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Enhancing Non-motorized Mobility within Construction Zones

FINAL REPORT

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16. Abstract

Acquisition of lanes and sidewalks for construction activities increases congestion and delays and compromises safety. Further, work zones impair access to local businesses, bus stops, nearby facilities, etc., while hindering mobility of pedestrians, cyclists, and emergency responders. The emphasis on non-motorized mobility varies significantly when temporary traffic control management plans are developed for small cities. Due to lack of specific instructions given to contractors and the potential liability issues, contractors tend to completely close access to non-motorized traffic without providing alternate routes or detours. Instead of using a detour, pedestrians and cyclists tend to pass through the construction zone or jaywalk which greatly increases the risk of accidents that could result in injuries and fatalities.

National and international publications, manuals, policies and guidelines were reviewed, and a survey was conducted to synthesize best practices and the minimum requirements of street components. A work zone and mobility management framework, a list of possible alternatives for managing non-motorized mobility within and around a construction zone, and a risk-based decision-support framework for selecting the most viable alternative to manage non-motorized mobility during construction activities were developed. In addition, strategies to manage access to emergency responders, local businesses, commercial and residential buildings, and various other facilities are also presented. Innovative technologies, infrastructure, and construction methods that can be used to enhance safety and mobility are also documented.

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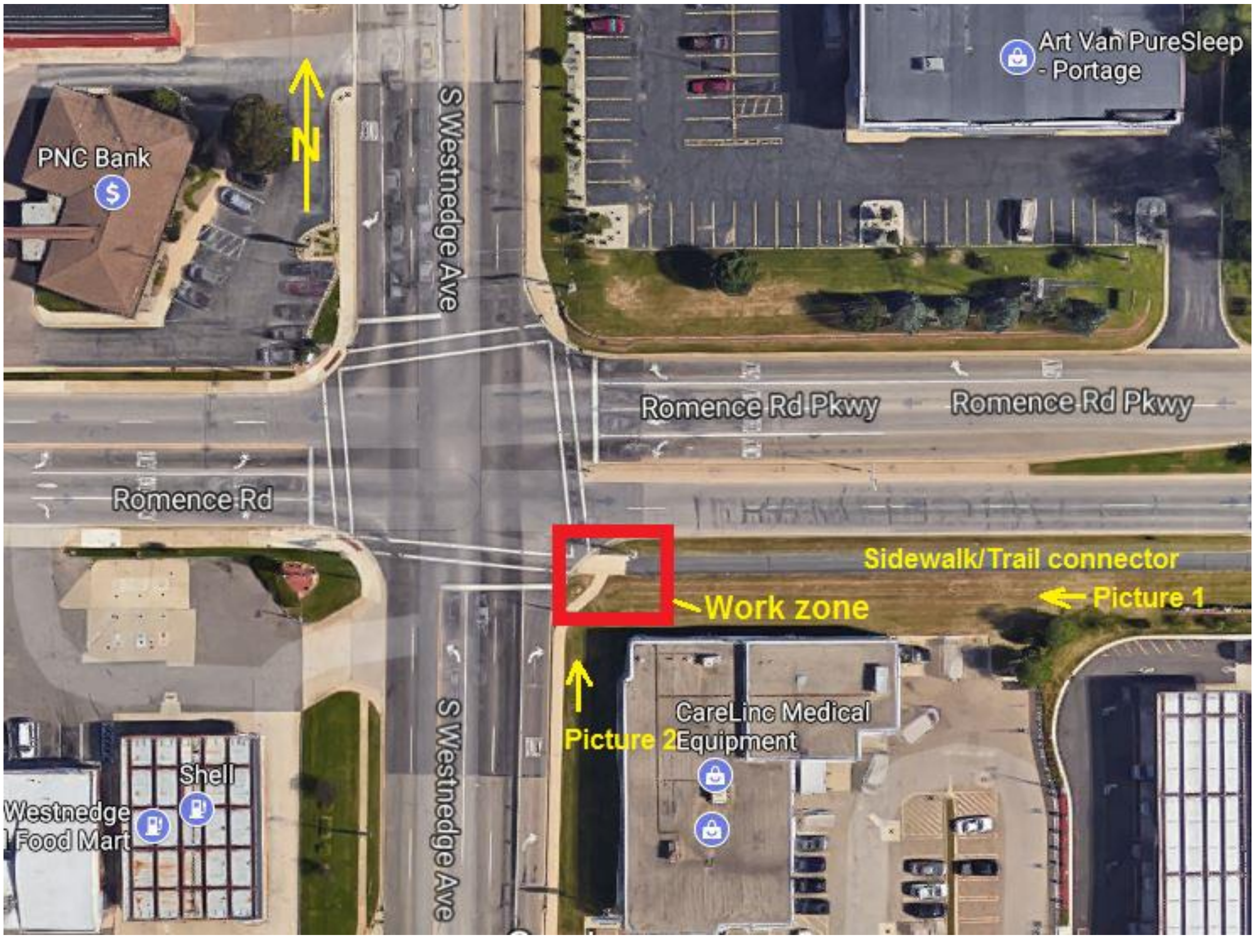
1 INTRODUCTION

