Michigan Department of Transportation

Crash Countermeasure and Mobility Effects

Final Report

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1. Introduction

The Michigan Department of Transportation (MDOT) has undertaken several initiatives to reduce crashes on its roadway network. In 2009, there were 2,201 reported crashes involving pedestrians and 866 reported crashes involving bicyclists in Michigan. In that year, 140 pedestrians and 21 bicyclists were killed in motor vehicle crashes. Bicyclists and pedestrians are legal roadway users. While bicyclists and pedestrians represented approximately 5% of all persons involved in crashes in Michigan in 2009, they represented 13% of fatalities. This disproportionately high fatality rate among bicyclists and pedestrians is of concern to MDOT.

MDOT would like to identify roadway improvements that would reduce the frequency and severity of crashes involving pedestrians and bicyclists. They also are concerned that some measures to protect pedestrians and bicyclists might result in unacceptable delays to other roadway users. This report provides a review of policies and design standards currently in use by MDOT that affect roadway improvements, as well as an analysis of best practices from across the country that have been shown to reduce crashes without affecting system mobility.

The purpose of this report is twofold. First, roadway improvements known as countermeasures are reviewed to determine their potential to reduce the frequency and severity of pedestrian and bicycle crashes. This review includes countermeasures currently in use by state and local agencies and those that are currently being studied. These countermeasures constitute best practices that have been implemented around the country. Some of these countermeasures are already being implemented in Michigan at varying levels of jurisdiction.

Second, the countermeasures were reviewed to determine the impacts they have on automobile mobility in addition to their potential to reduce crashes. Included is a discussion of vehicular and nonmotorized mobility to illustrate the relationship between mobility and the factors of speed, access, and delay.

2. Crash Countermeasures

A number of crash countermeasures are under development in one or more areas of the country and may not yet have data on potential crash reductions. The National Cooperative Highway Research Program (NCHRP) and other research programs have conducted studies to evaluate safety factors affecting pedestrians and bicyclists. Effectiveness of many of these countermeasures often is expressed using surrogate data on safety, including observed yielding by motorists to pedestrians or recorded compliance with traffic safety laws, reductions in speed, or other operational characteristics that have the potential to improve safety.

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

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

The Federal Highway Administration (FHWA) *Desktop Reference for Crash Reduction Factors* provides a summary of information on countermeasures collected from various studies.[1] The effectiveness of these improvements is measured as a percent change in crashes that resulted following the implementation of a countermeasure. The *Desktop Reference* provides information on measures specifically targeted at reducing pedestrian crashes.

In 2009, the FHWA launched the Crash Modification Factors Clearinghouse, an online repository and search tool designed to provide access to studies that have been published on various types of improvements intended to reduce crashes. The clearinghouse contains the countermeasures discussed below and provides information on alternative treatments or modifications to some countermeasures based on local application. Additionally, the clearinghouse provides direct access to studies that analyze the results of the countermeasure. These are provided with a confidence level rating, as many of the papers are independently prepared and may not have been peer-reviewed.

A concurrent MDOT research effort is underway to evaluate pedestrian safety countermeasures, which includes a literature review of signage and traffic control measures. These countermeasures are summarized in *Evaluating Pedestrian Safety Improvements: Signage and Traffic Control Countermeasures* and are included in this report.[2]

2.1. Intersection and Signal Improvements

The majority of crashes involving pedestrians and bicyclists occur at intersections. As such, there is a significant focus on intersection safety improvements.

2.1.1. ***Pedestrian signal heads*** should be included at all traffic signals in urbanized areas. ***Pedestrian countdown signals*** are now considered to be the standard by the MUTCD for new construction or when signal heads are replaced. Pedestrian countdown signals display the amount of available crossing time in seconds to complement the flashing DON'T WALK phases. When studied by FHWA, pedestrian countdown signals added to existing signalized intersections resulted in a 25% reduction in crashes[1] and increased the number of successful pedestrian crossings (pedestrians crossing before the flashing DON'T WALK phase ends) by 12%.[3] Adding pedestrian signals to an existing traffic signal costs approximately \$20,000 - \$40,000 for a four-leg intersection.[4] Adding pedestrian countdown signals typically cost between \$10,000 to \$15,000 per intersection to replace all pedestrian signal heads to as little as \$800 per intersection to add a countdown clock to each existing pedestrian signal head.[5] Pedestrian countdown signals have no effect on motorist delay if the signal timing is maintained. The countdown phase of the pedestrian signal may terminate either at the end of a green or yellow phase or in the middle of the yellow phase, depending on the clearance interval for motorists. More information about pedestrian countdown signal timing is provided in the MUTCD.

