volume, low speed roads are great for all roadway users
Louisiana	Changing speed limit sign with no additional treatment is not advised. Many speed studies intended to decrease speeds result in speed increase being justified by 85th.
Kalamazoo CO, MI	Reducing speed limits for speed control (a.k.a. speed traps) are not legal according to MSP and the state law. Speed limits are set based upon the free flow speed of traffic.

Appendix 3.33 Other Traffic Calming-Related Respondent Comments

Agency	Comment
Louisiana	Geometry and landscaping in new construction projects can help. Usually these are constructed in partnership with private development.
Milwaukee, WI	We're also building a network of bicycle boulevards that use multiple traffic calming treatments such as mini traffic circles, speed humps, and curb extensions to create a low-stress environment that prioritizes the street for people walking, bicycling, and playing.
Traverse City, MI	On street parking can also cause maintenance issues when vehicles are left illegally parked in the street overnight.

Appendix 3.34 State Agency Non-Motorized Guidelines – Responses by State

State Agency	Pedestrian Design Guide	Bicycle Design Guide	Transit Facility Design Guide	Complete Streets Policy/ Guide	Context Sensitive Design Policy/ Guide
South Dakota	Yes	Unsure	Unsure	No	Unsure
New York	Yes	Yes	Yes	Yes	Yes
Colorado	Yes	Yes	Unsure	Yes	Yes
Ohio	No	No	No	No	No
Nebraska	No	No	No	No	Unsure
Vermont	Yes	Yes	No	Yes	No
Connecticut	Yes	Yes	Unsure	Yes	No
Alaska	Yes	Yes	No	No	No
South Carolina	No	No	Unsure	Yes	Unsure
Wyoming	Yes	Yes	Unsure	No	Unsure
New Mexico	Yes	Yes	No	No	No
Montana	Unsure	Unsure	Unsure	No	Yes
New Jersey	Yes	Yes	Unsure	Yes	Yes
Utah	Yes	Yes	No	No	Yes
Massachusetts	Yes	Yes	Yes	Yes	Yes
Texas	No	No	No	No	No
Washington	Yes	Yes	Unsure	No	Unsure
Louisiana	Yes	No	No	Yes	No

Appendix 3.35 Local Agency Non-Motorized Guidelines – Responses by Local Agencies Outside of Michigan

Local Agency (US)	Pedestrian Design Guide	Bicycle Design Guide	Transit Facility Design Guide	Complete Streets Policy/ Guide	Context Sensitive Design Policy/ Guide
Washington D.C.	Yes	Yes	Unsure	Yes	Yes
Los Angeles, CA	No	No	No	Yes	No
Cambridge, MA	No	No	No	Yes	Yes
Burlington, VT	Yes	Yes	No	Yes	No
Fairbanks, AK	No	No	No	Yes	No
Chittenden County, VT	Yes	Yes	Unsure	Yes	Yes
Anchorage, AK	Unsure	Unsure	Unsure	Unsure	Unsure
Rochester, NY	Yes	Yes	No	Yes	No
Seattle, WA	Yes	Yes	Yes	Yes	Yes
Milwaukee, WI	Yes	Yes	No	Yes	No
South Bend, IN	No	No	Unsure	Yes	Unsure
New York, NY	Yes	Yes	Unsure	Yes	Yes
Corvallis, OR	Yes	Yes	Unsure	No	Yes

Appendix 3.36 Local Agency Non-Motorized Guidelines – Responses by Local Agencies within Michigan

Local Agency (MI)	Pedestrian Design Guide	Bicycle Design Guide	Transit Facility Design Guide	Complete Streets Policy/ Guide	Context Sensitive Design Policy/ Guide
Washtenaw County	No	No	No	Yes	Yes
Traverse City	Yes	Yes	No	Yes	No
Kalamazoo County	No	No	No	Yes	No
Grand Rapids	Unsure	Yes	Unsure	Unsure	No
Kent County	No	No	No	Yes	No
Lansing	No	No	No	Yes	No

Appendix 3.37 State Agency Written Responses to Non-Motorized Guidance Review Status

Agency	Has your agency reviewed its internal transportation practices, standards, guidance documents or other manuals (such as a road design manual or project scoping guidance) to identify content that can be modified to better address the needs of non-motorized road users? Please describe and provide links to any relevant documentation.
Colorado	CDOT is currently undergoing a re-write of it's Roadway Design Guide. When completed, it will merge the three basics of design: multi-modalism, context sensitive design and Performance Based Practical Design. This way we hope to bring biking and walking into more standard practices among all design projects.
Ohio	Yes, ODOT is currently developing a new standalone Multimodal Design Guide which will be a primary resource for Bicycle and Pedestrian Facility Design. Updates will be made to other existing resources to reflect new national best practices as appropriate in Ohio.
Nebraska	In-process
Alaska	As part of the new Alaska Statewide Active Transportation Plan (2019), we reviewed and made recommendations.
Wyoming	http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Highway_Safety/Pedestrian%20Bicycle/WY%20Bicycle%20and%20Pedestrian%20Transportation%20Plan_2016.pdf
New Mexico	Yes. NMDOT is currently developing a Statewide Pedestrian Safety Action Plan that has a heavy focus on internal practices and policies. Visit WalkSafeNewMexico.com for information on the planning process.
New Jersey	https://www.state.nj.us/transportation/eng/completestreets/resources.shtm
Utah	Yes, new standard drawings for bicycle and pedestrian facilities and Traffic Control bike/ped accommodation plans will be adopted by UDOT and incorporated into the Roadway Design Manual by the end of 2020.
Massachusetts	https://www.mass.gov/doc/controlling-criteria-and-design-justification-process-for-massdot-highway-division-projects-e/download
Texas	TxDOT is in the process of updating its roadway design manual/policies to expand guidance on bicycle, pedestrian, and context sensitive design.
Wisconsin	We are in the process of review for Design Manual and Traffic Manual. DM -- https://www.wsdot.wa.gov/Publications/Manuals/M22-01.htm revisions link indicated TM -- https://www.wsdot.wa.gov/Publications/Manuals/M51-02.htm New multimodal chapter (4) being developed, but drafts are not linked publicly yet.
Loiusiana	Some and in process http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Multimodal/Highway_Safety/Complete_Streets/Complete%20Streets%20Legislative%20Reports/2020_Complete_Streets_Report.pdf; http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Multimodal/Highway_Safety/Complete_Streets/Complete%20Streets%20Legislative%20Reports/2019%20Complete%20Streets%20Report.pdf

Appendix 3.38 Local Agencies outside Michigan - Written Responses to Non-Motorized Guidance Review Status

Agency	What funding sources does your agency utilize, primarily, for major ped/bike improvement projects?
Washington D.C.	Usually a mix of local and federal. For capital projects, they are probably financed with G.O. bond backed capital budget.
Los Angeles, CA	ATP, HSIP
Cambridge, MA	City funds.
Burlington, VT	Capital bonds
Fairbanks, AK	FHWA Surface Transportation Program (STP) and Congestion Mitigation & Air Quality (CMAQ) funds made available by our local MPO.
Chittenden CO, VT	unsure of specific funding sources beyond federal allocation and state funds
Anchorage, AK	FHWA funding for non-motorized transportation, Alaska State Highway funding, Capitol Improvement Project funding sources
Seattle, WA	Local transportation levy funds
Milwaukee, WI	- TAP & CMAQ - Some local funding
Corvallis, OR	Gas tax funding, grants and the Transportation Maintenance Fee

Appendix 3.39 Local Agencies within Michigan - Written Responses to Non-Motorized Guidance Review Status and Funding Questions

Agency	What funding sources does your agency utilize, primarily, for major ped/bike improvement projects?	Are there aspects of Michigan specific design manuals, guidance documents or policies that have caused your local agency to be unable to deliver the multi modal projects/designs you were seeking to implement? If so please share your experiences with us.
Washtenaw CO	MTF, Federal and State funds	No
Traverse City	City funds, State and Federal grants	MDOT has been flexible with granting us design exceptions if needed
Kalamazoo CO	Transportation Alternatives Funding program by MDOT.	-
Lansing	Act 51 (gas tax) revenue, grant funding (CMAQ, TAP, etc.) or combined with a road project (minimal increased cost)	Certification and acquisition of right of way is a large hurdle when using federal funds

Appendix 3.40 State Agency Non-Motorized Master Plan Responses

Agency	Does your agency maintain a master plan for non-motorized travel?	How often is this master plan evaluated and updated?	Please provide a link to this plan, if available.
South Dakota	No		
New York	Yes	More than 10 years	
Colorado	No		We have a statewide bicycle and pedestrian plan; however, it's been now rolled into our new 2045 Statewide Transportation Plan. So rather than being a separate plan, it's part of the overall transportation plan.
Ohio	No		We have a State & US Bike Route System which can be reviewed here: https://gis.dot.state.oh.us/tims/map?center=-82.67115560517148,40.46901224497112&level=7&visiblelayers=Assets:-1%7CBoundaries:-1%7CEnvironmental:-1%7CProjects:-1%7CRoadway%20Information:19%7CStrategic%20Transportation%20System:4 This is a current system that is open to bike travel and will eventually be signed one day. Strategic improvements will be made to this network in the long term to improve safety and comfort for people travelling by bike.
Nebraska	No		
Vermont	Yes	6 - 9 years	Bike/Ped policy plan is in the process of being updated and will be a Strategic Plan. Current version (2008) can be found here https://vtrans.vermont.gov/highway/local-projects/bike-ped
Connecticut	No		
Alaska	Yes	6 - 9 years	http://dot.alaska.gov/stwdplng/bikeped/index.shtml
South Carolina	No		
Wyoming	Yes	Less than 5 years	
New Mexico	Yes	5 years	NMDOT adopted the Prioritized Statewide Bicycle Network Plan in 2018. https://dot.state.nm.us/content/nmdot/en/Planning.html#BPE. The NM Bike Plan is a long range infrastructure improvement plan that identifies NMDOT owned and maintained roadways most appropriate for bicycle facility investment during roadway reconstruction and major rehabilitation. We are currently developing a Statewide Pedestrian Safety Action Plan, though not an infrastructure plan, it will identify corridors and areas for safety improvements.
Montana	Yes		https://www.mdt.mt.gov/pubinvolve/pedbike/
New Jersey	Yes	10 years	https://www.state.nj.us/transportation/commuter/pedsafety/planning.shtm
Utah	No	5 years	This is a working plan (local plans are compiled and merged with a UDOT facilities AT plan).
Massachusetts	Yes	5 years	https://www.mass.gov/service-details/bicycle-plan https://www.mass.gov/service-details/pedestrian-plan
Texas	Yes		https://www.txdot.gov/inside-txdot/modes-of-travel/bicycle/plan-design/strategic.html
Wisconsin	Yes	10 years	WSDOT's Draft Active Transportation Plan (revision to the Washington State Bicycle Facilities and Pedestrian Walkways Plan 2008) is in the first review stage (internal) now. No link to the old plan is available due to ADA accessibility (screen reader compatibility) issues.
Louisiana	Yes	More than 10 years	http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Multimodal/Highway_Safety/Bicycle_Ped/Pages/MasterPlan.aspx

Appendix 3.41 Local Agencies outside of Michigan Non-Motorized Master Plan Responses

Agency	Does your agency maintain a master plan for non-motorized travel?	How often is this master plan evaluated and updated?	Please provide a link to this plan, if available.
Washington D.C.	Yes	5 years	update is in progress now http://www.wemovedc.org/
Los Angeles, CA	Yes	10 years	https://planning.lacity.org/odocument/523f2a95-9d72-41d7-aba5-1972f84c1d36/Mobility_Plan_2035.pdf
Cambridge, MA	Yes	5 years	https://www.cambridgema.gov/CDD/Transportation/gettingaroundcambridge/bikesincambridge/bicyclenetworkplan https://www.cambridgema.gov/CDD/Transportation/programs/currentprograms/pedestrianplan.aspx
Burlington, VT	Yes	10 years	https://www.burlingtonvt.gov/sites/default/files/PlanBTVWalkBike_MasterPlan_final-PlanOnly.pdf
Fairbanks, AK	Yes	6-9 years	https://fastplanning.us/wp-content/uploads/2020/03/2012_NMP_Combined.pdf
Chittenden CO, VT	Yes	5 years	http://www.ccrpcvt.org/wp-content/uploads/2016/01/OFFICIAL_CCRPC_REVISED-4_13.pdf
Anchorage, AK	Yes	10 years	
Rochester, NY	Yes	More than 10 years	
Seattle, WA	Yes	Less than 5 years	https://www.seattle.gov/transportation/document-library/citywide-plans/modal-plans/pedestrian-master-plan , https://www.seattle.gov/transportation/document-library/citywide-plans/modal-plans/bicycle-master-plan
Milwaukee, WI	No		
South Bend, IN	No		
New York, NY	Yes	Less than 5 years	
Corvallis, OR	No		

Appendix 3.42 Local Agencies outside of Michigan Non-Motorized Master Plan Responses

Agency	Does your agency maintain a master plan for non-motorized travel?	How often is this master plan evaluated and updated?	Please provide a link to this plan, if available.
Washtenaw CO	No	Less than 5 years	
Traverse City	No		The plan is currently in draft form and being vetted through public outreach and our city commissions
Kalamazoo CO	No	5 years	
Grand Rapids		5 years	We have a Bike Plan that was just created.
Kent CO	No		
Lansing	Yes	6 - 9 years	https://www.lansingmi.gov/1952/Resources

Appendix 3.43 State Agency Responses to Non-Motorized Data Questions

Agency	What types of data collection/monitoring systems (including crowd sourcing data systems) are utilized to better understand pedestrian and bicyclist activity in your state?	Does your agency maintain an inventory of pedestrian and/or bicycle infrastructure (such as sidewalks, bicycle lanes, enhanced crossings, etc.)?
South Dakota		Only past TAP/TA projects.
New York		
Colorado	A limited amount of bike/ped counts are captured in various locations around the state using 24/7 counts We've also utilized STRAVA data for bicycle information.	We have an inventory of bicycle facilities, but not sidewalks or enhanced crossings.
Ohio	Streetlight data has activity metrics, using the bike and ped counting features on MioVision Cameras, MPOs/RTPOs do manual counts as well as short duration counts along their networks.	Only for the State & US Bike Routes System. We track existing facilities including Shared Lane, Conventional Bike Lane, Buffered Bike Lane, Separated Bike Lane, Paved Shoulder (4 feet or more), Shared Use Path, and Crossing. Currently developing a data schema for pedestrians which might be valuable and manageable at the statewide level.
Nebraska	None	not yet, in process
Vermont	We have used wiki-map to collect input on conditions for bicycling. We do regular non-motorized counts.	Somewhat. Working on more complete data regarding shoulders and bike lanes. Have data on ped signals around the state.
Connecticut	none	Yes
Alaska	Not consistent, some urban centers perform bike-ped counts	We are in the process of developing an inventory for non-motorized facilities
South Carolina		
Wyoming		Yes
New Mexico	some communities use Strava data to inform their planning efforts. I think one community looked at Streetlight data. The Mid-Region Metropolitan Planning Organization conducts short term pedestrian and bicycle counts.	no
Montana	Often reference Strava Heat map to better understand pedestrian and bicycle activity in a specific area.	MDT maintains an inventory of shared-use paths existing within MDT rights-of-way.
New Jersey	Manual counts in a few locations and in project development.	County sidewalk inventory, green bike lanes
Utah	Strava Metro is purchased by UDOT for use throughout the State of Utah. UDOT has also fostered relationships with several of the scooter companies to get their origin and destination data to understand trip trends/volumes.	Yes. UDOT recently completed a full inventory of all bicycle facilities on collectors and above throughout the state (GIS - associated with our roadway centerline dataset). UDOT has also done a full inventory of ped ramps and sidewalk on the entire UDOT system.
Massachusetts	counts	yes
Texas	Texas Bicycle and Pedestrian Count Exchange (https://mobility.tamu.edu/bikepeddata/); Strava Metro data	A pedestrian and bicycle facility inventory of the state network is currently in development.
Wisconsin	Annual manual counts and about 70 automated counters. Some portable counters are also used.	A sidewalk inventory is under development. Bicycle lane information is maintained, but does not record the type of bike lane. I am unsure if enhanced crossing information is maintained. Much data is available at the DOT regional level and most data is not highly accessible (such as in GIS format).
Louisiana	Ongoing research efforts at collecting ped/bike count data are happening across the state in effort to develop a standard, scalable method for regular collection. Data is also collected for small, one-off type projects or studies.	Not a maintained inventory but some sidewalk and infrastructure data is available.

Appendix 3.44 Local Agencies outside of Michigan Responses to Non-Motorized Data Questions

Agency	What types of data collection/monitoring systems (including crowd sourcing data systems) are utilized to better understand pedestrian and bicyclist activity in your state?	Does your agency maintain an inventory of pedestrian and/or bicycle infrastructure (such as sidewalks, bicycle lanes, enhanced crossings, etc.)?
Washington D.C.	surveys, models from MWCOG, inrix data, crowdsourced safety data	yes, in GIS and open data format
Los Angeles, CA	Manual counts	Yes, of bicycle lanes
Cambridge, MA	Ecototem bicycle counter Miovision traffic signal detection (vehicle, bicycle, pedestrian) Bikeshare usage data	Yes
Burlington, VT	Manual counts. By others (Regional Planning Commission, consultants or Transportation Research Center): cameras or tube counts.	Some. Sidewalks are inventoried and re-assessed every 5 years. Bicycle infrastructure is loosely inventoried in spreadsheets and maps.
Fairbanks, AK	Mobile and Permanent Bike & Ped Counters (ECO-Counters)	Yes
Chittenden Co, VT	turning movement counts, ecocounters on sidepaths/trails. developing a more formal count program in FY21.	yes and updated data are requested from municipalities
Anchorage, AK	We did data collection phase in our latest Non-motorized Plan update that included data for bicyclists and pedestrians. We also have counters installed on many of our paved multi-use trails. We used 2010 census data for pedestrians and bicyclists in the latest Non-motorized Plan.	We do but it is need of a substantial update. Our bicycle facilities are pretty up to date, but we are hoping to do a comprehensive update of our sidewalk and other pedestrian infrastructure data in the next couple of years.
Rochester, NY		
Seattle, WA	permanent counters, spot counters (video), tubes	Yes
Milwaukee, WI	- Manual bike/ped counts - Intersection turn counts (including bike/ped) - Permanent Eco-counters along trails - MULTI Eco-counter before/after projects	- Partial. We're in the process of updating and developing several inventories including: + bike lanes + traffic calming + bike racks
South Bend, IN	automatic counters on trails	Yes
New York, NY		
Corvallis, OR	Our agency does collect inventory (through GIS) of some bike/ped infrastructure. This is being developed further in the near future in hopes for different types of inventory collection. For example, we want to document: City bike corrals, bike shelters, bike racks, covered bike parking locations/details. Also, where sidewalks are NOT, public toilets, park benches, drinking fountains, etc. This is not only excellent information for general inventory along with reporting for improving future amenities but many of our city awards on bicycling and walkability ask about this so having a GIS to provide to them only helps our score.	Our bike share vendor (Zagster) was sold during the high-point of the pandemic. With that, our small bike share program vaporized. We are currently working with our MPO, (Oregon Cascades West Council of Governments) in partnership with Oregon State University, to design a bikeshare or micromobility system for the Corvallis community. This system will replace the original Pedal Corvallis bikeshare system, which operated from June 2016 – April 2020. The new system will integrate updated technology and industry standards, while building from the lessons learned from the original system. The scope of work puts forth a system plan (Aug '20 – Nov '20) then a Business Plan and Sponsorship Agreements Nov. '20 – May '21, a Vendor RFP Apr '21 – Jun '21 and finally, we are hopeful for a System Launch and Marketing Jul '21 – Oct '21.
Stoneham, MA		

Appendix 3.45 Local Agencies within Michigan Responses to Non-Motorized Data Questions

Agency	What types of data collection/monitoring systems (including crowd sourcing data systems) are utilized to better understand pedestrian and bicyclist activity in your state?	Does your agency maintain an inventory of pedestrian and/or bicycle infrastructure (such as sidewalks, bicycle lanes, enhanced crossings, etc.)?
Washtenaw CO	We utilize our planning organization WATS	We maintain pavement markings, pedestrian signals, and sidewalk ramps all other facilities are owned and maintained by the Townships.
Traverse City	Video and in person observations, bike counters	Yes, all sidewalk, signs, and pavement markings are maintained in a GIS inventory
Kalamazoo CO	None	Roadsoft
Grand Rapids	Bike counters	We keep track of some assets in GIS
Kent CO	none	we are developing one
Lansing	We have started to do bicycle tube counts and always count pedestrians when doing manual turning movement counts at intersections.	Yes. Information in GIS

Appendix 3.46 State Agency Responses to Micromobility Question

Agency	Micromobility (such as bike-share and e-scooter share) use has been popular for the past several years. As Micromobility users share the same facilities with pedestrians and cyclists, please describe any considerations or accommodations regarding infrastructure design to minimize conflicts between modes and improve safety.
Colorado	We've recently established a division within CDOT to look at different types of mobility. We currently don't have specific design standards for micromobility, but particularly in urban areas we're looking at their impact.
Ohio	We will include some universal considerations for micromobility within the forthcoming Multimodal Design Guide. Some local communities have signed agreements with micromobility companies that in order to operate in their jurisdiction they must provide the community with the O/D trip information for planning and other purposes. This might inform the addition of or design of future facilities that ensure safe interaction between modes.
Connecticut	Currently Connecticut is working on legislation with regards of what is considered Bike sharing programs and e-scooter share. With regards to infrastructure signs to minimize conflicts and improve safety bicycle lanes are designed in accordance federal and state safety requirements.
Montana	Cities want jurisdiction on managing bike-share and e-scooter regulations.
Utah	Micro mobility has been increasingly popular and UDOT intends to accommodate scooters as part of our bicycle/multi-modal network.
Louisiana	E-scooter share is not operating in Louisiana yet. Bike share uses bike or roadway facilities already in place.

Appendix 3.47 Local Agencies outside of Michigan Responses to Micromobility Question

Agency	Micromobility (such as bike-share and e-scooter share) use has been popular for the past several years. As Micromobility users share the same facilities with pedestrians and cyclists, please describe any considerations or accommodations regarding infrastructure design to minimize conflicts between modes and improve safety.
Washington D.C.	We've tried to increase protected "bike" lanes. have installed "micro mobility" parking corrals in the street (not on the sidewalk) in many locations to avoid scooters/bikes parked in curb ramps, blocking sidewalks, etc. Also, since capital bikeshare now has "dockless" e-bikes (that can still be docked in traditional bikeshare stations, or locked to public bike racks), traditional bike parking and bikeshare stations also serve to reduce MiMo conflicts with pedestrians, wheelchair users, etc.
Los Angeles, CA	Designated micromobility parking areas
Burlington, VT	Waiting for additional stencils to use in addition to bike lane stencils, making it more clear who is intended to use the roadway instead of sidewalks / paths!
Fairbanks, AK	We have one bike-share in the City, and we permit their bike racks to be installed all over the City on City sidewalks and plazas.
Chittenden County, VT	we have a small bikeshare system in the area (since spring 2018), and the hope is that more riders will demonstrate need for safer, better connected facilities. to date no specific infrastructure changes based on bikeshare system.
Anchorage, AK	We don't have either of these yet in Anchorage. The University of Alaska Anchorage had a limited bikeshare program for a few years but it was discontinued.
Seattle, WA	E-scooters legislation is being evaluated this Fall. They are permitted in bicycle facilities as allowed/regulated by State law.
Milwaukee, WI	- Developed an e-scooter pilot study - Explored partnerships with e-scooter operators and ways to possibly accept funding for infrastructure improvements - Formal partnership with docked bike share operator includes City providing infrastructure (stations and bikes)
South Bend, IN	Micro mobility devices permitted on trails and other separated facilities.
Corvallis, OR	Our bike share vendor (Zagster) was sold during the high-point of the pandemic. With that, our small bike share program vaporized. We are currently working with our MPO, (Oregon Cascades West Council of Governments) in partnership with Oregon State University, to design a bikeshare or micromobility system for the Corvallis community. This system will replace the original Pedal Corvallis bikeshare system, which operated from June 2016 – April 2020. The new system will integrate updated technology and industry standards, while building from the lessons learned from the original system. The scope of work puts forth a system plan (Aug '20 – Nov '20) then a Business Plan and Sponsorship Agreements Nov. '20 – May '21, a Vendor RFP Apr '21 – Jun '21 and finally, we are hopeful for a System Launch and Marketing Jul '21 – Oct '21.

Appendix 3.48 Local Agencies within Michigan Responses to Micromobility Question

Agency	Micromobility (such as bike-share and e-scooter share) use has been popular for the past several years. As Micromobility users share the same facilities with pedestrians and cyclists, please describe any considerations or accommodations regarding infrastructure design to minimize conflicts between modes and improve safety.
Washtenaw County	Detection within bike lane.
Traverse City	We have been using NACTO's guidance
Grand Rapids	We are working on a pilot on scooters and some bike share.
Lansing	E-scooters have been an issue, not in the conflict with cyclists, but with pedestrians on sidewalks in the downtown area. The City is using any revenue generated by e-scooters to improve non-motorized facilities.

Appendix 4:

Review of Best Practices for Bicycle Signal Detection

Introduction and Overview

Given that the overall goal of signal timing procedures is to provide safe crossings and reduce delay for all road users [*1*], the consideration of potential adjustments to timing parameters specific to bicycles represents an important component of the Michigan Department of Transportation's (MDOT) traffic signal practices. The differences in operating characteristics between motor vehicles and bicyclists, including travel speed, acceleration rates and deceleration rates, may require such modifications in order to safely accommodate these road users [*2, 3*]. While bicyclist accommodation should be considered as a part of all signal timing procedures, specific attention should be paid at intersections with high vehicular speeds or relatively long crossing distances where the need for bicycle-specific modifications is most likely [*1*].

This is consistent with the Michigan Manual on Uniform Traffic Control Devices (MMUTCD) which states that "signal timing and actuation shall be reviewed and adjusted to consider the needs of bicyclists" along bikeways [*4*]. Bicycle detection is included along actuated signalized intersection approaches in order to alert the signal controller that bicycle crossing demand is present [*5*]. Without appropriate detection, bicyclists must either wait for a vehicle actuate a green phase for their approach, dismount to push a pedestrian pushbutton, or otherwise cross illegally [*5*]. The inclusion of bicycle signal detection along bikeways can improve mobility, increase safety performance, and further help to establish bicycling as a legitimate mode of travel [*5*].

Given MDOT's efforts to "create better, safer roadways for all users by providing a variety of services and information supporting recreational cycling and bicycle commuting" [*6*], the department is working to incorporate additional bicycle-specific guidance into key design documents. For example, bicycle-specific timing considerations were added to the department's *Signal Timing Spreadsheet* in December 2020 [*7*]. However, the department currently only has limited experience with bicycle signal detection obtained during the design of a relatively small number of projects. As a part of OR19-072 *Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance and Technology Innovations*, MDOT requested the MSU research team to identify current best practices in bicycle signal detection to assist in the development of more detailed guidance in order to expand the use of bicycle detection in Michigan.

Objectives of the Review

This document summarizes a review of the available national guidance specific to bicycle signal detection as well as practices being employed by roadway agencies, including **(1) a review of detection systems** and **(2) common detection applications**. It should be noted that this review was focused on bicycle detection systems and concepts as opposed to the fundamental signal timing parameters (such as bicycle minimum green time) which are covered in the American Association of State Highway and Transportation Officials' (AASHTO) *Guide for the Development of Bicycle Facilities* [*8*] or NCHRP Report 812: *Signal Timing Manual* [*9*]. Additional detail on signal phasing strategies can also be found in the National Association of City Transportation Officials' (NACTO) *Urban Bikeway Design Guide* [*5*] and *Don't Give Up at the Intersection* [*10*]. Detailed information related to the operational performance and behavioral characteristics of bicyclists at signalized intersections can be found in the Oregon Department of Transportation's (ODOT) *Operational Guidance for Bicycle-Specific Traffic Signals in The United States* [*11*].

It is important to recognize that traffic signal design and operation specific to non-motorized road users is a rapidly developing field, as evidenced by ongoing NCHRP Project 03-133 *Traffic Signal Design and Operations Strategies for Non-Motorized Users* [*12*]. Additionally, both California [*13*] and Washington [*14*] have adopted laws which require actuated signals include bicycle detection as a part of upgrade projects. While this review represents the state-of-the-art in bicycle signal detection practices, new technology or research is continually being published as highway agencies experiment with these modern systems. MDOT should continue to monitor these developments as a part of the department's efforts to provide additional guidance for the safe and efficient design of bicycle facilities.

Bicycle Detection Systems

Appropriate bicycle signal detection systems should meet two primary criteria - accurately directing bicyclists along the bikeway and providing clear guidance on how to actuate the signal [*5*]. Detection devices can include traditional loop detection, video, or microwave detection systems, as well as bicycle-specific pushbuttons [*5*]. While not required, bicycle-specific signal heads are also commonly used in conjunction with detection systems in a range of potential design scenarios. This section provides an overview of the technology typically incorporated within bicycle detection systems.

Bicycle Signal Heads and Bicycle Signal Faces

Bicycle signal heads are an additional traffic control device which can be included in conjunction with an existing traffic signal [*5*]. While signage can be included to identify where crossing for bicyclists is controlled by pedestrian signal indications, independent signal heads can also be used which accommodate bicycle-specific phases or signal timing strategies – shown in **Figure 1** [*5, 15*]. The FHWA has also published an interim approval (IA-16) which allows for the optional use of bicycle signal faces [*16*]. It should be noted that the recent notice of proposed amendments to the Manual on Uniform Traffic Control Devices (MUTCD) published by the Federal Highway Administration (FHWA) includes language which will allow for the optional use of bicycle signal faces (**Figure 2**) in a manner consistent with IA-16 [*17*].

Figure 1. Options to Provide Signal Indications to Bicyclists, including Bicycle Signal Heads or Faces [*15*]

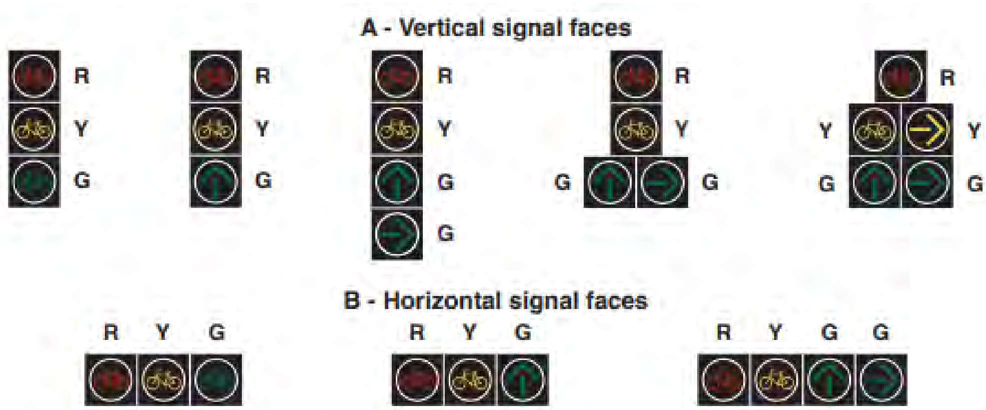


Figure 2. Typical Arrangements of Signal Sections in Bicycle Signal Faces [*16*]

It is important to recognize that IA-16 requires that the use of bicycle signal faces only be used in situations "where bicycles moving on a green or yellow signal indication in a bicycle signal face are not in conflict with any simultaneous motor vehicle movement at the signalized location, including right (or left) turns on red." [*16*]. California's MUTCD [13] also recommends that alternative means of addressing conflicts between vehicles and bicyclists should be considered prior to the use of bicycle signal faces. In general, bicycle signal heads should be considered at locations where bicycle-specific movements (such as a separated bicycle lane) need to be accommodated, where bicycle-specific phases (such as an "all-bike" phase or leading bicycle phasing) are being considered, or other complex locations where there are frequent conflicts between bicycles and turning motor vehicles [*1, 5*]. Bicycle signal heads have been used in a variety of common applications, including [*5, 18, 19*]:

- Shared use or sidepaths street crossings, particularly when bicycle clearance time varies from pedestrian clearance time.
- Intersections where a predominant bicycle movement conflicts with a predominant vehicular movement and splitting the signal phases can be beneficial.
- Intersections where a separated bicycle facility transitions to a conventional bicycle lane.
- Intersections with contra-flow bicycle moments which require a signal indication.
- Intersections where a leading bicycle phase or a bicycle only phase is desired.
- Complex intersections or intersections which have experienced a relatively high number of historical bicycle-involved traffic crashes.
- Locations where bicyclists are permitted to complete movements prohibited for vehicular traffic.
- Locations where the existing traffic signal heads are not visible to bicyclists.
- Locations where bicyclists are physically separated from vehicles and pedestrians.
- Intersections which are located near schools.

In scenarios where a bicycle signal is used to separate bicycle movements from right-turning vehicles, right turn on red shall be prohibited during the time that the bicycle signal is active [*5*]. Research conducted by ODOT included a survey of roadway agencies in the United States and Canada specific to bicycle signal design [*11*]. **Figure 3** provides a summary of the operational elements included within 63 signalized intersections with distinct bicycle signal heads. While this information provides an overview of typical practices of roadway agencies in North America, it should be noted that this data was published in 2012 and these practices have likely evolved over the last decade.

Design Element		Number of Intersections			Percent of Intersections		
		US	CN	Total	US	CN	Total
Detection Type	Loop	7	0	7	26%	-	11%
	Video	2	0	2	7%	-	3%
	Loop & push-button	4	0	4	15%	-	6%
	Push-button Only	2	0	2	7%	-	3%
	No Detection/ Recall	12	36	48	44%	100%	76%
	Unknown	0	0	0	-	-	-
Phasing Type	Exclusive	16	13	29	59%	36%	46%
	Concurrent	7	23	30	26%	64%	48%
	Leading interval	1	0	1	4%	-	2%
	Unknown	3	0	3	11%	-	5%
Restricted Movements	Yes	19	20	39	70%	56%	62%
	No	6	16	22	22%	44%	35%
	Unknown	2	0	2	7%	-	3%
Accompanying Signage	Yes	20	9	29	74%	25%	46%
	No	6	27	33	22%	75%	52%
	Unknown	1	0	1	4%	-	2%

Figure 3. Operational Elements of 63 Signalized Intersections with Bicycle Signal Heads [*11*]

Inductive Loops

Inductive loops which are commonly used for vehicle detection can also be employed to detect bicycles along bikeways with an appropriate configuration [*8*]. The metal incorporated in bicycles interrupt the horizontal magnetic field above the loop, commonly installed in a diagonal quadrupole configuration (**Figure 4**) which ensures that there is at least some horizontal magnetic field everywhere within the loop [*8*]. Diagonal quadrupole inductive loops can be used as a part of a range of bikeways, including shared use paths, bicycle lanes, as well as shared travel lanes [*8*].

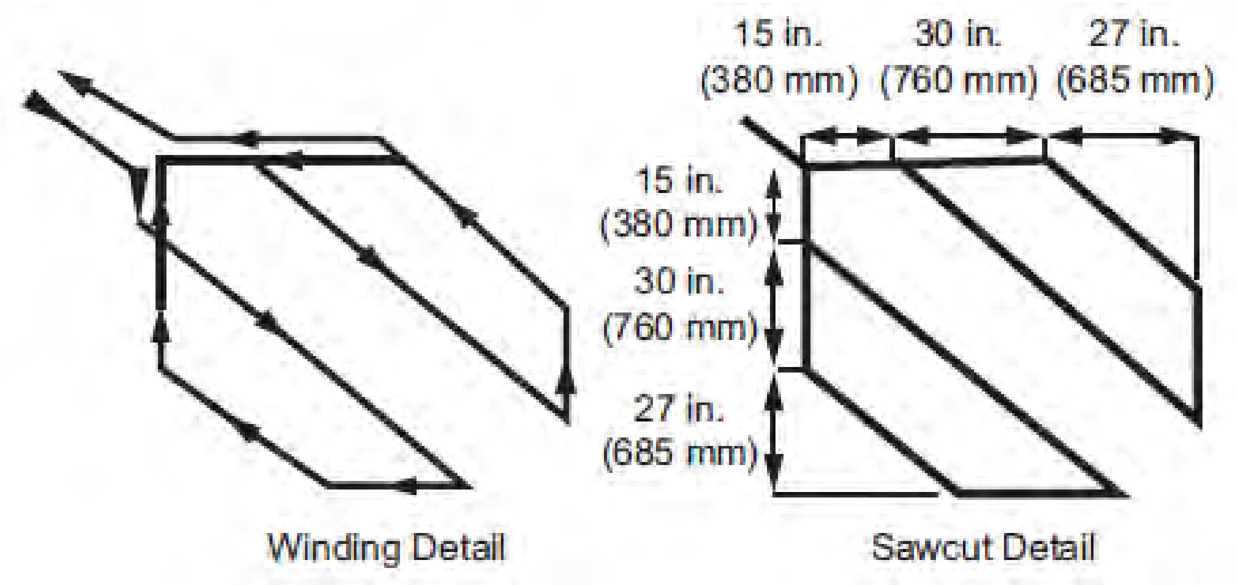


Figure 4. Diagram of a Diagonal Quadrupole Loop Detector [*8*]

The MMUTCD provides for an optional bicycle detector pavement marking symbol and supplementary R10-22 sign (**Figure 5**) to indicate the optimal position for a bicyclist to acuate traffic signals [*4*]. Roadway agencies have also developed public information campaigns in order to disseminate information to bicyclists within their jurisdiction on the most effective ways to be detected by an inductive loop [*20-22*].

Figure 5. Bicycle Detector Pavement Marking (Figure 9C-7) and R10-22 Sign [*4*]

Roadway agencies across the United States currently use inductive loops for bicycle detection in a variety of design scenarios [*23-34*]. An example of an inductive loop detector in California is shown in **Figure 6**. Additional information specific to designing inductive loop detectors for bicyclists can be found in FHWA's *Making Signal Systems Work for Cyclists* [*35*] or *Design Considerations for Detecting Bicyclists with Inductive Loop Detectors* published in the Transportation Research Record [*36*].

Figure 6. Example of Inductive Loop Bicycle Detector in California [*5*]

In scenarios where existing loop detection systems are intended to be used for bicycle detection, the sensitivity setting of the detection amplifier becomes a key consideration [*18*]. Guidance from Ontario suggests increasing the sensitivity as high as possible to ensure bicycles are detected without resulting in the system providing a steady call [*18*]. Prior research has shown that inductive loop detectors can accurately differentiate between vehicles and bicyclists in shared lanes with appropriate settings [*37*], However, the authors note that care must be taken during installation, calibration, and maintenance in order to ensure the systems are accurate. There has also been research which has shown more mixed results when attempting to use loop detection for bicycle count programs [*38*].

Microwave, Video, and Other Emerging Technologies

While the use of inductive loops is a common approach employed by roadway agencies around the United States for bicycle signal detection, agencies have also used modern technology, including a range of microwave, video, thermal or other detection systems [*39-42*]. These systems include a processor which analyzes from a unit or camera installed typically on signal mast arms or poles near the intersection [*8*]. Historically, video detection systems have struggled with detecting bicyclists in poor lighting or weather conditions but remain in use by highway agencies [*8, 18, 23, 34, 43*]. Agencies have also used LED detectors which "emit non-visible light into the detection area and measure the time taken for the light to reflect off of objects and return to the sensor" [*18*]. These systems have been shown to be able to reliably detect bicyclists in all weather and light conditions [*18*]. A thermal detection system was installed in Oregon in 2020 at three locations as a part of an evaluation of new technologies for bicycle detection [*41*].

Research conducted in Ireland [*44*] evaluated new potential systems to replace existing loop detection for bicyclists, including radar, thermal and video technologies. The authors noted that the existing inductive loop design struggled to detect cyclists who did not pass close enough to the loop, were actuated by vehicles, and a failed to detect bicycles with modern carbon fiber frames. The radar technology evaluated in the study was determined to perform best among the options evaluated to replace the existing inductive loop designs. The radar systems were installed at 12 locations and incorporated within the Sydney Coordinated Adaptive Traffic System (SCATS) in order to detect bicyclists and provide an appropriate phase, increase minimum green times or clearance intervals, collect count data, and implement leading bicycle phases.

It should be noted that there have been other studies which have investigated emerging technologies for bicyclist detection beyond (or in comparison to) inductive loops which can be referred to for more detailed information [*45-52*]. This represents an area of bicycle detection design which is constantly evolving as roadway agencies experiment with these modern systems and evaluation of these technologies is ongoing.

Bicycle Detection Indication Devices

Several state and local roadway agencies have experimented with the use of new devices which are intended to provide an indication to bicyclists that they have been detected [*53-55*], shown in **Figure 7**. Research is currently being conducted in Oregon to evaluate the use of these bicycle detector feedback confirmation devices [*56*]. Such indicator systems can represent a potential improvement to bicycle signal detection design as prior research has demonstrated that approximately half of cyclists did not understand the intent of the existing pavement marking and R10-22 sign [*57*]. An evaluation of a blue light feedback device at a signal intersection demonstrated an increase in the number of bicyclists who used the pavement marking as opposed to an adjacent pushbutton [*58*]. While these devices are relatively new and research is ongoing to determine the most effective applications, they represent a potential option to consider as a part of bicycle signal detection systems.

Figure 7. Example of Bicycle Detection Indication Devices [*53, 59*]

Pushbuttons

Bicycle-specific pushbuttons have also been used to actuate traffic signals; however, it should be noted that requiring a bicyclist to stop and potentially dismount represents a considerable drawback [*8*]. If pushbuttons are used, they should be located such that bicyclists are not required to dismount to actuate the signal [*5*]. Due to the energy required to accelerate a bicycle from a stop position, designers of bicycle facilities should consider that bicyclists may be reluctant to stop unless it is necessary [*18*]. Additionally, the design of pushbuttons should consider all potential bicycle road users (such as recumbent bicyclists) [*60*].

Applications of Bicycle Detection

Given the need to accommodate bicyclists as a part of actuated traffic signal operations, bicycle detection has a variety of common applications at signalized intersection approaches, including [*5*]:

- Shared lanes (or streets without bicycle lanes) where actuation of the signal is required.
- Locations with bicycle signal heads and/or actuated bicycle signal phases.
- Conventional bicycle lanes where actuation of the signal is required.
- Left-turn lanes with actuated left-turn phases where bicyclists may complete left-turn movements.
- Locations where the green signal phase may be insufficient for bicyclists to clear the intersection and an extension of the green phase is necessary.

Given that bicycle-specific phasing may be a relatively uncommon feature in many jurisdictions, consideration should be given to ensuring that clarity is provided to both bicyclists and vehicular traffic [*18*]. This section provides an overview of application concepts specific to the use of bicycle signal detection across a variety of roadway design scenarios.

Location of Bicycle Detection Zones

Bicycle detection zones should be located within the expected path of bicyclists, typically extending across the width of the bikeway [*8*]. These zones can include both advanced detection (often 60 to 120 feet upstream of the stop bar) as well as detection at the stop bar [*8, 61*]. The upstream detector can be used to provide extension time for the bicyclist and accommodate bicycle-specific stopping distances [*8*]. AASHTO guidance [*8*] recommends that advanced detection implemented along roadways should be located such that is not triggered right-turning vehicles. Common detection zone locations for both conventional facilities (including shared lanes and bicycle lanes) as well as separated bicycle facilities are shown in **Figure 8**.