1.1 OVERVIEW

Managing motorized vehicles and providing safe routes for non-motorized mobility during construction activities is a challenge. Acquisition of lanes, walkways, etc., for construction activities increases congestion and delays while compromising safety. Further, work zones impair access to local businesses, bus stops, nearby facilities, etc., while hindering mobility of pedestrians, cyclists, and emergency responders. On the other hand, emergency response teams need the fastest access to a location or a facility. The typical practice is to develop temporary traffic control management plans (TTCMPs) for accommodating motorized vehicles within work zones by reducing speed limits and adding safety cautions or detours via designated routes. Recent introduction of the complete street policies encourages non-motorized mobility (Smart Growth America 2013). However, the emphasis on managing non-motorized mobility during construction activities varies significantly. Specifically, less attention is paid for managing non-motorized mobility when the TTCMPs are developed for small cities. Hence, managing non-motorized mobility becomes the contractors' responsibility. Due to lack of specific instructions and the potential liability issues, contractors tend to completely close the access to non-motorized traffic without providing alternate routes within or around work zones.

Figure 1-1a shows a location of the work zone established for utility work at the intersection of Romence Road Parkway and South Westnedge Avenue in Portage, Michigan. The figure shows the location of the sidewalk on Romence Road Parkway and the direction of the pictures taken to document the site conditions. Portage has many trails. The sidewalk on Romence Road Parkway is a trail connector, which is heavily used by the community for accessing the trails for running, jogging, and cycling. This sidewalk is the only non-motorized path on Romence Road Parkway. As shown in Figure 1-1b, the sidewalk is completely closed without providing access to the crosswalk. Figure 1-1c shows that the sidewalk on the northbound of South Westnedge Avenue is also closed before the crosswalk. Temporary crosswalks or alternate routes are not provided. This promotes jaywalking leading to accidents, resulting in fatalities and injuries. Similar situations are observed in other countries, too. Figure 1-2 shows a situation in Berlin, Germany. Vehicle access is provided through a temporary lane that occupies a non-motorized path. With this situation, pedestrians and cyclists pass through the same lane provided for vehicle access increasing the risk of accidents. Figure 1-3 shows the closure of a building front for renovation activities. Due to lack of space available for non-motorized mobility, pedestrians navigate through the space available between traffic lanes and bus/tram shelters while cyclists use traffic lanes. Figure 1-4 shows a complete closure of a street for construction activities in Sofia, Bulgaria. Non-motorized mobility parallel to the street is maintained using protected space between the construction zone and the buildings located along the street (Figure 1-4b). However, a designated path in front of the construction zone for non-motorized traffic is not provided (Figure 1-4c). As a result, pedestrians are exposed to a greater risk due to conflict of their movements with the construction vehicles moving in and out of the construction site (Figure 1-5a and b). To avoid such situations TTCMP needs to include a plan for accommodating construction vehicles. Street parking for building residents is allowed in many cities due to space constraints. Figure 1-5c shows vehicles parked on a street that is parallel to the street closed for construction. This hinders access to emergency responders.