2.1.2. ***Installing pedestrian push buttons that confirm press*** have been shown to increase push button use by pedestrians and bicyclists, as well as increase the number of pedestrians and bicyclists that wait for the WALK phase rather than crossing in violation of the signal. These push buttons provide feedback to the user in the form of a beep or message, instilling confidence that the button works. These should be considered anywhere pedestrian-activated signals are used. The push buttons also reduced the number of pedestrians trapped in the roadway.[6] The cost of this treatment can range from $400 to $1,000.[5]

2.1.3. ***Exclusive left turns*** provide automobiles with an exclusive turning phase at signalized intersection, which can help to reduce conflicts between pedestrians and motorists. Exclusive left turns help to clear turning vehicles from the intersection before the pedestrian signal (leading) or at the end of the signal cycle (lagging).

2.1.4. ***The flashing yellow arrow*** is a change in the appearance of the signal phase for permitted left turns whereby a flashing arrow, accompanied with a regulatory sign posted at the signal, denotes that left turns are permitted for motorists but that motorists still must yield to oncoming traffic. The only costs associated with this countermeasure are the costs of altering the existing traffic signal phasing to display a flashing yellow arrow in place of a green circle and sign installation. Crash rates at intersections where the flashing yellow arrow was tested were lower than intersections with the conventional circular green.[7] Intersections with pedestrian crashes caused by left-turning vehicles should be prioritized for this measure.

2.1.5. Providing a ***leading pedestrian interval*** (LPI) provides pedestrians with 3 to 4 seconds of advance crossing time by releasing them during an all-red phase ahead of the adjacent green. By placing pedestrians in the crosswalk in advance of the green, it increases their visibility and decreases conflicts between motorists and pedestrians. Right turns on red (RTOR) should be prohibited where the LPI is installed. Research showed that where the LPI was tested, pedestrians were less likely to surrender their right of way to turning vehicles and there was decreased conflict between motorists and pedestrians crossing at the beginning of the WALK phase.[8] LPIs should be considered where turning vehicles pose a danger to pedestrians, particularly where right turns have been shown to cause pedestrian conflicts or crashes. Similar to the flashing yellow arrow, this countermeasure requires no capital investment if a pedestrian signal head is already present. Only a re-timing of the signal phases would be required.

2.1.6. Installing a ***midblock signal*** at uncontrolled pedestrian crossings with high levels of pedestrian traffic or at transit stops may also reduce crashes. This type of improvement is significant; while it is not be feasible at every pedestrian crossing, a pedestrian signal explicitly identifies the right-of-way that is assigned to each direction of travel. Pedestrian signals were shown to produce a 20-50% reduction in crashes with motorist compliance rates 95-99%. When accompanied with a pedestrian push button, the use of midblock signals resulted in pedestrians crossing against the light 40% of the time when wait times were 2 minutes, 20% with wait times between 1 and 2 minutes, and almost no violations when the pedestrian wait time was 30 seconds or less. This study also showed that fewer pedestrians were trapped in the roadway when midblock signals were implemented.[9] Appropriate locations for a midblock signal depend upon pedestrian and motor vehicle traffic volumes and speeds. Warrants for installing a signal at a midblock location can be found in the Manual on Uniform Traffic Control Devices (MUTCD). The minimum threshold for pedestrians per hour is 75, but depends on vehicular volumes as well. The cost of a midblock signal ranges from $50,000 - $75,000.[5]

2.1.7. At unsignalized locations, a ***pedestrian hybrid beacon***, formerly known as a HAWK, consists of two red lights above a yellow light that are dark when the beacon is not active. When activated, the beacon enters a series of signal phases to indicate that a pedestrian is crossing. In Arizona and St. Petersburg, Florida, when tested along with the recommended warning and regulatory signs, the hybrid beacon found a 69% reduction in all crashes and a compliance rate of motorists yielding to pedestrians between 94-99%.[10] The cost of pedestrian hybrid beacons varies based on the size of the roadway, but typically are less expensive than the cost of fully signalizing an intersection.