Figure 8. Bicycle Detection Zones at Conventional [*62*] and Separated Facilities [*19*]

When to Consider Distinct Bicycle Phases

Prior work [*11, 18*] has aggregated guidance from roadway agencies specific to criteria which should result in the consideration of distinct bicycle signal phases, including:

- Volume or delay criteria, such as peak hour bicycle traffic or existing considerable delays.
- Crash or conflict criteria, such as a history of bicycle-related traffic crashes or an expectation of potential conflicts due to geometric characteristics.

- Planning criteria, such as scenarios where the inclusion of a bicycle phase would help to complete a connected network.
- Geometric criteria, including unique configurations which may impede bicyclists.
- Signal timing criteria, such as situations where it may improve delay to provide a shorter green time for bicyclists when there are no pedestrians present.
- Other special situations such as proximity to adjacent school facilities.

Separated Bicycle Lanes

Separated bicycle lanes, which have historically been referred to as "cycle tracks" or "protected lanes", are exclusive facilities "located within or directly adjacent to the roadway and that is physically separated from motor vehicle traffic with a vertical element" [*61*]. FHWA's *Separated Bike Lane Planning and Design Guide* provides more detailed information specific to signal phasing strategies to accommodate separated bicycle lanes [*61*]. The Massachusetts Department of Transportation (MASSDOT) also developed a *Separated Bike Lane Planning & Design Guide* [*19*] in 2015 which provides detailed design guidance specific to separated bicycle lanes, including traffic signal strategies within Chapter 6.

The inclusion of a separated bicycle lane alone does not require the installation of a new signal at existing unsignalized intersections [*19*]. However, bicycle signals should be considered at all signalized intersections with separated bicycle lanes in order to provide a uniform indication for bicyclists (as opposed to a combination of pedestrian, vehicle, and bicycle signal indications along a single corridor) [*19*]. Distinct signal phases for bicyclists can be used to separate bicycle and vehicle movements at signalized intersections and represents an opportunity to reduce conflict points along separated bicycle lanes [*19, 61*]. Such protected signal phasing strategies can be considered at intersections with relatively high volumes of turning vehicles, unique or high-volume bicycle movements, or locations with two-way or contra-flow bicycle movements [*19*].

It is important to recognize that considerable delay for bicyclists at signalized intersections can result in poor compliance [*61*]. Bicycle signal detection will be necessary for actuated signal operations [*61*]. MassDOT's guidance [*19*] includes recommended thresholds for considering distinct bicycle phases, shown in **Figure 9**. It should be noted that guidance developed in British Columbia [*60*] also includes similar thresholds as those presented in **Figure 9**, split by low- and high-speed facilities. In scenarios which are below these thresholds or when a dedicated phase is not feasible, MassDOT's guidance [*19*] suggests considering a leading bicycle phase. A summary of potential separated bicycle lane signal phasing strategies noted by MassDOT [*19*] are provided in **Figure 10**.

Separated Bike Lane Operation	Motor Vehicles per Hour Turning across Separated Bike Lane			
	Two-way Street			One-way Street
	Right Turn	Left Turn across One Lane	Left Turn across Two Lanes	Right or Left Turn
One-way	150	100	50	150
Two-way	100	50	0	100

Figure 9. MassDOT Thresholds for Considering Distinct Bicycle Signal Phase [*19*]

Phasing Scheme	Description	Pros	Cons
Concurrent Bike Phase with Concurrent Permissive Vehicle Turns (see EXHIBIT 6H)	Provides a bicycle phase that runs concurrently with the parallel vehicle phase.	• Increased compliance when compared to following vehicle signals.	• Not appropriate in locations with high vehicle turning volumes. • Requires vehicles to yield when turning.
Concurrent Bike Phase with Leading Interval (see EXHIBIT 6I)	Provides an advanced green indication for the bike signal. Lead interval may provide **3 to 7 seconds** of green time for bicycles prior to the green phase for the concurrent vehicle traffic. Lead bike intervals may typically be provided concurrently with lead pedestrian intervals.	• Allows bicyclists to enter the intersection prior to vehicles. • Improved visibility for turning vehicles.	• Small increase to delay and queueing for vehicles. • Concurrent turns may not be appropriate with higher vehicle or bike volumes.
Concurrent Protected Bike Phase (see EXHIBIT 6J and EXHIBIT 6K)	Provides a bicycle phase that runs concurrently with the parallel through vehicle phase. Right and left vehicle turns across the bicycle facility operate under protected phases before or after the through phase.	• Provides full separation between turning vehicles and bicyclists. • Motorists are not required to yield when turning.	• Additional signal phase may increase delay, require longer cycle length. • Protected right turns require the provision of a right-turn lane.
Protected Bike Phase (see EXHIBIT 6L)	Provides a protected bike phase where all motor vehicle traffic is stopped. This may run concurrently with a parallel pedestrian phase. May be appropriate at locations with complex signal phasing for vehicles and/or unusual geometry for a bicycle facility may result in unexpected conflicts between users.	• Provides maximum separation between vehicles and bicyclists. • Allows turns from the bike facility across the vehicle lanes.	• Increases delay for motor vehicles. • Increases delay for bicyclists.

Figure 10. Separated Bicycle Lane Bicycle Signal Phasing Scenarios [*19*]

Two-way separated bicycle lanes along two-way streets can result in increased exposure potential conflicts between bicyclists crossing signalized intersections and vehicles completing turning movements [*19*]. In scenarios where geometric design features can not mitigate these concerns, consideration should be given to a protected bicycle phase [*19*], such as the example provided in **Figure 11**.

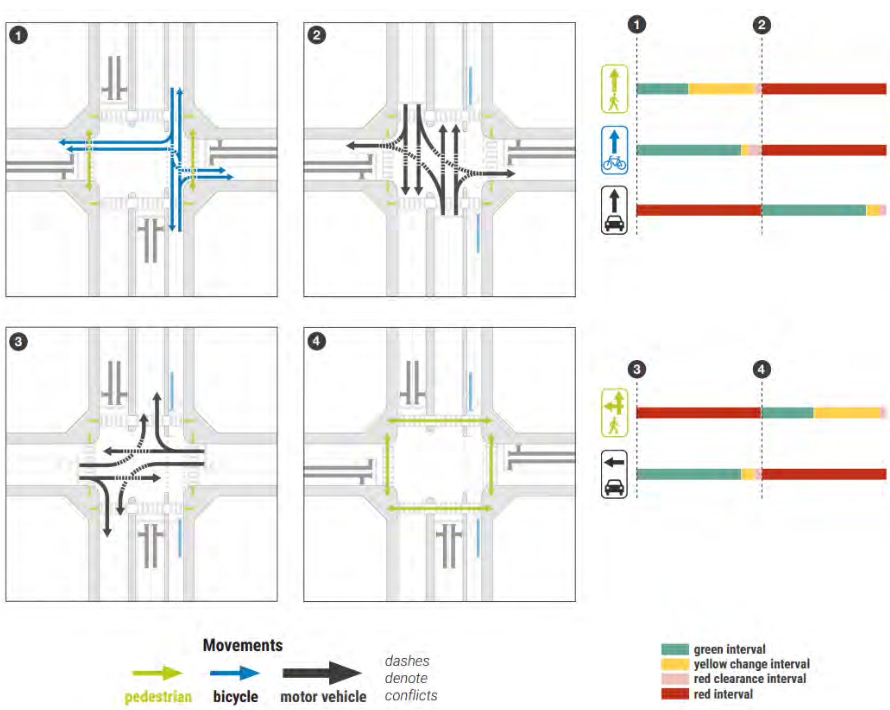


Figure 11. Example of Protected Bicycle Phase along Two-Way Separated Bicycle Lane [*19*]

An important concept along separated facilities is the design of bicycle signal faces which maximize visibility for bicyclists and minimize visibility for adjacent or conflicting vehicular movements [*61*]. This could include the consideration of visibility-limited bicycle signal faces. Consistent with the MMUTCD [*4*], "At installations where visibility-limited signal faces are used, signal faces shall be adjusted so bicyclists for whom the indications are intended can see the signal indications".

NO TURN ON RED restrictions should be considered at signalized intersections along separated bicycle lanes where turning vehicles may conflict with bicyclists, implemented on a permanent basis or part-time via dynamic signs and bicycle detection [*19*]. MassDOT guidance [*19*] notes five primary scenarios where NO TURN ON RED restrictions should be considered:

- Locations with two-stage bicycle turn boxes.
- Locations with two-way separated bicycle lanes.
- Locations with contra-flow bicycle lanes.
- Locations which include a protected bicycle signal phase.
- Locations with protected right turns are used to separate bicycle and pedestrian movements.
- Locations with a leading bicycle phase.

Shared-Use Paths, Sidepaths, and Trails

Bicycle detection may also be included along shared-use path or sidepath street crossings, particularly when bicycle clearance time varies from pedestrian clearance time [*5*]. The City of Portland has previously installed bicycle loop detection at four trail crossings (**Figure 12**) along a highway with a 60-foot crossing width and traffic volumes of greater than 15,000 vehicles per day [*1*]. These locations generally had relatively large distances to the nearest controlled crossing and trail user volumes of approximately 100 per hour. The crossings also included raised median islands with detection for road users who could not complete the crossing in a single movement.

Figure 12. Example of Bicycle Loop Detectors installed at a Trail Crossing in Portland [*1*]

References

1. Federal Highway Administration. BIKESAFE Bicycle Safety Guide and Countermeasure Selection System. Retrieved May 2020 from: http://www.pedbikesafe.org/bikesafe/index.cfm
2. Federal Highway Administration (2016). Achieving Multimodal Networks: Applying Design Flexibility & Reducing Conflicts. FHWA-HEP-16-055.
3. American Association of State Highway and Transportation Officials (2012). Guide for the Development of Bicycle Facilities: Fourth Edition.
4. Michigan Department of Transportation. Michigan Manual on Uniform Traffic Control Devices.
5. National Association of City Transportation Officials. Urban Bikeway Design Guide. Retrieved May 2021 from: https://nacto.org/publication/urban-bikeway-design-guide/
6. Michigan Department of Transportation. Biking in Michigan. Retrieved May 2021 from: https://www.michigan.gov/mdot/0,4616,7-151-9615_11223---,00.html
7. Michigan Department of Transportation (2020). Signal Timing Spreadsheet. Retrieved May 2021 from: https://mdotjboss.state.mi.us/TSSD/getCategoryDocuments.htm?categoryPrjNumbers=1403877,1403878,1403879,1403880,1403881,1403882,1403883,1403884,1403885&category=Traffic%20Signals
8. American Association of State Highway and Transportation Officials (2012). Guide for the Development of Bicycle Facilities: Fourth Edition.
9. Urbanik, T., A. Tanaka, B. Lozner, E. Lindstrom, K. Lee, S. Quayle, S. Beaird, S. Tsoi, P. Ryus, D. Gettman, S. Sunkari, K. Balke, and D. Bullock (2015). NCHRP Report 812: Signal Timing Manual. Transportation Research Board, Washington, D.C.
10. National Association of City Transportation Officials. Don't Give Up at the Intersection. Retrieved May 2021 from: https://nacto.org/publication/dont-give-up-at-the-intersection/
11. Monserre, C., M. Figliozzi, S. Thompson, and K. Paulson (2013). Operational Guidance For Bicycle-Specific Traffic Signals In The United States. FHWAW-OR-RD-14-06.
12. The National Academies of Sciences, Engineering, and Medicine. NCHRP 03-133 [Completed] Traffic Signal Design and Operations Strategies for Non-Motorized Users. Retrieved May 2021 from: https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4357
13. California State Transportation Agency (2014). California Manual on Uniform Traffic Control Devices. Retrieved May 2021 from: https://dot.ca.gov/-/media/dot-media/programs/safety-programs/documents/ca-mutcd/rev6/camutcd2014-rev6.pdf
14. Washington State Legislature. RCW 47.36.025. Vehicle-activated traffic control signals—Detection of motorcycles and bicycles. Retrieved May 2021 from: https://app.leg.wa.gov/rcw/default.aspx?cite=47.36&full=true#47.36.025
15. Federal Highway Administration (2016). Achieving Multimodal Networks: Applying Design Flexibility & Reducing Conflicts. FHWA-HEP-16-055.
16. Federal Highway Administration (2013). Interim Approval for Optional Use of a Bicycle Signal Face (IA-16). Retrieved May 2021 from: https://mutcd.fhwa.dot.gov/resources/interim_approval/ia16/
17. Federal Highway Administration (2020). National Standards for Traffic Control Devices; the Manual on Uniform Traffic Control Devices for Streets and Highways; Revision. Retrieved March 2021 from: https://www.federalregister.gov/documents/2020/12/14/2020-26789/national-standards-for-traffic-control-devices-the-manual-on-uniform-traffic-control-devices-for
18. Ontario Traffic Council (2015). Ontario Traffic Council Bicycle Traffic Signal Guide. Retrieved May 2021 from: https://ontario-traffic-council.s3.amazonaws.com/uploads/2015/01/OTC-Bicycle-Traffic-Signals-Guide1.pdf
19. Massachusetts Department of Transportation. Separated Bike Lane Planning and Design Guide. Retrieved May 2021 from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide

20. Portland Bureau of Transportation. Getting a Green Light on a Bicycle at an Intersection. Retrieved May 2021 from: https://www.portlandoregon.gov/transportation/article/660377
21. Oregon Department of Transportation. Getting a Green Light on Your Bicycle. Retrieved May 2021 from: https://www.oregon.gov/ODOT/Safety/Documents/GettingAGreenLight.pdf
22. City of Cincinnati, Ohio. Loop Detector Pavement Markings for Bicyclists. Retereived May 2021 from: https://www.cincinnati-oh.gov/bikes/bike-infrastructure/loop-detector-markings/loop-detectors-for-bikes/
23. Minnesota Department of Transportation (2020). Bicycle Facility Design Manual. Retrieved May 2021 from: https://www.dot.state.mn.us/bike/bicycle-facility-design-manual.html
24. Wisconsin Department of Transportation (2018). Wisconsin Bicycle Facility Design Handbook. Retrieved May 2021 from: https://wisconsindot.gov/Documents/projects/multimodal/bike/facility.pdf
25. Ohio Department of Transportation (2014). Traffic Engineering Manual - 400 TRAFFIC SIGNALS. Retrieved May 2021 from: https://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Documents/TEM%20Part04_011521.pdf
26. Nordback, K., D. Johnstone, and S. Kothuri (2017). Optimizing Short Duration Bicycle and Pedestrian Counting in Washington State. WA-RD 875.2.
27. Canoga. Bicycle Detection and Classification in Minneapolis. Retrieved May 2021 from: https://www.gtt.com/wp-content/uploads/79-1000-1359-Minneapolis-Bicycle-new.pdf
28. Maki, P.J. and P.S. Marshall (1997). Accommodating Bicycles at Signalized Intersections with Loop Detectors: A Case Study and Example. Institute of Transportation Engineers 67th Annual Meeting.
29. Colorado Department of Transportation (2015). Roadway Design Guide – Chapter 14 Bicycle and Pedestrian Facilities. Retrieved May 2021 from: https://www.codot.gov/business/designsupport/bulletins_manuals/roadway-design-guide/ch14
30. City of Phoenix. Bicycle Infrastructure Improvements. Retrieved May 2021 from: https://www.phoenix.gov/streets/safety-topics/featured-projects-recent-improvements
31. Transport for New South Wales. Bicycle detection at traffic lights. Retrieved May 2021 from: https://roads-waterways.transport.nsw.gov.au/roads/safety-rules/heavy-vehicles-riders/cyclists/traffic-lights.html
32. National Association of City Transportation Officials. Bicycle Signal Detector Loops, Madison, WI. Retrieved May 2021 from: https://nacto.org/case-study/bicycle-signal-detector-loops-madison-wi/
33. BikeWalk NC. Bicycle Detection at Traffic Signals. Retrieved May 2021 from: https://www.bikewalknc.org/bicycle-detection-at-traffic-signals/
34. Montana Department of Transportation (2007). Traffic Signal Design. Retrieved May 2021 from: https://www.mdt.mt.gov/other/webdata/external/traffic/manual/chapter_12.pdf
35. Federal Highway Administration (2008). Making Signal Systems Work for Cyclists. FHWA-HRT-08-004.
36. Kidarsa, R., T. Pande, S.V. VAnjari, J.V. Krogmeier, and D.M. Bullock (2006). Design Considerations for Detecting Bicyclists with Inductive Loop Detectors. Transportation Research Record: Journal of the Transportation Research Board, No. 1978.
37. Nordback, K., D. Piatkowski, B.N. Janson, W.E. Marshall, K.J. Krizek, and D.S. Main (2011). Using Inductive Loops to Count Bicyclists in Mixed Traffic. Journal of Transportation of the Institute of Transportation Engineers, Vol. 2.
38. Blanc, B., P. Johnson, M. Figliozzi, C. Monsere, and K. Nordback (2015). Leveraging Signal Infrastructure for Nonmotorized Counts in a Statewide Program: Pilot Study. Transportation Research Record: Journal of the Transportation Research Board, No. 2527, Transportation Research Board, Washington, D.C.

39. Oregon Department of Transportation. Traffic Signal Design Manual – Chapter 6 Detector Plan. Retrieved May 2021 from: https://www.oregon.gov/odot/Engineering/Documents_TrafficStandards/Signal-Design-2021_06.pdf
40. City of Pleasanton, California. Bicycle Detection, Intersector. Retrieved May 2021 from: http://www.cityofpleasantonca.gov/gov/depts/cd/traffic/information/intersector.asp
41. Washington County, Oregon (2020). New cyclist detection system is being tested. Retrieved May 2021 from: https://www.co.washington.or.us/LUT/News/cyclist-detection-system.cfm
42. Adler, E. (2016). Bike Detection Sensors Installed in Minnesota Intersections. Retrieved May 2021 from: https://www.govtech.com/fs/bike-detection-sensors-installed-in-minnesota-intersections.html
43. National Association of City Transportation Officials. N 130th Street Buffered Bike Lanes and Video Detection, Seattle, WA. Retrieved May 2021 from: https://nacto.org/case-study/buffered-bike-lanes-and-video-detection-on-n-130th-street-seattle-wa/
44. Devilly, O., K. Hosie, P. Cooling, and C.K. Manzira (2019). Cycle Safe Intersections - An Evaluation of Radar Bicycle Detectors in Dublin. European Transport Conference.
45. Lyons, A. (2014). Bike Detection Today – Technology Update. International Municipal Signal Association, Vol. LII.
46. Kimble, S.J. (2014). Leveraging Wireless Sensor Technology for Bicycle Detection and Counts. International Municipal Signal Association, Vol. LII.
47. Robinson, S. (2014). Bicycle Detection and Differentiation. International Municipal Signal Association, Vol. LII.
48. Shladover, S.E., A. Sharafsael, A. Cheong, J. Spring, and K. Leung (2010). Bicycle Detection and Operational Concept at Signalized Intersections Phase 2B: Testing a Bicycle Detection System. UCB-ITS-PRR-2012-3.
49. Shladover, S.E., Z. Kim, M. Cao, A. Sharafsaleh, J. Li, and K. Leung (2009). Bicycle Detection and Operational Concept at Signalized Intersections. UCB-ITS-PRR-2009-37.
50. Kothuri, S., K. Nordback, A. Schrope, T. Phillips, and M. Figliozzi (2017). Bicycle and Pedestrian Countsat Signalized Intersections Using Existing Infrastructure. Transportation Research Record: Journal of the Transportation Research Board, No. 2644.
51. Volling, M.T. (2013). A New Solution to the Growing Problem of Bicycle Detection. IMSA Journal, Vol LI.
52. Williams, L.T. (2020). Bicycle Detection and Timing Design at Signalized Intersections with Advanced Detection. Masters Thesis – University of Nevada, Reno.
53. City of Danville, California. Traffic Signal Bicycle Detection Upgrades. Retrieved May 2021 from: https://www.danville.ca.gov/736/Traffic-Signal-Bicycle-Detection-Upgrade
54. City of Madison, Wisconsin. Bicycle Detection Indicator. Retrieved May 2021 from: https://www.cityofmadison.com/bikeMadison/planning/planStage/documents/BicycleDetectionIndicator.pdf
55. Livewire Calgary (2019). Calgary cyclists to get detection information at Inglewood intersection. Retrieved May 2021 from: https://livewirecalgary.com/2019/04/22/calgary-cyclists-to-get-detection-information-at-inglewood-intersection/
56. Transportation Research and Education Center. Bicycle Detection and Feedback Assessment. Retrieved June 2021 from: https://trec.pdx.edu/research/project/1356/Bicycle_Detection_and_Feedback_Assessment
57. Bussey, S., C.M. Monsere, and P. Koonce (2014). Does the Bicycle Detector Symbol Change Cyclist Queueing Position at Signalized Intersections? 94th Meeting of the Transportation Research Board.

58. Boudart, J., R. Liu, P. Koonce, and L. Ookimoto (2015). Assessment of Bicyclist Behavior at Traffic Signals with a Detector Confirmation Feedback Device. Transportation Research Record: Journal of the Transportation Research Board, No. 2520, Transportation Research Board, Washington, D.C.
59. Bike Portland (2019). Blue light for bike riderse part of detection research project. Retrieved May 2021 from: https://bikeportland.org/2019/10/11/new-blue-light-for-bike-riders-part-of-detection-research-project-306124
60. British Columbia Ministry of Transportation (2019). British Columbia Active Transportation Design Guide. Retrieved May 2021 from: https://bicycleinfrastructuremanuals.com/manuals3/British%20Columbia%20Active%20Transportation%20Design%20Guide.pdf
61. Federal Highway Administration (2015). Separated Bike Lane Planning and Design Guide. FHWA-HEP-15-025.
62. National Highway Institute. Bicycle Facility Design Course (FHWA-NHI-142080). Retrieved May 2021 from: https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=bicycle&sf=0&course_no=142080

Appendix 5:

Details of Survey of Michigan Residents

Appendix 5: Details of Survey of Michigan Residents

Appendix 5.1 Michigan Resident Survey Questions on Walking and Bicycling Behaviors

1. How often do you travel **on foot** within your community for each of the following activities?

Q1	Daily	More than once a week	Once a week	More than once a month	Once a month	A few times a year	Never
Recreation or exercising							
Going to a store, restaurant, or another business							
Commuting to work or school							

2. How often do you travel **by bicycle** within your community for each of the following activities?

Q2	Daily	More than once a week	Once a week	More than once a month	Once a month	A few times a year	Never
Recreation or exercising							
Going to a store, restaurant, or another business							
Commuting to work or school							

3. In your community, how satisfied are you with the availability of:

Q3	Very Dissatisfied	Somewhat Dissatisfied	Neither Satisfied nor Dissatisfied	Somewhat Satisfied	Very Satisfied	Unsure/Not Applicable
Pedestrian facilities (for walking), such as sidewalks, walking trails, and pathways						
Bicycle facilities, such as bicycle lanes, bicycling trails, and pathways						

4. In your community, how safe do you feel when:

Q4	Very Unsafe	Somewhat Unsafe	Neither Safe nor Unsafe	Somewhat Safe	Very Safe	Unsure/Not Applicable
Walking						
Bicycling						
Crossing the street on foot						
Crossing the street on a bicycle						

5. If the safety and condition of the roadways, sidewalks, and pathways in your community were improved, how much more frequently would you walk and bicycle than you do now?

Q5	Multiple times a day more	Once a day more	At least once a week more	At least once a month more	At least once a year more	No change	Unsure
Walk							
Bicycle							

6. When traveling **on foot** in your community, do you typically take the most direct (fastest) route, or do you take a longer route that is safer or more comfortable?

Q6	Direct route	Longer route, but safer or more comfortable	Unsure/Not Applicable
Recreation or exercising			
Going to a store, restaurant, or another business			
Commuting to work or school			

7. When traveling **by bicycle** in your community, do you typically take the most direct (fastest) route, or do you take a longer route that is safer or more comfortable?

Q7	Direct route	Longer route, but safer or more comfortable	Unsure/Not Applicable
Recreation or exercising			
Going to a store, restaurant, or another business			
Commuting to work or school			

8. When walking or bicycling along a road that does not have a sidewalk or pathway, where do you typically position yourself?

Q8	Along the left edge or left shoulder of the roadway	Along the right edge or right shoulder of the roadway	In the middle of the roadway or a lane of traffic	Completely outside of the roadway (in the grass, etc.)	Unsure/Not applicable
Walking					
Bicycling					

9. Compared to the same period last year, how often have you gone walking or bicycling during the COVID-19 pandemic?

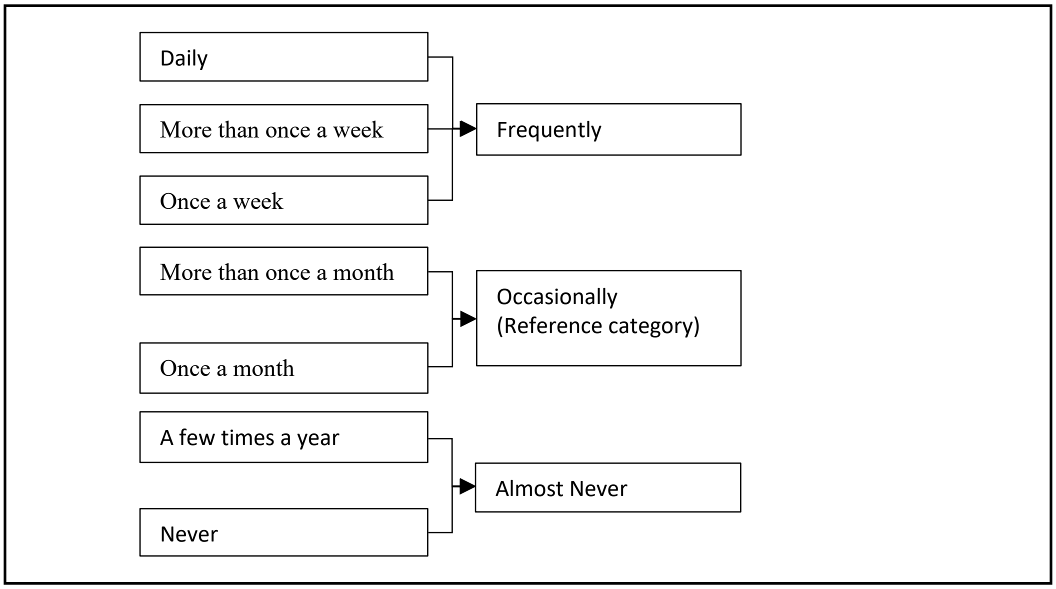
Q9	Much less frequently	Somewhat less frequently	About the same	Somewhat more frequently	Much more frequently	Unsure
Walking						
Bicycling						

10. In the future, do you intend to continue at your current frequency or change it?

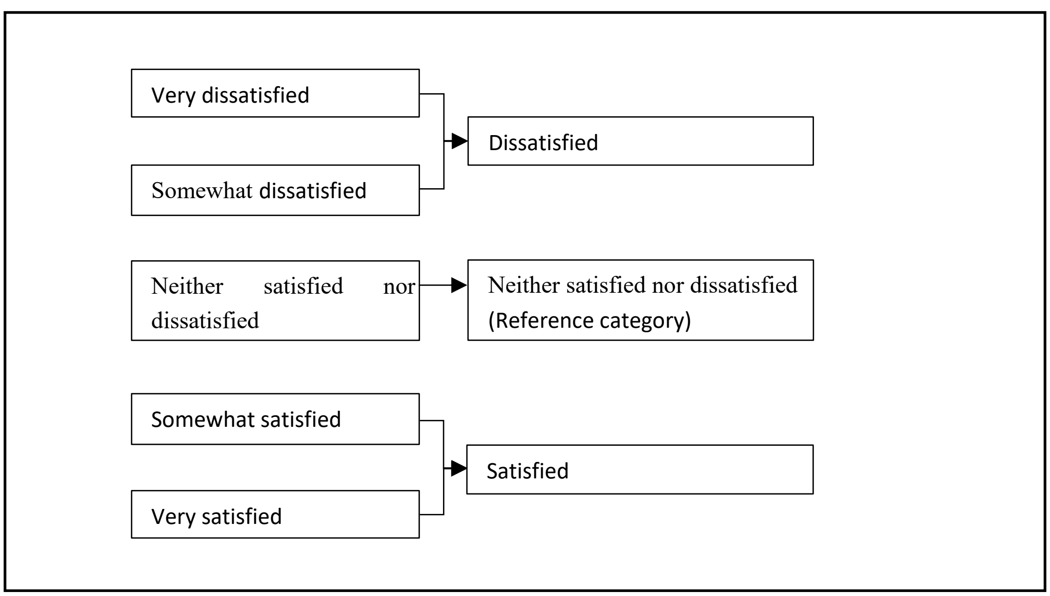
Q10	Plan to Increase	Plan to Decrease	Don't Plan to Change	Unsure
Walking				
Bicycling				

Appendix 5.2 Michigan Resident Survey Data Aggregation Scheme for Modeling

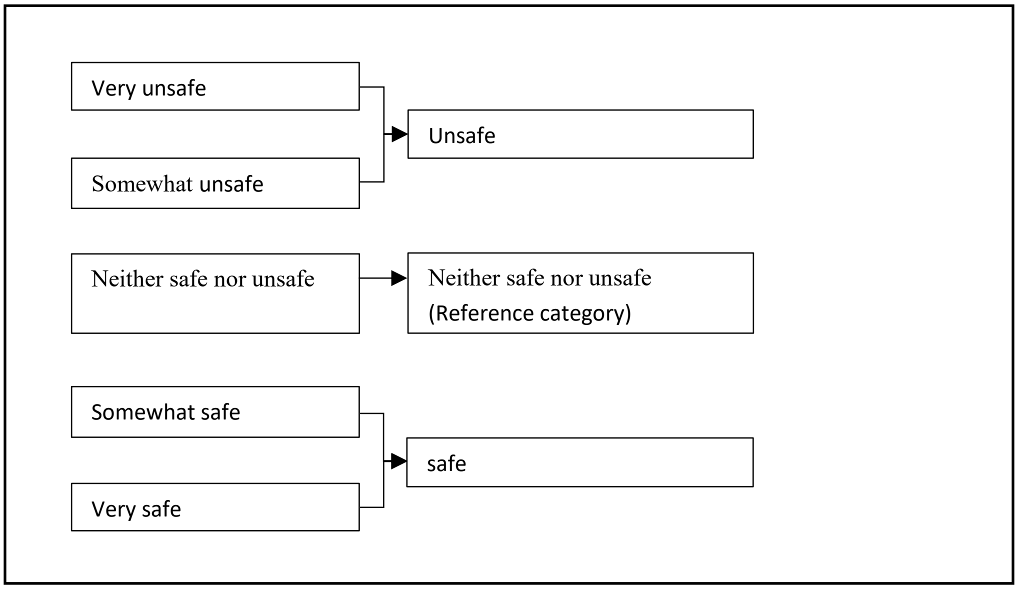
1. The original seven behavior categories in Questions 1 and 2 were aggregated into three new categories as shown as shown below for the purposes of developing multinomial logistic regression models.



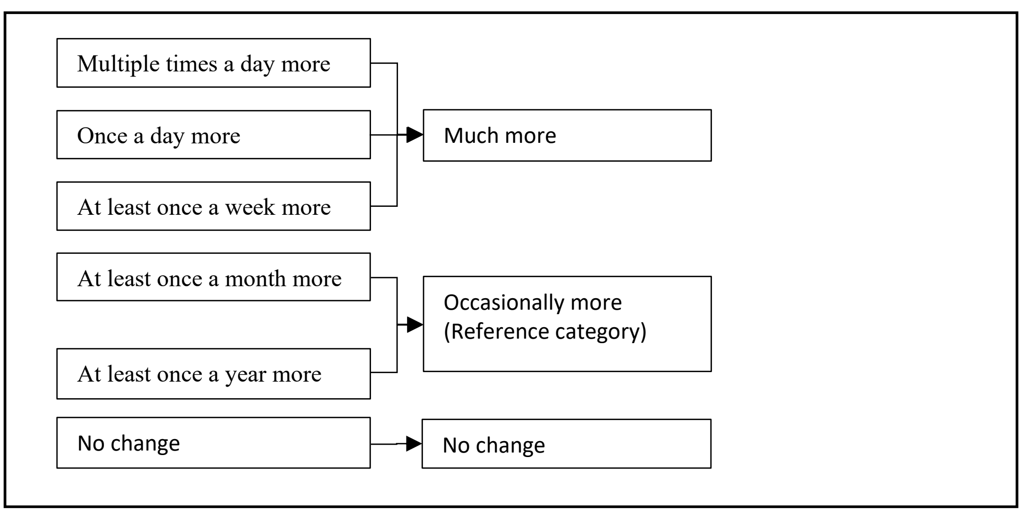
2. For satisfaction with pedestrian and biking facilities, the original five behavioral categories were aggregated in to three categories as shown below for the purposes of developing multinomial logistic regression models.



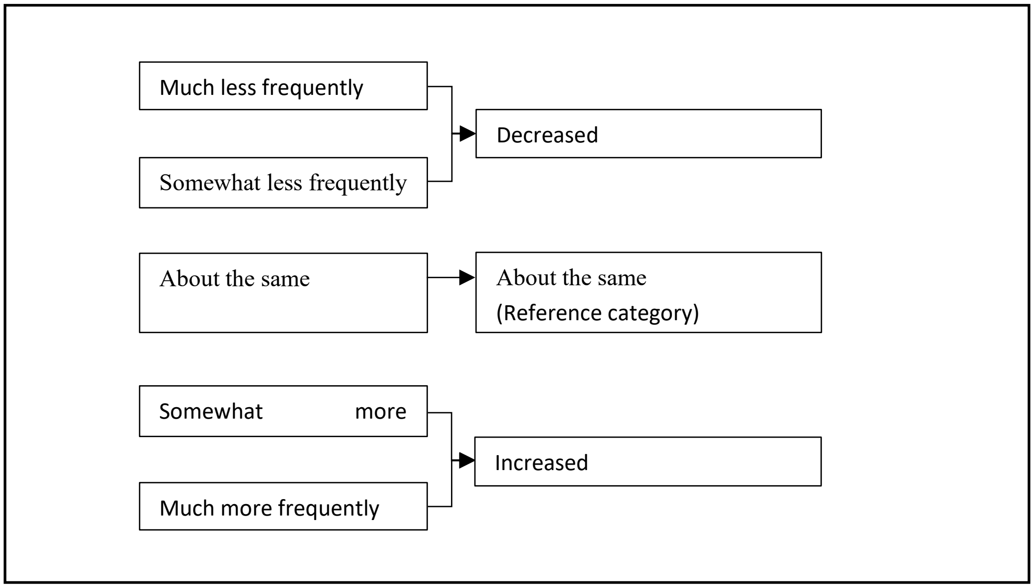
3. For community safety feeling, the original five behavioral categories were aggregated in to three categories as shown below for the purposes of developing multinomial logistic regression models.



4. For behavior with improved infrastructure conditions, the original five behavioral categories were aggregated into three categories as shown below for the purposes of developing multinomial logistic regression models.



5. For during-pandemic behaviors, the original five behavioral categories were aggregated into three categories as shown below for the purposes of developing multinomial logistic regression models.



6. For satisfaction with facilities, community safety feeling, behavioral change with improved condition, preferred routes, travel behavior without sidewalks, during-pandemic and post- pandemic responses, the "Unsure" category was not modeled.

Appendix 5.3 Michigan Resident Survey Multinomial Logistic Regression Results

General Walking Behavior Multinomial Logistic Regression Model Results

	Recreation or exercising[a]				Going to a store, restaurant, or another business[a]				Commuting to work or school[a]			
	Frequently		Almost Never		Frequently		Almost Never		Frequently		Almost Never	
Variable	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)
Age	0.000	1.000	0.022**	1.023	-0.007	0.993	-0.002	0.998	0.009	1.009	0.039**	1.040
Male	-0.040	0.961	-0.389	0.678	0.416	1.516	0.124	1.132	-0.210	0.810	-0.548	0.578
Female	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
White or Caucasian	-0.413	0.662	-0.731	0.482	0.533	1.703	0.777*	2.175	0.423	1.527	0.720	2.055
Other	0.014	1.015	-1.603	0.201	0.936	2.550	0.547	1.728	-0.811	0.444	-0.886	0.412
Black	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Hispanic	0.247	1.281	0.587	1.798	-0.489	0.613	-0.290	0.749	0.169	1.185	0.777	2.174
Non-Hispanic	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Married/ Living together	-0.148	0.862	-0.068	0.934	0.247	1.280	0.406	1.501	-0.520	0.595	0.055	1.057
Single	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Children not in the house	0.283	1.327	0.260	1.297	-0.075	0.928	0.077	1.080	-0.198	0.820	0.218	1.244
Children in the house	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
In labor force	0.103	1.108	0.046	1.047	-0.212	0.809	-0.396	0.673	0.719	2.052	-0.609	0.544
Not in labor force	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Below $30,000	0.176	1.193	0.479	1.614	-0.592*	0.553	-0.501	0.606	-0.143	0.867	-0.389	0.677
$30,000 to $59,999	-0.159	0.853	-0.121	0.886	-0.380	0.684	-0.190	0.827	-0.012	0.988	0.026	1.026
Above $59,999	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
≤High school graduate	-0.309	0.735	0.448	1.565	0.076	1.078	-0.149	0.862	-1.195*	0.303	-1.642**	0.194
Some college	-0.041	0.960	0.711*	2.035	-0.333	0.717	-0.113	0.893	-1.260*	0.284	-1.262*	0.283
≥ College graduate	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Rural community	-0.390	0.677	0.527	1.694	-0.172	0.842	0.040	1.041	-0.047	0.954	-0.001	0.999
Small city or town, village	-0.348	0.706	0.371	1.450	-0.308	0.735	0.044	1.045	-0.085	0.919	-0.031	0.969
A suburb	-0.469	0.625	0.124	1.131	-0.635	0.530	-0.025	0.975	-0.697	0.498	-0.091	0.913
Urban community	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Intercept	1.891**		-0.336		1.432*		0.904		1.838		2.203*	
Observations	919		919		918		918		914		914	
Nagelkerke	0.132		0.132		0.067		0.067		0.214		0.214	

Note: [a] The reference category is: Occasionally.

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

General Bicycling Behaviors Multinomial Logistic Regression Model Results

	Recreation or exercising[a]				Going to a store, restaurant, or another business[a]				Commuting to work or school[a]			
	Frequently		Almost Never		Frequently		Almost Never		Frequently		Almost Never	
Variable	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)
Age	0.000	1.000	0.020*	1.020	-0.006	0.994	0.008	1.008	0.007	1.007	0.046**	1.047
Male	-0.110	0.896	-0.733**	0.480	-0.122	0.885	-0.457	0.633	0.791	2.206	-0.162	0.850
Female	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
White or Caucasian	-0.639	0.528	-0.001	0.999	0.774	2.168	1.140**	3.126	-1.008	0.365	0.439	1.552
Other	-0.564	0.569	-0.739	0.477	1.911	6.759	0.658	1.932	-2.511	0.081	-1.442	0.236
Black	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Hispanic	0.758	2.134	1.296	3.655	-0.461	0.631	-0.225	0.798	0.138	1.148	-0.053	0.948
Non-Hispanic	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Married/ Living together	-0.796*	0.451	-0.032	0.969	0.233	1.262	0.141	1.152	-0.702	0.496	-0.116	0.890
Single	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Children not in the house	-0.089	0.915	0.651*	1.917	0.257	1.293	0.553	1.738	0.166	1.180	0.476	1.609
Children in the house	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
In labor force	0.694*	2.002	0.553*	1.739	-0.035	0.965	0.000	1.000	0.849	2.336	0.502	1.653
Not in labor force	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Below $30,000	-0.514	0.598	0.285	1.329	0.351	1.421	-0.066	0.936	-0.097	0.908	-0.482	0.618
$30,000 to $59,999	-0.226	0.798	-0.103	0.902	-0.083	0.920	0.062	1.064	-0.245	0.783	-0.269	0.764
Above $59,999	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
≤High school graduate	0.362	1.436	0.213	1.237	0.276	1.317	-0.145	0.865	0.313	1.368	-0.530	0.588
Some college	0.331	1.392	0.134	1.143	-0.496	0.609	-0.508	0.602	-0.393	0.675	-0.782	0.458
≥ College graduate	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Rural community	0.812	2.252	0.811	2.250	-0.496	0.609	-0.183	0.832	1.472	4.357	0.960	2.612
Small city or town, village	0.009	1.009	-0.284	0.753	-0.097	0.908	-0.501	0.606	0.094	1.098	-0.648	0.523
A suburb	0.412	1.510	-0.216	0.806	-0.635	0.530	-0.606	0.545	-0.303	0.738	-0.789	0.454
Urban community	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Intercept	0.587		0.752		-0.406		1.639*		0.260		1.989	
Observations	901		901		903		903		904		904	
Nagelkerke	0.140		0.140		0.081		0.081		0.173		0.173	

Note: a The reference category is: Occasionally.

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Satisfaction with Pedestrian and Bicycle Facilities Multinomial Logistic Regression Model Results

	Satisfaction with Pedestrian Facilities[a]				Satisfaction with Bicycle Facilities[a]			
	Dissatisfied		Satisfied		Dissatisfied		Satisfied	
Variable	B	Exp (B)	B	Exp (B)	B	Exp (B)	B	Exp (B)
Age	-0.014	0.986	0.009	1.009	-0.016*	0.984	0.009	1.009
Male	-0.652**	0.521	-0.448*	0.639	-0.196	0.822	-0.222	0.801
Female	0[b]		0[b]		0[b]		0[b]	
White or Caucasian	0.431	1.539	0.062	1.064	0.388	1.475	0.355	1.427
Other	0.352	1.422	0.048	1.049	-0.457	0.633	-0.172	0.842
Black	0[b]		0[b]		0[b]		0[b]	
Hispanic	0.800	2.225	0.750	2.117	0.502	1.652	0.357	1.429
Non-Hispanic	0[b]		0[b]		0[b]		0[b]	
Married/ Living together	0.208	1.232	0.275	1.316	0.065	1.067	-0.041	0.960
Single	0[b]		0[b]		0[b]		0[b]	
Children not in the house	0.548	1.730	0.288	1.333	0.911**	2.486	0.224	1.251
Children in the house	0[b]		0[b]		0[b]		0[b]	
In labor force	-0.078	0.925	0.073	1.076	-0.265	0.767	0.267	1.306
Not in labor force	0[b]		0[b]		0[b]		0[b]	
Below $30,000	-0.255	0.775	-0.240	0.787	-0.045	0.956	-0.205	0.814
$30,000 to $59,999	0.228	1.256	0.193	1.213	0.422	1.525	0.218	1.244
Above $59,999	0[b]		0[b]		0[b]		0[b]	
≤High school graduate	-0.931**	0.394	-0.871**	0.419	-0.494	0.610	-0.526*	0.591
Some college	-0.262	0.770	-0.346	0.707	0.043	1.044	-0.186	0.830
≥ College graduate	0[b]		0[b]		0[b]		0[b]	
Rural community	-0.029	0.972	-0.450	0.638	-0.279	0.757	-0.392	0.676
Small city or town, village	0.405	1.499	0.002	1.002	0.326	1.385	0.002	1.002
A suburb	0.335	1.398	0.286	1.331	0.282	1.326	0.400	1.492
Urban community	0[b]		0[b]		0[b]		0[b]	
Frequently for recreation	0.704*	2.023	0.493*	1.636	1.205**	3.338	0.991*	2.694
Occasionally for recreation	0.438	1.549	0.223	1.249	0.814	2.256	0.371	1.449
Almost never for recreation	0[b]		0[b]		0[b]		0[b]	
Frequently for services	0.114	1.120	0.415	1.514	1.025	2.787	-0.671	0.511
Occasionally for services	-0.359	0.698	-0.048	0.953	-0.351	0.704	-0.826	0.438
Almost never for services	0[b]		0[b]		0[b]		0[b]	
Frequently for commuting	0.031	1.032	0.114	1.120	-1.936**	0.144	-0.100	0.905
Occasionally for commuting	-0.852	0.427	-0.756	0.469	-0.637	0.529	-0.377	0.686
Almost never for commuting	0[b]		0[b]		0[b]		0[b]	
Intercept	-0.074		0.620		0.544		0.006	
Observations	846		846		772		772	
Nagelkerke	0.127		0.127		0.145		0.145	

Note: [a] The reference category is: Neither satisfied nor dissatisfied.