Complete closure of non-motorized facilities without providing safe access promotes conflicts of non-motorized traffic with work zone activities and live traffic. Trespassing and jaywalking are promoted when available non-motorized facilities are closed, and alternate safe routes are not provided within or around construction zones. Trespassing increases the risk of encountering with construction activities and equipment. Jaywalking promotes conflict between non-motorized traffic and live motorized traffic. Accident risk to cyclists increases when adequate space is not provided to navigate and maneuver. In addition to lack of regulated space for non-motorized mobility, presence of uneven surface conditions increases the risk of accidents due to tripping and falling leading to injuries and fatalities.



a) Work zone at the Romence Road and South Westnedge Avenue intersection

b) Closed sidewalk/trail connector on Romence Road Parkway (Picture 1)

c) Closed sidewalk on South Westnedge Avenue (Picture 2)

Figure 1-1. Work zone at the intersection of Romence Road Parkway and S Westnedge Avenue

a) A crane occupying a street

b) A pedestrian standing next to the crane and waiting to pass through the construction zone

c) A cyclist travelling through the lane provided for vehicles

Figure 1-2. Vehicle and non-motorized traffic conflicts due to construction activities in Berlin, Germany

a) A work zone designated for a building renovation project

b) Pedestrians travel between the bus/tram shelter and the traffic lanes

c) Pedestrians navigating through a bus/tram shelter and cyclists using traffic lanes

Figure 1-3. Vehicle and non-motorized traffic conflicts due to construction activities in Bremen, Germany

a) Complete street closure due to construction activities (non-motorized access parallel to the street is provided using the walkways located between the buildings and the work zone)

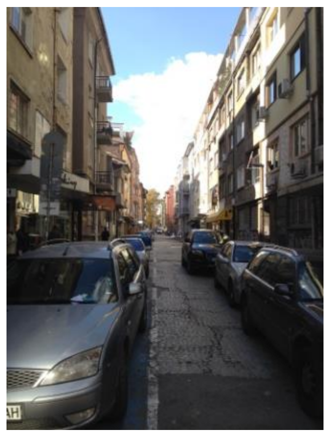
b) Access for non-motorized traffic

c) Unprotected non-motorized access provided in front of the work zone entrance

Figure 1-4. Non-motorized mobility management during construction activities in Sofia, Bulgaria

a) Pedestrians crossing the road in front of the work zone

b) Mobility impact due to construction vehicles



c) Vehicles parked on parallel streets hindering access to emergency responders

Figure 1-5. Impact of construction activities on non-motorized mobility and access to emergency responders

According to the U.S. National Highway Traffic Safety Administration (NHTSA) statistics, 5376 pedestrian and 818 cyclist fatalities were reported during the year 2015 (NHTSA 2017). During the same year 70,000 pedestrians and 45,000 cyclists were injured due to traffic accidents. One hundred and ten (110) pedestrian and cyclist fatalities within the work zones were due to traffic accidents, which is about 1.8% of all pedestrian and cyclist fatalities. When the work zone fatalities are considered, from 2015, pedestrian and cyclist fatalities accounted for 16%. Unfortunately, these rates remain mostly unchanged since 2006 (Table 1-1).

Table 1-1. Injuries and fatalities from 2006 to 2015 (NHTSA 2017)

Year	Injuries (in thousands)		Fatalities			
	Pedestrian	Cyclist	Pedestrian	Cyclist	Within work zones	Pedestrians and cyclists within work zones
2006	61	44	4,795	772	1010	138
2007	70	43	4,699	701	835	118
2008	69	52	4,414	718	720	124
2009	59	51	4,109	628	667	106
2010	70	52	4,302	623	576	81
2011	69	48	4,457	682	587	108
2012	76	49	4,818	734	609	101
2013	66	48	4,779	749	579	106
2014	65	50	4,910	729	669	116
2015	70	45	5,376	818	700	110

According to Shaw et al. (2016) the most common reasons for injuries and fatalities are (i) workers (usually the flaggers) hit by vehicles, (ii) discontinuous or inadequate pedestrian and cyclist accommodation that forces them to use risky alternatives, (iii) visual obstructions such as signs, delineation devices, materials, or equipment that interfere with the ability of drivers, pedestrians, cyclists, or workers to see each other, and (iv) vehicle intrusion into the work zone. The risky pedestrian behavior includes jaywalking, crossing busy highways during peak hours, climbing barriers to cross roads, and walking on the barriers as a short cut or for amusement (Bilton 2012). According to Ellis et al. (2008) providing continuous accommodation through or around a work zone, clear advance warning signage, adequate surface conditions, vehicle speed control, and proper signing and marking of detours and alternate routes reduce the risks.