Roadway agencies in Minnesota and Washington, DC have reported installation costs between $45,000 and $80,000. The Metropolitan Transportation Commission estimates the cost between $75,000 and $100,000, with $2,000 annual costs for operations.

Pedestrian hybrid beacons can be less disruptive to motor vehicle throughput than a midblock signal and can be installed in some locations where midblock signals cannot. Beacons that are installed within a system of coordinated signals can be configured to maintain that coordination. The MUTCD presents guidelines for when a pedestrian hybrid beacon could be used. The recommendations are a function of vehicular volumes and speeds, the crossing distance, and pedestrian volumes. The lowest threshold of pedestrian volumes is 20 per hour. Pedestrian hybrid beacons may be applicable at midblock crossings.

Additionally, FHWA has given interim approval to install pedestrian hybrid beacons at low volume intersections where a full signal is not warranted. Additional design guidance is available in the MUTCD. MDOT currently is reviewing these placement guidelines.

2.1.8. Adding a ***pedestrian-only phase*** to an existing signal identifies right-of-way for pedestrians, and as a result was shown to reduce pedestrian crashes by 34%.[1] This also is referred to as a pedestrian scramble phase. A pedestrian-only phase introduces a new phase to the overall signal cycle during which only pedestrians have the right-of-way and motor vehicle traffic is stopped in all directions. During this phase, pedestrians may cross in any direction across the intersection, including diagonally. A study of pedestrian-only phases in Toronto and Calgary found them to have significant increases in motor vehicle delay.[11] Pedestrian-only phases should be limited to intersections where pedestrian volumes are higher than vehicular volumes, and where a significant percentage of pedestrians would make diagonal crossings. In such cases, the increase in motorist delay may be balanced by a decrease in pedestrian delay.

2.1.9. Changing the ***placement of signal heads*** can improve pedestrian safety by increasing visibility of traffic control devices to motorists. Surrogate data was collected on the effectiveness of placing traffic signal heads on mast arms or in a box span configuration. This was shown to increase driver visibility of traffic signals and reduce red light running, which is a frequently identified driver action prior to crashes.[1] The cost of relocating signal heads varies based on the arrangement of existing signals, the placement of mast arms, and the number of signal heads that require relocation.

2.1.10. ***Roundabouts*** are an alternative intersection design that may improve pedestrian safety. The *FHWA Roundabout Technical Summary* details the aspects and implementation of roundabouts as a crash countermeasure at roadway intersections. Installing a roundabout in place of a stop-controlled or signalized intersection slows down all vehicles in lieu of requiring vehicles to take turns stopping at intersection approaches. In three separate studies reviewed in the technical summary, installation of roundabouts at intersections showed an overall decrease in all types of crashes by 35%, injury crashes by 76% and fatal crashes by 89%.[12] In a separate study, the occurrence of pedestrian crashes was shown to be reduced by 36%, which was attributed to the design of the roundabout, as the number of lanes pedestrians must cross at one time was reduced.[13]

Additional research was conducted about the accessibility implications and how roundabouts affect pedestrians with vision disabilities. A follow-up study by the FHWA, *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*, discusses how to address designs in a manner that does not limit access to pedestrians with vision disabilities. The study found that at single-lane roundabouts, visually impaired pedestrians experienced delays similar to those at similar signalized intersections. However, these results were attributed to low vehicle speeds and high yielding rates to the pedestrian. At roundabouts that allow higher speeds and/or where vehicles are not yielding at crosswalks, visually impaired pedestrians may experience higher delays. The study also found multi-lane roundabouts to be inaccessible by visually impaired pedestrians without the provision of additional crossing treatments such as a pedestrian hybrid beacon or raised crosswalk. Additional studies are underway to assess the impacts of using rectangular rapid flashing beacons (RRFB) at crosswalks at multilane roundabouts.