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Safety Perception Multinomial Logistic Regression Model Results

	Walking[a]				Bicycling[a]				Crossing the street on foot[a]				Crossing the street on a bicycle[a]			
	Unsafe		Safe		Unsafe		Safe		Unsafe		Safe		Unsafe		Safe	
Variable	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)
Age	0.001	1.001	0.024**	1.025	-0.009	0.991	0.007	1.007	0.004	1.004	0.026**	1.026	-0.010	0.990	0.006	1.006
Male	-0.512	0.599	0.180	1.197	-0.118	0.889	0.413	1.511	-0.103	0.902	0.144	1.155	-0.196	0.822	0.271	1.311
Female	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
White or Caucasian	0.882	2.417	0.880**	2.411	0.466	1.594	0.355	1.426	1.032*	2.806	0.850*	2.341	0.586	1.796	0.341	1.406
Other	-1.009	0.365	0.143	1.153	0.622	1.862	0.411	1.508	0.191	1.211	0.290	1.337	0.846	2.331	0.078	1.081
Black	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Hispanic	1.487*	4.423	0.687	1.988	0.979	2.663	0.705	2.024	0.506	1.659	0.217	1.242	0.524	1.689	0.275	1.317
Non-Hispanic	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Married/ Living together	-0.063	0.939	0.179	1.196	-0.012	0.988	-0.046	0.955	0.110	1.116	0.085	1.089	0.398	1.488	0.047	1.048
Single	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Children not in the house	0.188	1.207	-0.022	0.978	0.136	1.146	-0.145	0.865	0.016	1.016	-0.083	0.920	0.411	1.508	-0.272	0.762
Children in the house	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
In labor force	-0.204	0.815	0.022	1.022	-0.477	0.621	-0.088	0.916	0.342	1.407	0.031	1.032	-0.077	0.925	-0.161	0.851
Not in labor force	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Below $30,000	-0.298	0.742	-0.309	0.734	-0.357	0.700	-0.432	0.649	0.145	1.156	-0.418	0.659	0.091	1.095	-0.570	0.566
$30,000 to $59,999	-0.295	0.745	-0.221	0.802	-0.005	0.995	-0.144	0.866	-0.023	0.977	-0.265	0.767	-0.024	0.977	-0.182	0.834
Above $59,999	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
≤High school graduate	-0.208	0.812	-0.495	0.609	-0.516	0.597	-0.637*	0.529	-0.386	0.680	-0.741*	0.476	-0.669	0.512	-1.066**	0.344
Some college	0.255	1.291	0.013	1.013	-0.022	0.979	-0.189	0.828	0.412	1.510	0.026	1.026	0.070	1.072	-0.167	0.846
≥ College graduate	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Rural community	-1.266*	0.282	-0.351	0.704	-0.769	0.463	-0.229	0.795	-1.505**	0.222	-0.415	0.661	-0.957	0.384	0.249	1.282
Small city or town, village	-0.515	0.598	0.094	1.098	-1.024	0.359	-0.076	0.927	-0.730	0.482	0.321	1.378	-0.180	0.835	0.702	2.018
A suburb	-1.031*	0.357	-0.153	0.858	-0.649	0.523	-0.208	0.812	-1.037*	0.355	-0.504	0.604	-0.113	0.893	0.213	1.237
Urban community	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Frequently for recreation	0.002	1.002	0.625*	1.868	0.726	2.068	1.010*	2.746	0.001	1.001	0.526	1.692	1.504**	4.501	1.235*	3.438
Occasionally for recreation	0.101	1.106	0.434	1.544	0.503	1.653	0.522	1.685	-0.305	0.737	0.105	1.111	0.720	2.055	0.781	2.183
Almost never for recreation	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Frequently for services	-0.430	0.650	0.000	1.000	-0.615	0.540	-1.828**	0.161	0.573	1.774	0.514	1.673	-0.748	0.473	-1.676**	0.187
Occasionally for services	-0.266	0.766	-0.107	0.898	-1.094	0.335	-1.150*	0.317	0.134	1.143	0.345	1.413	-0.959	0.383	-0.865	0.421
Almost never for services	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Frequently for commuting	0.338	1.403	-0.127	0.880	-0.844	0.430	-0.399	0.671	-0.324	0.723	-0.459	0.632	-0.380	0.684	0.281	1.324
Occasionally for commuting	0.746	2.108	-0.221	0.801	-0.114	0.892	0.045	1.046	-0.179	0.836	-1.112*	0.329	-0.011	0.989	-0.323	0.724
Almost never for commuting	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Intercept	0.350		0.034		1.060		1.414*		-0.271		0.363		-0.077		1.345*	
Observations	882		882		625		625		874		874		623		623	
Nagelkerke	0.131		0.131		0.115		0.115		0.130		0.130		0.152		0.152	

Note: [a] The reference category is: Neither safe nor unsafe.

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Walking and Bicycling Intentions Multinomial Logistic Regression Model Results

	Walking[a]				Bicycling[a]			
	Much more		No change		Much more		No change	
Variable	B	Exp (B)	B	Exp (B)	B	Exp (B)	B	Exp (B)
Age	0.009	1.009	0.022*	1.022	0.013	1.013	0.035**	1.036
Male	0.030	1.030	0.216	1.241	-0.488	0.614	-0.204	0.815
Female	0[b]		0[b]		0[b]		0[b]	
White or Caucasian	0.002	1.002	1.176**	3.241	-0.410	0.664	0.331	1.392
Other	-1.129	0.323	-0.653	0.520	-2.570*	0.077	-1.223	0.294
Black	0[b]		0[b]		0[b]		0[b]	
Hispanic	-0.073	0.930	-0.830	0.436	0.189	1.208	-0.758	0.469
Non-Hispanic	0[b]		0[b]		0[b]		0[b]	
Married/ Living together	0.101	1.106	0.144	1.154	-0.211	0.809	-0.185	0.831
Single	0[b]		0[b]		0[b]		0[b]	
Children not in the house	0.064	1.066	0.244	1.277	0.593	1.809	0.220	1.246
Children in the house	0[b]		0[b]		0[b]		0[b]	
In labor force	-0.117	0.890	-0.099	0.906	0.455	1.576	0.040	1.041
Not in labor force	0[b]		0[b]		0[b]		0[b]	
Below $30,000	0.319	1.376	-0.037	0.963	0.141	1.151	0.041	1.042
$30,000 to $59,999	0.028	1.029	0.183	1.201	0.108	1.115	0.205	1.228
Above $59,999	0[b]		0[b]		0[b]		0[b]	
≤High school graduate	0.069	1.071	0.104	1.109	-0.139	0.870	0.231	1.260
Some college	-0.341	0.711	-0.432	0.649	-0.132	0.876	0.003	1.003
≥ College graduate	0[b]		0[b]		0[b]		0[b]	
Rural community	0.512	1.668	0.414	1.513	0.336	1.400	0.091	1.095
Small city or town, village	0.072	1.075	-0.113	0.894	1.109*	3.031	0.303	1.354
A suburb	-0.181	0.834	-0.240	0.786	0.078	1.081	-0.077	0.926
Urban community	0[b]		0[b]		0[b]		0[b]	
Frequently for recreation	1.335**	3.799	0.151	1.163	0.894	2.444	-1.223**	0.294
Occasionally for recreation	0.283	1.326	-0.627	0.534	0.238	1.269	-0.910*	0.402
Almost never for recreation	0[b]		0[b]		0[b]		0[b]	
Frequently for services	0.610	1.841	0.309	1.363	2.290*	9.879	1.484	4.411
Occasionally for services	0.094	1.099	-0.359	0.698	0.535	1.707	0.308	1.360
Almost never for services	0[b]		0[b]		0[b]		0[b]	
Frequently for commuting	0.334	1.396	-0.023	0.977	-0.225	0.799	-0.860	0.423
Occasionally for commuting	-0.272	0.762	-1.293*	0.274	-1.250	0.286	-1.301	0.272
Almost never for commuting	0[b]		0[b]		0[b]		0[b]	
Intercept	-0.059		-0.193		-0.769		0.143	
Observations	817		817		768		768	
Nagelkerke	0.230		0.230		0.297		0.297	

Note: [a] The reference category is: Occasionally more.

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Preferred Route on Foot Multinomial Logistic Regression Model Results

	Commuting to work or school[a]	
	Direct route	
Variable	B	Exp (B)
Age	0.008	1.008
Male	0.345	1.412
Female	0[b]	
White or Caucasian	0.695	2.003
Other	0.118	1.126
Black	0[b]	
Hispanic	0.929	2.531
Non-Hispanic	0[b]	
Married/ Living together	0.118	1.125
Single	0[b]	
Children not in the house	0.511	1.667
Children in the house	0[b]	
In labor force	0.736*	2.088
Not in labor force	0[b]	
Below $30,000	-0.135	0.874
$30,000 to $59,999	-0.391	0.676
Above $59,999	0[b]	
≤High school graduate	-0.260	0.771
Some college	-0.267	0.766
≥ College graduate	0[b]	
Rural community	-0.670	0.512
Small city or town, village	-0.056	0.945
A suburb	-0.183	0.833
Urban community	0[b]	
Frequently for recreation	-0.476	0.621
Occasionally for recreation	-0.714	0.490
Almost never for recreation	0[b]	
Frequently for services	0.328	1.389
Occasionally for services	-0.338	0.713
Almost never for services	0[b]	
Frequently for commuting	-0.227	0.797
Occasionally for commuting	-0.938	0.391
Almost never for commuting	0[b]	
Intercept	0.178	
Observations	271	
Nagelkerke	0.182	

Note: [a] The reference category is: Longer route, but safer or more comfortable

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Preferred Route by Bicycle Multinomial Logistic Regression Model Results

	Recreation or exercising[a]		Going to a store, restaurant, or another business[a]	
	Direct route		Direct route	
Variable	B	Exp (B)	B	Exp (B)
Age	0.005	1.005	0.004	1.004
Male	0.067	1.069	0.544	1.722
Female	0[b]		0[b]	
White or Caucasian	0.589	1.802	0.006	1.006
Other	0.288	1.334	-0.055	0.946
Black	0[b]		0[b]	
Hispanic	-0.199	0.819	-1.058	0.347
Non-Hispanic	0[b]		0[b]	
Married/ Living together	-0.064	0.938	-0.037	0.964
Single	0[b]		0[b]	
Children not in the house	-0.267	0.765	-0.079	0.924
Children in the house	0[b]		0[b]	
In labor force	0.196	1.217	0.851*	2.343
Not in labor force	0[b]		0[b]	
Below $30,000	0.208	1.231	0.296	1.345
$30,000 to $59,999	0.444	1.559	0.364	1.439
Above $59,999	0[b]		0[b]	
≤High school graduate	0.779*	2.180	0.518	1.678
Some college	0.722*	2.059	0.297	1.346
≥ College graduate	0[b]		0[b]	
Rural community	-0.284	0.753	0.357	1.429
Small city or town, village	-0.885	0.413	-0.389	0.678
A suburb	-0.238	0.788	-0.010	0.990
Urban community	0[b]		0[b]	
Frequently for recreation	-0.720	0.487	0.930	2.533
Occasionally for recreation	-0.486	0.615	-0.330	0.719
Almost never for recreation	0[b]		0[b]	
Frequently for services	1.916**	6.795	0.684	1.981
Occasionally for services	0.353	1.423	0.101	1.106
Almost never for services	0[b]		0[b]	
Frequently for commuting	-0.449	0.638	-1.766**	0.171
Occasionally for commuting	-2.034**	0.131	-3.019**	0.049
Almost never for commuting	0[b]		0[b]	
Intercept	-1.062		-0.678	
Observations	331		262	
Nagelkerke	0.148		0.245	

Note: [a] The reference category is: longer route, but safer or more comfortable.

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Travel Behavior Without Sidewalks Multinomial Logistic Regression Model Results

	Walking[a]						Bicycling[a]					
	Along the left side of the roadway		Along the right side of the roadway		Completely outside of the roadway		Along the left side of the roadway		Along the right side of the roadway		Completely outside of the roadway	
Variable	B	Exp (B)	B	Exp (B)	B	Exp (B)	B	Exp (B)	B	Exp (B)	B	Exp (B)
Age	0.024	1.024	0.024	1.024	0.006	1.006	0.031	1.032	0.042*	1.043	0.016	1.016
Male	-0.371	0.690	-0.673	0.510	-1.036*	0.355	1.097*	2.997	0.692	1.998	-1.247	0.287
Female	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
White or Caucasian	1.647*	5.194	1.310*	3.707	1.642*	5.165	1.419*	4.133	2.497**	12.145	2.426*	11.311
Black	-0.579	0.560	-0.496	0.609	-0.305	0.737	0[b]		0[b]		0[b]	
Hispanic	0[b]		0[b]		0[b]		-0.344	0.709	-0.855	0.425	-1.330	0.264
Non-Hispanic	0.340	1.405	0.400	1.492	0.710	2.034	0[b]		0[b]		0[b]	
Married/ Living together	0[b]		0[b]		0[b]		-0.344	0.709	-0.855	0.425	-1.330	0.264
Single	-0.182	0.833	-0.060	0.942	-0.338	0.714	0[b]		0[b]		0[b]	
Children not in the house	0[b]		0[b]		0[b]		-0.522	0.594	-0.934	0.393	0.095	1.099
Children in the house	0.464	1.591	0.395	1.485	0.171	1.186	0[b]		0[b]		0[b]	
In labor force	0[b]		0[b]		0[b]		-0.647	0.524	-0.968	0.380	-0.849	0.428
Not in labor force	0.018	1.018	-0.171	0.843	0.008	1.008	0[b]		0[b]		0[b]	
Below $30,000	0.496	1.642	0.632	1.881	0.527	1.693	-0.947	0.388	-0.408	0.665	-0.408	0.665
$30,000 to $59,999	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Above $59,999	-0.579	0.560	-0.496	0.609	-0.305	0.737	0.018	1.018	-0.026	0.974	0.469	1.598
≤High school graduate	-0.115	0.891	0.632	1.882	0.338	1.401	-0.791	0.454	-1.594**	0.203	-0.575	0.562
Some college	1.442	4.230	1.789*	5.986	2.070**	7.925	0.881	2.414	0.759	2.135	2.093*	8.111
≥ College graduate	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Rural community	-0.019	0.981	0.016	1.016	-0.386	0.680	1.535	4.639	1.256	3.510	2.406	11.085
Small city or town, village	1.428	4.170	1.493	4.452	1.169	3.217	1.515	4.550	1.580*	4.855	3.128*	22.835
A suburb	-0.534	0.586	-0.043	0.958	-0.424	0.655	0.546	1.727	0.656	1.927	2.728	15.304
Urban community	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Frequently for recreation	1.043	2.838	1.540*	4.662	1.448*	4.254	0.758	2.134	1.216	3.375	1.287	3.623
Occasionally for recreation	-0.206	0.814	0.579	1.784	0.364	1.439	0.437	1.548	1.158	3.183	2.070*	7.927
Almost never for recreation	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Frequently for services	-0.827	0.437	-0.716	0.489	-0.426	0.653	2.587	13.287	2.550	12.805	2.648	14.128
Occasionally for services	-0.847	0.429	-1.032	0.356	-0.489	0.613	0.860	2.363	-0.066	0.936	0.614	1.848
Almost never for services	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Frequently for commuting	-1.844**	0.158	-1.282	0.277	-1.993**	0.136	-3.519*	0.030	-4.501**	0.011	-4.848*	0.008
Occasionally for commuting	-1.972*	0.139	-1.654*	0.191	-2.195**	0.111	-3.345*	0.035	-4.044*	0.018	-3.946*	0.019
Almost never for commuting	0[b]		0[b]		0[b]		0[b]		0[b]		0[b]	
Intercept	0.397		-0.639		0.560		-1.304		-0.667		-4.545*	
Observations	622		622		622		610		610		610	
Nagelkerke	0.190		0.190		0.190		0.374		0.374		0.374	

Note: [a] The reference category is: In the middle of the roadway or a lane of traffic.

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

During-Pandemic Walking and Bicycling Behaviors Multinomial Logistic Regression Results

	Walking During-pandemic[a]				Bicycling During-pandemic[a]			
	Decreased		Increased		Decreased		Increased	
Variable	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)
Age	-0.016**	0.984	-0.034**	0.966	0.010	1.010	-0.023*	0.977
Male	-0.268	0.765	-0.352	0.703	-0.102	0.903	-0.523	0.593
Female	0[b]		0[b]		0[b]		0[b]	
White or Caucasian	-0.274	0.760	-0.034	0.967	-0.732*	0.481	-0.543	0.581
Other	-0.672	0.511	-0.243	0.784	-1.845	0.158	-0.135	0.874
Black	0[b]		0[b]		0[b]		0[b]	
Hispanic	0.911*	2.486	1.258**	3.519	0.228	1.256	-0.092	0.912
Non-Hispanic	0[b]		0[b]		0[b]		0[b]	
Married/ Living together	0.302	1.353	0.322	1.380	0.422	1.524	0.182	1.200
Single	0[b]		0[b]		0[b]		0[b]	
Children not in the house	0.166	1.180	-0.239	0.787	-0.017	0.983	-0.445	0.641
Children in the house	0[b]		0[b]		0[b]		0[b]	
In labor force	-0.013	0.988	0.318	1.374	0.102	1.108	0.443	1.557
Not in labor force	0[b]		0[b]		0[b]		0[b]	
Below $30,000	0.219	1.245	-0.298	0.743	0.652*	1.920	0.036	1.037
$30,000 to $59,999	0.360	1.433	0.018	1.018	0.719**	2.053	-0.163	0.849
Above $59,999	0[b]		0[b]		0[b]		0[b]	
≤High school graduate	-0.076	0.927	-0.529*	0.589	0.395	1.484	0.496	1.642
Some college	-0.137	0.872	-0.337	0.714	-0.495	0.610	0.161	1.175
≥ College graduate	0[b]		0[b]		0[b]		0[b]	
Rural community	-0.046	0.955	0.016	1.016	-0.286	0.751	-0.340	0.711
Small city or town, village	-0.189	0.827	-0.164	0.849	-0.484	0.617	-0.250	0.779
A suburb	-0.297	0.743	0.115	1.122	-0.636	0.529	0.199	1.220
Urban community	0[b]		0[b]		0[b]		0[b]	
Frequently for recreation	0.049	1.050	1.570**	4.805	1.139**	3.125	2.396**	10.984
Occasionally for recreation	0.893**	2.442	0.962**	2.617	0.180	1.197	1.757**	5.796
Almost never for recreation	0[b]		0[b]		0[b]		0[b]	
Frequently for services	0.585*	1.795	0.416	1.516	-1.530*	0.216	0.205	1.227
Occasionally for services	0.722*	2.059	0.664*	1.942	0.309	1.361	0.184	1.202
Almost never for services	0[b]		0[b]		0[b]		0[b]	
Frequently for commuting	-0.399	0.671	-0.745*	0.475	0.338	1.402	-0.723	0.485
Occasionally for commuting	-0.589	0.555	-0.261	0.770	0.271	1.311	-0.687	0.503
Almost never for commuting	0[b]		0[b]		0[b]		0[b]	
Intercept	-0.250		0.015		-1.391*		-1.104	
Observations	812		812		633		633	
Nagelkerke	0.234		0.234		0.241		0.241	

Note: [a] The reference category is: About the same

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Future Walking and Bicycling Intentions Multinomial Logistic Regression Results

	Walking Future Intention[a]				Bicycling Future Intention[a]			
	Plan to decrease		Plan to increase		Plan to decrease		Plan to increase	
Variable	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)	*B*	Exp (*B*)
Age	-0.020	0.980	-0.021**	0.980	-0.027*	0.973	-0.042**	0.959
Male	-0.080	0.923	-0.339	0.712	0.109	1.115	0.139	1.149
Female	0[b]		0[b]		0[b]		0[b]	
White or Caucasian	-0.290	0.748	-0.492	0.612	-0.942	0.390	-0.654	0.520
Other	-0.096	0.909	-0.232	0.793	0.054	1.056	0.641	1.897
Black	0[b]		0[b]		0[b]		0[b]	
Hispanic	1.040	2.828	0.149	1.161	0.718	2.050	0.794	2.212
Non-Hispanic	0[b]		0[b]		0[b]		0[b]	
Married/ Living together	-0.231	0.794	0.177	1.193	-0.284	0.753	-0.060	0.942
Single	0[b]		0[b]		0[b]		0[b]	
Children not in the house	0.269	1.309	-0.041	0.960	0.062	1.064	0.065	1.067
Children in the house	0[b]		0[b]		0[b]		0[b]	
In labor force	-0.245	0.783	-0.181	0.835	-0.338	0.713	-0.074	0.929
Not in labor force	0[b]		0[b]		0[b]		0[b]	
Below $30,000	0.113	1.119	-0.130	0.878	-0.717	0.488	-0.621	0.538
$30,000 to $59,999	0.259	1.295	0.153	1.165	-0.633	0.531	-0.487	0.615
Above $59,999	0[b]		0[b]		0[b]		0[b]	
≤High school graduate	-0.129	0.879	-0.343	0.710	-0.064	0.938	-0.676*	0.509
Some college	-0.375	0.687	-0.444*	0.641	-0.497	0.608	-1.017**	0.362
≥ College graduate	0[b]		0[b]		0[b]		0[b]	
Rural community	-0.610	0.543	-0.485	0.616	-0.219	0.803	0.302	1.352
Small city or town, village	-0.419	0.658	-0.236	0.790	-0.266	0.766	0.653	1.921
A suburb	-0.891	0.410	-0.524	0.592	-0.122	0.885	0.445	1.561
Urban community	0[b]		0[b]		0[b]		0[b]	
During-pandemic decreased	1.263**	3.535	1.417**	4.124	0.840	2.317	1.917**	6.799
During-pandemic about the same	-0.340	0.712	-0.698**	0.498	-0.643	0.526	-0.439	0.644
During-pandemic increased	0[b]		0[b]		0[b]		0[b]	
Intercept	-0.500		1.996**		0.909		1.707**	
Observations	741		741		572		572	
Nagelkerke	0.240		0.240		0.294		0.294	

Note: [a] The reference category is: Don't plan to change.

[b] This parameter is set to zero because it is redundant.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Appendix 6:

Details of Potential Updates to MDOT's Planning and Design Materials

Appendix 6: Details of Potential Updates to MDOT's Planning and Design Materials

Appendix 6.1 Summary of MDOT Documents Reviewed as a part of M2D2 Work Plan Process

MDOT Document	Summary of Recommendations and Current Status from *M2D2 Work Plan*
Road Design Manual	Recommendations included revisions to existing sections of the manual along with suggestions for potential new sections. Specific recommendations included: • Considering pedestrian, bicycle and transit modes in both traffic data and design speed selection. • Including guidance on the coordination of non-motorized and transit facilities. • Designing utilities to improve the safety and mobility of non-motorized road users. • Considering the safety and convenience for all modes of travel. These revisions were completed prior to this research project.
Bridge Design Manual	Similar to the *Road Design Manual*, recommendations included revisions to existing sections as well as potential new sections. Specific recommendations included: • Including estimates for both current and future multimodal traffic using the bridge. • Ensuring that the content considers the safety and mobility for all road users, including the accommodation of pedestrian and bicycle facilities. While a portion of the recommendations from the M2D2 process were integrated within the manual, others were found to be out of context. These changes are currently under review from the FHWA.
Act 51 Sidewalk Participation Rules	Recommended revisions included changing the laws or policies in order to allow for state participation in non-motorized facilities along state highways and bridges. Given that there is not a single document which covers these rules, updates are being integrated across several agency materials.
LAP Guidelines for Geometrics on Local Agency Projects	Recommended revisions included elements common to the entire document, the guidance provided for 4R, 3R, and preventative maintenance projects, as well as the design exception process. Specific recommendations included: • Allowing for design flexibility in both urban and rural areas where multiple modes are present and right-of-way limitations exist. • Considering all modes of travel as a part of the design speed and volume process. • Considering all modes as a part of crash analyses. • Considering the safety and mobility of all modes within the guidance. These revisions were completed prior to this research project.

MDOT Document	**Summary of Recommendations and Current Status from *M2D2 Work Plan***
Local Agency Program Application	The work plan recommends adding new fields to several sections within the form specific to pedestrians, bicyclists, and transit. A recommendation was also included to ensure that the *Work Zone Safety and Mobility* Policy referred to within the form also considers all travel modes. These revisions were completed prior to this research project.
Project Scoping Manual	Recommendations included ensuring that all travel modes are considered throughout the project development process and measuring the performance of non-motorized facilities. The work plan also recommends reviewing the forms included in the appendices of the manual to ensure they account for all travel modes. These revisions were completed prior to this research project.
Annual Call for Projects (CFP) Memo and Instructions	The work plan notes that while both the complete streets and context sensitive solution policies are well-defined in the materials, there is a limited amount of guidance towards applying them within the project development process. These revisions were completed prior to this research project.
Funding Templates	Recommendations include providing guidance specific to multimodal elements as a part of the repair and rebuild programs as well as the priority roads investment program. The work plan also suggests that the routine maintenance, capacity improvements, and safety and system operations categories can also potentially be used to address multimodal needs. These revisions were incorporated as a part of updating the Annual Call for Projects Memo and Instructions.
MDOT/FHWA Stewardship and Oversight Agreement	The work plan includes revisions to consider across several sections to ensure that multimodal considerations are included across the agreement, including the addition of multimodal performance measures. These revisions were nearly complete as of 2019. Note that this represents an FHWA document which MDOT does not have the authority to revise.
Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways	MDOT published the initial version of this document during the development of the *M2D2 Work Plan*. Recommendations specific to this initial publication included broadening the discussion of context sensitive solutions and complete streets policies, further consideration of roadway context and surrounding land use, and additional detail with respect to design treatments. These recommendations were considered as a part of a future update of the document completed in 2020.
Bus Stop and Shelter Guide	The M2D2 Work Plan recommended the development of a new document which establishes a comprehensive policy for the use, placement and design of transit stops. The department has since developed a draft document, completed in 2020. It should be noted that MDOT does not design or locate bus stops.

Appendix 6.2: Summary of Generalized Activities from USDOT Action Plan for State-Level Consideration

Summary of Generalized Activity from USDOT *Action Plan*	Document or Process	MDOT-Specific Current Status or Recommendation for Implementation
Update pedestrian and bicycle road safety audit guidance	Document	MDOT's RSA guidance document does not provide details for conducting RSAs which are focused on non-motorized road users. **The guidance document could be revised to include additional detail with respect to incorporating pedestrians and bicyclists into future RSAs.**
Develop guidance for countermeasures which are specific to pedestrians and bicyclists	Document	MDOT has funded a variety of completed, ongoing, and proposed research projects which are intended to develop guidance for such countermeasures – including OR19-072. **Continuing these efforts remains an important component of MDOT's safety program.**
Develop data-driven safety analysis tools specific to pedestrians and bicyclists, such as a risk assessment tool, crash analysis tools, or tools to estimate volumes	Process	MDOT has recently developed a "Pedestrian and Bicyclist Safety Risk Assessment Tool" as a part of a prior research effort. **Continuing these efforts remains an important component of MDOT's safety program.**
Develop guidance for stakeholders specific to implementing effective pedestrian crossings	Document	MDOT has recently updated crosswalk guidance in 2020 and has recently programmed an upcoming research project (OR22-004) to identify effective crossing enhancements along higher speed corridors. **Continuing these efforts represents an important component of MDOT's safety program.**
Develop training materials or programs to promote the available tools and resources for pedestrian and bicycle design	Both	MDOT has developed and refined a variety of training materials (such as "Best Design Practices for Walking and Bicycling in Michigan") to disseminate potential strategies. Additionally, MDOT has also sponsored "Training Wheels" courses to provide training on how to integrate pedestrian and bicycle facilities into existing infrastructure. **Continuing these efforts represents an important component of MDOT's safety program.**
Conduct educational campaigns to promote multimodal safety efforts	Process	MDOT has previously sponsored or partnered with communities to conduct educational campaigns, such as the "Driving Change Bicycle Safety" campaign with the City of Grand Rapids. **Continuing similar efforts represents an important component of MDOT's safety program.**
Conduct a summit or conference specific to pedestrian and bicycle safety	Process	MDOT helps to coordinate an annual Michigan traffic safety summit and has also helped to coordinate a 2016 pedestrian and bicycle safety conference with other safety partners. **Continuing similar efforts represents an important component of MDOT's safety program.**
Develop a strategic plan or action plan specific to pedestrian and bicycle safety	Document	The department participates in the development of a regularly updated safety plan as a part of the Governors Traffic Safety Advisory Commission (GTSAC) Pedestrian and Bicycle Safety action team as well as helped to coordinate the development of regional non-motorized safety plans. **Continuing these efforts represents an important component of MDOT's safety program.**
Ensure that pedestrians and bicyclists are considered as a part of the Strategic Highway Safety Plan (SHSP) and other strategic planning activities	Document	"At-Risk Road Users" are identified as an emphasis area within Michigan's SHSP. Additionally, the department helped to coordinate the development of regional non-motorized safety plans. **Continuing these efforts represents an important component of MDOT's safety program.**
Develop non-motorized safety targets	Process	MDOT has included a specific non-motorized fatality and serious injury target as a part of annual Highway Safety Improvement Program reporting requirements. The target was developed in a partnership with the Office of Highway Safety Planning and the University of Michigan Transportation

Summary of Generalized Activity from USDOT *Action Plan*	Document or Process	MDOT-Specific Current Status or Recommendation for Implementation
		Research Institute. **Continuing these efforts represents an important component of MDOT's safety program.**
Develop lighting guidance specific to multimodal travel	Document	While multimodal lighting concepts are noted within various department design documents, there is not a distinct document with this focus. **Consider the development of a distinct document which consolidates the department's policies and practices with respect to multimodal lighting design.**
Coordinate with law enforcement agencies to address multimodal safety concerns	Process	The department maintains a robust relationship with the Michigan State Police's Office of Highway Safety Planning for a variety of multimodal safety efforts. **Continuing these efforts represents an important component of MDOT's safety program.**
Promote noteworthy practices specific to speed management	Process	While the department has included information on speed management techniques within various design documents, there is not a distinct Michigan-specific resource for speed management practices. **Consider the development of a distinct document which identifies the potential strategies for speed management in Michigan – similar to Best Design Practices for Walking and Bicycling in Michigan.**
Conduct a comprehensive literature review specific to pedestrian and bicycle safety	Document	A comprehensive literature specific to pedestrian and bicycle design practices was conducted for OR19-072 as a part of Task 1. Additionally, other recent research efforts funded by the department include literature reviews which cover the research topic in greater detail. **The information available within these literature reviews represents an important resource for MDOT's safety program.**
Conduct and coordinate efforts to collect pedestrian and bicycle count data	Process	The department has recently programmed an upcoming research project (OR22-006) to leverage potential crowd-sourced data for the planning, design, analysis, and evaluation of pedestrian and bicycle traffic. **This effort represents a potentially important resource for MDOT's safety program.**
Develop local road safety plans which incorporate pedestrian and bicycle considerations	Document	The department helped to coordinate the development of regional non-motorized safety plans as well as overall local road safety plans. **Continuing these efforts represents an important component of MDOT's safety program.**
Provide technical assistance to implement pedestrian and bicycle safety treatments	Process	The department's pedestrian and bicycle safety coordinator and non-motorized engineering staff are available to provide technical assistance towards implementing potential safety treatments. MDOT also maintains a local safety initiative which helps local agencies analyze potential safety concerns and identify countermeasures. **However, the department should continue to seek opportunities towards providing additional technical assistance to local communities.**
Consider pedestrians and bicyclists as a part of the systemic safety approach	Both	MDOT employs a systemic safety approach which includes funding both trunkline and local safety projects on a systemic basis, including non-motorized specific treatments such as pedestrian countdown signals. **However, the department could consider incorporating other pedestrian and bicycle treatments into the list of approved systemic countermeasures.**
Conduct a comprehensive benchmarking pedestrian and bicyclist crash analysis study	Process	A comprehensive Michigan pedestrian and bicycle crash data evaluation was completed as a part of a prior research effort (RC-1572). **However, the department could consider completing a follow-up study with more recent data.**

Summary of Generalized Activity from USDOT *Action Plan*	Document or Process	MDOT-Specific Current Status or Recommendation for Implementation
Consider pedestrians and bicyclists as a part of connected and autonomous vehicle (CAV) planning	Document	While MDOT maintains a robust CAV program, the current strategic plan has only limited mentions of non-motorized road users. **Consider revisions to the strategic plan or other policy documents (such as the ITS *Strategic Plan*) to place an increased emphasis on pedestrians and bicyclists as a part of the CAV program.**
Develop guidance for transit planning and design specific to pedestrians and bicyclists	Document	MDOT has recently developed a draft *Bus Stop and Shelter Guide* which was reviewed as a part of this effort. **Continuing this effort represents an important component of MDOT's safety program.**
Conduct an assessment of Michigan's pedestrian and bicycle safety programs, including surveys of stakeholders	Process	While MDOT has recently completed an evaluation of it's engineering safety programs (OR15-194) as well as this effort intended to review design practices specific to pedestrians and bicyclists, a comprehensive external assessment of the non-motorized program has not been conducted. **Consider conducting an effort similar to OR15-194 which is specific to MDOT's overall pedestrian and bicycle program.**
Consider the impacts of alternative intersections and interchanges on multimodal travel	Document	While the update of *Best Design Practices for Walking and Bicycling in Michigan* now includes content which is specific to accommodating non-motorized road users at alternative intersections and interchanges, there is not a distinct Michigan-specific comprehensive resource. **Consider developing a distinct document which aggregates this information with a Michigan context. See NCHRP Report 948 for more information.**
Develop pedestrian specific crash modification factors	Both	MDOT's Time of Return (TOR) worksheet includes crash reduction factors for a variety of pedestrian and bicycle treatments. **The department should continue to update future iterations of the TOR worksheet (or other related tools) to include state-of-the-art research with respect to pedestrian and bicycle countermeasure safety impacts.**
Conduct studies of promising treatments specific to pedestrians and bicyclists	Process	The department funded this effort (OR19-072) with the intent to ensure that findings from recent studies of pedestrian and bicycle treatments are integrated into agency documents. Additionally, MDOT has funded a variety of prior research efforts to evaluate the use of potential non-motorized safety treatments. **Continuing these efforts represents an important component of MDOT's safety program.**
Seek opportunities to improve safety for first responders and highway workers	Process	First responders are incorporated within Michigan's SHSP as well as the GTSAC Traffic Incident Management action team. The department's Work Zone Safety and Mobility Manual provides guidance with respect to protecting highway workers in Michigan. C**ontinuing these efforts represents an important component of MDOT's safety program.**
Support measures to improve road safety for pedestrians and bicyclists	Process	The department has undertaken a variety of efforts, such as funding this research project (OR19-072), to help support measures to improve road safety for pedestrians and bicyclists. C**ontinuing these efforts represents an important component of MDOT's safety program.**
Ensure that the MMUTCD reflects the state-of-the-art with respect to pedestrian and bicycle devices	Document	The department has implemented new devices not covered in the existing MMUTCD consistent with the interim approval process. Future editions of the manual will also include the use of new pedestrian and bicycle traffic control devices consistent with the ongoing federal proposed rulemaking process. C**ontinuing these efforts represents an important component of MDOT's safety program.**

Summary of Generalized Activity from USDOT *Action Plan*	Document or Process	MDOT-Specific Current Status or Recommendation for Implementation
Ensure that tribal road safety efforts consider pedestrians and bicyclists	Process	MDOT maintains a relationship with 12 federally recognized sovereign Tribal governments, including a Tribal Affairs Coordinator whose role is to serve as a direct point of contact. **Continuing this effort and seeking out additional opportunities specific to non-motorized road users represents an important component of MDOT's safety program.**
Consider pedestrian and bicycle safety as a part of highway work zone planning and design	Document	The department's Work Zone Safety and Mobility Manual provides guidance with respect to accommodating non-motorized road users. C**ontinuing the use and refinement of the manual represents an important component of MDOT's safety program.**
Ensure that pedestrians and bicyclists are considered as a part of the Towards Zero Death campaign activities	Both	"At-Risk Road Users" are identified as an emphasis area within Michigan's SHSP which coordinates efforts towards the state's long term zero death vision. The GTSAC Pedestrian and Bicycle Safety action team also helps to coordinate efforts as a part of the zero-death vision. **Continuing these efforts represents an important component of MDOT's safety program.**
Consider new technologies which can help improve safety and mobility for road users with disabilities	Both	MDOT has funded this research project (OR19-072) in order to help incorporate new technologies into the department's design and planning processes. The department has also funded a range of other completed, ongoing, and programmed research efforts and other projects to evaluate the use of new technologies specific to pedestrians and bicyclists. C**ontinuing these efforts represents an important component of MDOT's safety program.**
Ensure that non-motorized road users are considered as part of the state's Highway Safety Improvement Program (HSIP) activities	Both	The department directly considers non-motorized road users within both the trunkline and local HSIP, including distinct funding for pedestrian and bicycle treatments. **Continuing these efforts as well as seeking additional opportunities to improve non-motorized safety as a part of the HSIP represents an important component of MDOT's safety program.**
Ensure that there are forums for stakeholders to coordinate pedestrian and bicycle activities	Process	The GTSAC Pedestrian and Bicycle Safety action team provides an important forum for stakeholders to coordinate pedestrian and bicycle activities in Michigan. **The department should continue to seek new opportunities to foster communication between stakeholders.**

Appendix 6.3: MSU Review of MDOT's Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways

No.	Location	Summary of Comment	MSU Recommendation
1	Entire Document	The content covered in the document is broader than just "crosswalks".	Consider revising the title to represent what is covered in the document.
2	Entire Document	The guidance is very focused on uncontrolled crossings, with some content on controlled crossings.	Consider revising the title to represent what is covered in the document.
3	Entire Document	There are some opportunities to clarify the language throughout the document.	Various editorial comments were provided which were intended to clarify technical elements for the reader.
4	Entire Document	There are various references to non-motorized plans throughout the document.	Ensure that these are referenced the same way throughout the document for consistency.
5	Entire Document	There are several other MDOT documents referred to within the guidance, but these items are not summarized.	Consider an appendix or table which summarizes the other relevant guidance documents identified in this document.
6	Draft Page 2	The document states that "Determining when and where to provide appropriate pedestrian treatments such as marked crosswalks and pedestrian signing on state trunkline is often complicated"	Some additional context here would be helpful for the reader beyond just "complicated". Draft language was provided.
7	Draft Page 2	The document provides a bulleted list of elements to consider as a part of installing crossing treatments.	This bulleted list could be improved by clarifying certain bullets and adding others, such as specifying median presence (instead of just referring to geometry generally) or including street lighting.
8	Draft Page 3	Context sensitive solutions are discussed, but no discussion of "complete streets".	The document could be enhanced by discussing complete streets concepts, an excerpt was provided from Smart Growth America
9	Draft Page 4	The crosswalk evaluation procedure presented on page 4 is effective but could be improved by providing the content in a separate form or checklist.	Consider developing a form, checklist or other document specific to this process.
10	Draft Page 4	Item G in step 1 discusses the use of RSA's as a part of considering a crossing.	RSAs are an important element with respect to considering crossing locations but suggest emphasizing this approach for corridors as opposed to a single crossing.
11	Draft Page 4	Item E in step 2 discusses stopping sight distance, but not other potentially relevant sight distance concerns.	Ensure that all relevant types of sight distance are considered - a cross-street intersection in the area of an uncontrolled crossing could include a potential intersection sight distance concern.
12	Draft Page 5	The figure on Towards Zero Death is pretty far into the document.	Consider moving the discussion of TZD and related concepts to the front of the document.
13	Draft Page 5	Item C in step 3 discusses the collection of gap data but this content is limited.	Consider providing either a reference to the electronic device guidelines or some of the content directly which provides more detailed information.
14	Draft Page 6	Item D of step 3 discusses collecting three years of pedestrian-related crash data - however - more years could potentially be informative given the small sample sizes associated with such crashes.	While three years is a good rule of thumb for traffic crashes to determine trends, considering as many years of crash data as possible (as far back as the existing conditions are maintained) may be beneficial.
15	Draft Page 6	The flowcharts and guidance specific to the flowcharts are separated by several pages.	Considering moving up the flowcharts to help readability.
16	Draft Page 6	Item A of step 4 contains a lot of useful guidance but could be communicated better via an additional figure or flowchart.	Consider developing a flowchart specific to item A of step 4.
17	Draft Page 6	R1-6 signs are mentioned but more information could be helpful.	Consider adding a distinct section for the use of R1-6 signs.
18	Draft Pages 6-23	The document becomes harder for a reader to follow after page 6.	Consider rearranging content to improve the flow of the document.
19	Draft Page 6	The descriptions of the various crossing types are important and helpful but could be improved with more detail.	Consider adding detail to each of the crossing types.
20	Draft Page 9	The multiple threat concept is referenced but not defined.	Consider defining what a multiple threat situation is within the document.
21	Draft Page 9	There are a variety of thresholds included on page 9 but only limited information as to how these were determined.	Consider adding references or more detailed information specific to these thresholds.
22	Draft Page 11	The MDOT pedestrian risk model is mentioned but not formally referenced.	This is an important tool, consider providing additional detail with respect to the risk model.
23	Draft Page 19	Figure 7a is critical but more detail is needed for the reader.	Consider providing more detail as to where the information in these figures is coming from (MMUTCD, etc.)

Appendix 6.4: MSU Review of Best Design Practices for Walking and Bicycling in Michigan

No.	Location	Summary of Comment	MSU Recommendation
24	Entire Document	The existing content is based upon the best available information at the time of initial publication, but more recent research and additional experience is available specific to many of these practices.	Consider revising the existing practices and updating the document to include new practices.
25	Pedestrian Clearance Time	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
26	Fixed Time Signals and Actuation	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
27	Countdown Pedestrian Signals	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
28	Accessible Pedestrian Signals	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.
29	Leading Pedestrian Intervals	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
30	Exclusive Pedestrian Phases	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
31	Exclusive Left-Turn Phases	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
32	Flashing Yellow Arrows	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
33	Median U-Turn Intersections	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
34	Right-Turn-on-Red Prohibitions	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
35	Advanced Stop Markings	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
36	Right-Turn Slip-Lane Design	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
37	Curb Extensions	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
38	Roundabouts	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
39	Signal Timing for Bicyclists	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.
40	Bicycle Signals	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
41	Bicycle Signal Detection	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
42	Intersection Bicycle Crossing Pavement Markings	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
43	Bicycle Boxes	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
44	Two-Stage Bicycle Turn Boxes	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.