Most of the studies have focused on pedestrian and cyclist fatalities and injuries due to motor vehicle related accidents. However, a majority of pedestrian injuries have resulted from not properly maintaining sidewalks and other pedestrian facilities (Table 1-2). Similarly, thirteen percent (13%) of injuries to cyclists have resulted from poor roadway or walkway conditions. Seventeen percent (17%) cyclists were injured during 2012 due to falling down from the bicycles. The statistics show the importance of maintaining pedestrian and cyclist facilities in good condition. Even though there is no data related to the condition of pedestrian and cyclist facilities within construction zones and resulting injuries, Figure 1-2a and b highlights the condition of such facilities and the need for identifying infrastructure and technology to maintain such facilities in acceptable condition.

Table 1-2. Sources of injured pedestrian and bicyclist in the U.S. (NHTSA 2017)

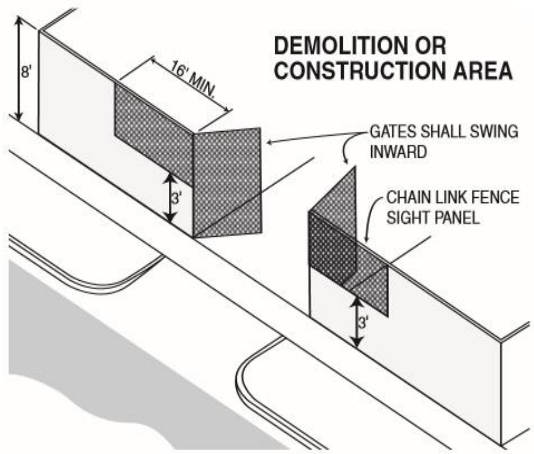
Sources of pedestrian injury	Percentage (%)	Sources of cyclist injury	Percentage (%)
Tripped on an uneven/cracked sidewalk	24	Hit by a car	29
Tripped/fell	17	Fell	17
Hit by a car	12	Roadway/walkway not in good repair	13
Wildlife/pets involved	6	Rider error/not paying attention	13
Tripped on stone	5	Crashed/collision	7
Stepped in a hole	5	Dog ran out	4

The U.S. Department of Transportation's (USDOT) strategic plan for the fiscal period 2014-18 outlined the safety goals (USDOT 2013). The USDOT's draft strategic plan for 2018-2022 calls for data-driven, risk analysis based approaches for developing solutions (USDOT 2017). At a time when the nation is working towards achieving "the safest possible outcomes for all users of the system, moving toward a transportation system with no casualties," research is needed to eliminate all the possibilities for pedestrian and cyclist related accidents within construction zones, thus to promote safety of motorized as well as non-motorized traffic.

Several guidelines and specifications are available to address the safe mobility requirements for non-motorized traffic during construction activities. According to the Manual on Uniform Traffic Control Devices (MUTCD) 2009 version, non-motorized traffic i) should not be led into conflicts with vehicles, equipment, and operations, ii) should not be led into conflicts with vehicles moving through or around the worksite, and iii) should be provided with a convenient and accessible path that replicates as nearly as practical the most desirable characteristics of the existing sidewalk(s) or footpath(s). Safe access to non-motorized traffic is provided following available guidelines and specifications. Fences are typically used to improve the safety of pedestrians and cyclists when moving adjacent to work zones and slow moving live motorized traffic (Figure 1-6a and b). The height of the fence depends on the distance between the work zone and non-motorized facility and elevation of the work zone. Tall protective barriers are provided to discourage pedestrian crossing over and jaywalking. A temporary crosswalk is provided when access to the crosswalk is lost due construction activities (Figure 1-7a). To control motorized traffic and provide access to a temporary crosswalk, advanced temporary traffic control (TTC) devices like Automatic Flagger Assistance Devices (AFAD) are installed

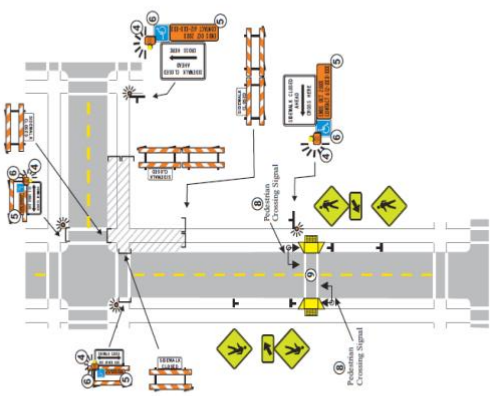
(Figure 1-7b). When the space is constrained due to construction activities, a temporary pathway is provided on an extended bike lane or a traffic lane to accommodate pedestrians and cyclists (Figure 1-8a). Figure 1-8b shows a temporary pathway provided around a work zone in Rochester, New York. Several options are available to provide temporary pathways, and the selection decision depends on the affected roadway feature(s) and construction activity requirements. Figure 1-8c shows a closure of a side walk adjacent to a construction site and detouring to use the sidewalk available in the other side of the road in Washington DC.