Roundabouts generally were shown to decrease or have no major impact on overall motorist delay, as roundabouts typically reduce the frequency with which vehicles must come to a complete stop. Roundabouts typically can provide intersection capacity greater than stop-controlled intersections and in some cases are comparable to signalized intersections. Single lane roundabouts can accommodate approximately 26,000 vehicles per day; multi-lane roundabouts can handle as many as 50,000 vehicles per day.[12] For intersections with volumes exceeding 50,000 vehicles per day, a signalized intersection may be preferred. Construction of a roundabout at an intersection ranges between $250,000 - $500,000 as a retrofit, but is comparable to an unsignalized intersection when done as part of roadway construction, and may cost less than constructing a signalized intersection.[14]

While 20 or 30-year projections may suggest a need for a two-lane roundabout, it would be appropriate to install a single-lane roundabout to handle current traffic volumes while acquiring the necessary right-of-way for a multilane roundabout to accommodate the future traffic volumes if and when they are met.[14]

2.1.11. ***Advance yield/stop markings*** at midblock crosswalks can help reduce crashes at multilane crosswalks where crossing pedestrians may not be seen by motorists approaching in adjacent lanes. The advance yield/stop markings (yield is the law in Michigan) are placed in advance of the crosswalk and have been shown to increase yielding distance by a motorist, which helps reduce conflicts.[15]

2.1.12. At a signalized intersection, ***advance stop bars*** may also reduce conflicts with pedestrians at intersection crosswalks. This was shown to reduce the occurrence of motorists stopping in the crosswalk from 25% to 7%,[16] and reduce the occurrence of right-turn-on-red violations.[17] The costs of advance yield markings and stop bars are minimal, roughly $200 to $500 per location, depending in the width of the street and the material used for the markings.[5]

2.1.13. Construction of an ***overpass or underpass*** as an alternative to providing a pedestrian crossing significantly reduces nonmotorized crashes. Crashes were reduced in the range of 60-95% among all studies surveyed. However, they are very expensive to construct and their implementation often does not eliminate pedestrians from crossing the road at grade. This is due in part to the dramatic increase in the overall distance a pedestrian often must travel as a result of the need for the facility to meet ADA slope requirements. Overpasses and underpasses typically exceed $500,000 in cost and may be as much as $2-3 million, depending on the constraints at the crossing.[18]

2.2. Roadway Improvements

Roadway improvements are changes to the traveled way including paving materials, pavement markings, changes to lane widths, number of lanes, intersection geometrics, horizontal or vertical deflection, or changes to on-street parking. Also included are infrastructure improvements provided outside the traveled way, including shoulders, sidewalks, and shared use paths.

2.2.1. When ***sidewalks*** are added to a roadway, the number of pedestrian crashes ~~is~~ reduced by 88%, while adding shoulders reduced pedestrian crashes by 70%.[19] These reductions were the result of eliminating crashes that involve pedestrians walking along the roadway. Sidewalks vary in price based on width, but a typical, 5-foot wide sidewalk costs between $55 and $90 per linear foot.[20]

2.2.2. Providing ***roadway illumination*** is one of the clearest ways to improve pedestrian safety at night without affecting motorist delay. More simply, improving roadway illumination at intersections was shown to help reduce crashes involving all modes, likely those associated with low light conditions, by 42% to 78%.[1] Roadway illumination can improve both bicyclist and pedestrian safety. Particular attention should be paid to roadway illumination where bicyclists and pedestrians are expected, both along the roadway and at crossings. An increasing number of communities are using LED lights for roadway lamps. The City of Los Angeles began a project in 2009 to convert its lamps to LED lights and projected the cost to be roughly $400 per fixture.[21] While LED lamps generally carry a higher cost than other materials, they have a longer life and therefore reduce the associated maintenance costs.

2.2.3. Reduction in the number of lanes on a roadway is referred to as a ***road diet***. Standard four-lane to three-lane road diets in various studies have been shown to reduce total crashes by 14% to 49%.[22] Road diets often result in lower speeds and shorter pedestrian crossings. Motorist delay impacts are minimal at daily volumes less than 15,000 vehicles per day. Road diets can be implemented without affecting automobile capacity for traffic volumes as high as up to 15,000 vehicles per day. Road diets may be effective at higher volumes as well; however a study would need to be conducted to determine the impacts. Traffic patterns will determine whether a road diet would be applicable. For instance, a roadway with many right turns would experience more delay than one with primarily through traffic. The cost of road diets is no different than conventional pavement markings required as part of roadway resurfacing. If a roadway is converted as part of a resurfacing project, the cost is similar to the cost of restriping the road with its original configuration. Otherwise a road diet would require grinding out existing pavement markings and installing new markings. Installation of bike lanes and pavement markings as part of a road diet typically cost less than $5,000 per mile.