No.	Location	Summary of Comment	MSU Recommendation
45	Combined Bicycle/Exclusive Turn Lanes	The content specific to this practice could be revised to reflect the most recent research and experience.	MSU has removed this content in consultation with the MDOT RAP.
46	Centerline Hardening	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.
47	Protected and Dedicated Intersections	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.
48	Alternative Intersections and Interchanges	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.
49	Marked Crosswalks	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
50	Advanced Yield Markings	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
51	Raised Crosswalks	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.
52	R1-6 Signs and Gateway Treatments	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
53	Refuse Islands	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
54	Rectangular Rapid-Flashing Beacons	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
55	Pedestrian Hybrid Beacons	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
56	Midblock Signals	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
57	Roadway Lighting	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
58	Grade Separated Crossings	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
59	Sidewalks and Paved Shoulders	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
60	Shared Use Paths and Sidepaths	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.
61	Road Diets	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
62	Raised Medians	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
63	On-Street Parking	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
64	Back-In Angled Parking	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
65	Shared Lane Markings	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
66	Bicycle Lanes	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
67	Colored Bicycle Lanes	This was included in the original content but is covered elsewhere in the revised draft.	MSU has removed this content in consultation with the MDOT RAP.

No.	Location	Summary of Comment	MSU Recommendation
68	Buffered Bicycle Lanes	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
69	Contra-Flow Bicycle Lanes	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
70	Left-Side Bicycle Lanes	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
71	Separated Bicycle Lanes	The content specific to this practice could be revised to reflect the most recent research and experience.	Consider updating this practice to reflect the most recent research and experience. MSU has provided revised content.
72	Transit Accommodation	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.
73	Bicycle Wayfinding	The existing content did not cover this potential practice.	Consider updating the document to include this practice. MSU has provided draft content.

Appendix 6.5: MSU Review of MDOT's Road Design Manual

No.	Location	Summary of Comment	MSU Recommendation
74	Entire Document	The non-motorized transportation project review detailed in Section 12.12.04 represents an important element of MDOT's design process for multimodal travel and could be emphasized further in the document.	Consider providing further references to this section throughout the document, including the areas mentioned within the MSU research team's comments where additional multimodal discussion could be added.
75	Section 1.02.01B	Existing and projected traffic data do not consider all modes of travel.	This section could be expanded to include guidance which considers multimodal travel counts or estimates (where available). This was also noted as a part of the M2D2 Workplan.
76	Section 1.02.12C	The information to include on plan sheets does not consider all modes of travel.	Consider adding multimodal elements to this list, such as the presence of pedestrian or bicycle infrastructure or transit stops.
77	Section 1.02.14 and Section 1.02.15	The discussion of detail grades does not consider all modes of travel.	These sections could be expanded to include language which ensures that pedestrians and bicyclists are considered as a part of the detail grading process. While multimodal considerations are discussed in item I of Section 2.02.03, they could also be mentioned here.
78	Section 1.02.16	The discussion of maintaining traffic and construction staging does not consider all modes of travel.	Consider adding language to ensure that multimodal travel elements are added to this discussion, including the list of items which are included on typical cross sections. This was also noted as a part of the M2D2 Workplan.
79	Section 3.01	The references do not include any multimodal-specific documents.	Consider adding documents which include geometric guidance for accommodating multimodal travel, such as the AASHTO Pedestrian and Bicycle guides or NACTO guidance. There could also be a note about design flexibility associated with these items.
80	Section 3.02	There are not multimodal-specific terms in the definition of terms.	Ensure that any relevant multimodal-specific terms are defined if revisions are made which include such terms.
81	Section 3.03	The general discussion of alignment notes that proper design leads to the safe and efficient movement of "traffic" which does not place a direct emphasis on multimodal travel.	Consider replacing "traffic" with language that emphasizes all modes of travel.
82	Section 3.06	The design speed discussion does not consider all modes of travel.	While the discussion of design speed in this context is specific to geometric design, this also represents an opportunity to remind designers of the implications of design speed on multimodal travel. This was also noted as a part of the M2D2 Workplan.
83	Section 3.07.01, Section 3.09.02, and Appendix 3A	The discussion of minimum lane width does mention that designers should consider all road users as a part of selecting lane widths. However, there is limited detail provided as to how lane width impacts pedestrians and bicyclists.	Expand the discussion of lane width within the manual to provide additional detail on how the selection of lane width impacts safety and mobility for pedestrians and bicyclists. Key references which discuss this in more detail include NACTO's Urban Street Design Guide and ITE's Designing Walkable Urban Thoroughfares: A Context Sensitive Approach.
84	Section 3.07.02B	The discussion of considering pedestrians and bicyclists when designing free flow ramps at interchanges is an important element of accommodating multimodal travel. However, additional detail could be included.	Consider providing additional detail in this section, such as how ensuring multimodal connectivity at interchanges is important for the overall network (not just in situations where there are free flowing ramps).
85	Section 3.07.04	The discussion of intersection geometric design does not consider all modes of travel.	Consider adding language to ensure that multimodal travel elements are added to this discussion. Key references which discuss this in more detail include NACTO's *Urban Street Design Guide* and *Don't Give Up at the Intersection*, ITE's Designing Walkable Urban Thoroughfares: A Context Sensitive Approach, and the upcoming publication from NCHRP 15-63 Guidance to Improve Pedestrian and Bicycle Safety at Intersections.
86	Section 3.08.01F	The safety review and crash analysis guidance does not consider all modes of travel.	Considering adding language to this discussion to note that such safety reviews should incorporate all road users.
87	Section 3.09.01	The general discussion of 3R minimum guidance notes that guidelines should ensure the "greatest traffic service".	While the safety of all road users is mentioned in this section, it is also important to consider connectivity and delay for pedestrians and bicyclists. Consider revising the discussion to emphasize this concept.

No.	Location	Summary of Comment	MSU Recommendation
88	Section 3.09.02 and Appendix 3A	While minimum shoulder width criteria are provided for 3R and 4R projects, a discussion of shoulder width similar to what is provided for lane width in Section 3.07.01 is not included.	Consider adding a discussion of how shoulder width design can impact safety and mobility for all road users. Key references for this include FHWA's Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts and Small Town and Rural Multimodal Networks as well as AASHTO's Ped and Bike guides. See also Section 6.05.
89	Section 3.09.02E	The stopping sight distance discussion provided in item E does not discuss pedestrian or bicycle facilities among the features warranting further consideration.	Consider adding pedestrian and bicycle features, such as an enhanced midblock crossing, among the items which warrant further consideration. This could also be extended to item F for horizontal curve radius.
90	Section 5.04	The right-of-way discussion does not emphasize all modes of travel.	While the AASHTO quote does mention "all elements of the highway cross section", a direct reference to potential pedestrian or bicycle facilities could be added to help ensure these users are considered. This was also noted as a part of the M2D2 Workplan.
91	Section 6.05.11	The discussion of centerline and shoulder corrugations does include provisions which consider bicyclists. However, the reasoning behind these provisions is not provided.	Consider including further discussion to detail how corrugations can potentially impact bicyclists. See FHWA's Rumble Strip Implementation Guide: Addressing Bicycle Issues on Two-Lane Roads as well as MDOT's centerline rumble strip Phase I and II research reports. **Note that this was addressed by MDOT on 5/24/2021 after MSU had reviewed a prior revision of the RDM.**
92	Section 6.05.13	The discussion of safety edges does not mention that they can offer benefits for bicyclists.	Consider noting that safety edges can also provide benefits for bicyclists. See FHWA's The Safety Edge Pavement Edge Treatment.
93	Section 6.08.05	The manual currently does not include a discussion of the use of curb extensions.	Consider adding a discussion of curb extensions to the manual - which could be provided within this section or another area of the manual.
95	Section 6.08.05	While item G includes some basic discussion of mid-block pedestrian crossings, there is not a distinct section which provides guidance specific to pedestrian crossings.	Consider adding a distinct section specific to crossing design. This could include a reference to other MDOT documents (such as MDOT's *Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways*) as well as national resources. This also an opportunity to integrate a variety of crossing treatments - such as refuge islands, PHBs, RRFBs, or R1-6 signs - which are not currently incorporated within the RDM.
96	Section 7.01	The discussion of roadside barriers and clear zones does not consider all travel modes.	Pedestrians and bicyclists should be considered as a part of the roadside barrier and clear zone design process, such as using barriers to shield pedestrians from the traffic stream. See AASHTO's Roadside Design Guide.
97	Section 7.04.06	The discussion of elements which are not directly considered as a part of pavement marking standards (such as lane width or storage lane lengths) does not include non-motorized facilities.	Consider expanding this discussion to refer to potential pedestrian or bicycle considerations which are not directly covered by applying pavement marking standards alone.
98	Section 9.03.01	While high pedestrian activity is noted as a consideration for the location of utilities under item A, bicycle and transit are not mentioned. They are mentioned within item D.	Consider adding language to ensure that all modes of travel are considered as a part of locating utilities. While there is some potential redundancy with item D, there is not a consistent focus on multimodal travel across this chapter.
99	Section 10.04.02	The discussion of the human environment does not specifically discuss multimodal travel.	Multimodal travel considerations are a key element of evaluating the human environmental impact. This discussion could be expanded to provide a more direct focus on multimodal travel (such as the school bus discussion in item D).
100	Section 10.04.04A	Item A only discusses maintaining vehicular and pedestrian traffic during construction.	Consider revising this item to emphasize accommodating bicycle travel and transit during construction. This would include the consideration of potential temporary facilities.
101	Section 12.01.03	The discussion of design speed for service roads does not consider all modes of travel.	Consider revising the examples and discussion in this section to incorporate pedestrians, bicyclists, and transit service.
102	Section 12.04	The discussion of temporary roads does not consider all modes of travel.	The use of temporary roads may impact pedestrian or bicycle safety and connectivity. Consider adding language this section to ensure that non-motorized road user needs are incorporated when designing temporary roads.
103	Section 12.05	The discussion of detours does not consider all modes of travel.	The use of detours can impact pedestrians, bicyclists, and transit users. Consider adding language to ensure that they are incorporated in the detour process.

No.	Location	Summary of Comment	MSU Recommendation
104	Section 12.08	The discussion of driveways, particularly driveways in urban environments in Section 12.08.03, does not consider all modes of travel.	While safety concepts, such as the 8-second sight distance criteria, are discussed within this section - there is not a direct focus pedestrians, bicyclists, or transit. Consider adding language to ensure that multimodal travel is incorporated in the driveway design process.
105	Section 12.11	The discussion of railroad crossings does not consider all modes of travel.	Railroad crossings can have a significant impact on safety and mobility for non-motorized users. Consider adding language to this section to ensure pedestrians and bicyclists are incorporated as a part of the design process.
106	Section 12.12.03	The discussion of off-road facilities does not include sidepaths.	Expand the discussion of off-road facilities to define and include sidepaths. There may also be other opportunities, such as Section 12.12.09, to integrate sidepaths into the RDM.
107	Section 12.12.03	The discussion of on-road bicycle facilities defines the basic concept but could be expanded.	Expand the discussion of on-road facilities to incorporate other types of bicycle facilities, such as separated lanes.
108	Section 12.12.10	The discussion of design features for on-road facilities could be updated to reflect new guidance.	Consider adding references to newer design guidance documents, such as the NACTO publications or FHWA's *Separated Bike Lane Planning and Design Guide*.
109	Section 12.12.10	The selection of on-road bicycle facility type is largely guided by the discussion of posted speed in item A.	While the posted speed is an important element with respect to selecting appropriate bicycle facilities, there are several other factors to incorporate. Consider adding to this discussion to provide more detail or refer to other resources, such as FHWA's *Bikeway Selection Guide*. Adding discussion specific to separated bicycle lanes could also be considered.
110	Section 12.12.10C	The discussion of signal timing for bicyclists in item C could be enhanced by including additional information.	WSP is currently developing language to supplement MDOT's *Electronic Traffic Control Device Guidelines* which will include accommodating minimum crossing time for bicyclists. Consider adding a reference to this document once complete.
111	Section 12.12.10	The discussion of accommodating bicycle lanes adjacent to exclusive right turn lanes could be updated to include the use of green colored pavements and modern intersection crossing pavement marking treatments.	Consider updating this discussion or providing a reference to FHWA's IA=14, NACTO guidance, or MDOT's pavement marking standards. This could also be an opportunity to discuss the impacts of right-0turn slip lane design on non-motorized road users.
112	Section 12.12.10C	The discussion of accommodating on-road bicycle facilities at intersections in item C does not include centerline hardening.	Consider updating this discussion to note centerline hardening as a design feature which can be used to protect bicycle facilities.
113	Section 12.12.10C	The discussion of accommodating on-road bicycle facilities at intersections in item C does not include bicycle boxes.	Consider adding a discussion of bicycle boxes pending the inclusion in the future editions of the MMUTCD.
114	Section 14.28	The list of items which are included in typical maintaining traffic schemes does not consider all modes of travel.	Consider adding a bullet to this list to ensure non-motorized road users are considered.
115	Section 14.29	The list of items typically considered as a part of the preliminary geometric review does not consider all modes of travel.	Consider adding a bullet to this list to ensure non-motorized road users are considered.
116	Section 14.46	The items considered as a part of the final geometric and safety review does not consider all modes of travel.	Consider adding a bullet to the list of items which includes multimodal elements.
117	Section 14.54.03	The list of attendees for final project coordination meetings does not include pedestrian or bicycle staff.	Under the if applicable section, there could be benefits associated with non-motorized-specific staff attending FPC meetings. Consider adding the engineer or coordinator to this list.
118	Section 14.67	The potential agenda items for pre-construction meetings does discuss safety but not multimodal issues specifically.	Consider adding a bullet to emphasize pedestrians, bicycles, and transit in the pre-construction meeting process.

Appendix 6.6: MSU Review of MDOT's Bridge Design Manual

No.	Location	Summary of Comment	MSU Recommendation
119	Section 2.02.13	The traffic and safety data discussed within this section does not consider all modes of travel.	As noted within this section, there are scenarios where specific traffic and safety data may be relevant to bridge design decisions. In addition to the items mentioned currently within this section, this could also include elements which are specific to pedestrians, bicyclists, or transit. Consider revising this section to place an increased emphasis on collecting data related to adjacent non-motorized facilities or transit routes as well as relevant volume and crash data. This was also noted as a part of the M2D2 *Work Plan*.
120	Section 7.01	While there is a discussion of pedestrian and bicycle bridge loading in Section 7.01, there is not general guidance for accommodating all travel modes within a typical bridge cross-section beyond a reference to AASHTO guides.	Consider adding a distinct section within Section 7.01 which provides a general discussion of other modes of travel. See Section 7.01.15 as a potential example which details providing shoulder widths which are sufficient to accommodate work zone safety. See FHWA's *Achieving Multimodal Networks or PEDSAFE/BIKESAFE* for language which could be used to provide a general discussion.
121	Section 7.02.27	The discussion of sidewalk width includes detailed design guidance for pedestrians. However, only a general reference to shared-use paths or bicycle lanes is provided.	Consider adding language to provide a discussion of accommodating bicycle lanes or shared used paths within a bridge cross-section where appropriate.
122	Section 12.01.01	Similar to Comment #121, Section 12.01.01 provides a specific threshold for pedestrians but only a general comment for other types of facilities.	Consider adding language to provide a discussion of accommodating bicycle lanes or shared used paths within a bridge cross-section where appropriate.

Appendix 6.7: MSU Review of MDOT's Project Scoping Manual

No.	Location	Summary of Comment	MSU Recommendation
123	Entire Document	While there is discussion of pedestrian facilities throughout the manual, there is limited information with respect to bicycle facilities.	Consider adding language throughout the document which emphasizes and provides guidance with respect to bicycle facilities. Comments are included which identify specific areas of the document where there are opportunities to provide expanded bicycle facility discussion.
124	Entire Document	The FHWA's Incorporating On-Road Bicycle Networks into Resurfacing Projects provides guidance for integrating bicycle facilities into an agency's resurfacing activities.	Consider providing a reference to this document and integrating strategies identified within the guide where appropriate.
125	Page 1-1	The introduction does discuss multimodal travel and also mentions design "flexibility".	While the current introduction does include discussion of multimodal concepts, there could be additional emphasis on design flexibility specific to pedestrians and bicyclists (rather than just the general "uniqueness"). See FHWA's *Achieving Multimodal Networks* for language specific to design flexibility for multimodal travel.
126	Page 1-2	The list of benefits mentions "Safe Route to School".	Correct to "Safe Routes to School" or SRTS per the website (https://saferoutesmichigan.org/). Ensure that this is consistent throughout the document (Also see Page 6-39).
127	Page 1-2	The list of benefits does mention "all legal users" and other MDOT initiatives but does not specifically mention "context sensitive design".	Consider adding a reference to context sensitive design to the list of benefits or similar language to ensure there is a direct reference to this concept.
128	Page 1-4	The AASHTO bicycle guide includes a typo.	Correct the bullet to the AASHTO *Guide for the Development of Bicycle Facilities.* There are other references to this document which can also be corrected.
129	Page 1-4	There may be additional pedestrian or bicycle specific guidance to include list of references beyond the AASHTO documents.	While not official MDOT design documents, the NACTO guides could be referenced for potential design concepts to consider as a part of the scoping process. Also see comment #124 regarding FHWA's *Incorporating On-Road Bicycle Networks into Resurfacing Projects*.
130	Chapter 2	The focus of the front end of Chapter 2 and the "mix of fixes" discussion does not emphasize safety or multimodal concepts as a part of the program development process.	Consider adding a discussion of safety and multimodal considerations to the front end of the chapter to provide a clear emphasis on this part of the program. Safety is not discussed until the funding templates are introduced on Page 2-12.
131	Page 2-12	While the safety discussion does include pedestrian considerations, there is no direct mention of bicyclists.	Consider adding bicycle safety concerns to this discussion.
132	Page 2-13	The ITS discussion does mention all transportation modes, but the list of examples does not include systems which are specifically focused on non-motorized users.	Consider listing any elements which could be considered as "ITS" which are focused pedestrians or bicyclists.
133	Page 3-8	The content specific to Michigan's SHSP appears to be outdated.	Revise this section to reflect the most recent SHSP.
134	Page 3-9	The potential safety improvements to consider in the first paragraph does not include examples of treatments focused on pedestrians or bicyclists.	Consider adding examples which are focused on pedestrians or bicyclists.
135	Page 3-9	This second paragraph does not discuss MDOT's systemic safety approach which does not require a TOR analysis.	Consider providing an overview of the systemic safety approach within this section.
136	Page 3-10	The discussion of widening bridges as a part of the 3R projects does not directly discuss multimodal travel.	Consider adding language to this section to emphasize the potential for accommodating non-motorized road users as a part of geometric improvements.

No.	Location	Summary of Comment	MSU Recommendation
137	Page 3-13	The "Other Strategies" section includes a discussion of road diets and roundabouts but there are a variety of other potential strategies here which could be noted.	See the revised MDOT *Best Design Practices for Walking and Bicycling* in Michigan, the updated Michigan SHSP, and FHWA's Incorporating On-Road Bicycle Networks into Resurfacing Projects for potential options.
138	Page 6-5	The discussion of safety treatments for 3R/4R projects and design speed has a clear focus on vehicular traffic and does not directly mention non-motorized road users.	Consider adding language to this section to emphasize non-motorized road users with respect to both safety improvements and design speed.
139	Page 6-8	The traffic and safety projects section does not discuss MDOT's systemic safety approach which does not require a TOR analysis.	Consider providing an overview of the systemic safety approach within this section.
140	Page 6-9	The link to the Work Zone Safety and Mobility Manual no longer works.	Update the link to the new location.
141	Page 6-15	The Safety Review, Crash Analysis and Road Safety Audit section does not directly mention non-motorized road users.	Consider adding language to provide an emphasis on pedestrians and bicyclists as a part of such safety analyses.
142	Page 6-15	This section does not discuss MDOT's systemic safety approach which does not require a TOR analysis.	Consider providing an overview of the systemic safety approach within this section.
143	Page 6-16	The traffic data discussion is focused on vehicular traffic and does not discuss potential pedestrian or bicycle data to collect.	Consider adding discussion of potential pedestrian and bicycle traffic counts where available or collecting data from MDOT's *Pedestrian and Bicycle Safety Risk Assessment Tool*.
144	Page 6-22	The inclusion of “(i.e. curb ramps)” implies that this comprehensively covers accessibility considerations.	Remove the “(i.e. curb ramps)” or otherwise modify the language to refer to broader accessibility concepts.
145	Page 6-33	The corridor coordination section does not provide a specific emphasis on multimodal travel.	This section represents a potential opportunity to discuss the importance of connected non-motorized networks. Consider adding language to emphasize this concept.
146	Page 6-40	The discussion of elderly road users does not specifically discuss multimodal travel.	Consider adding language to this section to emphasize multimodal concepts specific to elderly road users, such as walking speeds.
147	Page 6-49	The criteria for considering ABC projects does not directly include multimodal travel.	Consider adding language to this criteria to emphasize potential multimodal criteria.
148	Page 7-6	The "site issues" which are investigated under the field review does not specifically address multimodal travel.	Consider adding language to this bullet to emphasize potential multimodal considerations.
149	Page 7-13	The sidewalk section does provide consideration for both pedestrians and transit, but does not consider bicycle facilities	Consider expanding this section to provide comprehensive coverage of multimodal design elements.
150	Page 7-15	There is a typo in the reference to the AASHTO *Highway Safety Manual*	Correct the typographical error.
151	Page 8-27	Non-motorized paths are included but not bicycle-specific facilities.	Consider expanding this section to discuss both sidepaths/shared-used paths as well as bicycle facilities.
152	Page 9-6	The table of needed information and tools doesn't directly include any non-motorized information.	Consider adding multimodal information to this table - such as the presence of non-motorized facilities as well as non-motorized volume, crash, or risk data.

No.	Location	Summary of Comment	MSU Recommendation
153	Page 9-8	The van tour discussion beginning on Page 9-8 does not directly discuss multimodal travel.	The van tours represent an important opportunity to identify potential multimodal needs during the project development process. Consider adding language to emphasize pedestrian, bicyclist, and transit modes during van tours.
154	Page 12-2	The discussion related to conducting van tours and field reviews in the rain does not consider all modes of travel.	Conducting such reviews during inclement weather may also result in underestimating the presence of non-motorized road users. Consider adding language to emphasize the potential impact on non-motorized road users if van tours or field reviews are conducted in inclement weather.
155	Page 12-2	The discussion related to the personnel involved in scope review meetings does not specifically discuss multimodal experience.	The reference to incorporating "technical experts" provides an opportunity to ensure that staff focused on multimodal travel are included in the process. This discussion could be extended to the "Input from Other Disciplines" on the following page.
156	Page 12-5	The early identification of maintaining traffic needs discussion does not identify the potential impacts on all modes of travel.	Consider adding language which emphasizes accommodating pedestrians, bicyclists, and transit modes as a part of maintaining traffic.

Appendix 6.8: MSU Review of MDOT's Bus Stop and Shelter Guide

No.	Location	Summary of Comment	MSU Recommendation
157	Foreword	While the details about the Office of Passenger Transportation is an important introduction to provide context for the manual, the forward does not adequately describe the overall document.	Consider expanding the foreword to provide an overview of how the guidance fits into the agency's overall project development and design process as well as what will be included in the document.
158	Entire Document	There is a distinct list of references within the document.	Consider adding a table of key references within the document that includes relevant Michigan design standards as well as conceptual references such as the NACTO documents. The Task 1 literature review includes a variety of documents which could be considered specific to pedestrian and bicycle design concepts (See Section 2.8).
159	Section 1.1	The discussion of the construction and permitting process could have its own distinct section.	Consider creating a section which details the construction and permitting process and refocus the "primary" guidance section on general concepts.
160	Section 1.1	The fact that shelters are the responsibility of the transit service is a critical detail which could merit its own subsection.	Consider creating a distinct subsection for this concept which includes additional information. This could also be noted within the foreword.
161	Section 1.2	The punctuation in the bulleted list is inconsistent.	Revise the punctuation to be consistent in the bulleted list.
162	Section 1.2	The discussion of bus stop locations includes useful information but could be more detailed.	Consider expanding this discussion and adding references such as TCRP Report 19 or other relevant guidance documents.
163	Section 1.3	The discussion included within the spacing and positioning section is useful but could also be more detailed.	Consider expanding this section and adding references. For example, NACTO's *Transit Street Design Guide* has language to support the starting/stopping discussion. Additionally, much of the content is focused on spacing rather than positioning which is discussed in other areas of the document. Consider either revising the section title or reorganizing the content to address this.
164	Section 1.3	There is a grammatical error in the first sentence of this section (accessibility reliability).	Revise the sentence to fix the grammatical error.
165	Section 1.3	The discussion of bus stop spacing which varies based upon land use is useful information but could be expanded.	Consider expanding this discussion and adding references to justify the thresholds. References would be helpful for a reader who is in between and could use additional guidance to determine the appropriate spacing.
166	Chapter 2	There is only limited information provided with respect to lighting guidance.	Considering adding a distinct subsection specific to lighting which includes references to other guidance. For example, NACTO's *Transit Street Design Guide* discusses the use of lamps which are less than 25 feet high.
167	Section 2.1	While ADA-compliance is discussed within this section, this is a critical concept for bus stop design and could be expanded upon.	Consider expanding the discussion of ADA-compliance within a distinct subsection. This subsection could consolidate much of the ADA considerations which are spread in multiple areas of the document.
168	Section 2.1	The discussion of bus stop positioning in the third bullet could be more detailed.	Consider expanding this discussion within its own subsection as opposed to a single bullet in this list. NACTO's *Transit Street Design Guide* could be referenced for more detailed guidance, in addition to other national resources (See Task 1 Literature Review).
169	Section 2.2	While the discussion in this section includes useful information to meet ADA standards, other resources can provide more detailed information beyond the ADA requirements.	Consider adding additional language from other documents - such as the NACTO *Transit Street Design Guide* which provides information on design dimensions beyond what's currently included.
170	Section 2.3 and 2.5	While Section 2.3 details basic shelter requirements and Section 2.5 discusses additional features for specific situations, this information is not comprehensive.	Consider reorganizing the content so that bus shelter guidance is included within one subsection. Also consider expanding the discussion for the additional features for park and ride and transfer sites. There could be additional scenarios where additional features would be included as a part of an effective design.

Appendix 6.9: MSU Review of MDOT's Traffic and Safety Note 207C: Guidelines for Pedestrian Push Button Use & Location

No.	Location	Summary of Comment	MSU Recommendation
171	Entire Document	While Note 207C does provide adequate basic guidance for the location of pushbuttons, there could be additional context provided in an extended format.	Consider moving the information included in Note 207C to the *Electronic Traffic Control Device Guidelines* (where there is similar existing content) and expanding the guidance provided beyond just one page. This could include additional images or diagrams to describe common scenarios.
172	Entire Document	The subject of Note 207C implies that both the use and location of pushbuttons will be discussed, while the purpose states that the intent is to promote uniform location.	Consider rewording the subject and purpose to bring the intent into alignment. Additionally, content could be included which discusses the "use" of pushbuttons as the majority of the content is currently focused on location. Also see Comment #171.
173	Entire Document and Related Documents	"Push button" is written as one or two words (alternatively "pushbutton") throughout MDOT's guidance.	Consider ensuring that this is consistent throughout MDOT's documentation. This is particularly important as practitioners referencing these documents may use text search functions to find information related to pushbuttons. Note that the MUTCD refers to the device as a "pushbutton" and the action to "push button".
174	First Paragraph of Page 1	A formal definition of pushbutton devices could be provided at the front end of the guidance.	Consider adding a formal definition of pushbutton devices, such as the language included within the MMUTCD.
175	Page 1	The text guidance for the location of the pushbutton could be expanded beyond the basic overview.	Consider adding more detail for the guidance of pushbutton location – For example, FHWA's PEDSAFE guidance notes that pushbuttons should be "generally no more than 6 feet from the edge of the roadway". FHWA's Achieving Multimodal Networks notes that pushbuttons on the same corner should be separated by at least 10 feet.
176	Entire Document	Accessible pedestrian signal concepts are not discussed in the note.	While it may be too lengthy to include a detailed discussion of accessible pedestrian signal concepts, a statement could be included which notes that these road users should be considered when designing pedestrian pushbuttons. This could also include a reference to where more detailed information can be obtained.

Appendix 6.10: MSU Review of MDOT's Local Agency Programs Guidelines for Geometrics on Local Agency Projects

No.	Location	Summary of Comment	MSU Recommendation
177	A-2	Paragraph 3 mentions AASHTO national guidance but does not specifically refer to the pedestrian and bicycle guides.	Consider referring to the AASHTO pedestrian and bicycle guides in paragraph 3, in addition to the NACTO documents.
178	C-3	The list of potential 3R project examples includes items which would cover non-motorized safety treatments (such as shoulder widening or traffic control devices) but does not specifically discuss non-motorized safety treatments.	Consider adding a bullet which identifies common pedestrian or bicycle safety treatments which would fall under 3R work, such as the installation of a median refuge island.
179	C-3	The link in the second to last paragraph to MDOT's *Road Design Manual* no longer works.	Update the link to MDOT's *Road Design Manual*.
180	C-6	The 3R minimum guidelines include a minimum paved shoulder width of 3 feet for high volume or multilane roadways.	While it is recognized that 3 feet represents the minimum guideline, guidance included in FHWAs *Small Town and Rural Multimodal Networks* recommended a 4-foot minimum width shoulder where feasible.
181	C-7	While the "Safety Review and Crash Analysis" section notes that a comprehensive safety review would already have been completed, this section only makes a reference to considering site-specific conditions for "all users".	Consider revising this language (in paragraph 3) to specifically discuss considering treatments for non-motorized road users. While such treatments may have been considered as a part of the safety review, this represents an additional opportunity to ensure that potential improvements for pedestrians and bicyclists are thoroughly considered in the design process.
182	C-7	The "Design Traffic Volume (ADT)" section is focused on vehicular traffic only.	While the intent of this section is to discuss the annual daily traffic volumes served by the roadway as a part of geometric design, this section also offers an opportunity to discuss daily volumes of pedestrian and bicycle traffic. Consider adding language to this section to ensure that the volume of non-motorized road users is considered in the design process.
183	C-7	The "Design Speed" section does not consider all modes of travel.	While the discussion of design speed in this context is specific to geometric design, this also represents an opportunity to remind designers of the implications of design speed on multimodal travel. This was also noted as a part of the M2D2 *Work Plan*.
184	C-8	While pedestrian volume is noted under the considerations for usable bridge width at the top of the page, bicyclists are not mentioned.	Consider adding bicyclists or generalizing this language to non-motorized road users.
185	C-8	The bullets which identify items to consider for evaluating the replacement or widening of a bridge does not include non-motorized road users.	Bridges can represent a potential barrier for non-motorized connectivity. Consider adding an item to ensure that non-motorized connectivity is considered when evaluating bridge replacement or widening.
186	C-9 to C-11	The discussion of clear zones, tree removal, and roadside obstacles does not specifically emphasize non-motorized road users.	Roadside obstacles can represent a potential impediment to non-motorized safety and connectivity. Additionally, these items can also impact the available sight distance which represents a potential safety concern – particularly at minor street crossings where vehicles may not see or expect pedestrians or bicyclists within the roadway while completing a turning movement. Consider adding language within these sections which emphasizes the significance of non-motorized road users.

No.	Location	Summary of Comment	MSU Recommendation
187	C-11	The discussion within the “Intersection Design” section mentions “all users” but not specifically pedestrians and bicyclists. Additionally, there is no discussion of the potential impact intersections may have on non-motorized connectivity.	Consider adding language which emphasizes pedestrians and bicyclists within the intersection design section. Specifically, this language could focus on the potential opportunity to improve both safety and connectivity for non-motorized road users. For example, 3R projects may present an opportunity to reduce crossing widths.
188	C-12	The “Traffic Control Devices” and “Signing” sections do not specifically discuss non-motorized road users.	Considering adding language to emphasize that there may be opportunities to implement optional traffic control devices which enhance the facility for non-motorized road users as a part of a 3R project. For example, this could include an enhanced crossing treatment.
189	C-12	The discussion with the “Supplemental Safety Measures” section does not include treatments which are specific to pedestrians and bicyclists.	Consider adding an additional block of supplemental safety measures which are specific to non-motorized road users. See MDOT’s *Best Practices for Walking and Bicycling in Michigan* for examples. This was also noted as a part of the M2D2 *Work Plan*.
190	D-4 to D-5	The “Safety Review and Crash Analysis” section mentions “all users” but does not place a specific emphasis on pedestrians and bicyclists.	Consider adding language which emphasizes the opportunity to make low-cost safety improvements for non-motorized road users as a part of preventative maintenance projects. FHWA’s *Incorporating On-Road Bicycle Networks into Resurfacing Projects* provides some guidance specific to bicyclists. For example, the opportunity to review pavement marking design as a part of a preventative maintenance project may allow for low-cost improvements which can enhance both safety and connectivity – such as the inclusion of a high visibility crosswalk.

Appendix 6.11: MSU Review of MDOT's Roundabout Guidance Document

No.	Location	Summary of Comment	MSU Recommendation
191	Entire Document	The document includes links to the first edition of the national roundabout informational guide that no longer works.	Update the links to the second version of the guide (NCHRP Report 672).
192	Entire Document	The document is based upon the first edition of the NCHRP roundabout guide.	Consider reviewing the document for items which were revised in the second version of the guide (NCHRP Report 672), outside of the non-motorized elements considered within this review.
193	Page i and Page 1	The foreword and introduction do not specifically mention non-motorized road users.	Consider adding language to these sections to emphasize pedestrians and bicyclists as a core consideration within the guidance to set the stage for the rest of the document.
194	Section 2.1	The first paragraph of Section 2.1 lists high level items which should be considered as a part of comparing a roundabout to other intersection types but does not specifically mention non-motorized road users.	Consider emphasizing pedestrians and bicyclists as a high-level consideration when comparing roundabouts to other intersection types.
195	Section 2.2	While the presence of non-motorized facilities is included as a typical data requirement, only existing pedestrian counts are mentioned as a desirable item. There is no mention of bicyclist counts or activity levels.	Consider revising this section to provide an increased emphasis on both pedestrian and bicycle activity levels. This could also include noting the presence of surrounding land uses which may indicate the potential for pedestrians with disabilities or relatively slow walking speeds (such as elderly road users). Additionally, the surrounding pedestrian and bicycle transportation network should be considered – not just the presence of immediately adjacent facilities.
196	Sections 2.3 and 2.4	These sections describe scenarios where roundabouts may be either beneficial or where caution should be exercised. However, there is no discussion of non-motorized concerns in either list.	Consider adding discussion to both sections which emphasizes scenarios where roundabouts may either be beneficial or have potential concerns related to pedestrians and bicyclists. See NCHRP Report 672.
197	Section 3.1	The statistics and information provide in this section are very outdated. Additionally, there is no discussion specific to non-motorized road users.	Consider updating the statistics and data included in Section 3.1, including statistics related to pedestrians and bicyclists.
198	Section 3.2	This section lists geometric design features which can improve safety but does not have a focus on pedestrians and bicyclists.	Consider adding geometric design principles which may specifically benefit non-motorized road users. See NCHRP Report 672.
199	Section 3.3	This section does not specifically discuss analyzing historical safety data specific to non-motorized road users. Additionally, the safety tools referred to in this section are outdated.	Consider adding discussion that emphasizes pedestrians and bicyclists when evaluating historical crash data. Additionally, the guidance should be updated to refer readers to MDOT's current safety tools – such as the HSM worksheet.
200	Section 4.4	The splitter island general guidance section is limited and refers the reader to national guidance.	The design of splitter islands represents an important component of roundabout design for pedestrians and therefore more detail could enhance the guidance for non-motorized road users. See NCHRP Report 672.
201	Section 4.9	This section was initially developed based upon the first edition of the NCHRP roundabout guide.	Consider reviewing the document for items which were revised in the second version of the guide (NCHRP Report 672). Additionally, NCHRP Research Report 834 also provides additional detail for the design of pedestrian crossings at roundabouts.
202	Section 4.10	This section was initially developed based upon the first edition of the NCHRP roundabout guide.	Consider reviewing the document for items which were revised in the second version of the guide (NCHRP Report 672). Additionally, refer to the AASHTO *Guide for the Development of Bicycle Facilities* for more information.

203	Section 6.2	The lighting section does not specifically discuss lighting focused for pedestrians or bicyclists.	Consider adding language to this section which emphasizes non-motorized road users when designing lighting at roundabouts.
204	Page 3 of Appendix B	The bullet within the list provided in Section 3.3 which refers to fewer approach lanes for roundabouts does not mention that this space can also be used for non-motorized facilities.	Consider adding a note that the reduced approach lanes potentially allows for space to provide pedestrian and bicycle facilities.
205	Page 3 of Appendix B	The list provided in Section 3.3 does not cover all potential pedestrian and bicyclist considerations.	See Comment #195.

Appendix 6.12: MSU Review of MDOT's Guidelines for Traffic Safety Planning in School Areas

No.	Location	Summary of Comment	MSU Recommendation
206	Entire Document	While this document does not directly overlap with MDOT's *School Area Traffic Control Guidelines*, they are related.	Consider merging the two documents into one concise set of guidance which comprehensively covers traffic safety planning and traffic control in school zones. Also see Comment #216 in Appendix M.
207	Entire Document	The content within the document is based upon ITE guidance from the 1980's. While the topics discussed in the guidance are still relevant and appropriate, the content is dated in many instances – particularly the content quoted from the ITE guidance.	Consider developing a revised modern version of this document which fulfills the stated purpose of the document ("a procedure outlined for selection of those locations where additional control may be needed"). There is a significant amount of content which is now covered in other resources – a revised version should include references to these other MDOT resources and ensure that the guidance is consistent. For brevity, individual comments are not provided which are specific to the content quoted from prior ITE guidance. Instead, general comments are provided which are intended to identify potential areas of dated content.
208	Entire Document	The document provides a heavy emphasis on pedestrians, with only limited mention of bicyclists.	Bicycling represents an important mode of travel for completing trips to school. Consider expanding the guidance beyond the content from ITE to incorporate bicycling throughout the document.
209	Entire Document	There is a heavy emphasis on grade separation throughout the document.	While grade separation remains an option in specific circumstances, the content within the document would be greatly improved by providing additional focus on other potential treatments.
210	Entire Document	The Safe Routes to School content is dated.	Consider updating the references and content related to Safe Routes to School throughout the document.
211	Entire Document	The safety performance and crash data content is dated.	There are several areas within the document where crash data or systemic safety concerns are outlined based upon the knowledgebase from the 1980's. Consider updating this material, such as the references to collecting "one to three years" of crash data. Additionally, MDOT has a variety of modern safety tools which could be referenced.
212	Entire Document	The description of various traffic studies is dated.	Consider updating this material and referencing other MDOT documentation, such as the *Electronic Traffic Control Device Guidelines*, where appropriate.
213	Entire Document	Funding sources beyond Safe Routes to School are not discussed in great detail.	Consider adding information about other potential funding sources, such as the Transportation Alternatives Program.
214	Page 14	Table 2 includes many common treatments, but the terminology is outdated and there are additional modern treatments which should be included.	Consider updating Table 2. See MDOT's *Best Practices for Walking and Bicycling in Michigan* for examples.
215	Page 39	This map is outdated.	Update this page to reflect the current MDOT regions.

Appendix 6.13: MSU Review of MDOT's School Area Traffic Control Guidelines

No.	Location	Summary of Comment	MSU Recommendation
216	Entire Document	While this document does not directly overlap with MDOT's *Traffic Safety Planning in School Areas*, they are related.	Consider merging the two documents into one concise set of guidance which comprehensively covers traffic control in school zones. Also see Comment #206 in Appendix L.
217	Entire Document	While the relevant section of the Michigan Vehicle Code is mentioned on Page 2, there is not a detailed discussion of school zones within the document.	Consider adding content to specifically discuss the establishment of school zones if the document is not merged with MDOT's *Traffic Safety Planning in School Areas* as noted in Comment #216. This could include a reference to MDOT's *Traffic Safety Planning in School Areas*.
218	Entire Document	Much of the content in the document has some direct overlap or is related with the MMUTCD.	Consider adding references to specific sections of the MMUTCD where more detailed information can be found. Additionally, consider including a reference to the MMUTCD in the general section on Page 1 of the document. Finally, consider adding the MMUTCD figure or table numbers for content which is directly from the MMUTCD for easy reference.
219	Page 1	There is no reference or link for the Michigan Standard Highway Signs Book.	Consider adding a link where the reader can obtain this information, such as MDOT's Standard Highway Signs webpage.
220	Pages 1 - 6	Figure 1 appears five pages after it is referenced at the end of page one and after there is discussion of each sign.	Consider either moving up Figure 1 or including an image of each sign within the relevant subsection so that the reader can see the sign being discussed while reading the related content.
221	Page 13	The discussion of crosswalk pavement markings is a core concept to school area traffic control and more detail could be included.	Consider adding more detail to this section, including references to MDOT's pavement marking standards or crosswalk guidelines.
222	Page 15	The discussion of how to determine safe gaps as a part of a school area signal warrant has limited detail, such as not defining the variable "T".	While the formula provided is consistent with existing ITE guidance, additional detail could be provided in order for the reader to complete the suggested analysis. An example calculation would also be helpful.
223	Pages 13-16	The discussion of the various traffic control options is heavily focused on signalization, with only brief mentions of modern crossing enhancements such as PHBs or RRFBs.	Consider modifying and reordering the guidance to both move up and place additional emphasis on various enhanced crossing treatments outside of signalization. This could include moving up the discussion of intersection vs. midblock crossings, and then detailing each crossing type in sequential order of the thresholds for considering each treatment (i.e. RRFB → PHB → Traffic Signal) – similar to the approach in MDOT's current crosswalk guidance.
224	Pages 13-16	The use of R1-6 signs as an enhanced crossing treatment is not discussed in the guidance.	The MMUTCD allows for the use of R1-6 signs for school crossings, including the optional S4-3p plaque. Consider including discussion of enhanced crossing treatments beyond the electronic options, such as the R1-6 gateway treatment.
225	Page 17	The cost participation section could be expanded to detail potential funding opportunities.	Consider expanding this section to discuss potential funding sources (such as TAP, SR2S, or the HSIP).
226	Page 21	The word choice in item #2 of the steps to assure proper use of structures related to "less safe" routes may be suboptimal.	Consider modifying the word choice, such as "unmarked" or "undesirable" as opposed to less safe.

Appendix 6.14: MSU Review of MDOT's Sight Distance Guidelines

No.	Location	Summary of Comment	MSU Recommendation
227	Entire Document	While much of the content is based upon the AASHTO *Green Book*, there are no direct references to pedestrians or bicyclists (or the related AASHTO guides) included within the document.	Consider adding a section to the front of the document which highlights the importance of considering non-motorized road users as a part of designing for safe sight distances. Additionally, consider seeking opportunities within the document to highlight pedestrian and bicycle considerations. AASHTO's pedestrian and bicycle guides include content related to sight distances which could be incorporated. NACTO guidance includes content which may be helpful for emphasizing the importance of sight distance for pedestrian and bicycle design in urban areas.
228	Entire Document	MDOT's *Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways* refers to the *Sight Distance Guidelines* for stopping sight distance considerations. While the document does provide the necessary information to evaluate stopping sight distance, there is not specific guidance related to stopping sight distance and crossings.	Consider adding content related to pedestrian crossings, including a reference to MDOT's *Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways*. Additionally, consider adding references or content from AASHTO's *Guide for the Planning, Design, and Operation of Pedestrian Facilities*.
229	Entire Document	The document does not discuss considerations specific to ensuring stopping sight distance for bicycle facilities.	Consider adding content related to ensuring adequate sight distance related to bicycle facilities. Refer to AASHTO's *Guide for the Development of Bicycle Facilities*.