a) Pedestrian pathway separated from work zone and live traffic by using fences (Hawaii 2013)



b) A typical construction site with tall fences (Slcdocs 2017)

Figure 1-6. Fences to seperate non-motorized traffic from work zone and live traffic



a) Temporary crosswalk is provided if crosswalk available in the intersection is impaired (MN MUTCD 2015)

b) Automatic Flagger Assistance Devices (AFAD) is used to control motorized traffic

Figure 1-7. Implementation of a temporary crosswalk and an AFAD

a) Separated pedestrian and cyclist temporary pathway

b) Temporary pathway is provided around the road in Greece town (Rochester, NY)

c) Non-motorized is detoured via the nearest sidewalk (Washington DC)

Figure 1-8. Temporary pathway to provide access to non-motorized traffic

Besides providing safe access routes, a better approach is to use less-invasive construction method and technology to reduce work duration, work zone length, and construction activity requirements. As an example, several trenchless pipe technologies such as slip-lining, cured-in-place lining, spin-cast lining, joint sealing, directional boring, and pipe bursting are available. These technologies ensure reduction of work duration and length along with improved service life. Available infrastructure and technology can be used to promote non-motorized mobility. As an example, Figure 1-9a and b show a pushbutton activated trolley system installed in a stairway in Prague, Czech Republic to provide access to mobility-disabled people. Hence, infrastructure and technology can be used to provide access to people with special needs when managing non-motorized mobility in work zones. Craig et al. (2017) developed an in-vehicle message alert system to send messages to the driver's smartphone to alert the driver about upcoming road changes. A Bluetooth service is installed in the work zone to scan a GPS sensor on the smartphone and send audible and/or visual messages. When a driver is one and quarter (1.25) miles away from a work zone, an introductory message similar to the one shown in Figure 1-10a appears in the driver's smartphone to make the driver aware of the upcoming road changes due to a work zone. When the driver is one (1) mile away, an audio message similar to the one shown in Figure 1-10b is sent to the driver's smartphone informing the distance to the work zone and posted reduced speed limit ahead. When the driver enters the work zone, an audio-visual message similar to the one shown in Figure 1-10c is sent to alert driver and request a speed reduction. Typically, several variable-message signs (VMS), as shown in Figure 1-10d, are required to warn drivers about upcoming road changes. Deployment of in-vehicle message systems could reduce the need for having a large number of VMS.

a) Pushbutton to call the platform

b) Platform of the trolley system

Figure 1-9. Pushbutton activated trolley system

In-vehicle message alert system

Message Placement
Mile Marker 1.25

Introductory Drive (Before Transition Zone)

a) A text message is sent to the driver when the driver is 1.25 miles away from the site.

Audio-Only Message

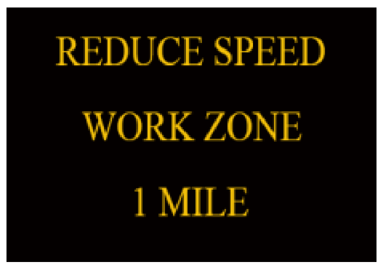
"Work Zone Ahead"
"1 Mile"
"Reduce Speed"

b) An audio message is sent to the driver when the driver is one mile away from the site.

Audio-Visual Message (Icon)

c) An audio-visual message is sent to the driver when the driver enters a work zone.