2.2.4. In recent studies, ***marked crosswalks*** have been shown to have significant reductions in pedestrian crashes under certain conditions. In Zegeer, et al. (2005), crash data were compared for marked and unmarked crosswalks in two-lane and multilane roadways, on roadways with and without medians, and roadways with varying levels of average daily traffic. The study calculated pedestrian crashes per million crossings to normalize crash data across several cities with various levels of pedestrian traffic at crossings. On roadways with three or more lanes, no median and more than 15,000 vehicles per day, marked crosswalks were shown to have 4.9 times fewer crashes per million crossings than unmarked crosswalks. On roadways with three or more lanes with medians and more than 15,000 vehicles per day, marked crosswalks were shown to have 4.3 times fewer crashes than unmarked crosswalks. On multilane roadways with no medians and between 12,000 and 15,000 vehicles per day, marked crosswalks were shown to have 4.2 times fewer crashes; for roadways less than 12,000 vehicles per day, the difference in crashes was shown to be not statistically significant.

Marked crosswalks range in price from $400 to $1200 per crossing, depending on the style of crosswalk and pavement marking material.[4] Less expensive designs (transverse lines) and materials (paint) typically are less visible and have shorter life spans than thermoplastic pavement markings and continental “ladder style” crosswalk markings. Highly visible continental style crosswalk markings are

recommended at midblock and uncontrolled intersection locations.

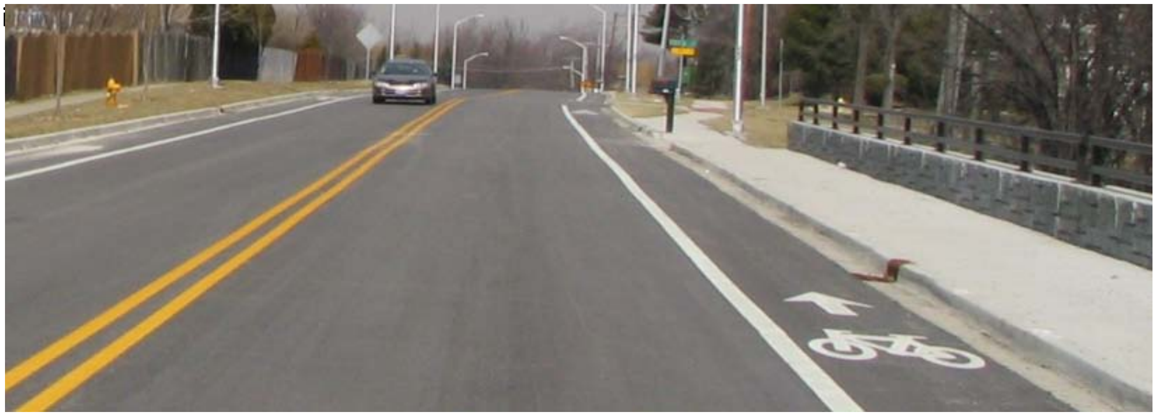
2.2.5. Installation of a continuous, ***raised median*** was shown to reduce all crashes by 40%.[23] At unsignalized intersections, pedestrian crashes were shown to be reduced by 69%. Crashes were reduced by 46% when installed at marked crosswalks, 29% at unmarked crosswalks, and an average reduction in pedestrian crashes of 25% for all intersection locations.[1] Raised medians may cost anywhere from $150 to $300 per linear foot.[4]

2.2.6. ***Pedestrian refuge islands*** are areas of the roadway where medians or curbs are constructed to protect pedestrians at crossings, allowing them to cross one lane or group of lanes at a time. They differ from medians in that they are not continuous, but are short and installed at a pedestrian crossing. Installation of median refuge islands on multilane roadways reduced pedestrian crashes by 56%.[1]