Appendix 7:

MSU Update to *Best Design Practices for Walking and Bicycling in Michigan*

Best Design Practices for

Walking and Bicycling

in Michigan

Michigan Department of Transportation

Table of Contents

Acknowledgements

These materials were originally developed for the Michigan Department of Transportation (MDOT) by **T.Y. Lin International** in 2012 as a part of a sponsored research project entitled "*Sharing the Road: Optimizing Pedestrian and Bicycle Safety and Vehicle Mobility*" (RC-1572) including participation from Western Michigan University and the Corradino Group.

Michigan State University updated these materials in 2020 for MDOT as a part of a subsequent sponsored research project entitled "*Synthesis of National Best Practices on Pedestrian and Bicycle Design, Guidance and Technology Innovations*" (OR19-072).

Overview

Toward Zero Deaths™ National Strategy on Highway Safety

As a part of **MDOT's *Towards Zero Death*** vision, the department has sponsored several recent research initiatives in order to accelerate progress towards the department's ultimate vision of zero fatalities and serious injuries on Michigan's roadways. Additionally, supporting mobility for all users of the transportation system is key MDOT's mission of "providing the highest quality integrated transportation services for economic benefit and improved quality of life". This document summarizes best design practices with respect to engineering improvements which can improve both safety and mobility for pedestrians and bicyclists. The guidance is intended to serve as a toolbox of potential treatments which can be considered by practitioners based upon MDOT's research, resources developed at the federal-level, as well as best practices identified from other state and local agencies. It is important to note that the guidance included in this resource is consistent with both the **Michigan Manual on Uniform Traffic Control Devices (MMUTCD)** and relevant interim approvals published by the Federal Highway Administration (FHWA). Specific design practices may not be included in the MMUTCD and require a request to experiment from the FHWA. More information on the experimentation process can be found on **FHWA's website**.

The best practices included in this guidance are categorized by treatments intended to improve (1) signalized intersections, (2) unsignalized crossings and (3) corridors. A summary matrix is provided for each category which details the potential impacts of each best practice with respect to safety performance and mobility. Potential safety performance impacts are characterized as "better" or "no difference" based upon prior research. Potential mobility impacts are characterized as "better", "no difference", or "worse" based upon the expected change in delay after a treatment is implemented. Distinct characterizations for safety performance and mobility impacts are provided for motor vehicles, pedestrians and bicyclists. A generalized cost estimate is also provided for implementing each best practice, characterized as "low" (less than $20,000), "medium" ($20,000 to $100,000), or "high" (greater than $100,000).

Each best practice is then detailed in a single-page format, including the "what", "where", "why", and "how" of implementing each treatment. Supporting photographs, figures or other visual aids are included for each best practice. Key references for each practice are included for more detailed information.

Funding Sources

There are a several potential funding sources which can be leveraged to implement treatments intended to improve safety and mobility for non-motorized road users in Michigan. While details on core funding programs are detailed below, there may be additional opportunities available to fund **pedestrian** and **bicycle** projects by contacting MDOT.

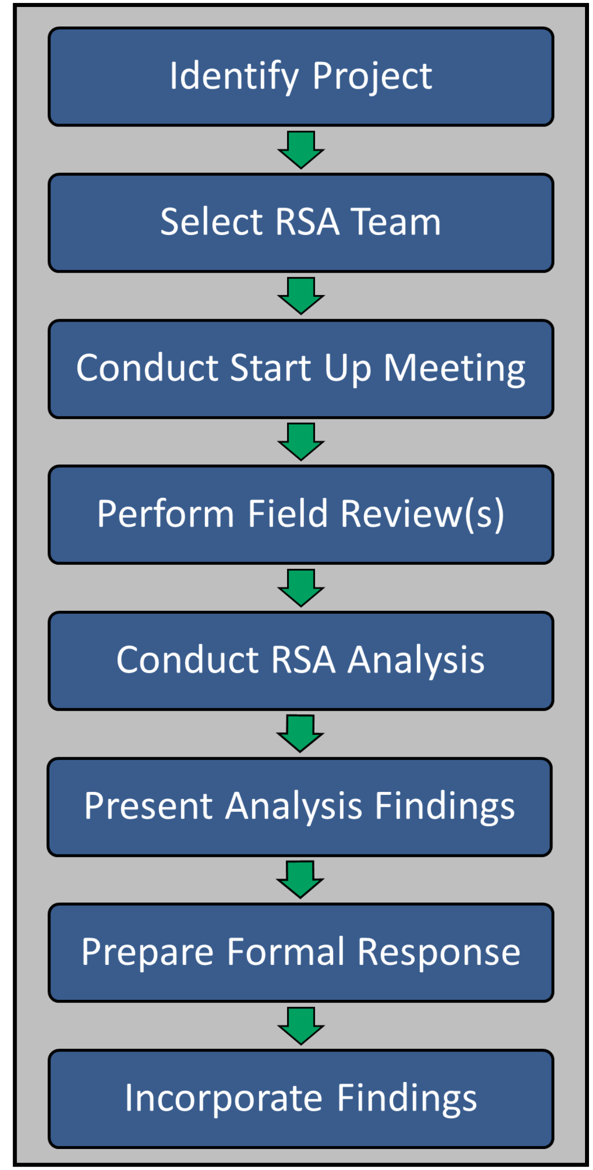
Safe Routes to School (SRTS) is "an international movement—and now a federal program—to make it safe, convenient, and fun for children, including those with disabilities, to bicycle and walk to school." Michigan's SRTS program is managed by MDOT and supported by the Michigan Fitness Foundation. The competitive program provides "Major Grants" which include up to $220,000 per school for potential infrastructure improvements. A variety of potential infrastructure improvements can be funded by the major grants, including sidewalks, bicycle lanes, trails, bicycle parking, traffic calming treatments, lighting, remote drop-off locations and a range of traffic control devices. It should be noted several items can not be funded by SRTS grants, including (but not limited to) preliminary engineering, professional services, bus stop improvements, landscaping, or required traffic signal warrant studies.

The Transportation Alternatives Program (TAP) is a competitive grant program via federal transportation funds designated by the United States Congress for projects which enhance the intermodal transportation system and safe alternative transportation options. Michigan's program includes approximately $24.5M in annual funding, including $17.6M administered by MDOT and the remaining $6.9M administered by metropolitan planning organizations. The program prioritizes projects which demonstrate a competitive concept and a high likelihood of constructability. Refer to **MDOT's *TAP Applicant Guide*** for more information.

The Highway Safety Improvement program (HSIP) is a core federal aid program intended to "achieve a significant reduction in traffic fatalities and serious injuries on all public roads through the implementation of infrastructure-related highway safety improvements". While there are distinct calls for projects along the state trunkline and locally-owned roadways, the treatments outlined within this document are commonly funded as a part of Michigan's HSIP.

Road Safety Audits

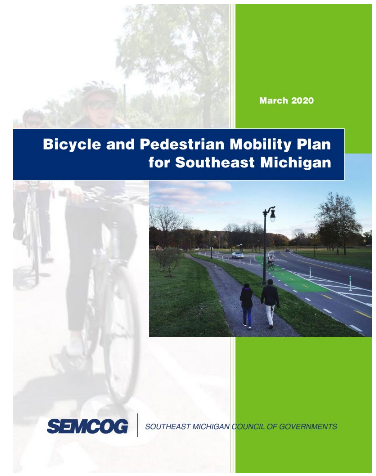
Road safety audits (RSAs) are a formal safety performance examination of an existing or future road or bridge project by an independent, multi-disciplinary RSA team. RSAs contribute to the MDOT's *Towards Zero Death* vision by providing an unbiased assessment of a highway location in an effort to identify potential safety issues and solutions. RSAs can be conducted at any stage of the project development process and includes eight steps (shown right). It is important to note that RSAs consider the needs of all road users, including pedestrians and bicyclists. RSA teams are generally comprised of trained MDOT employees as independent reviewers and facilitated by a contracted consultant. The audit team focuses in four specific areas, including geometry, operations, road users and the environment.

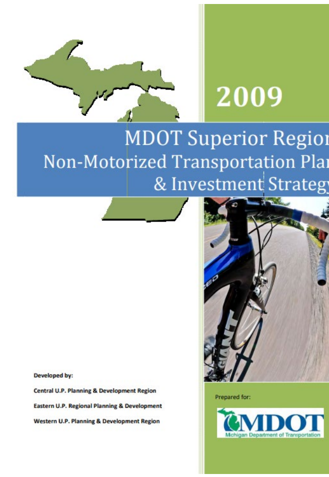


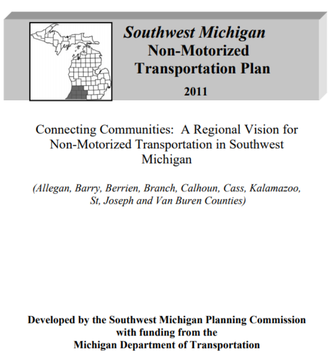
For More Information: ***MDOT's Road Safety Audit Guidance***

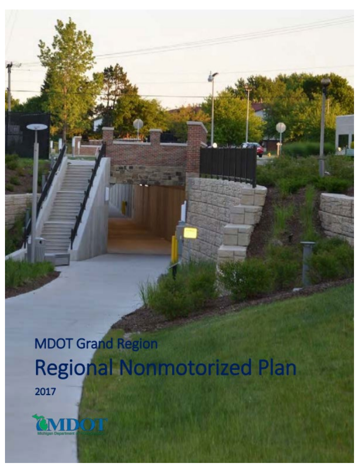
Non-Motorized Safety Plans

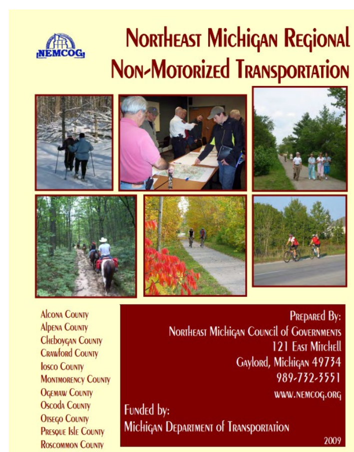
Regional non-motorized safety plans have been developed across the state of Michigan intended to help ensure a coordinated approach towards improving the state's transportation system to meet the needs of pedestrians and bicyclists. The plans employ a data-driven approach to evaluate the current state of the system at a regional level, identify potential opportunities for improvement, prioritize investments, and encourage a cooperative approach among stakeholders. Each regional plan was developed by a team which included staff from MDOT, metropolitan planning organizations, local highway agencies, private consultants, and stakeholder groups.

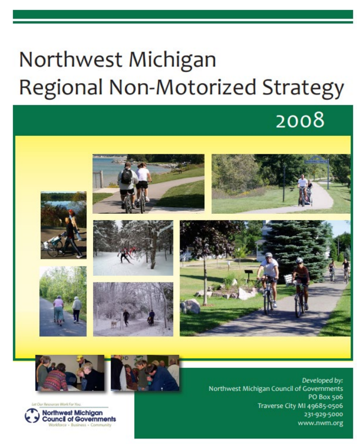


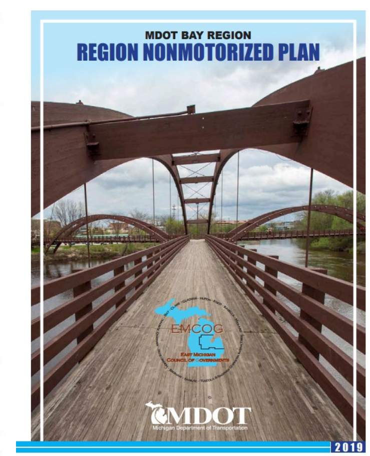












For More Information: ***Michigan's Regional Non-Motorized Plans***

Signalized Intersection Improvements

Best Practice	Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
	Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Pedestrian Clearance Time	No Difference	Better	No Difference	Worse	Better	No Difference	Low
Fixed Time Signals and Actuation	No Difference	No Difference	No Difference	No Difference	Better	No Difference	Low
Countdown Pedestrian Signals	Better	Better	No Difference	No Difference	Better	No Difference	Low
Accessible Pedestrian Signals	No Difference	Better	No Difference	No Difference	Better	No Difference	Low
Leading Pedestrian Intervals	No Difference	Better	No Difference	Worse	Better	No Difference	Low
Exclusive Pedestrian Phases	No Difference	Better	No Difference	Worse	Worse	Worse	Low
Exclusive Left-Turn Phases	Better	Better	Better	Worse	Better	Better	Low
Flashing Yellow Arrows	Better	No Difference	No Difference	Better	No Difference	No Difference	Low
Median U-Turn Intersections	Better	No Difference	No Difference	Better	Better	Better	High
Right-Turn-on-Red Prohibitions	Better	Better	Better	Worse	Better	Better	Low
Advance Stop Markings	Better	Better	No Difference	No Difference	Better	No Difference	Low
Right-Turn Slip-Lane Design	Better	Better	No Difference	Better	Better	No Difference	Med/High
Curb Extensions	Better	Better	No Difference	No Difference	Better	No Difference	Medium
Roundabouts	Better	Better	Better	Better	Better	Better	High
Signal Timing for Bicyclists	No Difference	No Difference	Better	Worse	No Difference	Better	Low
Bicycle Signals	No Difference	No Difference	Better	Worse	No Difference	Better	Medium
Bicycle Signal Detection	No Difference	No Difference	Better	No Difference	No Difference	Better	Low/Med.
Intersection Bicycle Pavement Markings	No Difference	No Difference	Better	No Difference	No Difference	Better	Low
Bicycle Boxes	No Difference	Better	Better	No Difference	No Difference	Better	Low
Two-Stage Bicycle Turn Boxes	No Difference	No Difference	Better	No Difference	No Difference	Better	Low
Centerline Hardening	No Difference	Better	Better	No Difference	Better	Better	Low
Protected/Dedicated Intersections	No Difference	Better	Better	No Difference	Better	Better	High
Alternative Intersections/Interchanges	Better	Better	Better	Better	Better	Better	High

Pedestrian Clearance Time

What	For the purposes of determining pedestrian intervals, pedestrian clearance times are calculated using a walking speed of 3.5 feet per second. In situations where pedestrians who use wheelchairs routinely use the crosswalk, speeds less than 3.5 feet per second should be considered.
Where	All new or rehabilitated pedestrian signals should be timed with this signal timing according to the MMUTCD [1] and MDOT's Electronic Traffic Control Device Guidelines [2].
Why	Studies have shown that the previous standard walking speed of 4.0 feet/second was an average walking speed and thus was not adequate time to allow most pedestrians to cross the street [3].
How	Details can be found in *Section 4E.06* of the MMUTCD [1] and *Section 4.2* of the MDOT Electronic Traffic Control Device Guidelines [2].
Key Reference s	1) Michigan MUTCD (MDOT - 2011) 2) MDOT Electronic Traffic Control Device Guidelines (MDOT) 3) Field Studies of Pedestrian Walking Speed and Start-Up Time (Knoblaugh, Peitrucha, and Nitzburg - 1996)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	No Difference	Worse	Better	No Difference	Low

Fixed Time Signals and Actuation

What	Fixed time signals have an automatic pedestrian phase built into the signal cycle. For signals which are fully or semi-actuated, or when the time required for pedestrians to cross the intersection is the controlling factor in determining signal timing, pushbuttons or other passive detection devices should be considered [1].
Where	In general, fixed time signals should be used where pedestrian traffic is routine. Pedestrian actuation should be used where pedestrian crossings are infrequent.
Why	Requiring pedestrians to call for the walk interval can increase their delay and should only be used where pedestrian traffic is limited. Fixed-time signals increase mobility for pedestrians.
How	Details on implementing pedestrian detection can be found in MDOT *Traffic and Safety Note 207B* [1], *Section 4E.08* of the MMUTCD [2], *Section 3.0* of MDOT's Electronic Traffic Control Device Guidelines [3], and FHWA's PEDSAFE website [4].
Key References	1) Traffic and Safety Note 207B: Guidelines for Pedestrian Push Button Use & Location (MDOT -2005) 2) Michigan MUTCD (MDOT - 2011) 3) MDOT Electronic Traffic Control Device Guidelines (MDOT) 4) Push Buttons & Signal Timing (FHWA PEDSAFE)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	No Difference	No Difference*	Better	No Difference	Low**

*If signal needs to be re-timed for pedestrian walking speeds may be a slight increase in motor vehicle delay; **If signal timing is maintained

Countdown Pedestrian Signals

What	Countdown pedestrian signals provide pedestrians with an indication of the number of seconds left in the flashing DON'T WALK interval [1]. The remaining number of seconds is displayed concurrent with the flashing UPRAISED HAND indication and counts down to the end of the flashing UPRAISED hand indication [2]. After the countdown display reaches zero, the number indication goes dark and a steady UPRAISED HAND indication is provided [2].
Where	Countdown displays are mandatory for all new installations per *Section 3.3* of the Michigan Electronic Traffic Control Device Guidelines [2].
Why	Countdown pedestrian signals have been shown not only to reduce pedestrian-involved crashes by approximately 9 percent, but total crashes by approximately 8 percent [1]. Research has also demonstrated that the device is generally well-understood by pedestrians and improved crossing behavior [1, 3].
How	Details on the use of countdown pedestrian signals can be found in *Section 4E.07* of the MMUTCD [4], *Section 3.3* of the MDOT's Electronic Traffic Control Device Guidelines [2], and Developing Guidelines for Use of Pedestrian Count Down Traffic Signals [3].
Key References	1) Safety Evaluation of Pedestrian Count Down Signals (FHWA – 2019) 2) MDOT Electronic Traffic Control Device Guidelines (MDOT) 3) Developing Guidelines for Use of Pedestrian Countdown Traffic Signals (MDOT – 2007) 4) Michigan MUTCD (MDOT - 2011) 5) A justification for pedestrian countdown signals at signalized intersections: The safety impact on senior motorists (Boateng, R., Kwigizile, V., Miller, J., and Oh, J.S. – 2019)

[3]


[5]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	No Difference	No Difference	Better	No Difference	Low

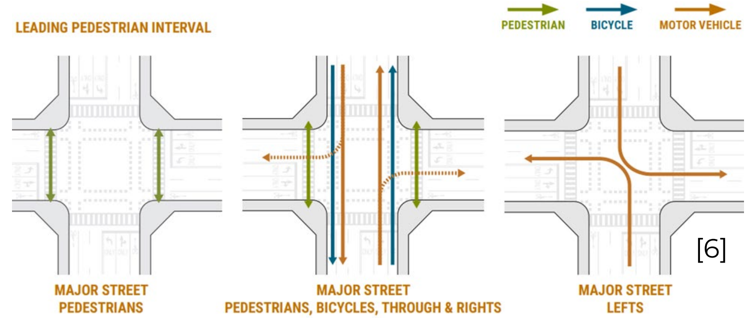
Accessible Pedestrian Signals

What	Accessible pedestrian signals are devices which can provide information in non-visual formats such as audible tones, speech messages or vibrating surfaces for pedestrians with visual disabilities [1]. Given that pedestrians with vision disabilities rely on the sound of vehicles beginning to move which often corresponds with the beginning of a green interval, the existing environment can be insufficient to provide these road users with the information needed to safely cross the roadway at a signalized location [1].
Where	These devices should be considered at specific locations based upon an engineering study which considers general pedestrian needs as well as the needs of pedestrians with visual disabilities [1].
Why	Research has demonstrated that accessible pedestrian signals can help to improve the crossing performance of pedestrians with vision disabilities, including better judgement of the beginning of the WALK interval, a reduction in crossings which begin during the DON'T WALK interval, reductions in delay, and more crossings completed before the end of the pedestrian interval [2].
How	Details can be found in *Section 4E.09* of the MMUTCD [1], *Section 3.4* of the Michigan Electronic Traffic Control Device Guidelines [3], MDOT Traffic and Safety Note *207C* [4], and NCHRP's Accessible Pedestrian Signals: A Guide to Best Practices [2].
Key References	1) Michigan MUTCD (MDOT - 2011) 2) Accessible Pedestrian Signals: A Guide to Best Practices (Harkey, D., Carter, D., Bentzen, B., and Barlow, J. – 2010) 3) MDOT Electronic Traffic Control Device Guidelines (MDOT) 4) Traffic and Safety Note 207C – (MDOT – 2005)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	No Difference	No Difference	Better	No Difference	Low

Leading Pedestrian Intervals

What	Conventionally, pedestrian crossing signal phases are run concurrent with adjacent circular green vehicle phases – resulting in potential conflicts between turning vehicles and pedestrians completing crossing movements [1]. Leading pedestrian intervals provide pedestrians with a head start entering the intersection, typically ranging between 3 to 7 seconds, before motor vehicles are given a green signal [1].
Where	Leading pedestrian intervals should be considered at intersections with a history of conflicts between turning vehicles and pedestrians, particularly at locations where volumes are high enough to consider a dedicated interval for pedestrian-only traffic [2].
Why	Research has demonstrated that the implementation of leading pedestrian intervals has reduced conflicts between pedestrians and turning motor vehicles as well as reducing the number of pedestrians ceding the right-of-way to turning vehicles [3]. Research sponsored by the FHWA suggested an approximate 13 percent reduction in pedestrian-related crashes [1].
How	The MMUTCD allows for the use of leading pedestrian intervals as noted in *Section 4E.06* [4]. Appropriate accessible pedestrian signals should be used in conjunction with leading pedestrian intervals [5]. Right turn on red prohibitions [5] and curb extensions [2] should also be considered in conjunction with leading pedestrian intervals.
Key References	1) Safety Evaluation of Protected Left-Turn Phasing and Leading Pedestrian Intervals on Pedestrian Safety (Goughnour, E., Carter, D., Lyon, C., Persaud, B., Lan, B., Chun, P., Hamilton, I., and Signor, K. – 2018) 2) Urban Street Design Guide (NACTO -2018) 3) Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections (Van Houten, R., Retting, R., Farmer, C., and Van Houten, J. – 2000) 4) Michigan MUTCD (MDOT - 2011) 5) Leading Pedestrian Interval – (FHWA PEDSAFE) 6) Achieving Multimodal Networks (FHWA – 2016)



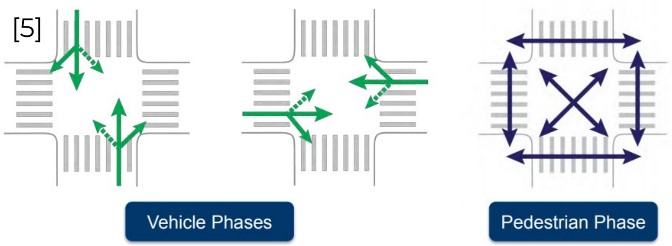
Example of Leading Pedestrian Interval [1]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	No Difference	Worse	Better	No Difference	Low

Exclusive Pedestrian Phases (Scramble or Barnes Dance)

What	Exclusive pedestrian phases, which have also been referred to as "pedestrian scrambles" or a "Barnes Dance", allow for pedestrians to cross the street at signalized intersections while all motor vehicle traffic remains stopped [1]. This often involves allowing pedestrians to cross the intersection in a diagonal directions.
Where	Exclusive pedestrian phases can be considered at intersections with high pedestrian volumes with equivalent desire lines in all directions, relatively high levels of motor vehicle turning movements, or other situations which involve atypical geometry or limited sight distance [1].
Why	Research conducted in New York demonstrated reductions in pedestrian-related crashes with the implementation of an exclusive pedestrian phase [2]. While motor vehicle crashes slightly increased after the implementation of the exclusive pedestrian phase, this effect was not statistically significant.
How	A comprehensive engineering study should be conducted prior to the implementation of an exclusive pedestrian phase. It is important to note that while exclusive pedestrian phases can improve safety performance, delays for both motor vehicles and non-motorized road users will always be worse compared to conventional signal timing strategies [3]. Therefore, designers should consider other signal timing strategies, such as leading pedestrian intervals, when investigating an exclusive pedestrian phase.
Key References	1) Achieving Multimodal Networks (FHWA – 2016) 2) The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections - Lessons from a New York City Experience (Chen, L., Chen, C., and Ewing, R. – 2012) 3) Guide for the Planning, Design, and Operation of Pedestrian Facilities, 1st Edition (AASHTO – 2004) 4) Meet Los Angeles: Pedestrian Scramble (NACTO – 2017) 5) Walk This Way: Exclusive Pedestrian Signal Phase Treatments Study (NYDOT – 2017)

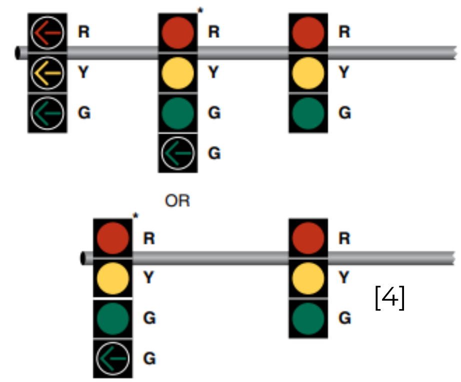
Example of a Pedestrian Scramble in Los Angels [4]



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	No Difference	Worse	Worse	Worse	Low

Exclusive Left-Turn Phases

What	Currently, three types of left-turn phases are used in Michigan [1]: • **Permissive-protected (lagging)** where the left-turn movement begins with a permissive phase (left-turns must yield to opposing traffic) and ends with a protected phase • **Protected-permissive (leading)** where the left-turn movement begins with a protected phase and ends with a permissive phase (left-turns must yield to opposite traffic) • **Protected-only** where left-turn movements can only be made during exclusive phase and conflicts with opposing vehicles and pedestrians are eliminated.
Where	Despite the fact that left-turn phases can improve the level of service for left-turn movements, they often reduce the overall intersection level of service [1]. Therefore, left-turn phasing should only be implemented after a comprehensive engineering study demonstrates that such phasing is necessary for the safe and efficient operation of an intersection [1].
Why	Permissive phasing has previously been associated with conflicts between pedestrians and left-turning vehicles [2]. Research conducted in New York demonstrated a 43 percent reduction in pedestrian-involved crashes after conversion to protected-only left-turn phasing [3]. Recent research sponsored by the FHWA suggested that reductions may be higher at locations with high levels of pedestrian traffic [2].
How	More detailed information can be found in *Section 2.0* of the Michigan Electronic Traffic Control Device Guidelines [1] and *Section 4D.17* of the MMUTCD [4].
Key References	1) MDOT Electronic Traffic Control Device Guidelines (MDOT) 2) Safety Evaluation of Protected Left-Turn Phasing and Leading Pedestrian Intervals on Pedestrian Safety (Goughnour, E., Carter, D., Lyon, C., Persaud, B., Lan, B., Chun, P., Hamilton, I., and Signor, K. – 2018) 3) Safety Countermeasures and Crash Reduction in New York City – Experience and Lessons Learned (Chen, L., Chen, C., Ewing, R., McKnight, C., Srinivasan, R., and Roe, M. – 2012) 4) Michigan MUTCD (MDOT - 2011)



[4]

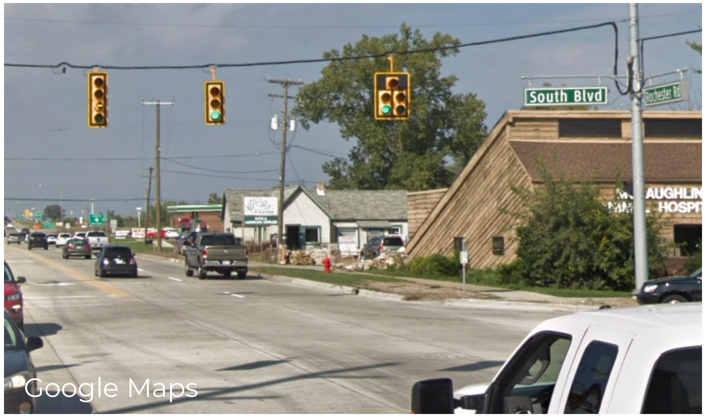

Google Maps

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Worse	Better	Better	Low

Flashing Yellow Arrows

What	Flashing yellow arrows are an innovative traffic signal head for left-turn lanes which consists of a four-arrow display, including a steady red arrow, a steady yellow arrow, a flashing yellow arrow and a study green arrow [1]. Flashing yellow arrows replace the existing flashing red indications which were commonly used in Michigan [1].
Where	Flashing yellow arrows have been included as a part of new signal installations or modernizations involving left-turn phasing since 2008 with the long-term intent to replace all flashing red indications [1].
Why	While research conducted in Michigan did not demonstrate safety benefits specific to non-motorized road users [2], studies have consistently demonstrated reductions in vehicular crashes when implemented at an intersection which currently does not include fully protected left-turn phasing [3].
How	More detailed information can be found in MDOT's Flashing Yellow Arrow Left-Turn Signal Guidelines [1], *Section 2.0* of the Michigan Electronic Traffic Control Device Guidelines [4], and *Section 4D.20* of the MMUTCD [5].
Key References	1) Flashing Yellow Arrow Left-Turn Signal Guidelines (MDOT – 2007) 2) Evaluating Pedestrian Safety Improvements: Final Report (Van Houten, R., LaPlante, J., and Gustafson, T. – 2012) 3) Crash Modification Factors for the Flashing Yellow Arrow Treatment at Signalized Intersections (Srinivasan, R., Lan, B., Carter, D., Smith, S., and Signor, K. – 2018) 4) MDOT Electronic Traffic Control Device Guidelines (MDOT) 5) Michigan MUTCD (MDOT - 2011)

[1]

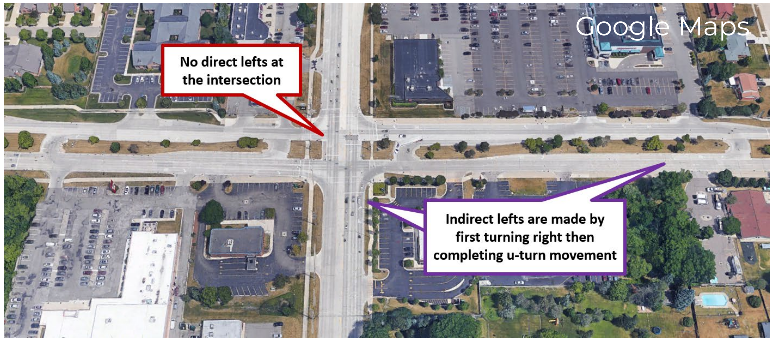


Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better*	No Difference	No Difference	Better**	No Difference	No Difference	Low

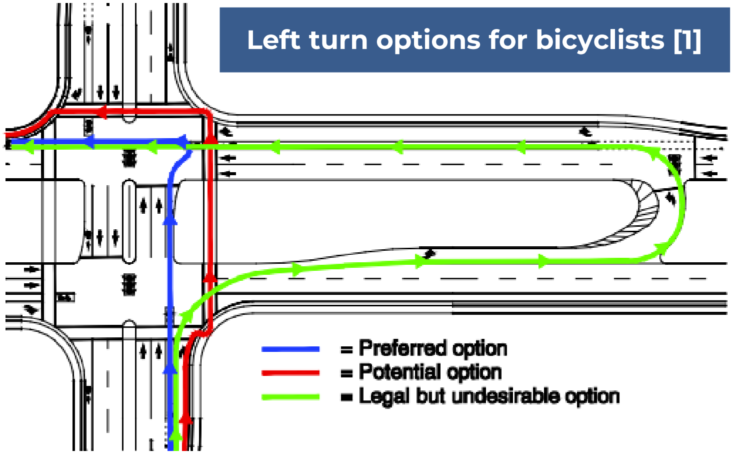
*When implemented at locations which currently do not include fully protected left-turn phasing; **When installed to replace fully protected left-turn phasing

Median U-Turn Intersections (Michigan Lefts)

What	Median U-turn intersections, also known as a "Michigan Lefts", are an alternative intersection design which accommodate left-turn movements via directional crossovers within the median. Pedestrians cross the intersection via conventional crosswalks (often involving a two-stage crossing along approaches with the median), and bicyclists have three potential options to navigate the intersection (shown right) [1].
Where	Median U-turn intersections should be considered at locations where traffic growth on arterial roadways results in a situation where congestion or safety concerns are observed, particularly involving left-turn conflicts [2].
Why	While median U-turn intersections have previously been shown to improve operational and safety performance for motor vehicles, the unique characteristics of this design can result in both benefits and challenges to non-motorized road users [1].
How	More information can be found in FHWA's Median U-Turn Intersection Informational Guide [1], MDOT's Michigan Intersection Guide [2], MDOT's Road Design Manual [3] and MDOT's geometric guidance and design information [4].
Key References	1) Median U-Turn Intersection Informational Guide (FHWA – 2014) 2) Michigan Intersection Guide (MDOT – 2008) 3) Road Design Manual (MDOT) 4) Geometric Traffic and Safety/Standards and Special Details (MDOT)



Left turn options for bicyclists [1]

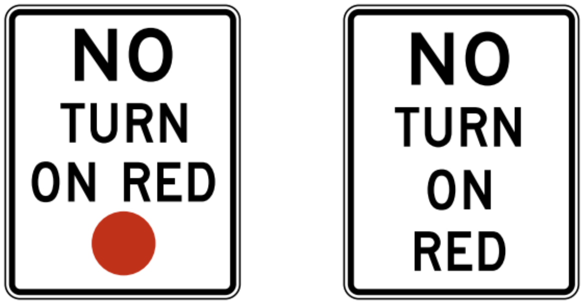


Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	No Difference	No Difference	Better	Better	Better*	High

*Assuming that bicyclists progress through the intersection using a two-stage left turn

Right-Turn-on-Red Prohibitions

What	Permissible right-turn-on-red movements were incorporated in the 1970s due to the operational benefits; however, these movements are also associated with detrimental impacts on non-motorized users [1]. Right-turn-on-red prohibitions involve signing an intersection approach with either a static or dynamic illuminated sign [2].
Where	The prohibition of right-turn-on-red movements should be considered after an engineering study demonstrates that one of the following situations exist [2]: • Approaches which have sight distance restrictions to the left which inhibit right-turn movements • Approaches which have experienced more than three right-turn-on-red crashes during a 12-month period • Intersections with a railroad crossing within 100 feet and additional criteria are met
Why	Despite the fact that the law requires vehicles to come to a full stop when completing a right-turn-on-red movement, drivers often do not comply and may be distracted by looking for vehicles approaching from their left [1]. Research has demonstrated that allowing right-turn-on-red movements increases all crash types, including crashes involving pedestrians and bicyclists [3].
How	More information can be found on FHWA's PEDSAFE website [1], MDOT's Traffic Sign Design, Placement and Application Guidelines [2], and *Section 2B.54* of the MMUTCD [4].
Key References	1) Right-Turn-on-Red Restrictions – (FHWA PEDSAFE) 2) Traffic Sign Design, Placement, and Application Guidelines (MDOT – 2019) 3) Highway Safety Manual (AASHTO – 2010) 4) Michigan MUTCD (MDOT - 2011)

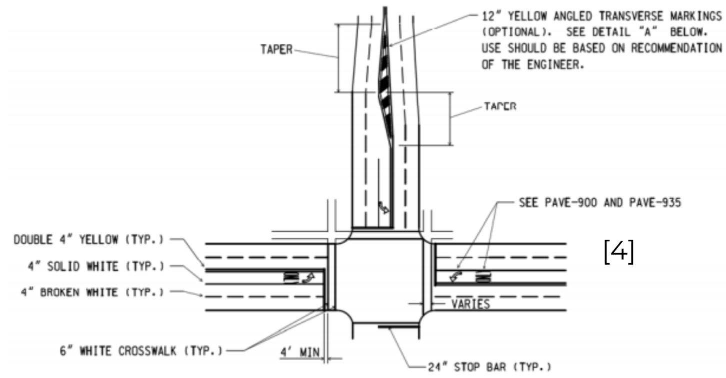


R10-11 R10-11a [4]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Worse	Better	Better	Low

Advanced Stop Markings

What	Advanced stop markings involve implementing the stop bar further back than the standard 4 feet minimum in order to improve visibility of bicyclists and pedestrians, ranging from 15 to 30 feet [1].
Where	Advanced stop markings should be considered at locations with frequent conflicts between pedestrians and right-turning vehicles, as well as locations with a history of right-turn-on-red conflicts [1].
Why	Research has demonstrated that advanced stop bars reduce conflicts between vehicles turning right on red and cross traffic, increase the number of full stops by vehicles turning right on red, and provide more time for drivers to react to pedestrians in adjacent crosswalks [1]
How	More information can be found in FHWA's Signalized Intersection Informational Guide [1], FHWA's PEDSAFE website [2], *Section 3B.16* of the MMUTCD [3], and MDOT's Pavement Marking Standards [4]
Key References	1) Signalized Intersections Informational Guide (FHWA – 2013) 2) Advanced Stop Lines at Traffic Signals (FHWA PEDAFE) 3) Michigan MUTCD (MDOT - 2011) 4) Pavement Markings (MDOT) 5) Infrastructure Reference Guide (MnDOT – 2016)



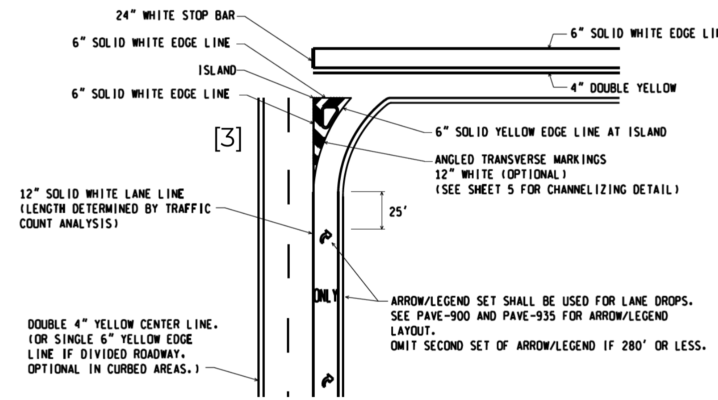
[4]

[5]

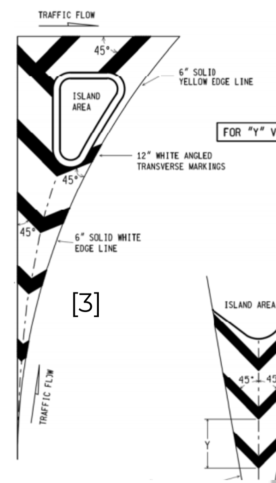
Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	No Difference	No Difference	Better	No Difference	Low

Right-Turn Slip-Lane Design

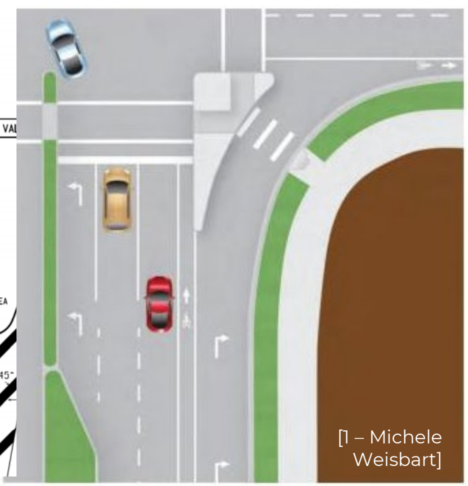
What	Right-turn slip-lanes should include several key design features, including crossing islands (also referred to as "pork chop" islands) which create a channelized right turn [1]. These raised islands should be large enough to accommodate pedestrians waiting to complete a crossing movement and incorporate accessibility features such as curb ramps [1].
Where	These designs should be considered at signalized intersections with relatively high right-turn volumes as well as locations with considerable skew or other geometric features which result in longer pedestrian crossing distances [1].
Why	Right-turn slip-lanes with appropriate design features can help to reduce turning speeds, increase visibility, and reduce pedestrian crossing distances [1]. Research has demonstrated that designs with improved approach angles can reduce the frequency of traffic crashes [2].
How	More information can be obtained from FHWA's PEDSAFE website, and MDOT's Pavement Markings Standards [3].
Key References	1) Improved Right-Turn Slip-Lane Design (FHWA PEDSAFE) 2) Safety Impacts of a Modified Right Turn Lane Design at Intersections (Shattler and Hanson – 2016) 3) Pavement Markings (MDOT)



[3]



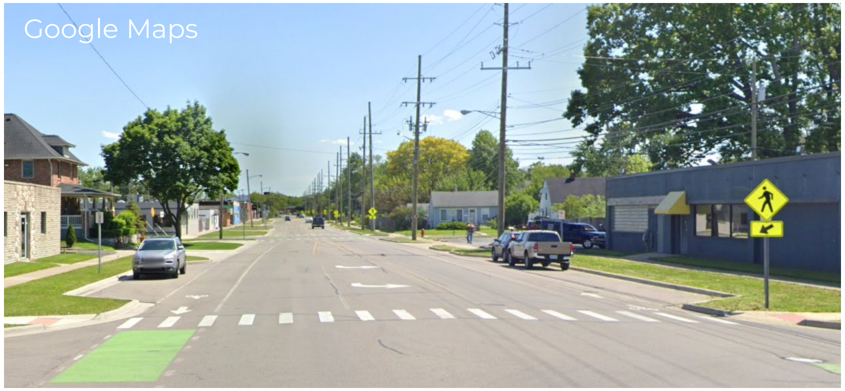
[3]


[1 – Michele Weisbart]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	No Difference	Better	Better	No Difference	Med/High

Curb Extensions

What	Curb extensions (also referred to as "bulb-outs") involve extending the sidewalk or curb line into a parking lane in order to reduce the effective width of the street [1-3].
Where	Curb extensions should be considered where a parking lane, bus stop or loading zone is adjacent to either an intersection or midblock location [1-3]. Curb extensions can also be used as a part of gateway treatments [2].
Why	Curb extensions reduce pedestrian crossing distances, improve visibility, reduce curb radii, incorporate space for curb ramps, keep vehicles from parking near the intersection, as well as both visually and physically narrowing the roadway [1-3].
How	More information can be found on FHWA's PEDSAFE website [1], NACTO's Urban Street Design Guide [2], and ITE's Designing Walkable Urban Thoroughfares [3].
Key Reference s	1) Curb Extensions (FHWA PEDSAFE) 2) Urban Street Design Guide (NACTO – 2018) 3) Designing Walkable Urban Thoroughfares: A Context Sensitive Approach (ITE – 2010)



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	No Difference	No Difference	Better	No Difference	Med