VMS



d) Typically used variable-message signs (VMS)

Figure 1-10. In-vehicle message alert system and VMS to alert drivers about upcoming road changes (Craig et al. 2017)

The safety and accessibility for pedestrians and cyclists can be enhanced if (a) the cities have policies for managing non-motorized access, (b) engineers and planners have a framework for evaluating a site for developing alternatives and guidelines to accommodate non-motorized traffic, and (c) contractors have access to means and methods of implementing the guidelines. Most of the construction activities in small cities are handled by local contractors who do not have a large workforce to conduct research to identify the latest technology for managing construction activities and providing facilities for non-motorized traffic. Hence, the guidelines for managing non-motorized access provided with a project award needs to include a list of technologies and infrastructure that the contractors can consider while implementing the guidelines. Thus, this study is initiated to synthesize policies, guidelines, infrastructure, and technology (including less-invasive construction methods) necessary for managing non-motorized traffic within or around construction zones. Also, best practices are synthesized to identify or develop a set of tools that highway agencies and city officials can be used for planning purposes. When implementing a selected management plan, the synthesized list of technologies and infrastructure can be used to address the constraints for managing non-motorized mobility.

1.2 OBJECTIVE AND SCOPE

The objective of this research is to synthesize policies, guidelines, infrastructure, and technology that can be used to develop means and methods for improving non-motorized mobility within construction zones located in small cities.

To accomplish the objectives, the following tasks are performed:

- Review state-of-the-art and practice.
- Survey of practices in green, walk-friendly, and bike-friendly cities.
- Develop a risk-based decision support framework for non-motorized access planning.
- Develop reports and other publications.

1.3 REPORT ORGANIZATION

The report is organized into 6 chapters:

- Chapter 1 includes an overview and project objective and scope.
- Chapter 2 documents policies, guidelines, and minimum requirements of street components for managing non-motorized mobility, components of a temporary traffic control (TTC) zone, TTC devices, public outreach tools and methods, infrastructure for managing non-motorized mobility, construction methods and technologies that promote reduced work duration and work zone length, along with advanced technologies for enhanced safety.
- Chapter 3 includes a list of cities identified for the survey, the survey questionnaire, policies and guidelines (other than the MUTCD) used in those cities, public outreach tools and methods, and case studies of managing non-motorized mobility within or around construction zones.
- Chapter 4 includes a work zone and mobility management framework, options for space management during construction, a level-of-service evaluation matrix and a performance rating system for pedestrian and cyclist facilities, alternatives for managing non-motorized mobility within or around a construction zone, a risk-based decision-support framework, and alternatives to provide access to different facilities.

- Chapter 5 provides a summary, conclusions, and recommendations.
- Chapter 6 includes the list of references.

The report appendices include the following:

- Appendix A: Abbreviations
- Appendix B: Policies, guidelines, and minimum requirements of street components
- Appendix C: Non-motorized mobility planning tools
- Appendix D: Advanced technologies

2 STATE-OF-THE-ART AND PRACTICE REVIEW

2.1 OVERVIEW

Non-motorized mobility can be promoted if practices around the world are synthesized, and the best practices are implemented after evaluating the risk associated with each alternative selected for a site. Innovative technologies, infrastructure, and less-invasive construction methods can be used to enhance safety and promote non-motorized mobility within and around construction zones. Less-invasive construction methods help to reduce work duration and work zone length. These methods, when combined with appropriate technologies, can enhance mobility and safety. This chapter documents policies, guidelines, and minimum requirements of street components for managing non-motorized mobility, components of a temporary traffic control (TTC) zone, TTC devices, public outreach tools and methods, infrastructure for managing non-motorized mobility, construction methods and technologies that promote reduced work duration and work zone length, along with advanced technologies for enhanced safety.

2.2 POLICIES, GUIDELINES, AND MINIMUM REQUIREMENTS OF STREET COMPONENTS

Policies and guidelines are developed by national and international highway agencies to manage non-motorized traffic within and around construction zones. The Americans with Disabilities Act (ADA), Americans with Disabilities Act Accessibility Guidelines (ADAAG), and Public Right-Of-Way Accessibility Guidelines (PROWAG) have provided minimum requirements of street components for pedestrians and people with special needs. The American Association of State Highway and Transportation Officials (AASHTO) (2012) (Guide for the Development of Bicycles Facilities) and the Highway Design Manuals (HDMs) of different DOTs provide the minimum requirements of street components for cyclists. Periodically, these policies, guidelines, and the minimum requirements of street components are reviewed and updated. The most recent policies, guidelines, and the minimum requirements of street components are reviewed and synthesized. Table 2-1 presents the policies and guidelines related to pedestrians. Table 2-2 presents the minimum requirement of street components for pedestrian facilities. Table 2-3 presents four classes of bike ways with their definitions. Table 2-4 presents the policies and guidelines related to cyclists. Table 2-5 presents the minimum requirement of street components for four classes of bike ways.