2.2.7. ***Pork chop islands***, also known as corner turning islands, consist of a wedge-shaped curb constructed between a channelized right-turn lane and through lanes at an intersection. Similar to pedestrian refuge islands, these can reduce the total crossing length and provide a pedestrian refuge at intersections. According to FHWA, pork chop islands reduce pedestrian crashes by 29%. Pedestrian refuge islands typically cost between $6,000 and $40,000, while pork chop islands can range from $15,000 to $200,000 depending on the size and reconstruction needs of the intersection.[5]

2.2.8. ***Modifying on-street parking*** is another countermeasure that has been studied for its potential to reduce crashes. Angled or diagonal parking is not permitted on trunk-line highways. Section 14.41.05 of the Michigan Design Manual states that the typical standard width of trunk line roadways is four lanes, which may result in on-street parking being eliminated in order to accommodate future traffic. However, if a mutual agreement is reached between the Department and the municipality that four lanes are not needed and the on-street parking lanes are not required to accommodate future traffic growth, improvements to existing on-street parking may be considered to address access, mobility, and safety needs. ***Reverse-angle or rear-in diagonal parking*** changes the configuration for on-street parking so that cars back into a space rather than backing out. A study was conducted to identify the benefits to motorists, and was shown to increase motorist visibility when entering and leaving parking spaces [24]. Crash data were not collected for this study; rather, the review highlighted the effects it has on traffic flow and bicyclist visibility. Reverse-angle parking eliminates the condition where a motorist must back out of a parking space into traffic. This is particularly important where bicyclists are expected on-street. In addition, children are directed back toward the curb when they exit a vehicle, and trunk loading and unloading takes place at the curb. The costs associated with this countermeasure are minimal.

2.2.9. The installation of ***bike Lanes*** was shown to reduce bicycle crashes by 50%.[25] Bike lanes have shown an increase in bicycling behaviors that are attributed with increased safety,



the occurrence of adult bicyclists riding on sidewalks, a particular hazard for bicycle crashes. Bike lanes are most appropriate on streets with greater than 3,000 average daily traffic and a posted speed limit between 25 mph and 35 mph.

2.2.10. At speeds higher than 35 mph or on roadways where greater separation of vehicles and bicyclists is desired, a ***buffered bike lane*** provides additional flexibility.[26] A buffered bike lane is a standard bike lane with a painted buffer between the bike lane and motor vehicle travel lane. The buffer is typically a 3-foot strip demarcated by diagonal hatching. The cost of striping a bike lane on an existing roadway is approximately $5,000 per mile. The cost of a buffered bike lane may cost up to twice as much as a typical bike lane due to the additional material required. The National Association of City Transportation Officials currently does not provide design guidance with respect to ADT. With respect to posted speed, wide shoulders on trunk line highways with posted speeds of up to 55 mph have been shown to accommodate bicyclists.

2.2.11. A ***marked shared lane*** consists of a through travel lane with a bicycle symbol and a chevron arrow to identify the intended path of a bicyclist in the shared lane. Shared lane markings are primarily used to fill in gaps in a bicycle network, but can also be used to denote streets that are recommended for bicyclists but do not have adequate width for a full bike lane. An example of marked shared lanes used to fill in gaps is where a bike lane must terminate at an intersection to make room for a right-turn lane. A marked shared lane could be used in this case to continue the bike facility through the intersection and suggest the most appropriate positioning for the bicyclist. The marking also communicates to drivers that the travel lane is shared by motorists and bicyclists. When used alongside on-street parking, the shared lane marking is installed at 11 feet or more from the curb to identify the intended riding location for bicyclists, with the intent of moving cyclists out of the door zone. When studied, shared lane markings were found to increase bicyclist visibility to motorists, and reduce the occurrence of wrong-way riding and bicycle riding on the sidewalk, all of which were attributed to help reduce the occurrence of crashes.[27]

Shared Lane Marking: sdotblog.seattle.com

According to guidance in the MUTCD, shared lane markings may be used on roadways with speed limits of 35 mph or lower, wherever there is inadequate space for an exclusive bike lane, to navigate bicyclists on the intended bicycling path through an intersection, or on any roadway where it may be helpful to remind bicyclists and motorists to share the lane. While shared lane markings do not provide exclusive space for bicyclists like a bike lane, they can be a helpful addition to completing gaps in a bicycle network.