Roundabouts

What	Modern roundabouts are an alternative intersection design which is becoming widely adopted by highway agencies across the United States [1], where traffic travels counterclockwise around a central island and must yield to circulating traffic [2]. A key design feature of modern roundabouts is the speed control provided by geometric features [2].
Where	Mini-roundabouts (up to 15,000 vehicles per day), single-lane roundabouts (up to 25,000 vehicles per day) , and multilane roundabouts (up to 45,000 vehicles per day) may be appropriate under a range of traffic scenarios [2]. Roundabouts may present challenges to pedestrians with visual disabilities and appropriate accommodations should be considered [3]. Multilane roundabouts are generally not recommended for locations with a high level of pedestrian activity due to the potential for "multiple-threat" crashes [3].
Why	Research has demonstrated that roundabouts can reduce the frequency of fatal and injury crashes [2]. The lower speeds associated with roundabouts can help to improve the safety of non-motorized road users by increasing yielding compliance [2].
How	More information can be found in ITE's Designing Walkable Urban Thoroughfares: A Context Sensitive Approach, NCHRP Report 672 – Roundabouts: An Informational Guide [2], FHWA's, PEDSAFE website [3], MDOT's Roundabout Design Aid [4], MDOT Pavement Marking Standards [5], and *Chapter 3C* of the MMUTCD [6].
Key References	1) Designing Walkable Urban Thoroughfares: A Context Sensitive Approach (ITE – 2010) 2) NCHRP Report 672: Roundabouts: An Informational Guide (NCHRP – 2010) 3) Roundabouts (FHWA PEDSAFE) 4) Roundabout Design Aid (MDOT – 2019) 5) Pavement Markings (MDOT) 6) Michigan MUTCD (MDOT - 2011)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Better	Better	Better	High

Signal Timing for Bicyclists

What	Given that the overall goal of signal timing procedures is to provide safe crossings and reduce delay for all road users, potential adjustments to minimum green intervals (shown right), clearance intervals, and extension time should be considered specific to bicyclists [1].
Where	While bicyclist accommodation should be considered as a part of all signal timing procedures, specific attention should be paid at intersections with high vehicular speeds or relatively long crossing distances where the need for bicycle-specific modifications are most likely [1].
Why	The differences in operating characteristics between motor vehicles and bicyclists, including travel speed, acceleration rates and deceleration rates, may require such modifications in order to safely accommodate these road users [2, 3].
How	More information can be found in AASHTO's Guide for the Development of Bicycle Facilities [3], FHWA's Separated Bike Lane Planning and Design Guide [4], and *Part 9* of the MMUTCD [5].
Key References	1) Optimizing Signal Timing for Bicyclists (FHWA BIKESAFE) 2) Achieving Multimodal Networks: Applying Design Flexibility & Reducing Conflicts (FHWA – 2016) 3) Guide for the Development of Bicycle Facilities (AASHTO – 2012) 4) Separated Bike Lane Planning and Design Guide (FHWA – 2015) 5) Michigan MUTCD (MDOT - 2011)

Standing Bicycle Crossing Time [3]

U.S. Customary

$$BCT_{standing} = PRT + \frac{V}{2a} + \frac{(W+L)}{V}$$

where:

$BCT_{standing}$	=	bicycle crossing time (s)
W	=	intersection width (ft)
L	=	typical bicycle length = 6 ft (see Chapter 3 for other design users)
V	=	attained bicycle crossing speed (ft/s)
PRT	=	perception reaction time = 1s
a	=	bicycle acceleration (1.5 ft/s^2)

Minimum Green Time [3]

U.S. Customary

$$BMG = BCT_{standing} - Y - R_{clear}$$

$$BMG = PRT + \frac{V}{2a} + \frac{W+L}{V} - Y - R_{clear}$$

where:

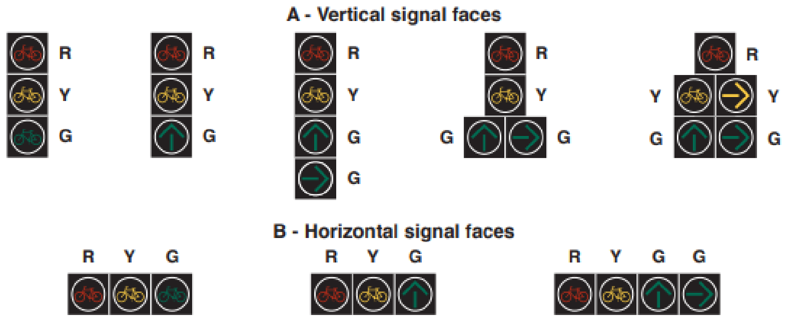
BMG	=	bicycle minimum green time (s)
$BCT_{standing}$	=	bicycle crossing time (s)
Y	=	yellow change interval (s)
R_{clear}	=	all-red (s)
W	=	intersection width (ft)
L	=	typical bicycle length = 6 ft (see Chapter 3 for other design users)
V	=	bicycle speed crossing an intersection (ft/s)
PRT	=	perception reaction time = 1s
a	=	bicycle acceleration (1.5 ft/s^2)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	Worse	No Difference	Better	Low

Bicycle Signals

What	Bicycle signal heads are an additional traffic control device which can be included in conjunction with an existing traffic signal [1]. While signage can be included to identify where crossing for bicyclists is controlled by pedestrian signal indications, independent signal heads can also be used which accommodate bicycle-specific phases or signal timing strategies [1, 2]. The FHWA has also published an interim approval (IA-16) which allows for the optional use of bicycle signal faces (shown right) [3].
Where	Bicycle signal heads should be considered at locations where bicycle-specific movements (such as a separated bicycle lane) need to be accommodated, where bicycle-specific phases (such as an “all-bike” phase or leading bicycle phasing) are being considered, or other complex locations where there are frequent conflicts between bicycles and turning motor vehicles [1, 4].
Why	Bicycle signal heads can help to improve both safety and operational performance at signalized intersections where bicycle-specific guidance is required [4].
How	More information can be found in NACTO’s Urban Bikeway Design Guide [1], FHWA’s Interim Approval for Optional Use of a Bicycle Signal Face [3], FHWA’s BIKESAFE website [4], NACTO’s Don’t Give Up at the Intersection [5], and *Part 9* of the MMUTCD [5].
Key References	1) Urban Bikeway Design Guide (NACTO – 2018) 2) Achieving Multimodal Networks: Applying Design Flexibility & Reducing Conflicts (FHWA – 2016) 3) Interim Approval for Optional Use of a Bicycle Signal Face (FHWA – 2013) 4) Bicycle Signal Heads (FHWA BIKESAFE) 5) Don’t Give Up at the Intersection (NACTO – 2019) 6) Michigan MUTCD (MDOT - 2011)

[2]



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	Worse	No Difference	Better	Medium

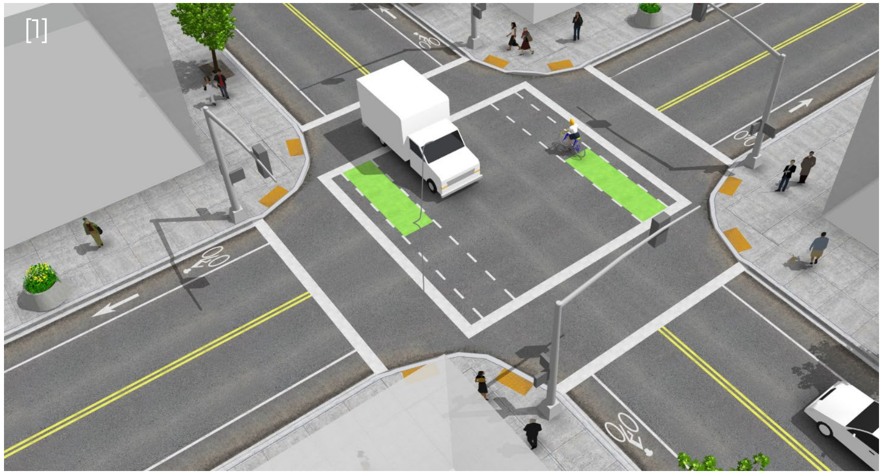
Bicycle Signal Detection

What	Bicycle detection includes technology implemented at actuated signals in order to alert the signal controller of bicycle crossing demand [1]. Without appropriate detection, bicyclists must either wait for a vehicle actuate a green phase for their approach, dismount to push a pedestrian pushbutton, or otherwise cross illegally [1]. Detection devices can include traditional loop detection, video or microwave detection systems, as well as bicycle-specific pushbuttons [1].
Where	Bicycle detection should be considered along approaches where actuation is required, bicycle-specific signal heads or timing is present, or clearly marked locations where bicyclists should wait [1].
Why	Appropriate bicycle detection can help to reduce unsafe crossing behaviors by reducing delay [2] and provide extended green time for bicyclists to clear signalized intersections [1].
How	More information can be found in NACTO's Urban Bikeway Design Guide [1], FHWA's BIKESAFE website [2], FHWA's Separated Bike Lane Planning and Design Guide [3], and AASHTO's Guide for the Development of Bicycle Facilities [4]
Key References	1) Urban Bikeway Design Guide (NACTO – 2018) 2) Bike-Activated Signal Detection (FHWA BIKESAFE) 3) Separated Bike Lane Planning and Design Guide (FHWA – 2015) 4) Guide for the Development of Bicycle Facilities (AASHTO – 2012)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	No Difference	No Difference	Better	Low/Med

Intersection Bicycle Crossing Pavement Markings

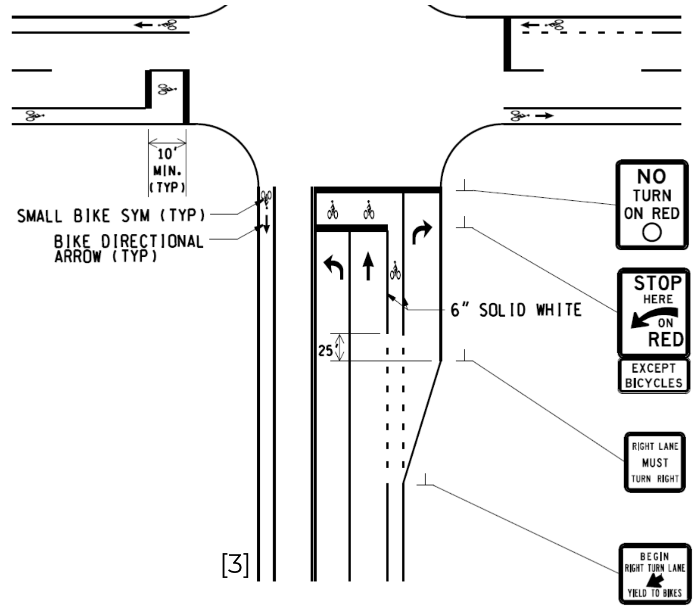
What	Bicycle-specific pavement markings can be implemented which help to guide bicyclists on the intended path through intersections, driveways and ramps [1]. While there are variety of designs currently in use, the FHWA published an interim approval (IA-14) which allows for the optional use of green colored pavements (shown right) [2].
Where	Intersection bicycle crossing pavement markings should be considered at wide or complex locations, along roadways with bicycle-specific facilities, and other situations where common vehicle movements may frequently encroach into the bicycle space [1].
Why	Intersection crossing pavement makings can help to raise awareness for both drivers and bicyclists to potential conflict areas, reinforce bicyclist priority over turning vehicles, reduce bicyclist stress, and increase the visibility of bicyclists [1].
How	More information can be found in NACTO's Urban Bikeway Design Guide [1], Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes [2], *Part 9* of the MMUTCD [3], MDOT's Pavement Markings Standards [4], and FHWA's Separated Bike Lane Planning and Design Guide [5].
Key References	1) Urban Bikeway Design Guide (NACTO – 2018) 2) Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes (FHWA – 2011) 3) Michigan MUTCD (MDOT - 2011) 4) Pavement Markings (MDOT) 5) Separated Bike Lane Planning and Design Guide (FHWA – 2015)



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	No Difference	No Difference	Better	Low

Bicycle Boxes

What	Bicycle boxes are a designated area at the head of an approach to a signalized intersection which provides bicyclists with a space to wait in front of stopped vehicles during the red signal phase [1, 2]. The FHWA published an interim approval in 2016 which provides for the optional use of an intersection bicycle box [2].
Where	Bicycle boxes should be considered at locations with relatively high turn volumes or conflicts (particularly involving left-turning bicyclists or right-turning vehicles) [1]. The implementation of a bicycle box along an intersection approach also requires the prohibition of right-turn-on-red movements [1, 2].
Why	Bicycle boxes can help to improve the visibility of bicyclists, reduce delay for bicyclists, facilitate bicycle left-turning movements, reduce "right-hook" conflicts, and group bicyclists together to minimize their impact on traffic flow [1]. Bicycle boxes can also provide benefits for pedestrians as potential vehicle encroachments into the crosswalk are reduced [1].
How	More information can be found in NACTO's Urban Bikeway Design Guide [1], FHWA's Interim Approval for the Optional Use of an Intersection Bicycle Box [2], MDOT's Pavement Marking Standards [3], and FHWA's Separated Bike Lane Planning and Design Guide [4].
Key References	1) Urban Bikeway Design Guide (NACTO – 2018) 2) Interim Approval for Optional Use of an Intersection Bicycle Box (FHWA – 2016) 3) Pavement Markings (MDOT) 4) Separated Bike Lane Planning and Design Guide (FHWA – 2015)



[3]


Google Maps

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	Better	No Difference	No Difference	Better	Low

Two-Stage Bicycle Turn Boxes

What	Two-stage bicycle turn boxes represent a designated area for bicyclists to queue to turn outside of the travel path of other bicycles and motor vehicles [1]. When used at signalized intersections, bicyclists would proceed to the turn box on a green indication and reorient within the turn box while waiting for the appropriate signal indication on the cross street [1]. The FHWA published an interim approval (IA-20) for the optional use of two-stage bicycle turn boxes in 2017 [1].
Where	Two-stage turn boxes should be considered at signalized intersections, multilane or highway speed roadways where bicyclists commonly turn left from a right-side bicycle facility [2]. While IA-20 only provides for the use at signalized intersections, two-stage bicycle turn boxes have also been implemented at midblock or unsignalized locations [2, 3].
Why	Two-stage turn boxes can help bicyclists safely and comfortably complete turning movements by reducing conflicts between the bicyclist completing the turn and motor vehicles or other bicyclists [2].
How	More information can be found in NACTO's Urban Bikeway Design Guide [2], FHWA's Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes [1], and FHWA's Separated Bike Lane Planning and Design Guide [3].
Key Reference s	1) Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes (FHWA – 2017) 2) Urban Bikeway Design Guide (NACTO – 2018) 3) Separated Bike Lane Planning and Design Guide (FHWA – 2015)

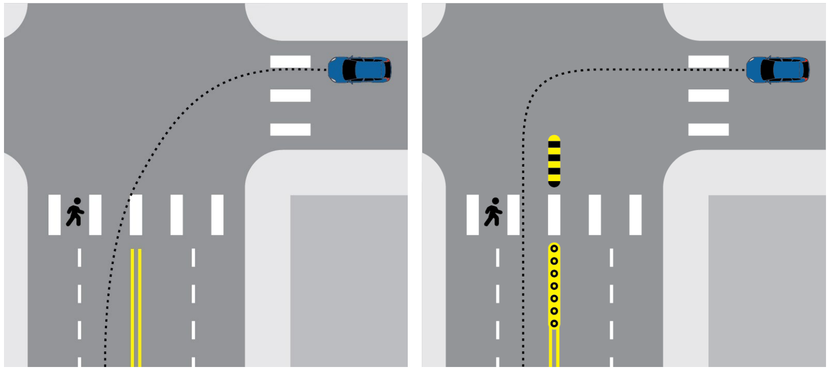

[3]


[2]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	No Difference	No Difference	Better	Low

Centerline Hardening

What	Centerline hardening, wedges, or other turn-related traffic calming treatments typically involving speed humps and bollards have been used which are intended to reduce conflicts between turning vehicles and non-motorized road users [1]. Several different configurations have been evaluated which alter vehicle paths to limit crossing over into crosswalks or bicycle facilities (shown right) [1, 2].
Where	Centerline hardening treatments should be considered at locations with historical conflicts between vehicles and non-motorized road users as well as where geometric characteristics exist which may lead to potential crossover concerns – particularly involving larger vehicles [2].
Why	Research has demonstrated that centerline hardening and similar turn-related traffic calming treatments have improved driver behavior [1, 2] and safety performance [2].
How	More information can be found on MDOT's Pavement Marking Standards [3], New York DOT's Left Turn Traffic Calming webpage [2], NACTO's Don't Give Up at the Intersection [4], and a study conducted by IIHS in 2020 [1].
Key References	1) The Effects of Left-Turn Traffic-Calming Treatments on Conflicts and Speeds in Washington, D.C. (Wen, H. and Cicchino, J. – 2020) 2) Left Turn Traffic Calming (NYDOT) 3) Pavement Markings (MDOT) 4) Don't Give Up at the Intersection (NACTO – 2019) 5) Simple Infrastructure Changes Make Left Turns Safer for Pedestrians (IIHS – 2020)

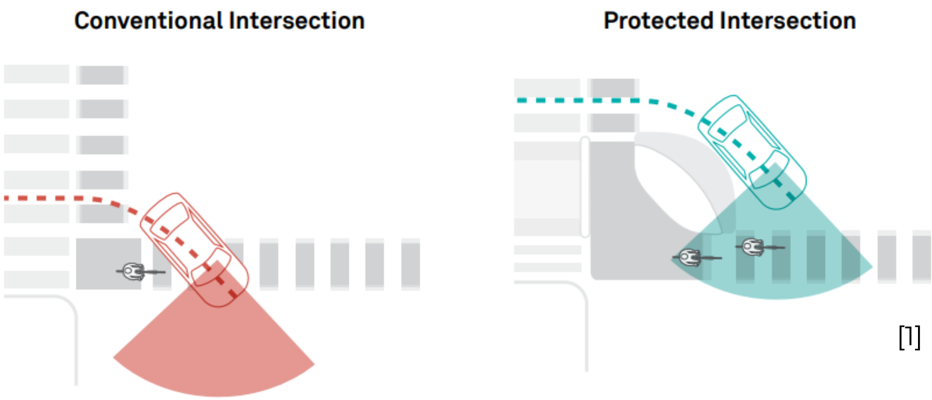


[2]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	Better	No Difference	Better	Better	Low

Protected and Dedicated Intersections

What	Protected intersection designs keep bicycles and vehicles physically separated up until the intersection, where bicyclists have a dedicated path through the intersection (upper right) [1]. Dedicated intersections include corner wedges, centerline hardening, speed bumps or crosswalk separators to discourage vehicles from encroaching on the bikeway (lower right) [1].
Where	Protected intersections should be considered at along urban streets where parking-protected or buffered bicycle lanes are provided [1]. Dedicated intersections should be considered where there is not enough room for a full bicycle setback [1].
Why	Protected and dedicated intersections include design features which can help to reduce motor vehicle turning speeds, improve visibility and reduce crossing distances [1].
How	More information can be found in NACTO's Don't Give Up at the Intersection [1].
Key References	1) Don't Give Up at the Intersection (NACTO – 2019)



[1]

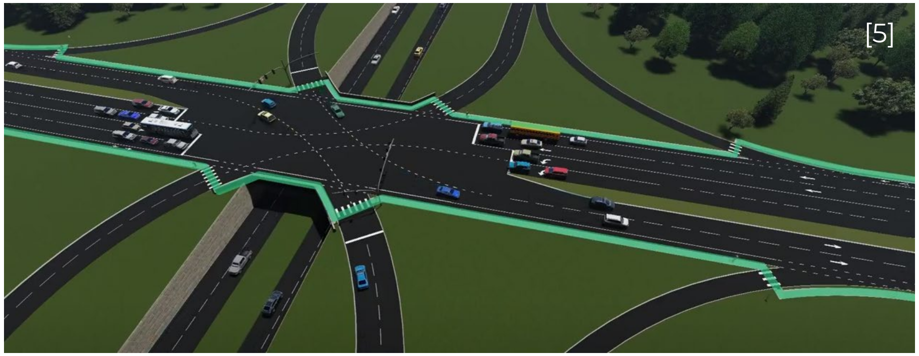
Example of a Dedicated Intersection [1]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	Better	No Difference	Better	Better	High

Alternative Intersections and Interchanges

What	Alternative intersections and interchanges, such as diverging diamond interchanges or restricted crossing u-turn intersections, are becoming more popular among highway agencies [1]. These alternative designs often involve reversing traffic lanes from their conventional direction as well as other complex geometric conditions which may result in confusion or other safety concerns for non-motorized road users [1].
Where	Additional information and accommodation for non-motorized road users should be considered at locations where such alternative designs are being implemented [1].
Why	The unfamiliar traffic flows and patterns involved with these alternative designs requires additional information for all road users about the direction of vehicular traffic, crossing locations and bicycle-specific facilities [1].
How	More information can be found in AASHTO's Guide for the Development of Bicycle Facilities [2], FHWA's PEDSAFE website [3], FHWA's Alternative Intersections/Interchanges Informational Report [4], VDOT's Innovative Intersections and Interchanges website [5], ITE's Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges [6], and FHWA's Diverging Diamond Interchange Informational Guide [7].
Key References	1) Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges (NCHRP – In Process) 2) Guide for the Development of Bicycle Facilities (AASHTO – 2012) 3) Pedestrian Accommodations at Complex Intersections (FHWA PEDAFE) 4) Alternative Intersections/Interchanges: Information Report (FHWA – 2010) 5) Innovative Intersections and Interchanges (VDOT - 2019) 6) Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges: An ITE Proposed Recommended Practice (ITE – 2014) 7) Diverging Diamond Interchange Informational Guide (FHWA – 2014)


Google Maps


[5]

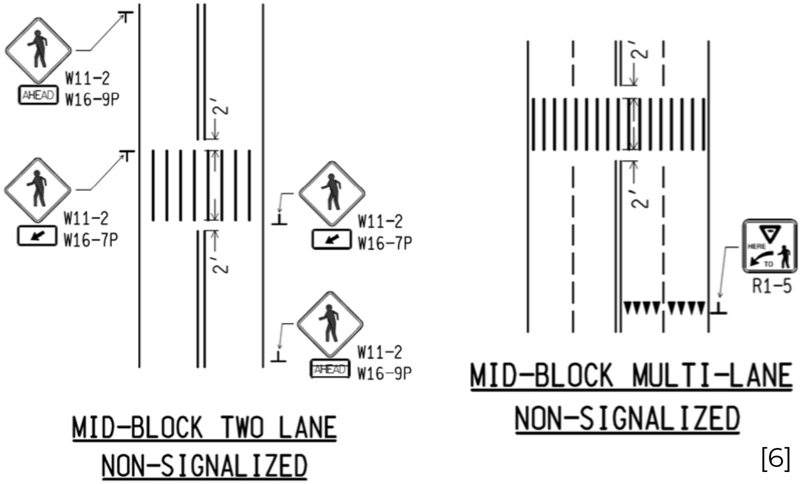
Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Better	Better	Better	High

Unsignalized Pedestrian Crossing Improvements

Best Practice	Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
	Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Marked Crosswalks	No Difference	Better	Better	No Difference	Better	Better	Low/Med
Advanced Yield Markings	Better	Better	No Difference	No Difference	Better	Better	Low
Raised Crosswalks	No Difference	Better	No Difference	No Difference	Better	No Difference	Medium
R1-6 Signs and Gateway Treatments	No Difference	Better	No Difference	No Difference	Better	No Difference	Low
Refuge Islands	Better	Better	Better	No Difference	Better	Better	Low/Med
Rectangular Rapid-Flashing Beacons (RRFBs)	No Difference	Better	Better	No Difference	Better	Better	Medium
Pedestrian Hybrid Beacons (PHBs)	Better	Better	Better	Worse	Better	Better	Med/High
Midblock Signals	No Difference	Better	Better	Worse	Better	Better	Med/High
Roadway Lighting	Better	Better	Better	No Difference	Better	Better	Medium
Grade Separated Crossings	Better	Better	Better	Better	Better	Better	High

Marked Crosswalks

What	Marked crosswalks are intended to indicate the optimal or preferred location for pedestrians to cross roadways as well as designate the right-of-way for drivers to yield to pedestrians [1]. While the MMUTCD provides for a variety of marking patterns, high-visibility crosswalk markings are recommended [1, 2].
Where	The MMUTCD states that "crosswalk lines should not be used indiscriminately" and that an engineering study should be conducted before installing crosswalks at uncontrolled locations which considers the number of lanes, median presence, the distance from adjacent intersections, pedestrian and vehicular volumes, speed limit, lighting as well as other appropriate factors [2].
Why	Midblock crossings can provide a convenient location for pedestrians to cross the street where intersection crossings are either infrequent or requires traveling out-of-direction [3]. Appropriately designed midblock crossings can help warn drivers of the potential presence of pedestrians and encourage pedestrians to cross at the safest midblock location [3].
How	More information can be found in FHWA's Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations [4], *Section 3B.18* of the MMUTCD [2], MDOT's Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways [5], and MDOT Pavement Marking Standards [6].
Key References	1) Marked Crosswalks (FHWA PEDSAFE) 2) Michigan MUTCD (MDOT - 2011) 3) Designing Walkable Urban Thoroughfares: A Context Sensitive Approach (ITE – 2010) 4) Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations (FHWA – 2005) 5) Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways (MDOT – 2020) 6) Pavement Markings (MDOT)

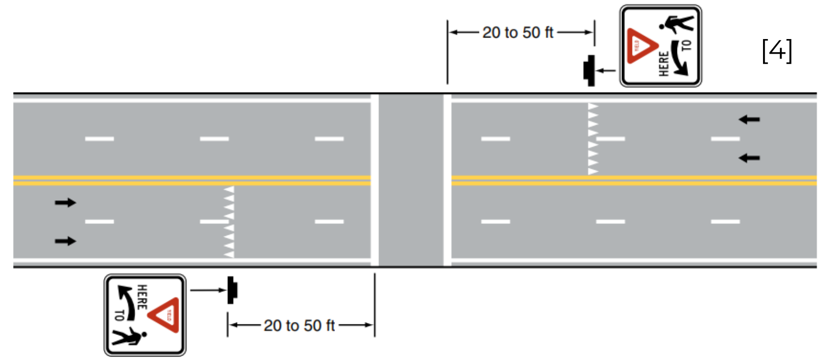


[6]

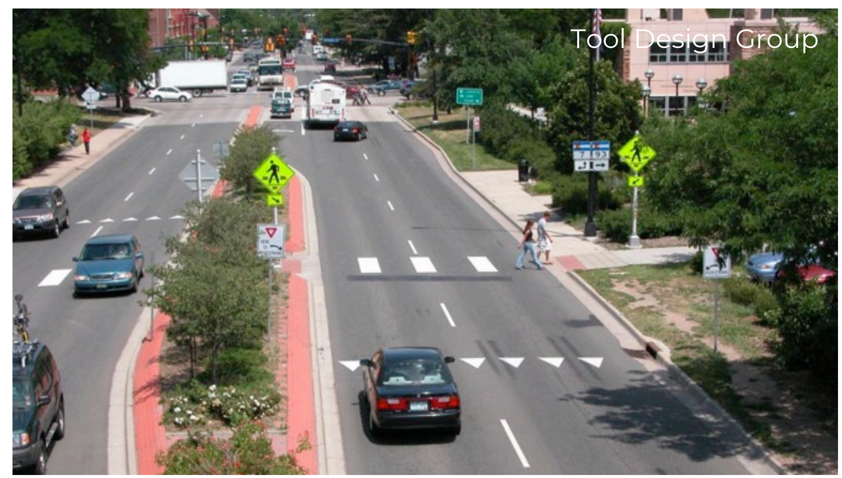
Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	Better	No Difference	Better	Better	Low/Med

Advanced Yield Markings

What	Advanced YIELD markings involve implementing the yield markings upstream of an uncontrolled marked crosswalk [1]. The treatment increases the distance at which drivers either yield to pedestrians, which can increase visibility and help reduce the likelihood of "multiple-threat" crashes [1, 2]
Where	Advanced YIELD markings should be considered at uncontrolled marked crossings where there are frequent pedestrian conflicts or visibility may be limited, particularly crossings on roads with four or more lanes and speed limits of 35 MPH or greater [3].
Why	Research has consistently demonstrated that advanced YIELD markings reduce conflicts between vehicles and pedestrians as well as increase driver yielding compliance [2]. Research has shown reductions in both total (11.4%) and pedestrian-involved crashes (25.0%) after implementation [2].
How	More information can be found in FHWA's PEDSAFE website [1], NCHRP's Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments [2], FHWA's Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations, and *Section 3B.16* of the MMUTCD [4].
Key References	1) Advance Yield/Stop Lines (FHWA PEDAFE) 2) Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments (NCHRP – 2017) 3) Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations (FHWA – 2018) 4) Michigan MUTCD (MDOT - 2011)



[4]



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	No Difference	No Difference	Better	Better	Low

Raised Crosswalks

What	Raised crosswalks are ramped speed tables which span the entire width of the roadway [1, 2]. Raised crosswalks are demarcated with appropriate pavement markings and serve as a traffic calming measure where the crosswalk is at grade with the adjacent sidewalk [1, 2].
Where	Raised crosswalks can be considered along two or three lane roadways with speed limits of 30 MPH or less and daily traffic volumes below 9,000 vehicles per day [1, 2]. Midblock crossings along truck routes, emergency routes and arterial streets may not be appropriate for raised crosswalks [2].
Why	Research has demonstrated that the implementation of raised crosswalks has resulted in improved driver yielding compliance and reductions in pedestrian-involved collisions [1, 2].
How	More information can be found on FHWA's PEDSAFE website [1], FHWA's Raised Crosswalk Countermeasure Tech Sheet [2], and *Section 3B.25* of the MMUTCD [3].
Key References	1) Raised Pedestrian Crossings (FHWA PEDSAFE) 2) Raised Crosswalk Tech Sheet (FHWA – 2018) 3) Michigan MUTCD (MDOT - 2011)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	No Difference	No Difference	Better	No Difference	Medium

R1-6 Signs and Gateway Treatments

What	In-street pedestrian crossing signs (MUTCD R1-6) are intended to remind road users of right-of-way laws at unsignalized pedestrian crossings [1]. The sign can be used in combination with other visibility enhancements to improve driver yielding compliance [1]. The R1-6 has been used as a part of a "gateway" treatment where signs are placed on the edge of the road as well as all lane lines which requires drivers to drive between two signs [2].
Where	The gateway treatment can be implemented at roadway crossings with speed limits of 35 MPH or less which posses a range of geometric characteristics [2]. **It is important to note that a FHWA Request to Experiment is required for configurations which involve placing the R1-6 on an edge line or the curb [2].**
Why	Research has demonstrated that the gateway treatment was associated with an increase in driver yielding compliance and a decrease in vehicular speeds [2].
How	More information can be found in MDOT's User Guide for R1-6 Gateway Treatment for Pedestrian Crossings [1], *Section 2B.12* of the MMUTCD [2], and MDOT's Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways [3].
Key Reference s	1) In-Street Pedestrian Crossing Sign (FHWA PEDSAFE) 2) User Guide for R1-6 Gateway Treatment for Pedestrian Crossings (MDOT – 2018) 3) Michigan MUTCD (MDOT - 2011) 4) Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways (MDOT – 2020)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	No Difference	No Difference	Better	No Difference	Low

Refuge Islands

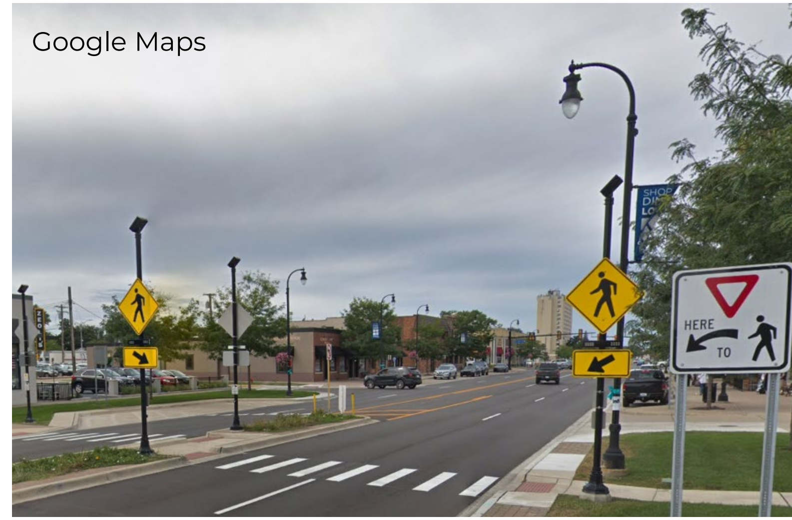
What	Refuge islands, also referred to as crossing islands, are areas located within a highway crossing where a pedestrian can take refuge and separate crossings into two stages [1]. Refuge islands must include a raised median at least six feet in width, with larger widths preferred to accommodate bicycles adjacent to shared-use paths [1]. Additional treatments, such as curb extensions, high-visibility crosswalk markings, and R1-6 signs should also be considered in conjunction with the installation of a refuge island [2].
Where	While refuge islands should be considered across a broad range of midblock crossing environments, they are highly desirable for crossings of roadways with four or more lanes - particularly where posted speed limits exceed 30 MPH or daily traffic volumes exceed 9,000 vehicles per day [2].
Why	Appropriately designed refuge islands can enhance the visibility of crossings, reduce approach speeds, and reduce crossing distances [2]. Research has demonstrated a 26% reduction in total crashes and a 32% reduction in pedestrian-involved collisions [3].
How	More information can be found in MDOT's User Guide for R1-6 Gateway Treatment for Pedestrian Crossings [1], FHWA's Pedestrian Refuge Island Tech Sheet [2], and *Section 31.06* of the MMUTCD [4].
Key References	1) Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways (MDOT – 2020) 2) Pedestrian Refuge Island Tech Sheet (FHWA – 2018) 3) Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments (NCHRP – 2017) 4) Michigan MUTCD (MDOT - 2011) 5) Field Guide for Selecting Countermeasures at Uncontrolled Pedestrian Crossing Locations (FHWA – 2018)

[5]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	No Difference	Better	Better	Low/Med

Rectangular Rapid-Flashing Beacons (RRFBs)

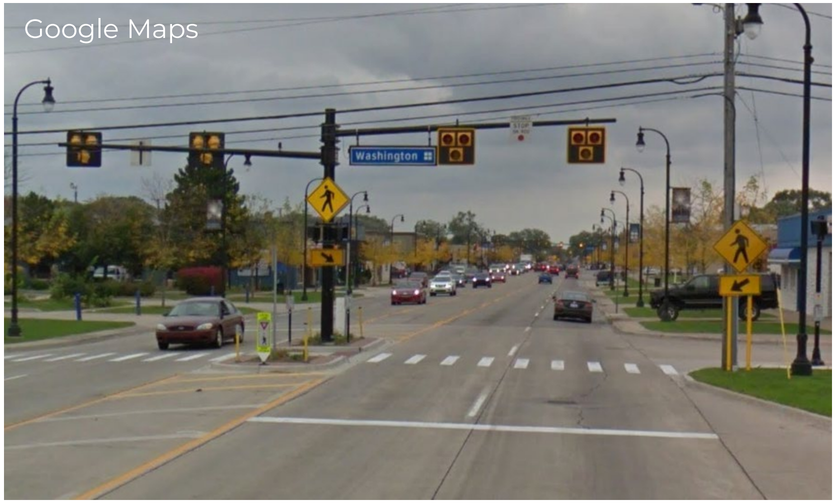
What	Rectangular rapid-flashing beacons (RRFBs) are "pedestrian-actuated conspicuity enhancements for pedestrian and school crossing warning signs under certain limited conditions" [1]. RRFBs "use rectangular-shaped high-intensity light-emitting-diode (LED)-based indications, flashes rapidly in a combination wig-wag and simultaneous flash pattern and may be mounted immediately adjacent to the crossing sign" [1]. It is important to note that FHWA published an interim approval (IA-21) in 2018 which allows for the optional use of RRFBs after an agency requests permission [1].
Where	RRFBs require an engineering analysis of the site conditions and should be considered where drivers are not expecting pedestrians or where special emphasis is required [2]. RRFBs can be used in a variety of scenarios, including midblock crossings, uncontrolled intersection crossings, and the approach to or egress from roundabouts [2].
Why	RRFBs can improve the conspicuity of crossings and have been shown to improve driver yielding compliance as well as reduce pedestrian-involved crashes by 47% when used in the appropriate setting [2].
How	More information can be found in FHWA's Interim Approval 21 – Rectangular Rapid-Flashing Beacons at Crosswalks [1], MDOT's Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways [2], FHWA's Rectangular Rapid-Flashing Beacon Tech Sheet [3], *Section 1.4.1* of MDOT's Electronic Traffic Control Device Guidelines [4], and MDOT's Rectangular Rapid-Flashing Beacon Special Detail [5].
Key References	**1) Interim Approval 21 – Rectangular Rapid-Flashing Beacons at Crosswalks (FHWA - 2018)** **2) Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways (MDOT – 2020)** **3) Rectangular Rapid-Flashing Beacon Tech Sheet (FHWA – 2018)** **4) MDOT Electronic Traffic Control Device Guidelines (MDOT)** **5) Rectangular Rapid Flashing Beacon Special Detail (MDOT – 2013)**



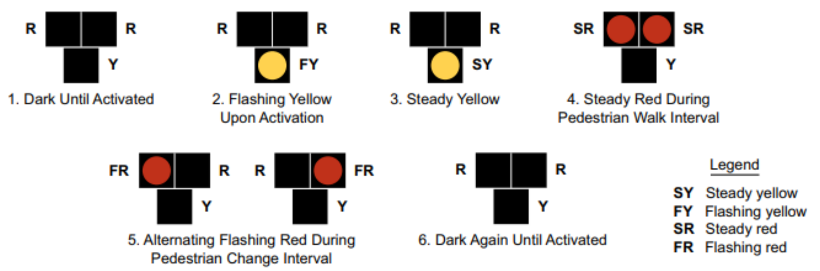
Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	Better	Worse	Better	Better	Medium

Pedestrian Hybrid Beacons (PHBs)

What	Pedestrian hybrid beacons (PHBs), which have previously referred to as "high-intensity activated crosswalk beacons" or HAWK signals, are "a special type of hybrid beacon used to warn and control traffic at an unsignalized location to assist pedestrians in crossing a street or highway at a marked crosswalk" [1, 2]. PHBs include two red lenses above a single yellow lens and rest in dark until actuated by a pedestrian (shown lower right) [3].
Where	PHBs are intended to serve as an alternative when signal warrants are not met but crossing demand exists and vehicle speeds or volumes are high [2, 3]. PHBs should only be considered for crosswalks which are at least 100 away from an adjacent intersection or driveway [2].
Why	Research has demonstrated reductions in both total and pedestrian-involved crashes associated with PHBs [4].
How	More information can be found in *Chapter 4F* of the MMUTCD [1], MDOT's Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways [2], FHWA's Pedestrian Hybrid Beacon Tech Sheet [3], and *Section 1.4.2* of MDOT's Electronic Traffic Control Device Guidelines [5].
Key Reference s	1) Michigan MUTCD (MDOT - 2011) 2) Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways (MDOT – 2020) 3) Pedestrian Hybrid Beacon Tech Sheet (FHWA – 2018) 4) Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments (NCHRP – 2017) 5) MDOT Electronic Traffic Control Device Guidelines (MDOT)



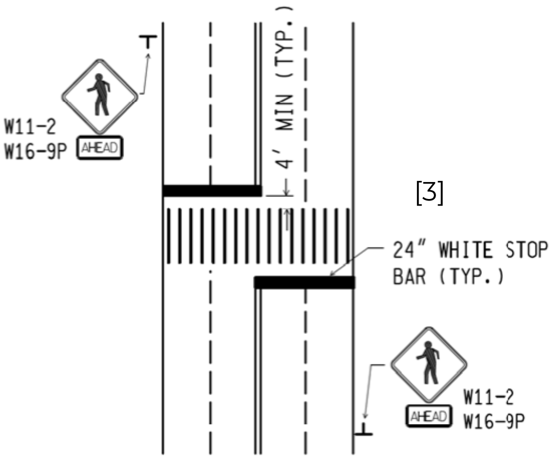
Sequence for a Pedestrian Hybrid Beacon [1]



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Worse	Better	Better	Med/High

Midblock Signals

What	A midblock signal is a full traffic signal for vehicles in one direction and pedestrians in the cross direction. The signal is often pedestrian actuated and therefore only interrupts traffic flow at times when pedestrians are wanting to cross.
Where	Midblock signals may be desired where large volumes of pedestrians are crossing midblock to access a particular destination, such as a transit station. The MMUTCD has guidelines for the pedestrian volumes warranting a midblock signal.
Why	As a full traffic signal, a midblock signal has a very high compliance rate with motorists. The compliance rate for pedestrians decreases the longer a pedestrian has to wait for a WALK signal. The best compliance was found when pedestrians had to wait less than 30 seconds for the walk signal.
How	More information can be found in *Section 4C.05* of the MMUTCD [1], MDOT's Electronic Traffic Control Device Guidelines [2], MDOT's Pavement Design Standards [3], and MDOT's Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways [4].
Key References	1) Michigan MUTCD (MDOT - 2011) 2) MDOT Electronic Traffic Control Device Guidelines (MDOT) 3) Pavement Markings (MDOT) 4) Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways (MDOT – 2020)



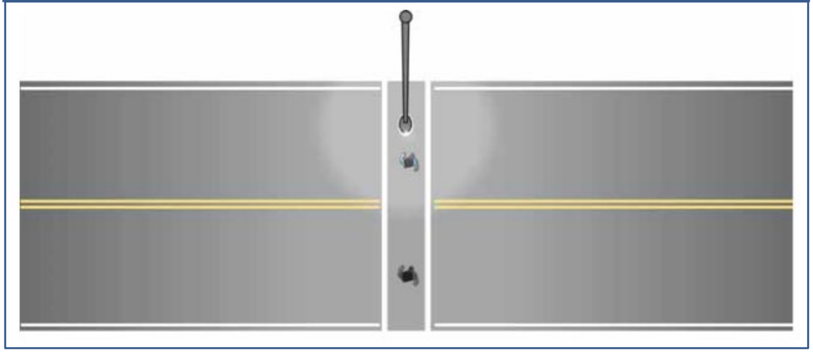
[3]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	Better	Worse	Better	Better	Med/High

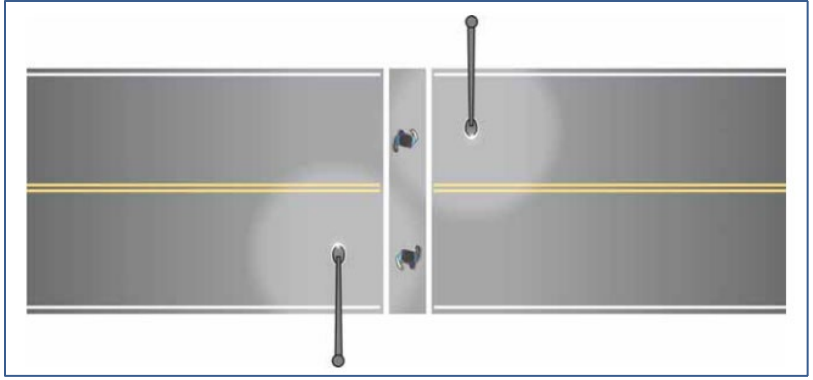
Roadway Lighting

What	Roadway lighting which illuminates crosswalks and reduces glare for drivers is an important consideration in designing for non-motorized road users [1]. While traditionally one luminaire has been installed directly over the crosswalk, new designs now include two luminaires placed upstream of the crosswalk [2].
Where	Sufficient roadway illumination should be considered at all marked crossings where pedestrian and bicyclist crossing activity is observed or expected.
Why	The appropriate quality and placement of lighting can increase comfort and safety for all road users [1]. Overhead lighting can generally provide greater visibility than headlights alone to illuminate crosswalks [2].
How	More information can be found in FHWA's Informational Report on Lighting Design for Midblock Crosswalks [2], *Section 9.03.01* of MDOT's Road Design Manual [3], and MDOT's Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways [4].
Key References	1) Lighting and Illumination (FHWA PEDSAFE) 2) Informational Report on Lighting Design for Midblock Crosswalks (FHWA – 2008) 3) Road Design Manual (MDOT) 4) Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways (MDOT – 2020)