Table 2-1. Policies and guidelines regarding pedestrians

Policies (MUTCD 2009)

- *The various TTC provisions for pedestrian and worker safety set forth in MUTCD Section 6D shall be applied by knowledgeable (for example, trained and/or certified) persons after appropriate evaluation and engineering judgment.*
- *Advance notification of sidewalk closures shall be provided by the maintaining agency.*
- *If the TTC zone affects the movement of pedestrians, adequate pedestrian access and walkways shall be provided. If the TTC zone affects an accessible and detectable pedestrian facility, the accessibility and detectability shall be maintained along the alternate pedestrian route.*

Guidelines

MUTCD (2009)

- *Pedestrians should not be led into conflicts with vehicles, equipment, and operations.*
- *Pedestrians should not be led into conflicts with vehicles moving through or around the worksite.*
- *Pedestrians should be provided with a convenient and accessible path that replicates as nearly as practical the most desirable characteristics of the existing sidewalk(s) or footpath(s).*
- *Pedestrians should be separated from the worksite by appropriate devices that maintain the accessibility and detectability for pedestrians with disabilities.*
- *Pedestrians should not be exposed to unprotected excavations, open utility access, overhanging equipment, or other such conditions.*
- *Pedestrian detours should be avoided since pedestrians rarely observe them and the cost of providing accessibility and detectability might outweigh the cost of maintaining a continuous route. Whenever possible, work should be done in a manner that does not create a need to detour pedestrians from existing routes or crossings.*

Litman et al. (2016)

- *Barricades and pylons can be used to create a temporary passageway for pedestrians. This is particularly important in urban areas. Sidewalk closures should be avoided or minimized as much as possible. Passageway should be wide enough to accommodate a wheel chair, and should have ramps where there are height changes.*
- *Construction signs should not obstruct bicycle and pedestrian paths. Where this is unavoidable, do not block more than half the path or sidewalk.*
- *Bus stops must remain accessible to pedestrians. Where necessary, bus stops may be relocated provided clear and noticeable signs are provided.*
- *Additional lighting may be required at night to identify hazards.*

Table 2-2. The minimum requirements of street components for pedestrian facilities

Design elements (PROWAG 2011 and Sinclair 2017)		**Criteria**
Pedestrian access route	Width	Min. 4 ft (preferable 5 ft)
	Grade	Matching street grade, where feasible max. 5%
	Cross slope	Max. 2%
	Surface	Firm, stable, and slip resistant
	Vertical discontinuity	Max. 0.5 in.
	Horizontal opening	Max. 0.5 in.
	Flangeway gaps	Max. 2.5 in. for non-freight track
		Max. 3.0 in. for freight track
	Passing space	Min. 5 × 5 ft at interval of max. 200 ft
Perpendicular curb ramp	Width	Min. 4 ft
		Min. 3 ft between handrail
	Rise	Max. 2.5 ft
	Grade breaks	Perpendicular to the direction of the ramp (not permitted on the ramp runs, turning spaces)
	Cross slope	Max. 2%
	Counter slope	Max. 5%
	Turning space	Min. 4 × 4 ft, at the top of the curb ramp
	Running slope	Min. 5% and max. 8.3%
	Running slope (turning space)	Max. 2%
	Slope (flared sides)	Max. 10%
Parallel curb ramp	Width	Min. 4 ft
		Min. 3 ft between handrails
	Rise	Max. 2.5 ft
	Grade breaks	Perpendicular to the direction of the ramp (not permitted on the ramp runs, turning spaces)
	Cross slope	Max. 2%
	Counter slope	Max. 5%
	Turning space	Min. 4 × 4 ft at the bottom of the curb ramp
	Running slope	Min. 5% and max. 8.3%
	Running slope (turning space)	Max. 2%

Table 2-2. The minimum requirements of street components for pedestrian facilities (contd.)