2.2.12. ***Green, high-visibility bike lane*** and crossing treatments also have been studied for the potential to reduce crashes when installed in conflict zones (e.g. near intersections or where motorists and bicyclists must cross paths). This treatment, intended to reduce bicyclist-motorist conflicts, consists of a painted bike lane or crossing treatment. Green, high-visibility bike lanes will be included in the next version of the MUTCD. As such, they were issued interim approval in April 2011 and may be used upon request in bicycle lanes or extensions of bicycle lanes. Where tested, implementation has been shown to improve safety through a variety of surrogate measurements: reduce wrong-way bicycle riding in traffic, reduce bicycle riding on sidewalks, improve stopping behavior, and increase motorist awareness of the presence of bicycle traffic.

Studies reviewing the before-and-after change in signaling, yielding, and conflict avoidance behavior by bicyclists and motorists found an 11% increase in motorist yielding behavior to bikes, a 5% increase in motorist use of turn signals, and a 6% increase in bicyclists scanning the roadway for nearby vehicles when using the green bike lane.[28] Green bike lanes vary in price depending on whether a shared lane marking, bike lane, or high-visibility/green bike lane is installed. Typical prices range from $20,000 to $30,000 per mile, and include pavement markings and warning and regulatory signs as recommended by AASHTO.[21]

Due to the large amount of pavement marking material that is required for a painted bike lane, maintenance on these is typically higher than for symbols, lane lines, and stop bars. As a result, common application in the United States has been for short segments where roadway agencies want to identify areas of potential conflict due to weaving or merging bicycle and automobile traffic.

2.3. Operations and Enforcement

Laws regarding pedestrians and bicyclists are often misunderstood. It is important to know what is expected of them and of motorists when encountering pedestrians and bicyclists, in making improvements for these modes. The following *Pedestrian and Bicyclist Rules and Responsibilities* is a brief summary of the rules and responsibilities of pedestrians and bicyclists according to Michigan laws.

Motorists must yield to pedestrians in crosswalks in the half of the roadway on which the vehicle is traveling. Pedestrians may not, however, leave the curb or sidewalk when it would be impossible for a vehicle to yield in time. Pedestrians may cross outside of a crosswalk, provided that they yield to motorists. At signalized intersections, a pedestrian may not cross on a yellow or red signal and may not cross diagonally unless there is a diagonal crosswalk marked. Where there are sidewalks along a roadway, the pedestrian is required to use the sidewalk and may not be walking along the roadway. Where there are no sidewalks, the pedestrian is required to walk along the shoulder, facing traffic.[29]

The same rules and responsibilities that apply to motorists also apply to bicyclists. This includes yielding to pedestrians in crosswalks and on sidewalks. Bicyclists must obey all traffic signs and signals and signal their turns. Bicyclists may not ride against traffic and are expected to ride to the right with the following exceptions:

- When overtaking or passing another vehicle
- Preparing to turn left
- When conditions make the right-hand edge of the roadway unsafe for bicycling
- In a right-turn lane when the bicyclist intends to continue straight
- On a one-way road with 2 or more lanes, in which case the bicyclist may ride to the far left

Bicyclists may pass between lanes of traffic when passing vehicles, but may not pass on the right of other vehicles, unless in a marked bike lane. Bicyclists are not required to use a bike lane and are permitted to ride no more than two abreast. Bicyclists are also required to use a front light between sunset and sunrise and be equipped with a red reflector on the rear. A lamp emitting a visible red light may be used in addition to the red reflector.

Bicyclists are not required, nor is it recommended that they use the sidewalk; however, they are not prohibited from using sidewalks by state statute. Local laws may differ, particularly in business districts.[31]

2.3.1. ***Prohibiting left-turns*** was shown to reduce pedestrian intersection crashes by up to 10%.[20] While this was shown to reduce pedestrian crashes, such prohibitions typically shift left-turning traffic to other locations, unless the prohibition is done as part of a Michigan Left installation (see section 2.1.3). As an alternative, separating WALK and turn signal phases can reduce crashes 34%.[20]