Traditional Midblock Crosswalk Lighting Layout [2]



New Design Midblock Crosswalk Lighting Layout [2]



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	No Difference	Better	Better	Medium

Grade Separated Crossings

What	Grade separated crossings, such as pedestrian bridges or underpasses, allow for the uninterrupted flow of non-motorized road user movements [1].
Where	Grade separated crossings should only be considered as a last resort given that they are costly and poorly utilized when a direct grossing at-grade can be completed [1]. Grade separated crossings may be appropriate at freeways, high-speed arterials, railroads and natural barriers where implementing at-grade crossings is not feasible [1].
Why	Research has demonstrated reductions in both total and pedestrian-involved crashes associated with overpasses and underpasses [2].
How	More information can be obtained on FHWA's PEDSAFE website [1], MDOT's Michigan Bridge Design Manual [3], as well as AASHTO's Pedestrian [4] and Bicycle [5] Guides.
Key References	1) Pedestrian Overpasses/Underpasses (FHWA PEDSAFE) 2) Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes (FHWA – 2008) 3) Michigan Bridge Design Manual (MDOT) 4) Guide for the Planning, Design, and Operation of Pedestrian Facilities (AASHTO – 2004) 5) Guide for the Development of Bicycle Facilities (AASHTO – 2012)

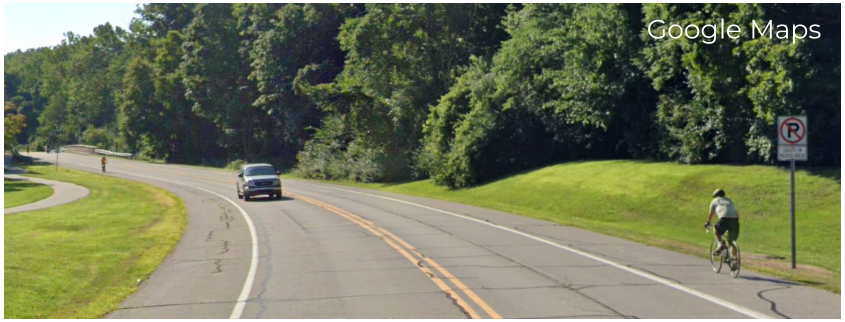
Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Better	Better	Better	High

Corridor Improvements

Best Practice	Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
	Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Sidewalks and Paved Shoulders	Better	Better	Better	Better	Better	Better	Med/High
Shared Use Paths and Sidepaths	No Difference	Better	Better	Better	Better	Better	High
Road Diets	Better	Better	Better	No Difference	Better	Better	Low/Med
Raised Medians	Better	Better	Better	Better	Better	Better	High
On-Street Parking	Worse	Better	Better	Worse	Better	Better	Varies
Back-In Angle Parking	Better	Better	Better	Worse	No Difference	Better	Varies
Shared Lane Markings	No Difference	No Difference	Better	No Difference	No Difference	Better	Low
Bicycle Lanes	No Difference	No Difference	Better	Better	No Difference	Better	Medium
Buffered Bicycle Lanes	No Difference	No Difference	Better	Better	Better	Better	Med/High
Contra-Flow Bicycle Lanes	No Difference	No Difference	Better	Better	No Difference	Better	Medium
Left-Side Bicycle Lanes	No Difference	No Difference	Better	Better	No Difference	Better	Medium
Separated Bicycle Lanes	Better	Better	Better	Better	Better	Better	High
Transit Accommodation	Better	Better	Better	Better	Better	Better	High
Bicycle Wayfinding	No Difference	No Difference	Better	No Difference	No Difference	Better	Low

Sidewalks and Paved Shoulders

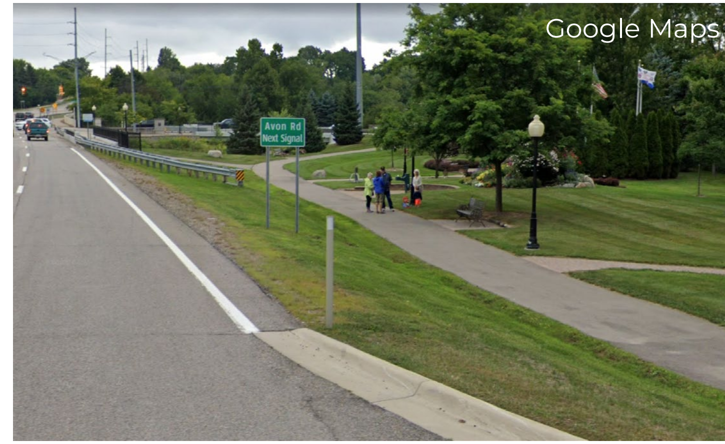
What	Sidewalks are intended to provide a dedicated space for pedestrians that is safe, comfortable, and accessible [1]. The inclusion of paved shoulders along a highway can also offer a variety of benefits for non-motorized road users, including providing space for travel, facilitating safer passing behaviors and increasing comfort [2].
Where	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.
Why	Sidewalks serve a variety of key functions in cities, including providing access and mobility for pedestrians, enhancing connectivity and promoting walking [3]. Wide paved shoulders "can greatly improve bicyclist safety and comfort, particularly on higher-speed, higher-volume roadways" [2]. Research has shown that the inclusion sidewalks have reduced pedestrian-involved crashes by 88% and paved shoulders of at least four feet in width have reduced pedestrian-involved crashes by 71% [4].
How	More information can be found in FHWA's Small Town and Rural Multimodal Networks [1], FHWA's Achieving Multimodal Networks [2], NACTO's Urban Street Design Guide [3], and MDOT's Road Design Manual [5].
Key References	**1) Small Town and Rural Multimodal Networks (FHWA – 2016)** **2) Achieving Multimodal Networks: Applying Design Flexibility & Reducing Conflicts (FHWA – 2016)** **3) Urban Street Design Guide (NACTO – 2018)** **4) Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes (FHWA – 2013)** **5) Road Design Manual (MDOT)**



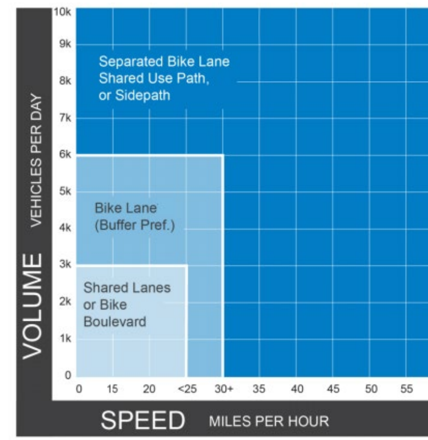
Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Better	Better	Better	Med/High

Shared Use Paths and Sidepaths

What	Shared use paths provide non-motorized road users with a travel area separated from vehicular traffic [1]. Sidepaths, or a shared use path which is located parallel to an adjacent roadway, have been used extensively in Michigan (shown upper right) [2].
Where	Shared use paths have a variety of applications, but are often included adjacent to parks, rivers, beaches, greenbelts or utility corridors [1]. While the installation of a shared use path or sidepath should consider bicycle user comfort thresholds, best practices, available right-of-way, highway network characteristics and adjacent land uses, the included chart (lower right) can help to identify scenarios where such facilities may be appropriate for an "interested but concerned" design user [2].
Why	Shared use paths and sidepaths can help to provide a more comfortable experience for non-motorized road users [1].
How	More information can be found in MDOT's Sidepath Intersection and Crossing Treatment Guide [2], AASHTO's Guide for the Development of Bicycle Facilities [3], MDOT's Pavement Marking Standards [4], *Chapter 12* of MDOT's Road Design Manual [5], and *Section 9C.03* of the MMUTCD [6].
Key References	1) Small Town and Rural Multimodal Networks (FHWA – 2016) 2) Sidepath Intersection and Crossing Treatment Guide (MDOT – 2018) 3) Guide for the Development of Bicycle Facilities (AASHTO – 2012) 4) Pavement Markings (MDOT) 5) Road Design Manual (MDOT) 6) Michigan MUTCD (MDOT - 2011)



Bicycle Facility Selection for Interested but Concerned Design Users [2]

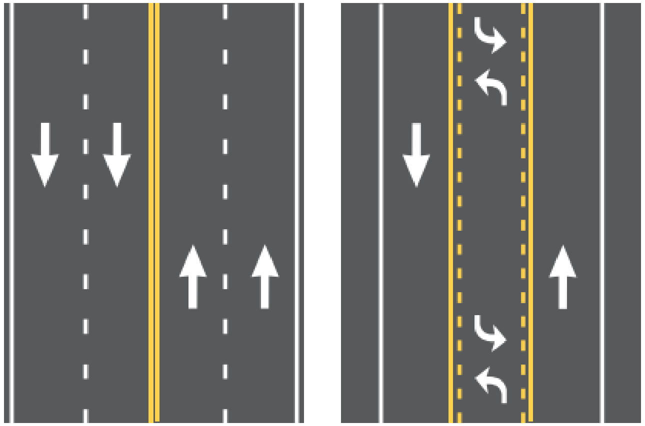


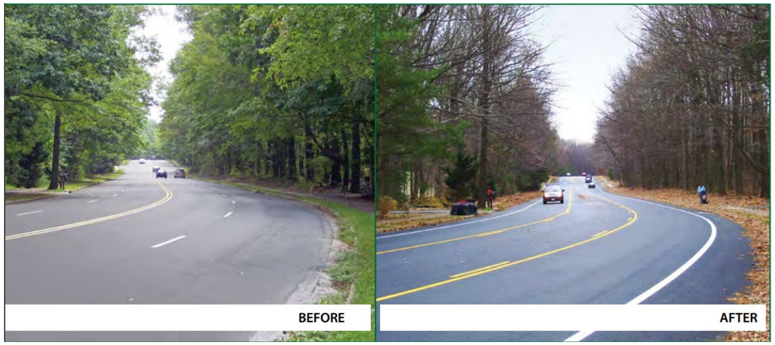
Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	Better	Better	Better	Better	Better	High

Road Diets

What	Road diets represent "the reallocation of road space through the reduction of the number of motorized traffic lanes" [1]. While there are a variety of potential roadway reconfigurations, the most common road diet involves the conversion of a four-lane undivided roadway to a two-lane roadway which includes a center two-way left-turn lane [2]. This reallocation of space allows for the inclusion of bicycle facilities, refuge islands, transit applications or parking [2].
Where	There are a variety of factors which need to be considered in order to determine if a road diet is appropriate and feasible for a given corridor, including the surrounding land use, access point density, right-of-way considerations, traffic volumes, and speed [2].
Why	Road diets can offer a variety of traffic safety benefits as four-lane undivided highways often suffer from relatively poor safety performance at higher traffic volumes due to conflicts between through traffic and left-turning vehicles [2]. The implementation of a road diet can also offer safety benefits specific to pedestrians and bicyclists given the ability to reduce crossing distances and incorporate dedicated bicycle facilities [2].
How	More information can be found in FHWA's Road Diet Conversions: A Synthesis of Safety Research [1], FHWA's Road Diet Informational Guide [2], and MDOT's Safety and Operational Analysis of 4-Lane to 3-Lane Conversions (Road Diets) in Michigan [3].
Key References	1) Road Diet Conversions: A Synthesis of Safety Research (FHWA – 2013) 2) Road Diet Informational Guide (FHWA – 2014) 3) Safety and Operational Analysis of 4-Lane to 3-Lane Conversions (Road Diets) in Michigan (MDOT – 2012)

Before and After Road Diet Conversion [2]





Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	No Difference*	Better	Better	Low/Med

*Depending on the daily traffic volumes served by the roadway, 4-lane to 3-lane conversions may not be feasible when volumes exceed 15,000 to 25,000 vehicles per day

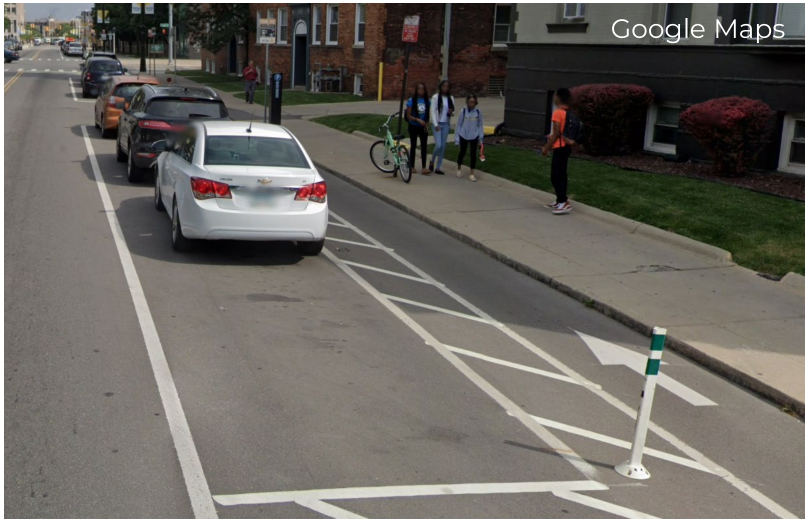
Raised Medians

What	Raised medians are curbed sections in the center of a roadway which can help to facilitate crossing movements by allowing non-motorized road users to complete two-stage crossings, reducing the effective crossing distance [1].
Where	Raised medians can provide the largest benefits along roadways with relatively high traffic volumes or speeds [1]. Consideration should also be given to whether the space allocated to a raised median could be better used by providing other design features specific to non-motorized road users, such as wider sidewalks or bicycle lanes [1].
Why	Raised medians separate opposing traffic streams, restrict turning movements, reduce effective crossing distances, improve non-motorized road user visibility, as well as provide an area for lighting and landscaping [1]. Research has shown that the implementation of a raised median has reduced both total and pedestrian-involved crashes [2].
How	More information can be found on FHWA's PEDSAFE website [1], FHWA's Safety Benefits of Raised Medians and Pedestrian Refuge Areas [2], MDOT's Road Design Manual [3], and *Section 31.06* of the MMUTCD [4].
Key Reference s	1) Raised Medians (FHWA PEDSAFE) 2) Safety Benefits of Raised Medians and Pedestrian Refuge Areas (FHWA) 3) Road Design Manual (MDOT) 4) Michigan MUTCD (MDOT - 2011)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Better	Better	Better	High

On-Street Parking

What	On-street parking is the placement of parked vehicles on the roadway closest to the curb. On-street parking may be either parallel (upper right) or angle parking. While on on-street parking is key to serving the needs of certain land uses adjacent to urban streets, the presence of on-street parking can have both positive and negative impacts related to non-motorized road users [1-3].
Where	Parallel parking is generally included along higher-volume urban arterials, while angled parking is generally included along low-speed and low-volume collector avenues and streets [3]. On-street parking should not be included along roadways with speeds greater than 35 MPH [3]. It should be noted that while pull-in angle parking is not permitted on state trunkline highways, back-in may be considered [4].
Why	On-street parking can result in lower travel speeds, reduce the crossing width, and serve as a buffer between vehicles and pedestrians walking along a sidewalk [1-3]. On-street parking can also reduce walking distances to destinations for disabled persons [3]. Appropriate design treatments can also reduce the potential for conflicts between bicyclists, vehicles pulling into or out of parking spacings, as well as opening vehicle doors [2].
How	More information can be found on FHWA's PEDSAFE [1] and BIKESAFE [2] websites, FHWA's Designing Walkable Urban Thoroughfares [3], *Section 2.2.3* of MDOT's Geometric Design Guidance [4], MDOT's Pavement Marking Standards [5], and *Section 3B.19* of the MMUTCD [6].
Key References	1) On-Street Parking Enhancements (FHWA PEDSAFE) 2) Parking Treatments (FHWA BIKESAFE) 3) Designing Walkable Urban Thoroughfares: A Context Sensitive Approach (ITE – 2010) 4) Geometric Design Guidance (MDOT – 2017) 5) Pavement Markings (MDOT) 6) Michigan MUTCD (MDOT - 2011)

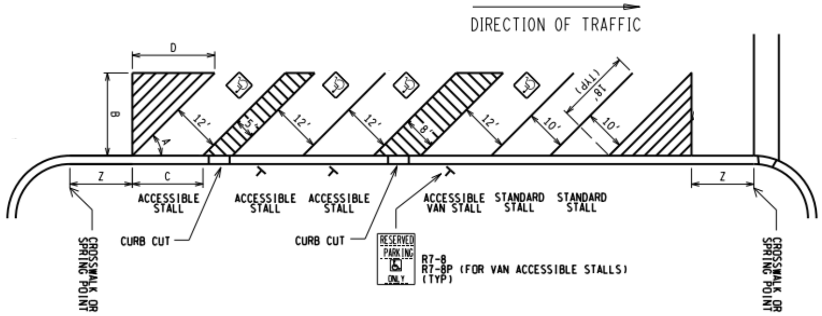


Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Worse	Better	Better	Worse	Better	Better	Varies

Back-In Angle Parking

What	Back-in angle parking is the placement of angle parking where the front of the vehicle is parked facing the travel lane with the back of the vehicle at the curb.
Where	Given that conventional angle parking is not permitted on state trunkline highways, back-in angle parking can be used to increase on-street parking capacity in specific downtown areas [1]. MDOT provides specific criteria for the consideration of back-in angle parking in these scenarios [1].
Why	Back-in angle parking has several advantages over conventional angle parking, including providing drivers access to their trunk at the curb instead of the street, directing children to the curb due to the direction of open doors, and improving visibility for drivers when pulling out of a parking space [2].
How	More information can be found in *Section 2.2.3* of MDOT's Geometric Design Guidance [1], FHWA's PEDSAFE website [2], and MDOT's Pavement Marking Standards [3].
Key Reference s	1) Geometric Design Guidance (MDOT – 2017) 2) On-Street Parking Enhancements (FHWA PEDSAFE) 3) Pavement Markings (MDOT)

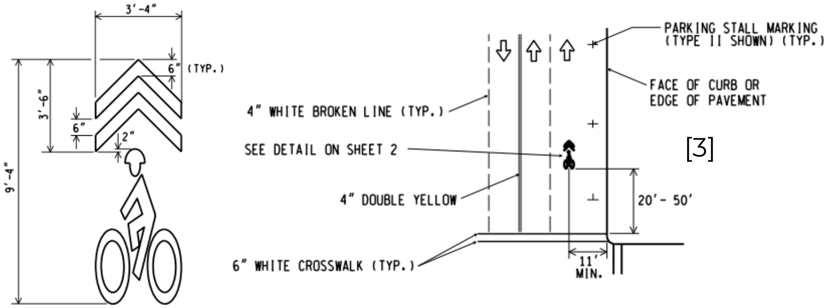
MDOT's Back-In Angle Parking Detail [3]



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Worse	No Difference	Better	Varies

Shared Lane Markings

What	Shared lane markings, also referred to as “sharrows”, are pavement markings intended to indicate a shared lane environment for bicycles and vehicles [1]. Shared lane markings are comprised of a bicycle symbol with chevrons [2].
Where	Shared lane markings are used along non-freeways within urban areas in order to designate a bicycle route [2]. The design is only used along roadways with speeds of 35 MPH or less and are not used along shoulders or bicycle lanes [2].
Why	Shared lane markings can help to route bicyclists to avoid on-street parking, assist bicyclists with lateral positioning, warn drivers of the position within a lane a bicyclist will likely occupy, promote safe overtaking behaviors, and reduce the likelihood of wrong-way bicycling [2]. The markings can also help to reduce sidewalk riding, indicate the proper path for bicyclists, as well as inform other road users of the bicycle route [1].
How	More information can be found in NACTO’s Urban Bikeway Design Guide [1], MDOT’s Pavement Marking Standards [3], and *Section 9C.07* of the MMUTCD [2].
Key Reference s	1) Shared Lane Markings (NACTO – 2018) 2) Michigan MUTCD (MDOT - 2011) 3) Pavement Markings (MDOT)



[3]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	No Difference	No Difference	Better	Low

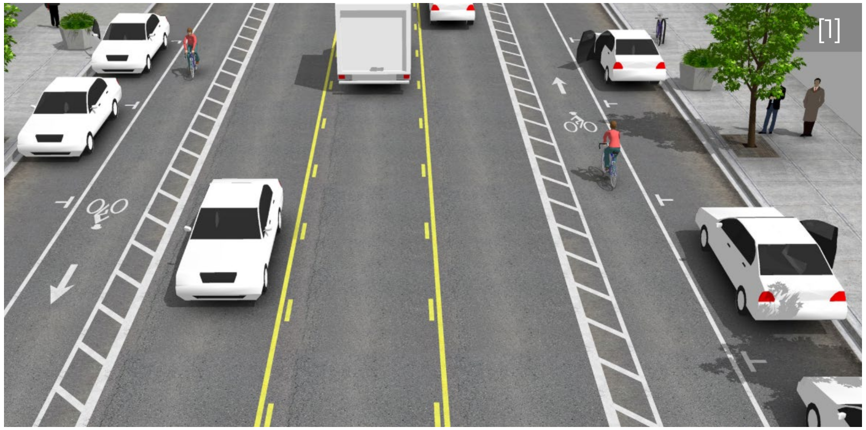
Bicycle Lanes

What	Bicycle lanes are "a portion of the roadway that has been designated by striping, signage, and pavement markings for the preferential or exclusive use of bicyclists." [1]. While the MMUTCD does include provisions for conventional bicycle lanes [2], it is important to note that FHWA published an interim approval in 2011 (IA-14) which allows for the optional use of green colored pavement in both marked bicycle lanes as well as extensions through intersections and other conflict areas [3].
Where	Bicycle lanes provide the largest benefit on roadways which serve greater than 3,000 vehicles per day with speeds between 25 MPH and 35 MPH [1].
Why	Bicycle lanes allow bicyclists to ride at their preferred speed, facilitate predictable behavior between vehicles and bicyclists, increase bicyclist comfort, creates a separation between vehicles and bicyclists, as well as increase the capacity for streets which serve mixed bicycle and vehicle traffic [1].
How	More information can be found in NACTO's Urban Bikeway Design Guide [1], *Section 9C.04* of the MMUTCD [2], FHWA's Interim Approval for Optional Use of Green Colored Pavement Markings [3], *Section 12.12.10* of MDOT's Road Design Manual [4], MDOT's Pavement Marking Standards [5], and AASHTO's Guide for the Development of Bicycle Facilities [6].
Key Reference s	**1) Bike Lanes (NACTO – 2018)** **2) Michigan MUTCD (MDOT - 2011)** **3) Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes (FHWA – 2011)** **4) Road Design Manual (MDOT)** **5) Pavement Markings (MDOT)** **6) Guide for the Development of Bicycle Facilities (AASHTO – 2012)**

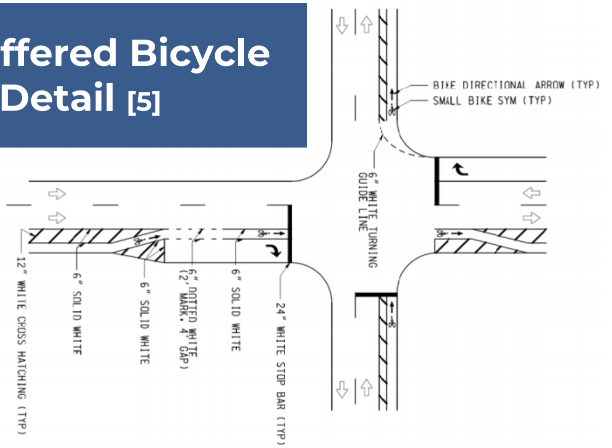
Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	Better	No Difference	Better	Medium

Buffered Bicycle Lanes

What	Buffered bicycle lanes are similar to conventional bicycle lanes except that a designated buffer space is included to separate the bicycle lane from travel or parking lanes [1]. FHWA has recognized that buffered bicycle lanes are allowable per the 2009 MUTCD [2].
Where	Buffered bicycle lanes can be considered along any route where a conventional bicycle lane would be appropriate, in addition to streets with higher speeds or traffic volumes (particularly truck volumes) [1].
Why	Buffered bicycle lanes can help to create a greater shy distance between vehicles and bicyclists, provide space for bicyclists to overtake other bicyclists, encourage bicyclists to ride outside the “door” zone adjacent to on-street parking, and improve the perceived safety of the bicycle network [1].
How	More information can be found in NACTO’s Urban Bikeway Design Guide [1], *Section 9C.04* of the MMUTCD [3], *Section 12.12.10* of MDOT’s Road Design Manual [4], and MDOT’s Pavement Marking Standards [5].
Key Reference s	1) Buffered Bike Lanes (NACTO – 2018) 2) Bicycle Facilities and the Manual on Uniform Traffic Control Devices (FHWA) 3) Michigan MUTCD (MDOT - 2011) 4) Road Design Manual (MDOT) 5) Pavement Markings (MDOT)



MDOT’s Buffered Bicycle Lane Detail [5]



Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	Better	Better	Better	Med/High

Contra-Flow Bicycle Lanes

What	Contra-flow bicycle lanes are designed to allow bicyclists to ride in the direction opposite of the vehicular traffic stream [1]. Contra-flow bicycle lanes allow for the conversion of a one-way street into a two-way street for bicyclists [1]. The FHWA has recognized that contra-flow bicycle lanes are allowable per the 2009 MUTCD [2].
Where	Contra-flow bicycle lanes can be considered along routes where frequent wrong-way bicycle movements are occurring, where alternatives require out-of-direction travel or would include uncomfortable streets for bicyclists, where two-way a connection is needed for bicyclist facilities [1]. Contra-flow bicycle lanes are appropriate along low speed and low volume streets unless a buffer or physical separation is included [1].
Why	Contra-flow bicycle lanes can help to provide connectivity for bicyclists, reduce the likelihood of wrong-way or sidewalk riding, reduce out-of-direction travel and utilize streets which are more appropriate for on-street bicycle facilities [1].
How	More information can be found in NACTO's Urban Bikeway Design Guide [1], *Section 9C.04* of the MMUTCD [3], *Section 12.12.10* of MDOT's Road Design Manual [4], and MDOT's Pavement Marking Standards [5].
Key Reference s	1) Contra-Flow Bike Lanes (NACTO – 2018) 2) Bicycle Facilities and the Manual on Uniform Traffic Control Devices (FHWA) 3) Michigan MUTCD (MDOT - 2011) 4) Road Design Manual (MDOT) 5) Pavement Markings (MDOT)

[1]


[1]

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	Better	No Difference	Better	Medium

Left-Side Bicycle Lanes

What	Left-side bicycle lanes represent the placement of a conventional bicycle lane on the left-side of either one-way or two-way divided streets [1]. The FHWA has recognized that left-side bicycle lanes are allowable per the 2009 MUTCD [2].
Where	Left-side bicycle lanes can be considered along one-way streets or two-lane streets divided by a median, streets with frequent bus stops or loading zones, streets with a high turnover of on-street parking, streets with relatively high volumes of right-turning vehicles or left-turning bicyclists, streets where a lane is added on the right-hand side (such as a freeway off-ramp), or other scenarios where it would allow for favorable alignment to connect to other bicycle facilities [1].
Why	Left-sided bicycle lanes improve visibility of bicyclists by placing them on the driver's side, minimize potential conflicts with vehicles in on-street parking opening doors, and reduce potential conflicts with bus stops or loading zones located along the right-side of the street [1].
How	More information can be found in NACTO's Urban Bikeway Design Guide [1], *Section 9C.04* of the MMUTCD [3], *Section 12.12.10* of MDOT's Road Design Manual [4], and MDOT's Pavement Marking Standards [5].
Key References	**1) Contra-Flow Bike Lanes (NACTO – 2018)** **2) Bicycle Facilities and the Manual on Uniform Traffic Control Devices (FHWA)** **3) Michigan MUTCD (MDOT - 2011)** **4) Road Design Manual (MDOT)** **5) Pavement Markings (MDOT)**

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	Better	No Difference	Better	Medium

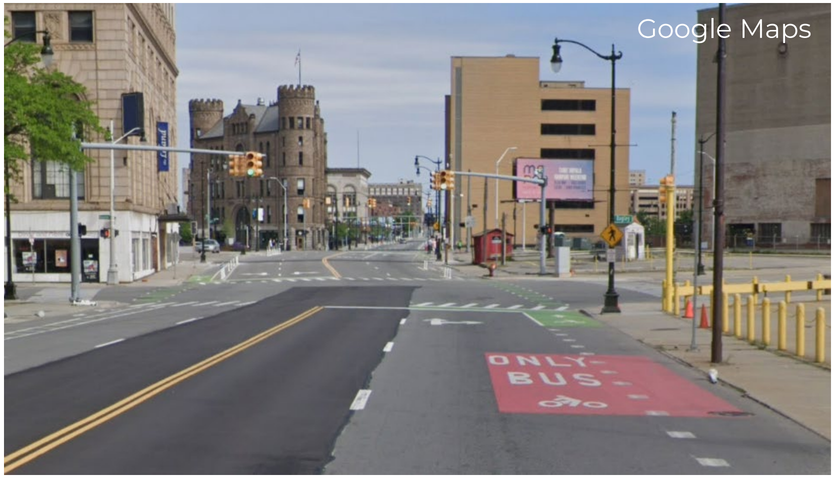
Separated Bicycle Lanes

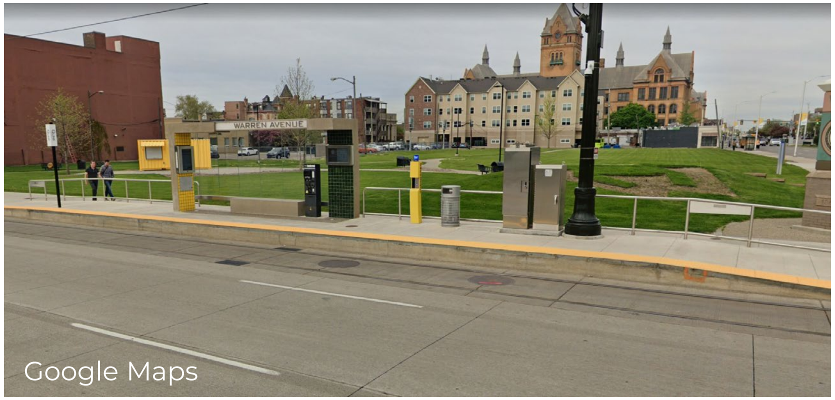
What	Separated bicycle lanes, also known as “cycle tracks” or “protected bicycle lanes”, are exclusive bicycle facilities located either within or adjacent to a roadway and are physically separated from vehicles via a vertical element [1]. Separated bicycle lanes can operate either as one-way or two-way facilities [1]. The vertical element separation can be provided by delineator posts, bollards, concrete barriers, raised medians, raised lanes, planters, parking stops, or parked cars [1].
Where	Separated bicycle lanes can be implemented along urban corridors with a variety of characteristics in order to serve a broad range of potential road users [1]. The FHWA supports a flexible design process through a context sensitive approach which considers the available options for separation as well as accommodating driveways, transit stops, intersections, parking and loading zones [1].
Why	Separated bicycle lanes can help to organize all traffic modes into designated space, reduce pedestrian crossing distances, and decrease “leapfrogging” behavior between buses and bicyclists [1]. Research has demonstrated reductions in total traffic crashes [1]. While crashes involving bicyclists have increased at locations where separated bicycle lanes were implemented, these increases were offset by increases in bicycle volumes associated with the new facilities [1].
How	More information can be found in FHWA’s Separated Bike Lane Planning and Design Guide [1], *Section 9C.04* of the MMUTCD [2], *Section 12.12.10* of MDOT’s Road Design Manual [3], and MDOT’s Pavement Marking Standards [4].
Key Reference s	1) Separated Bike Lane Planning and Design Guide (FHWA – 2015) 2) Michigan MUTCD (MDOT - 2011) 3) Road Design Manual (MDOT) 4) Pavement Markings (MDOT)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Better	Better	Better	High

Transit Accommodation

What	Highway agencies must maintain streets which share space with transit routes through Michigan [1]. There are specific design concepts or elements which can be applied to all roadways which carry transit vehicles [1]. It should be noted that FHWA published an interim approval (IA-22) which allows for the optional use of red-colored pavement for transit lanes [2].
Where	Transit routes are incorporated within a broad range of roadway environments, and include a variety of transit amenities, surrounding land uses, ridership, and vehicle types [1].
Why	Appropriate accommodation of these transit routes into the right-of-way can help to ensure that transit riders can use the system safety and comfortably [1].
How	More information can be found in MDOT's M2D2 Guidebook [1], FHWA's Interim Approval for Optional Use of Red-Colored Pavement for Transit Lanes [2], NACTO's Transit Street Design Guide [3], FTA's Manual on Pedestrian and Bicycle Connections to Transit [4], FHWA's Pedestrian Safety Guide for Transit Agencies [5], and TCRP's Guidelines for Providing Access to Public Transportation Stations [6].
Key Reference s	1) M2D2 Guidebook (MDOT - 2019) 2) Interim Approval (IA-22) for Optional Use of Red-Colored Pavement for Transit Lanes (FHWA 2019) 3) Transit Street Design Guide (NACTO – 2018) 4) Manual on Pedestrian and Bicycle Connections to Transit (FTA – 2017) 5) Pedestrian Safety Guide for Transit Agencies (FHWA – 2008) 6) Guidelines for Providing Access to Public Transportation Stations (TCRP – 2015)





Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Better	Better	Better	Better	Better	Better	High

Bicycle Wayfinding

What	Bicycle wayfinding is provided by a system of comprehensive signing and pavement markings intended to guide bicyclists along preferred bicycle routes [1]. Signs are generally placed at intersections, key locations or other decision points along the route [1]. It should be noted that FHWA published an interim approval (IA-15) for the optional use of an alternative design for the U.S. Bicycle Route (M1-9) Sign in 2012 [2].
Where	Wayfinding should be considered along streets or bicycle facilities which are incorporated into the bicycle network [1]. Signs can be used to help direct users to destinations such as on-street bikeways, commercial areas, public transit, schools, parks or trails, hospitals, as well as other community destinations [1].
Why	Wayfinding can help to familiarize bicyclists with the network, identify the optimal route, reduce the barrier to entry for some bicyclists, estimate the time to destinations, and indicate to drivers they are traveling along a route where bicycles are likely present [1].
How	More information can be found in NACTO's Urban Bikeway Design Guide [1], FHWA's Interim Approval for the Optional use of an Alternative Design for the U.S. Bicycle Route (M1-9) Sign [2], FHWA's Bicycle Facilities and the MUTCD [4], and *Sections 9B.20 and 9B.21* of the MMUTCD [5], and AASHTO's Guide for the Development of Bicycle Facilities [6].
Key References	1) Bike Route Wayfinding Signage and Markings System (NACTO – 2018) 2) Interim Approval for the Optional Use of an Alternative Design for the U.S. Bicycle Route (M1-9) Sign (FHWA – 2012) 3) U.S. Bicycle Routes in Michigan (MDOT) 4) Bicycle Facilities and the Manual on Uniform Traffic Control Devices (FHWA – 2017) 5) Michigan MUTCD (MDOT - 2011) 6) Guide for the Development of Bicycle Facilities (AASHTO – 2012)

Potential Safety Impacts			Potential Mobility Impacts			Cost Estimate
Motor Vehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
No Difference	No Difference	Better	No Difference	No Difference	Better	Low

Appendix 8:

MSU Draft of *Tools for the Planning and Design of Pedestrian Crossing Enhancements*

Tools for the Planning and Design of Pedestrian Crossing Enhancements

Source: Google Maps

MDOT
Michigan Department of Transportation

June 2021

Overview

Toward Zero Deaths®
National Strategy on Highway Safety

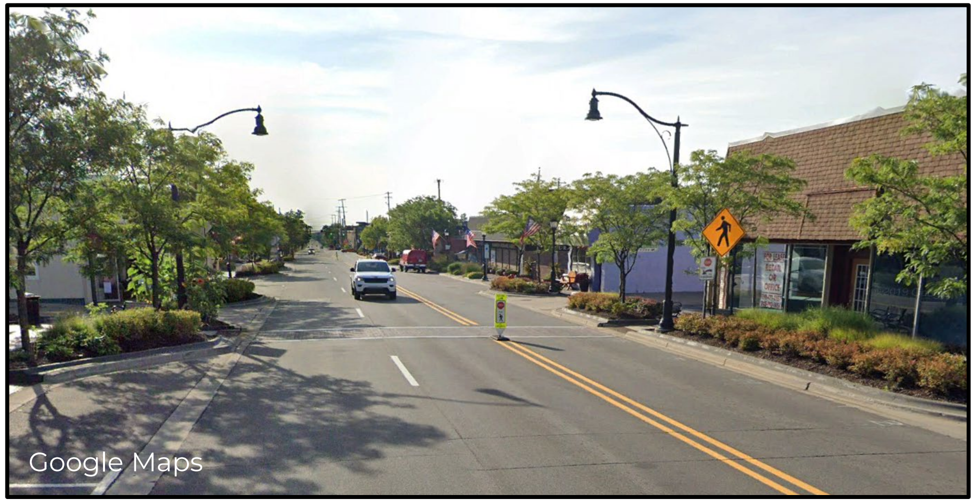
As a part of MDOT's mission to provide ***"the highest quality integrated transportation services for economic benefit and improved quality of life"***, the department is working to create better, safer roadways for all users. The design and planning of roadways which supports the safety and mobility of non-motorized road users represents a key opportunity towards achieving the state's ultimate ***Towards Zero Death*** vision. While pedestrians must regularly cross the state's highway network in order to reach their destination, it is important to recognize such pedestrian crossing movements can represent a considerable safety risk [1]. These risks may be mitigated by the application of appropriate engineering treatments to enhance the level of awareness of pedestrians by motorists.

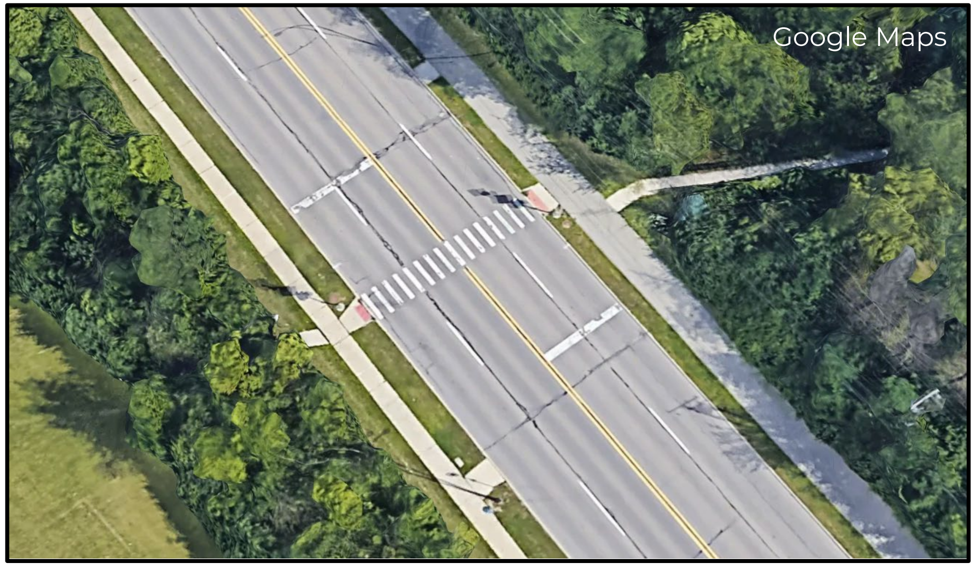
Pedestrians must cross Michigan's highway network at both controlled and uncontrolled locations. Uncontrolled pedestrian crossings "occur where sidewalks or designated walkways intersect a roadway at a location where no traffic control (i.e. traffic signal or STOP sign) is present" [2]. Uncontrolled crossings occur at both intersections and non-intersection locations (also referred to as "midblock") [2]. FHWA's *Achieving Multimodal Networks* notes the underlying principle that regardless of their location, pedestrian crossings should always "provide a safe and comfortable locations to cross the street" [3].

Midblock crossings are intended to "provide convenient locations for pedestrians to cross" roadways where the nearest controlled intersection crossings require "substantial out-of-direction travel" [4]. Given that pedestrians will often take the most direct and convenient path to their destination when intersections are spaced relatively far apart, such midblock crossings represent an important component of a transportation system which protects pedestrians and encourages walking [4]. However, the decision to install marked crosswalks, including enhanced crossing treatments, represents a complex decision-making process which should incorporate a broad range of engineering factors. The MMUTCD states that "crosswalk lines should not be used indiscriminately" and includes guidance to perform an engineering study before installing a marked crossing at an uncontrolled location [5].

This document is intended provide an overview of the planning and design process for implementing pedestrian crossing enhancements in Michigan, including both national and state-specific resources. The document is structured in four sections (shown right) which include information specific to distinct steps of the planning and design process. It should be noted that while this tool does not directly describe pedestrian crossing requirements per the Americans with Disabilities Act (ADA), any potential improvements must meet these requirements [6].

1. **Site Identification**
2. **Site Analysis**
3. **Treatment Selection**
4. **Design and Planning Resources**





Structure

1	Site Identification	Pedestrian Crossing Risk Analysis	State and Local Safety Plans	Gather Stakeholder and Public Input
2	Site Analysis	Collect Site-Specific Characteristics	Conduct Detailed Crash Analysis	Road Safety Audits
3	Treatment Selection	Elements of Pedestrian Crossings	Michigan's Standard Crossing Treatments	Criteria for Selecting Crossing Treatments
4	Design and Planning Resources	Funding Sources	Michigan-Specific Technical Resources	National Technical Resources

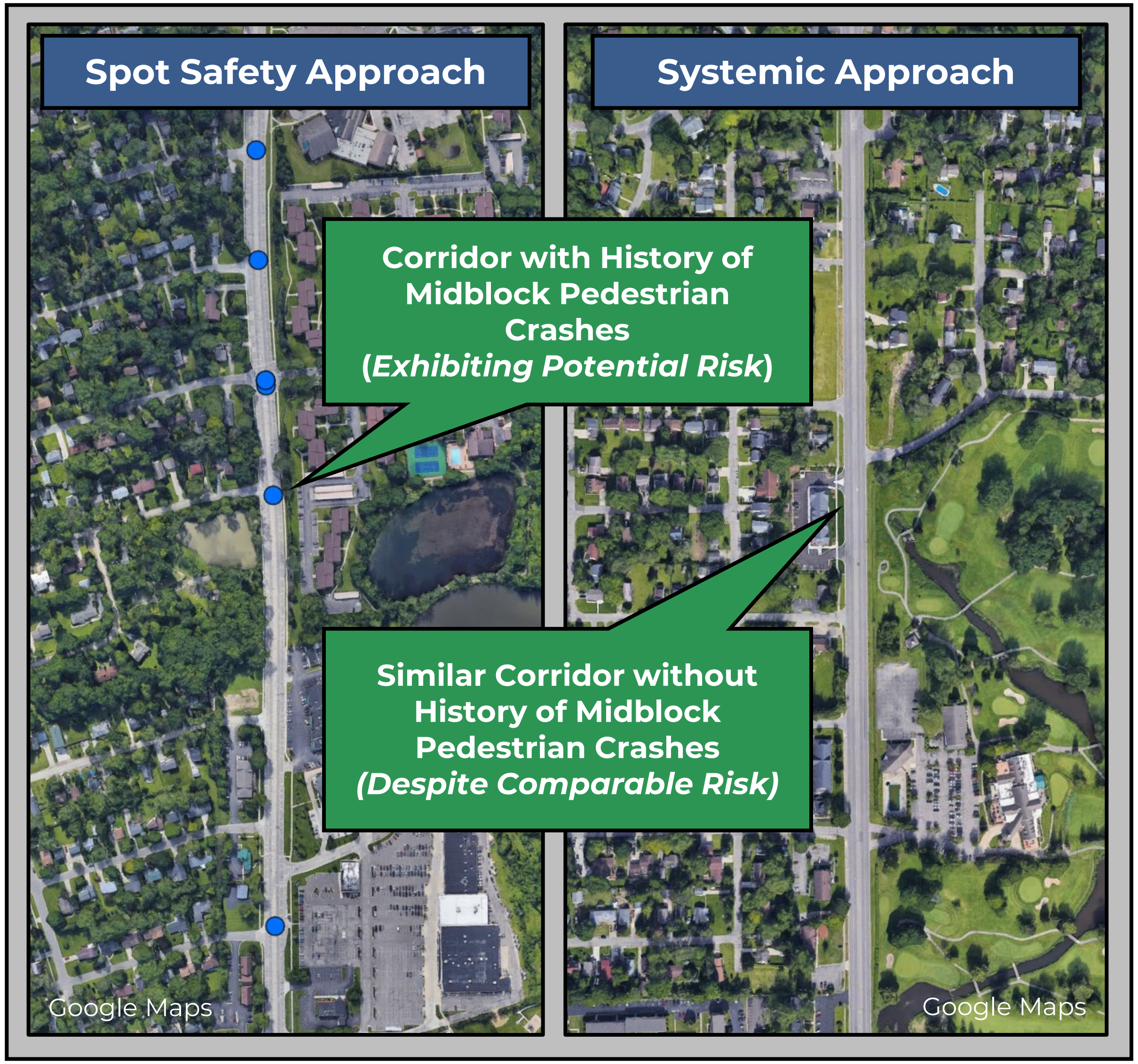
Pedestrian Crossing Risk Analysis

1 Site Identification

In order to maximize the cost-effectiveness of the safety funding available to implement pedestrian crossing enhancements, it is necessary to prioritize locations along the highway network which pose potentially increased relative risks to crossing pedestrians. There are several data-driven approaches which can be employed to screen the highway network in order to identify and prioritize sites. This includes both **spot safety** and **systemic safety** approaches to assessing pedestrian crossing risks (*visualized right*).