2.3.2. In areas where pedestrian traffic is anticipated or observed, ***prohibiting right-turn-on-red*** (RTOR) has the potential to reduce conflict between pedestrians and motorists at crosswalks. Prohibiting RTOR may be done at all times or during specific times, and is identified with signs at the intersection. In 2002, research showed that 5% to 15% of all crashes involved pedestrians and that RTOR crashes were only fatal approximately 0.05% of the time. However, this study stated that prohibiting RTOR at signalized intersections with high levels of pedestrian traffic is beneficial to reduce conflict between motorists and pedestrians.[30]

2.3.3. ***Regulatory and warning signs*** at intersections also have the potential to reduce conflict between motorists and pedestrians. Installing signs that remind drivers to yield to pedestrians may increase the number of motorists yielding to crossing pedestrians.[31] Additionally, installing ***signs that warn pedestrians of turning vehicles*** was shown to increase pedestrians looking for turning vehicles when LED signs were installed showing animated eyes during the walk phase. After installation, pedestrians looking for turning vehicles before crossing increased from 3% to 29%, reduced the number of pedestrians who did *not* look for turning vehicles from 17% to 2.5%, and reduced pedestrian conflict with turning motorists from 2.7% to 0.5%.[32] The cost of this countermeasure is between $500 and $800 per pedestrian signal.[5]

2.3.4. Placing ***in-street "Yield to Pedestrian" signs*** in the roadway increases the visibility of crosswalks and reminds motorists of the right of way laws at unsignalized crosswalks. When installed in the center of two-lane roadways, in-street signs were shown to have higher motorist yielding behavior when compared to crosswalk locations on two-lane roadways without in-street signs.[33] The costs of these signs, including installation is less than $300 per sign.[34]

3. Vehicular and Nonmotorized Mobility

3.1. Mobility

The Institute of Transportation Engineers (ITE) defines mobility as "the conditions associated with the ability to travel, such as average speed, delay, congestion levels and availability of modal options," or "the ability of people and goods to move quickly, easily and cheaply to their destination."[35] Mobility is a description of the ease or freedom with which transportation system users can move within the transportation network.

3.2. Speed, Delay and Access

For the purposes of this report, we identify that mobility is a function of speed, access, and delay. Impedance to mobility may be measured as congestion. These factors must be considered when designing a transportation facility. However, although speed traditionally has been the primary factor in determining mobility, it is total travel time, which is a function of speed and delay that provides a better overall measure of mobility than speed alone.

When seeking to maximize mobility for a given mode, pursuing a design that maximizes speed for that mode can create conflicts with other transportation system users and with other modes. Speed creates safety concerns where pedestrians and bicyclists are roadway users. For example, roadways designed for higher speeds, which require greater sight and stopping distances, increase the likelihood of crashes. Crash severity also increases with speed, resulting in an increased likelihood of severe and fatal crashes. Pedestrians and bicyclists, the most vulnerable roadway users, are disproportionately affected by this risk.

Delay is the amount of time experienced by a transportation system user that is greater than the amount of time experienced when traveling between two points without interruption. It is important to note that nonmotorized user delays are just as important as motor vehicle delays. Delay is caused by environmental factors, such as traffic control devices and roadway conditions, or by other transportation system users. In traffic engineering, approach delay is a measure of delay for transportation system users approaching a traffic control device and control delay is the amount of delay experienced as a result of the traffic control device. Minimizing approach delay and control delay can decrease total travel time. Speed has nothing to do with either of these measures.

Access is the ease with which a transportation system user can physically enter and exit the transportation system. The number and frequency of access points varies based on user factors including typical travel speed and length of trip and the land use through which the roadway is traversing. Generally, nonmotorized transportation system users travel at lower speeds and typically travel shorter distances than motorized users, and thus have greater needs for more frequent access to fronting land uses, as well as across roadways. Frequent access points may be desirable for short trips and all nonmotorized travel, but frequent vehicular access points across a sidewalk may be an impediment to nonmotorized travel and access. Finally, it is important to note that almost every motorized trip requires some nonmotorized travel at either end for ultimate accessibility.

The transportation system as a whole should provide mobility to all transportation system users by achieving a design of facilities that allows an appropriate speed for motor vehicle traffic, while maximizing access and minimizing delay for all users. Often, transportation facilities appear to have been designed with the goal in mind to safely maximize speed of only the motorized users, which eventually limits access, mobility, and safety for all. Design speed is therefore a factor that should be selected to maximize safety while providing access and mobility for all roadway users.

4. References

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