Traditional **spot safety** analysis methods represent a reactive approach which involves mapping historical crash data (typically three to five years) to visually identify locations or corridors which have experienced a cluster of pedestrian-involved collisions. **Systemic safety** analysis methods represent a proactive approach to identifying pedestrian crash risk based upon the roadway characteristics of specific locations or corridors (as opposed to crash history). Given the rare and random nature of pedestrian-involved collisions, many roadways may present considerable crossing-related safety risk without exhibiting a history of such crashes. The systemic approach relies on an aggregated analysis of pedestrian-involved crash data to identify roadways with characteristics which are associated with increased relative pedestrian crash risk.

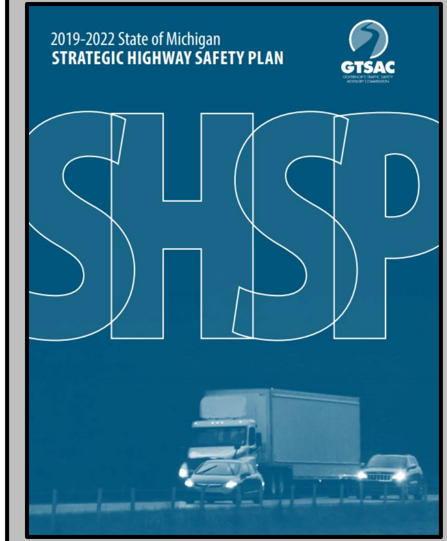
Historical traffic crash data in Michigan can be obtained from the **Michigan Office of Highway Safety Planning's *Michigan Traffic Crash Facts* website** [7] or **Michigan Technological University's *Roadsoft* tool** [8]. Additional information specific to identifying potential locations using the spot safety approach can be found in ***FHWA's Guidebook on Identification of High Pedestrian Crash Locations*** [9]. Additional information specific to identifying potential locations using the systemic safety approach can be found in **NCHRP Research Report 893: *Systemic Pedestrian Safety Analysis*** [10].

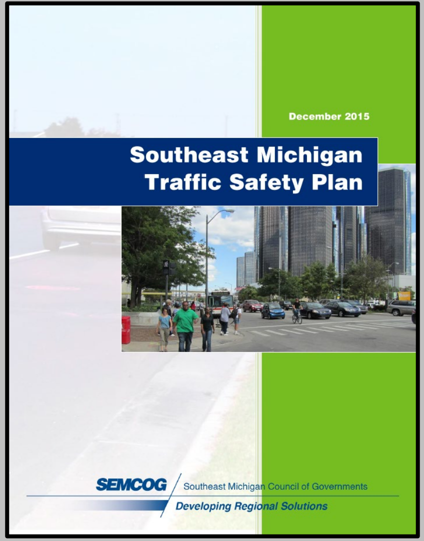


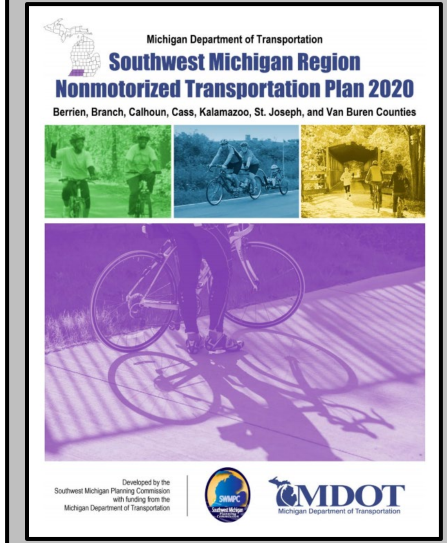
State and Local Safety Plans

MDOT, regional planning organizations, local highway agencies, and other stakeholders have previously partnered to develop a series of safety plans intended to help guide future investment in Michigan's transportation network. These plans can provide a valuable resource in identifying both countermeasure strategies as well as potential locations for improvement.

Name of Plan	Description
2012 State of Michigan Strategic Highway Safety Plan [11]	Statewide plan to coordinate efforts towards Michigan's long-term Towards Zero Death vision. Pedestrian and bicycle safety is a focus within the plan, including the strategy to "promote the use of best practices when designing and operating facilities".
Regional Traffic Safety Plans	Regional planning organizations partnered with MDOT in order to develop traffic safety plans intended to guide While each region has taken a unique approach to their plan, they generally include a benchmark of current safety performance, completed and planned projects, and potential strategies for improvement.
Regional Non-Motorized Investment Plans	Each region within Michigan has developed a plan intended to help coordinate future investment in the non-motorized transportation system. While each region has taken a unique approach to their plan, they generally include a benchmark of current safety performance, completed and planned projects, and potential strategies for improvement.
Michigan Pedestrian and Bicycle Safety Action Plan 2019-2022 [12]	The plan is a living document developed by the *Pedestrian and Bicycle Safety Action Team* which represents a compilation of the activities and initiatives to address pedestrian and bicycle safety in Michigan.





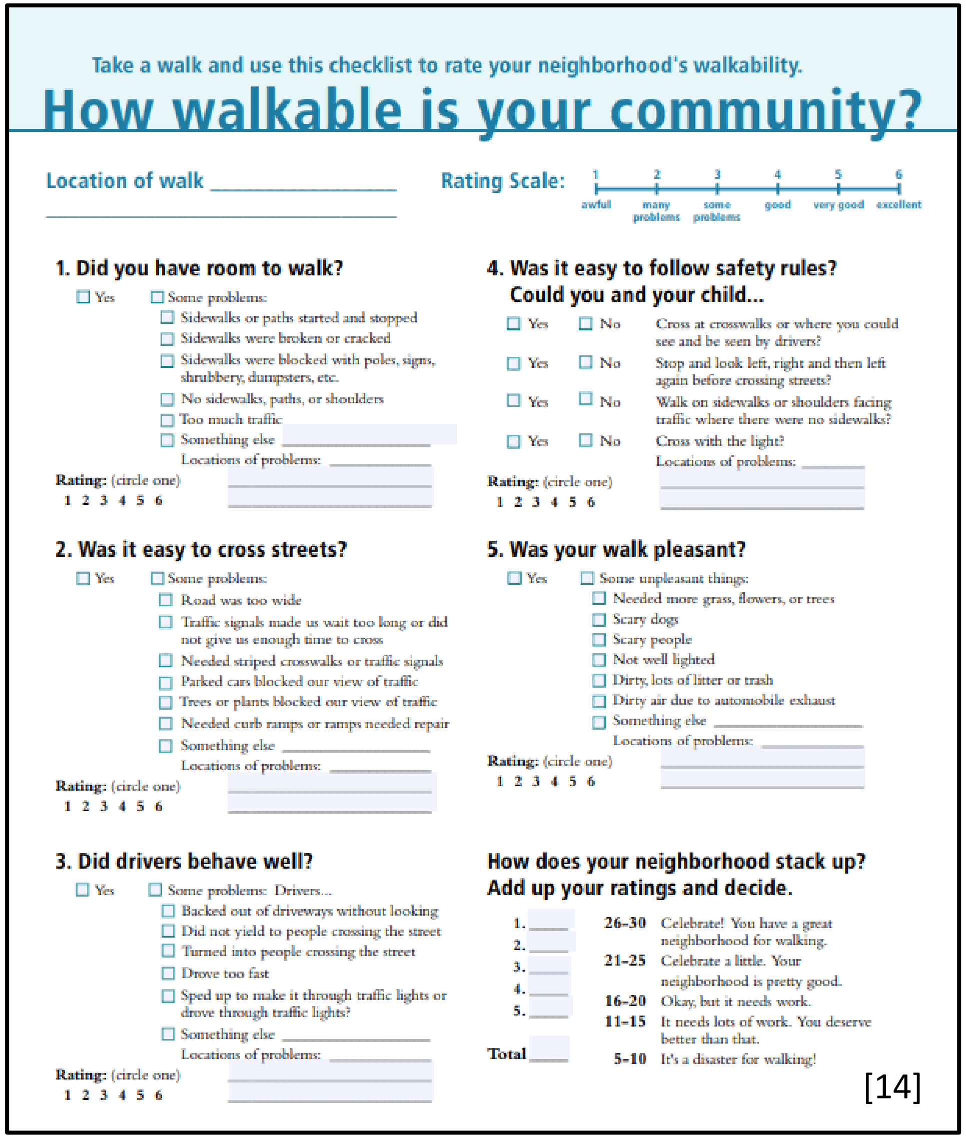


Gather Stakeholder and Public Input

Stakeholder and public input is a key component of developing successful transportation safety improvements [13]. This input is particularly important when identifying and prioritizing sites for potential crossing enhancements given the limited availability of pedestrian demand data as well as the rare and random nature of pedestrian-involved collisions. While MDOT and local agencies have processes in place for receiving and responding to input from the public, proactively seeking input specific to pedestrian safety represents a considerable opportunity as a part of identifying sites for potential crossing enhancements.

Walkability audits [14] represent one potential method of engaging stakeholders and raising general awareness related to pedestrian safety. Community leaders can engage residents within specific neighborhoods to conduct an audit using a checklist (*shown right*) to assess the street network within a local area. The results of the audit can be used to identify locations with the potential for improvement.

For more information on engaging the public in transportation decision-making refer to ***FHWA's Public Involvement Techniques for Transportation Decisionmaking*** [15]. Additionally, the FHWA provides guidance for the use of virtual public involvement tools which can help to increase meaningful public involvement in planning and project development [16]. MDOT also maintains guidance for virtual public involvement in public involvement procedures [17].


Take a walk and use this checklist to rate your neighborhood's walkability.

How walkable is your community?

Location of walk ______________

Rating Scale: 1 awful, 2 many problems, 3 some problems, 4 good, 5 very good, 6 excellent

1. Did you have room to walk?
☐ Yes ☐ Some problems:
☐ Sidewalks or paths started and stopped
☐ Sidewalks were broken or cracked
☐ Sidewalks were blocked with poles, signs, shrubbery, dumpsters, etc.
☐ No sidewalks, paths, or shoulders
☐ Too much traffic
☐ Something else ______
Locations of problems: ______
Rating: (circle one) 1 2 3 4 5 6

2. Was it easy to cross streets?
☐ Yes ☐ Some problems:
☐ Road was too wide
☐ Traffic signals made us wait too long or did not give us enough time to cross
☐ Needed striped crosswalks or traffic signals
☐ Parked cars blocked our view of traffic
☐ Trees or plants blocked our view of traffic
☐ Needed curb ramps or ramps needed repair
☐ Something else ______
Locations of problems: ______
Rating: (circle one) 1 2 3 4 5 6

3. Did drivers behave well?
☐ Yes ☐ Some problems: Drivers...
☐ Backed out of driveways without looking
☐ Did not yield to people crossing the street
☐ Turned into people crossing the street
☐ Drove too fast
☐ Sped up to make it through traffic lights or drove through traffic lights?
☐ Something else ______
Locations of problems: ______
Rating: (circle one) 1 2 3 4 5 6

4. Was it easy to follow safety rules? Could you and your child...
☐ Yes ☐ No Cross at crosswalks or where you could see and be seen by drivers?
☐ Yes ☐ No Stop and look left, right and then left again before crossing streets?
☐ Yes ☐ No Walk on sidewalks or shoulders facing traffic where there were no sidewalks?
☐ Yes ☐ No Cross with the light?
Locations of problems: ______
Rating: (circle one) 1 2 3 4 5 6

5. Was your walk pleasant?
☐ Yes ☐ Some unpleasant things:
☐ Needed more grass, flowers, or trees
☐ Scary dogs
☐ Scary people
☐ Not well lighted
☐ Dirty, lots of litter or trash
☐ Dirty air due to automobile exhaust
☐ Something else ______
Locations of problems: ______
Rating: (circle one) 1 2 3 4 5 6

How does your neighborhood stack up? Add up your ratings and decide.
1. ___
2. ___
3. ___
4. ___
5. ___
Total ___

26-30 Celebrate! You have a great neighborhood for walking.
21-25 Celebrate a little. Your neighborhood is pretty good.
16-20 Okay, but it needs work.
11-15 It needs lots of work. You deserve better than that.
5-10 It's a disaster for walking!

[14]

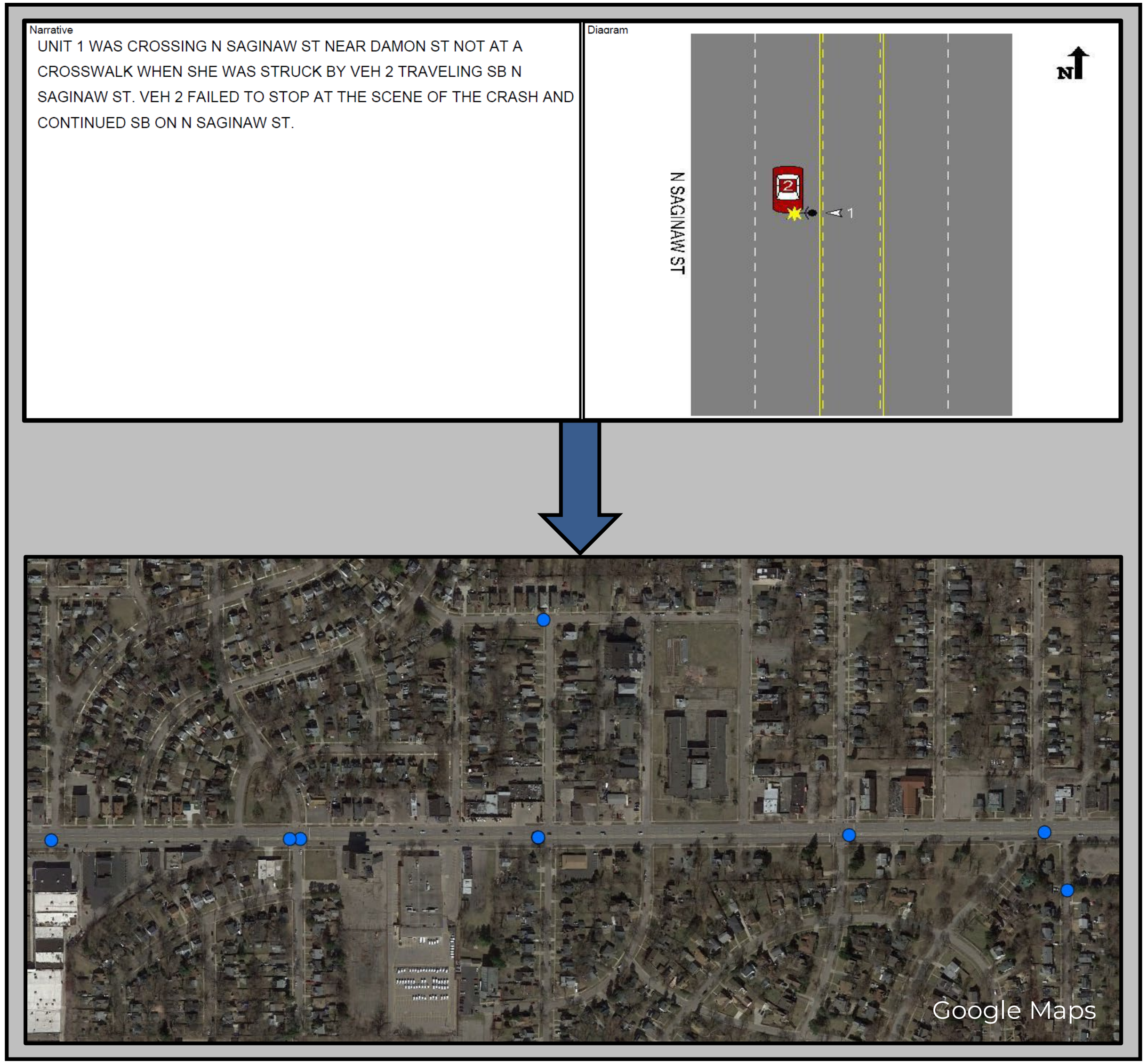
Collect Site-Specific Characteristics

The planning and design of pedestrian crossing enhancements represents a complex decision-making process which should incorporate a broad range of engineering factors. Site-specific characteristics which can be collected to conduct a more detailed evaluation of sites identified via the network screening process outlined in **Section 1** are summarized in the table below. See ***Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways*** [18] for more detailed information related to collecting site-specific characteristics.

Characteristic	Description
Non-Motorized Demand and Behavior Information	Pedestrian and bicycle count data can be collected or may be available from local agencies. For example, SEMCOG maintains **a map of pedestrian and bicycle count data** for locations within Southeast Michigan. Additionally, pedestrian crossing behavior can be observed which may help to identify preferred crossing routes or other site-specific circumstances. Typical characteristics of pedestrians present in the local area (such as children, the elderly, or disabled persons) can also be identified.
Distance to the Nearest Controlled Crossing	The distance to the nearest controlled pedestrian crossing can be obtained by reviewing satellite imagery or as a part of a site visit. This includes marked crosswalks at intersections where through vehicle movements are controlled by traffic control devices (such as a traffic signal, STOP or YIELD signs, or an existing beacon).
Existing Surrounding Non-Motorized Facilities	The presence of existing non-motorized facilities can be collected by visiting the site or reviewing satellite imagery. This could include sidewalk coverage, existing marked crossings, adjacent trails or shared-use paths, bicycle lanes, or other facilities which are specific to non-motorized road users. Connectivity with the surrounding non-motorized transportation network is a key consideration for the planning and design of future crossing enhancements.
Historical Traffic Crash Data	Historical traffic crash data involving non-motorized road users can be obtained from either the **Michigan Office of Highway Safety Planning's *Michigan Traffic Crash Facts* website** [7] or **Michigan Technological University's *Roadsoft* tool** [8].
Vehicular Speed Data	Vehicular speed data to collect could include the posted speed limit of the roadway, observed operating speeds (such as the mean or 85th percentile) of vehicles traveling along the roadway, as well as the design speed of the roadway. It should be noted that the posted speed limit represents a direct input into the treatment selection process outlined in **Section 3**.
Vehicle Traffic Characteristics	The annual average daily traffic (AADT) volume for the roadway can be collected from statewide or local agency resources where available. For example, MDOT maintains a robust **traffic monitoring program** and local agencies may maintain their own resources (such as **SEMCOG's *Traffic Volume Map***). The percentage of trucks can often be obtained from historical traffic count data. There may also be circumstances which require hourly count data is required to conduct traffic studies to determine if minimum warrants are met for specific treatments. Site-specific driver behavior observed in the field may also provide insight when designing future crossing enhancements.
Roadway Cross-Section	The cross-section of the existing roadway, including the total crossing distance, can be obtained by reviewing satellite imagery, design documents, or collected as a part of a site visit. This includes the number of through lanes, the number of exclusive turn lanes, existing medians, shoulders, or other design features such as curb extensions or on-street parking. It should be noted that the number of through lanes represents a direct input into the treatment selection process outlined in **Section 3**.
Sight Distance Considerations	Ensuring that stopping sight distance is available is a key consideration for potential new marked pedestrian crossings. The sight distance at proposed crossings can be collected on all vehicular approaches as a part of a site visit. See **MDOT's *Road Design Manual*** [20] or ***Sight Distance Guidelines*** [21] for more information.
Adjacent Intersection Characteristics	The characteristics of intersections which are adjacent to the proposed crossing can be collected as a part of a site visit. This includes the type of intersection (i.e. signalized, stop-controlled, or a roundabout), marking crossing presence, signal phasing (such as the presence of a leading pedestrian interval) or other signal timing information, as well as adjacent queue lengths which could impact the potential crossing.
Parking Characteristics	The presence of on-street parking can be obtained by reviewing satellite imagery or as a part of a site visit. The site-specific parking characteristics can also be obtained by observing behavior in the field which could potentially impact the design of future pedestrian crossings.
Existing Traffic Control Devices	The presence of existing traffic control devices (such as signs, pavement markings, or electronic devices) along the roadway can be obtained as a part of a site visit.
Existing Pedestrian Design Features	The presence of existing pedestrian design features (such as curb extensions or refuge islands) can be obtained as a part of a site visit.
Lighting	The presence of existing lighting along the roadway (including both vehicle-focused and pedestrian-focused) lighting can be obtained as a part of a site visit.
Surrounding Land Use	The surrounding land use around the roadway and the potential crossing can be obtained by reviewing satellite imagery as well as during a site visit. Specifically, the presence of schools, residential developments, senior care facilities, or certain businesses represent important pedestrian destinations which result in adjacent crossing demand. This general context of the roadway (urban, suburban, rural) also always an important role in the **context sensitive solution** approach employed by MDOT.
Adjacent Transit Stops	The presence of adjacent transit stops is an important consideration when locating potential crossing enhancements. The location of adjacent transit stops can be obtained as a part of a site visit or reviewing routes from the relevant transit authority.
Available Right-of-Way	The available right-of-way impacts the potential design options and can be obtained as a part of reviewing design documents or a site visit. MDOT also maintains **right-of-way maps** which are available as a reference but should be verified by other sources.

Conduct Detailed Crash Analysis

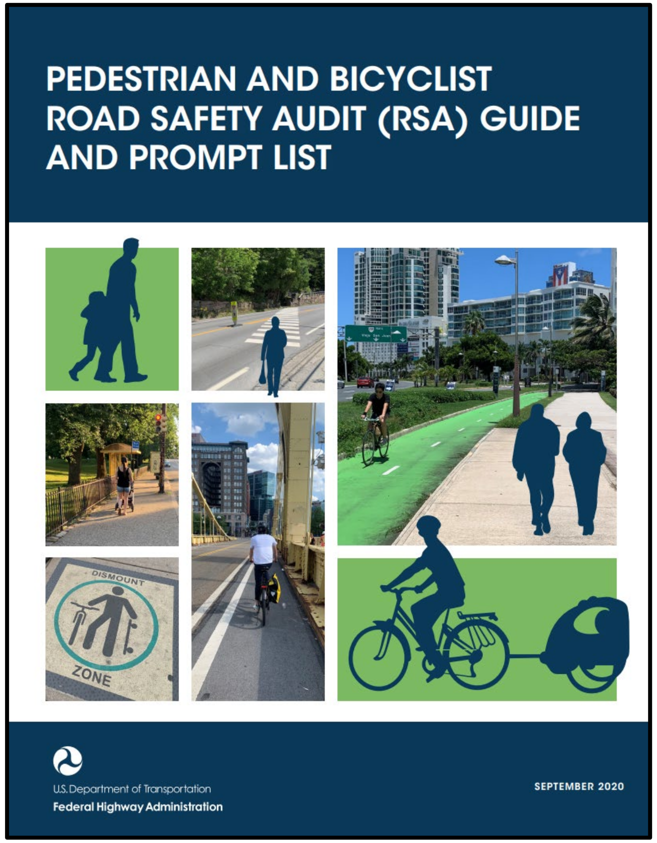
As a part of a site-specific analysis, it can be helpful to conduct a more detailed crash analysis beyond the network screening process outlined in **Section 1** to identify potential safety concerns present along the corridor of interest. This process involves obtaining the **Michigan UD-10 Crash Report Forms** associated with crashes occurring along the corridor. The narrative and diagram included within each report can be reviewed to determine the precise location and circumstances of the collision. This process can include categorizing crashes into groups in order to determine potential trends. The University of North Carolina Highway Safety Research Center has previously developed the ***Pedestrian and Bicycle Crash Analysis Tool*** [22] which includes 12 crash type groups specific to pedestrian-involved crashes which can be applied to this process. **FHWA's PEDSAFE Pedestrian Safety Guide and Countermeasure Selection System** [23] provides detailed guidance related to the causes and potential countermeasures for each crash type. A detailed crash diagram can be developed from this process (*shown right*) which can help to visualize potential patterns.



Road Safety Audits

Road safety audits (RSAs) are a formal safety performance examination of an existing or future road or bridge project by an independent, multi-disciplinary RSA team. RSAs contribute to the MDOT's *Towards Zero Death* vision by providing an unbiased assessment of a highway location in an effort to identify potential safety issues and solutions. RSAs can be conducted at any stage of the project development process and includes eight steps (shown below). It is important to note that RSAs consider the needs of all road users, including pedestrians and bicyclists. RSA teams are generally comprised of trained MDOT employees as independent reviewers and facilitated by a contracted consultant. The audit team focuses in four specific areas, including geometry, operations, road users, and the environment.

While **MDOT's *Road Safety Audit Guidance*** [24] details the RSA process in Michigan and which identifies projects where audits should be conducted, there are also opportunities conduct RSAs specific to pedestrians and bicyclists. ***FHWA's Pedestrian and Bicyclist Road Safety Audit (RSA) Guide and Prompt List*** [25] includes information to support RSA's which are focused on pedestrians and bicyclists.



1. Identify Project
2. Select RSA Team
3. Conduct Start Up Meeting
4. Perform Field Review(s)
5. Conduct RSA Analysis
6. Present Analysis Findings
7. Prepare Formal Response
8. Incorporate Findings

Elements of Pedestrian Crossings

NCHRP Synthesis 498: *Application of Pedestrian Crossing Treatments for Streets and Highways* [26] developed a list of typical elements which comprise pedestrian crossings, including infrastructure and design features as well as traffic control devices (summarized in the table below). Effective pedestrian crossing enhancements include a combination of these elements which are selected based upon the design scenario, such as the geometric or traffic characteristics of the crossing location. More detailed information on these elements specific to designing pedestrian crossing enhancements within Michigan can be found in ***Best Design Practices for Walking and Bicycling in Michigan*** [27] as well as the **additional resources provided in Section 4**.

Infrastructure and Design Features	Traffic Control Devices
Raised Medians	High-Visibility Crosswalk Markings
Refuge Islands	Advanced Stop/Yield Signs and Bars
Raised Crosswalks	Pedestrian Signal Heads and Countdown Signals
Curb Extensions	Pedestrian Hybrid Beacons (PHBs)
Reduced Corner Radii	Rectangular Rapid-Flashing Beacons (RRFBs)
Road Diets	Overhead or Roadside Mounted Flashing Beacons
Narrow Lane Widths	Pedestrian Only Crossing Phases
Grade Separated Crossings	Leading Pedestrian Intervals (LPIs)
Corridor-Wide Speed Calming	Right-Turn on Red Restrictions
Enhanced Illumination	R1-6 Signs and Gateway Treatments
	Pedestrian Warning Signs
	Parking Restrictions
	In-Pavement Flashing Warning Lights

MDOT's Standard Crossing Treatments

MDOT's crosswalk guidance [18] includes four crossing treatment categories (labeled A through D) which are intended to represent the primary uncontrolled crossing treatments employed by the department for trunkline highways that are appropriate for commonly encountered situations. It is important to recognize that these treatments may not be comprehensive and additional applicable alternative treatments could be available depending on the situation [18]. Criteria for selecting an appropriate treatment type is provided on the following page based upon the roadway configuration at the crossing, traffic volume, and the posted speed limit. While these crossing types are summarized in the table below, see ***Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways*** [18] for more information specific to the selection of the standard crossing treatments.

Crossing Type	Description
A	• Use marked special emphasis crosswalks (See **MDOT PAVE 945 series** [28]) • Use standard pedestrian warning signs (W11-2) and consider the need for advanced warning signs • Consider the use of R1-6 in-street sign gateway treatment (See **R1-6 User Guide** [29]) • If the location is a designated school crossing, the standard school crossing signs should be used (S1-1)
B	• Use marked special emphasis crosswalks (See **MDOT PAVE 945 series** [28]) • Use standard pedestrian warning signs (W11-2) and consider the need for advanced warning signs, including potential dynamic electronic devices • Consider the use of R1-6 in-street signs, including a potential gateway treatment, in low-speed urban settings (See **R1-6 User Guide** [29]) • Consider potential geometric improvements (such as curb extensions or refuge islands) based upon the characteristics of the existing roadway • Consider RRFBs if the criteria is met from the crosswalk guidance [18], and refer to Crossing Type D • If the location is a designated school crossing, the standard school crossing signs should be (S1-1)
C	• When the posted speed limit is greater than or equal to 45 mph, determine if traffic calming measures can be installed to effectively reduce operating speeds in order to reduce the posted speed limit to 40 mph • Evaluate if a raised median could be implemented within the roadway cross-section • If these conditions can be met, refer to **Crossing Type B**. Otherwise, refer to **Crossing Type D**.
D	• Crossing three or more though lanes in a given direction along roadways with a speed limit of 40 mph or more is not suitable for an uncontrolled marked crosswalk • Consider the use of a PHB, pedestrian traffic signal, or grade-separated pedestrian crossing. Refer to the **crosswalk guidance** [18], or the **MMUTCD** [5] for criteria. • Such crossings must consider signal progression, grades, physical constraints, and other engineering-related factors.

Criteria for Selecting Crossing Treatments [18]

Roadway Configuration at the Location of the Crossing Treatment	Number of Lanes Crossed to Reach Refuge	Number of Multiple Threat Lanes*	Roadway ADT and Posted Speed Limit															
			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
Two-Lane (One-Way)	2	1	A	A	A	B	A	A	B	B	A	A	B	B	A	A	B	B
Two-Lane Two-Way Undivided	2	0	A	A	A	B	A	A	B	B	A	A	B	B	A	A	B	B
Three-Lane with Refuge Island **or** Two-Lane with Raised Median	1	0	A	A	A	B	A	A	B	B	A	A	B	B	A	B	B	B
Two-Lane with Center Left-Turn Lane	3	1	A	A	B	B	A	B	B	B	A	B	B	B	A	B	B	B
Four-Lane Two-Way Undivided	4	2	A	B	B	C	A	B	C	C	A	B	C	C	B	B	C	C
Five-Lane with Refuge Island **or** Four Lane with Raised Median	2	2	A	A	B	B	A	B	B	C	A	B	C	C	B	B	C	C
Five-Lane with Center Left-Turn Lane	5	2	A	B	C	C	B	B	C	C	C	C	C	D	C	C	C	C
Six-Lane (with or without Raised Median)	3 - 6	4	A	B	D	D	B	B	D	D	D	D	D	D	D	D	D	D

**Multiple threat lanes represent travel lanes where a pedestrian crossing in front of a stopped or slowed vehicle in an adjacent travel lane could step out in front of a moving vehicle in the same direction*

Funding Sources

Source	Description
Highway Safety Improvement Program (HSIP) [30]	Core federal aid program intended to "achieve a significant reduction in traffic fatalities and serious injuries on all public roads through the implementation of infrastructure-related highway safety improvements" [30]. While there are distinct calls for projects along the state trunkline and locally-owned roadways, the implementation of crossing enhancements are eligible in both programs.
Safe Routes to School (SRTS) [31]	SRTS is "an international movement—and now a federal program—to make it safe, convenient, and fun for children, including those with disabilities, to bicycle and walk to school." The competitive program provides "Major Grants" which include up to $220,000 per school for potential infrastructure improvements. Crossing enhancements are eligible for the program, however, the cost of traffic studies to determine if minimum warrants are met for specific devices can not be funded by the grants.
Transportation Alternatives Program (TAP) [32]	TAP is "a competitive grant program for projects such as bike paths, pedestrian and bicycle safety improvements, and preservation of historic transportation facilities that enhance Michigan's intermodal transportation system and provide safe alternative transportation options". The elements of crossing enhancements summarized in Section 3 are eligible as long as they conform with the MMUTCD and AASHTO guidance.

Michigan Resources

Document	Summary of Role in Pedestrian Crossing Planning and Design
Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways [18]	Guidance document which provides a "step-by-step" procedure for identifying the appropriate location and type of pedestrian crossing on Michigan's trunkline highways.
Michigan MUTCD [5]	The "official manual for the uniform system of traffic control devices for the State of Michigan" which provides the standards for traffic control devices in the state, including devices related to pedestrian crossing treatments.
Electronic Traffic Control Device Guidelines [33]	Document which is intended to "provide guidelines and recommendations for the use and operation of electronic traffic control devices in the state of Michigan", including the use of PHBs and RRFBs.
Road Design Manual [20]	The department's road design manual includes guidance to integrate pedestrian crossings into the design process.
Pavement Marking Standards [28]	The department's pavement marking standards include details for marked crosswalks in several environments.
Traffic Signal Details [34]	The department's traffic signal special details include drawings specific to PHBs and RRFBs.
Best Design Practices for Walking and Bicycling in Michigan [27]	Toolbox of design practices which have been shown to improve safety and/or mobility for non-motorized road users.
Traffic Sign Design, Placement, and Application Guidelines [35]	Guidance document intended to "provide additional guidance to designers on the appropriate design, placement, and application" of signing, including signs related to pedestrian crossings.

National Resources

Reference	Summary
NCHRP Synthesis 498: Application of Pedestrian Crossing Treatments for Streets and Highways [26]	The synthesis document summarizes the commonly used pedestrian crossing treatments used in the United States, including policies and practices employed by highway agencies towards prioritizing treatment locations.
FHWA's Step Studio [13]	Comprehensive set of tools to identify appropriate countermeasures to improve pedestrian safety developed as a part of FHWA's Every Day Counts Round 5 (EDC-5) initiative.
FHWA's Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations [2]	Guidance document developed by the FHWA which provides information to support the installation of engineering countermeasures specific to uncontrolled pedestrian crossing locations.
AASHTO's Guide for the Planning, Design, and Operation of Pedestrian Facilities [36]	Document which provides guidance specific to the planning, design and operation of pedestrian facilities along both streets and highways.
NCHRP Research Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments [1]	Research report which quantities the safety benefits of RRFBs, PHBs, pedestrian refuge islands, and advanced YIELD or STOP markings and signs.
FHWA's Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations [37]	Research report which evaluated pedestrian crash history at uncontrolled locations with both marked and unmarked crosswalks. The document includes recommendations to improve safety at uncontrolled locations.
FHWA's Pedestrian Safety Guide and Countermeasures Selection System (PEDSAFE) [38]	Tool developed by the FHWA which provides practitioners with the latest information specific to improving safety and mobility for pedestrians.
TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings [39]	Report which summarizes the findings of a research project intended to recommend engineering treatments for pedestrian crossings of high-volume, high-speed roadways at unsignalized intersections. The report also includes recommended modifications to the MUTCD pedestrian signal warrant.

Reference List

1. Zeeger, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N.J. Thirsk, C. Lyon, B. Persaud, J. Zeeger, E. Ferguson, and R. Van Houton (2017). NCHRP Research Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments. National Academies of Sciences, Washington, D.C.
2. Blackburn, L., C. Zeeger, and K. Brookshire (2018). Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations. Federal Highway Administration, Washington, D.C.
3. Federal Highway Administration (2016). Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts. Washington, D.C.
4. Institute of Transportation Engineers (2010). Designing Walkable Urban Throughfares: A Context Sensitive Approach.
5. Michigan Department of Transportation (2013). Michigan Manual on Uniform Traffic Control Devices.
6. United States Department of Justice Civil Rights Division. Information and Technical Assistance on the Americans with Disabilities Act. Retrieved June 2021 from: https://www.ada.gov/
7. Michigan Office of Highway Safety Planning (2021). Michigan Traffic Crash Facts. Retrieved June 2021 from: https://www.michigantrafficcrashfacts.org/
8. Michigan Technological University. Roadsoft. Retrieved June 2021 from: https://www.roadsoft.org/
9. Fitzpatrick, K., R. Avelar, and S. Turner (2018). Guidebook on Identification of High Pedestrian Crash Locations. Federal Highway Administration, FHWA-HRT-17-106.
10. Thomas, L., L. Sandt, C. Zegeer, W. Kumfer, K. Lang, B. Lan, Z. Horowitiz, A. Butsick, J. Toole, and R.J. Schneider (2018). NCHRP Research Report 893: Systemic Pedestrian Safety Analysis. The National Academies of Sciences, Transportation Research Board.
11. Governor's Traffic Safety Commission (2019). 2019-2022 State of Michigan Strategic Highway Safety Plan.
12. Michigan Pedestrian and Bicycle Safety Action Team (2018). Michigan Pedestrian and Bicycle Safety Action Plan 2019-2022.
13. Federal Highway Administration. STEP Studio: Tools for Selecting and Implementing Countermeasures for Improving Pedestrian Crossing Safety. Retrieved June 2021 from: https://safety.fhwa.dot.gov/ped_bike/step/resources/docs/step_studio.pdf
14. National Highway Traffic Safety Administration. Walkability Checklist. Retrieved June 2021 from: https://www.nhtsa.gov/sites/nhtsa.gov/files/walkingchecklist.pdf
15. Federal Highway Administration (2015). Public Involvement Techniques for Transportation Decisionmaking – 2015 Update. Retrieved June 2021 from: https://www.fhwa.dot.gov/planning/public_involvement/publications/pi_techniques/fhwahep15044.pdf
16. Federal Highway Administration (2020). Virtual Public Involvement. Retrieved June 2021 from: https://www.fhwa.dot.gov/planning/public_involvement/vpi/
17. Michigan Department of Transportation. Inclusion of Virtual Public Involvement (VPI) in Michigan Department of Transportation's Public Involvement Procedures. Retrieved June 2021 from: https://www.michigan.gov/documents/mdot/Guidance_on_Inclusion_of_Virtual_Public_Involvement_704413_7.pdf
18. Michigan Department of Transportation (2020). Guidance for Installation of Pedestrian Crosswalks on Michigan State Trunkline Highways.
19. Michigan Department of Transportation. Traffic and Safety/Standards and Special Details – Pedestrian/Bicyclist. Retrieved June 2021 from: https://mdotjboss.state.mi.us/TSSD/getCategoryDocuments.htm?categoryPrjNumbers=1403862&category=Pedestrian/Bicyclist
20. Michigan Department of Transportation. Road Design Manual. Retrieved June 2021 from: https://mdotjboss.state.mi.us/stdplan/englishroadmanual.htm
21. Michigan Department of Transportation (2015). Sight Distance Guidelines. Retrieved June 2021 from: https://mdotjboss.state.mi.us/TSSD/getTSDocument.htm?docGuid=7608e140-5def-4ad2-90c9-40e4abb822a5&fileName=mdot_sight_distance_guidelines.pdf
22. Pedestrian and Bicycle Information Center. Pedestrian and Bicycle Crash Analysis Tool (PBCAT). Retrieved June 2021 from: https://www.pedbikeinfo.org/pbcat_us/index.cfm
23. Federal Highway Administration. PEDSAFE: Selecting Improvements for Pedestrians. Retrieved June 2021 from: http://www.pedbikesafe.org/pedsafe/guide_analysis.cfm#crashtypeanalysis
24. Michigan Department of Transportation (2019). Road Safety Audit Guidance. Retrieved June 2021 from: https://mdotjboss.state.mi.us/TSSD/getTSDocument.htm?docGuid=2b81405d-38a4-4c52-b08a-28051f01af3c&fileName=10241.pdf
25. Federal Highway Administration (2020). Pedestrian and Bicyclist Road Safety Audit (RSA) Guide and Prompt List. Retrieved June 2021 from: https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa20042.pdf
26. Thomas, L., N.J. Thirsk, C.V. Zegeer (2016). NCHRP Synthesis 498: Application of Pedestrian Crossing Treatments for Streets and Highways. The National Academies of Sciences, Transportation Research Board.
27. Michigan Department of Transportation. Best Design Practices for Walking and Bicycling in Michigan.
28. Michigan Department of Transportation. Traffic and Safety/Standards and Special Details – Pavement Markings. Retrieved June 2021 from: https://mdotjboss.state.mi.us/TSSD/getCategoryDocuments.htm?categoryPrjNumbers=1403856,1403857,1403858,1403859,1403860&category=Pavement%20Markings
29. Western Michigan University and T.Y. Lin International (2018). User Guide for R1-6 Gateway Treatment for Pedestrian Crossings. Michigan Department of Transportation.
30. Federal Highway Administration (2021). Highway Safety Improvement Program. Retrieved June 2021 from: https://safety.fhwa.dot.gov/hsip/
31. Michigan Fitness Foundation (2021). About Safe Routes to School. Retrieved June 2021 from: https://saferoutesmichigan.org/
32. Michigan Department of Transportation. Transportation Alternatives Program. Retrieved June 2021 from: https://www.michigan.gov/mdot/0,4616,7-151-9621_17216_18231---,00.html
33. Michigan Department of Transportation (2021). Electronic Traffic Control Device Guidelines.
34. Michigan Department of Transportation. Traffic and Safety/Standards and Special Details – Traffic Signals. Retrieved June 2021 from: https://mdotjboss.state.mi.us/TSSD/getCategoryDocuments.htm?categoryPrjNumbers=1403877,1403878,1403879,1403880,1403881,1403882,1403883,1403884,1403885&category=Traffic%20Signals
35. Michigan Department of Transportation (2021). Traffic Sign Design, Placement, and Application Guidelines.
36. American Association of State Highway and Transportation Officials (2004). Guide for the Planning, Design, and Operation of Pedestrian Facilities.
37. C.V. Zeeger, J.R. Stewart, H.H. Huang, P.A. Lagerway, J. Feaganes, and B.J. Campbell (2005). Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines. Washington, D.C.
38. Federal Highway Administration. Pedestrian Safety Guide and Countermeasures Selection System (PEDSAFE). Retrieved March 2021 from: http://www.pedbikesafe.org/pedsafe/
39. Fitzpatrick, K., S. Turner, M. Brewer, P. Carlson, B. Ullman, N. Trout, E.S. Park, J. Whitacre, N. Lalani, and D. Lord (2006). TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. National Academies of Sciences, Washington, D.C.