Blended transitions	Width	Min. 4 ft
	Grade breaks	Perpendicular to the direction of the ramp (not permitted on the ramp runs, turning spaces)
	Cross slope	Max. 2%
	Counter slope	Max. 5%
Transit stops	Clear length	Min. 8 ft, perpendicular to the street
	Clear width	Min. 5 ft, parallel to the street
	Grade (parallel street)	Same as the street
	Grade (perpendicular street)	Max. 2%
	Surface	Firm, stable, and slip resistant
Landings	Slope	Any direction
	Width	Min. the widest ramp
	Length	Min. 5 ft
	Direction change	Min. 5 × 5 ft
	Surface	Firm, stable, and slip resistant
	Handrails	Required
Lighting[1]	Surface of Route	One foot-candle (one lumen per square foot or 10.764 lux)
Stairway[1]	Width	Min. 5 ft for public and 4.5 ft for private
	Treads	Min. 11 in.
	Riser indoor depth	Min. 7.5 in.
	Risers outdoor depth	Between 4.5 in. and 7 in.
	Tread (T) to riser (R) ratio	2R + T = 26 to 27 in.
	Height between landings	Max. 12 ft
	Landing length	Min. 5 ft
1 Source: Pedestrian Facility Guidebook (1997)		

Table 2-3. Classes of bike way with definition

Class of bike ways	**Definition**
Class I (bike path)	A bicycle facility that is separated from motorized vehicular traffic.
Class II (bike lane)	A lane designated for exclusive or preferential use by bicycles through the application of pavement striping or markings and signage.
Class III (bike route)	A roadway designated for bicycle use through the installation of directional and informational signage.
Class IV (shared roadway)	A roadway where cyclist share traffic lane with motorized traffic.

Table 2-4. Policies and guidelines regarding cyclists

Policies

MUTCD (2009) Section 6G.11

If the TTC zone affects the movement of bicyclists, adequate access to the roadway or shared-use path shall be provided (MUTCD (2009) Section 6G.11).

NCUTCD (BTC) (2013) Section 6G.05

The minimum TTC sign and plaque sizes for shared-use paths shall conform to those shown in Table 9B-1 of MUTCD (2009). The minimum TTC sign and plaque sizes for on-street bikeways shall conform to MUTCD (2009) Chapter 6F (NCUTCD (BTC) (2013) Section 6G.05).

Guidelines

MUTCD (2009) Section 6G.05

- *If a designated bicycle route is closed because of the work being done, a signed alternate route should be provided. Bicyclists should not be directed onto the path used by pedestrians.*
- *Where bicycle usage is high, the typical applications should be modified by giving particular attention to the provisions set forth in Section 6D of MUTCD (2009), Section 6G, Section 6F.74 of MUTCD (2009) , and in other Sections of Part 6 related to accessibility and detectability provisions in TTC zones.*
- *Bicyclists should not be exposed to unprotected excavations, open utility access, overhanging equipment, or other such conditions.*

NCUTCD (BTC) (2013) Section 6G.05

- *The continuity of a bikeway should be maintained through the TTC zone, if practical.*
- *If a bikeway detour is unavoidable, it should be as short and direct as practical*.
- *On-road bicyclists should not be directed onto a path or sidewalk intended for pedestrian use except where such a path or sidewalk is a shared-use path, or where no practical alternative is available (such as might be the case on a bridge in the course of a rehabilitation project*.
- *If a portion of a bikeway is to be closed due to construction activities and the detoured bikeway follows a complex path not in the original bikeway corridor, then a full detour plan should be developed and implemented. The TTC for the detour of the bikeway should include all necessary advance warning (W21 series) signs, detour (W4-9 series) signs, and any other TTC devices necessary to guide bicyclists along the detour route.*

Litman et al. (2016)

- *Construction signs should not obstruct bicycle and pedestrian paths. Where this is unavoidable, do not block more than half the path or sidewalk.*
- *Additional lighting may be required at night to identify hazards.*

Table 2-5. The minimum requirements of street components for bike ways

<table>
<tr><th colspan="4">Design elements (California Highway Design Manual (2015))</th><th>Criteria</th></tr>
<tr><td rowspan="14">Width of bikeway</td><td rowspan="3">Class I
(Bike paths)</td><td colspan="2">Two-way</td><td>Min. 8 ft is preferred
10 ft or 12 ft for heavy cyclist volume</td></tr>
<tr><td colspan="2">One-way</td><td>Min. 5 ft</td></tr>
<tr><td colspan="2">Bike path on structure (bridge and overpass)</td><td>Min. 10 ft</td></tr>
<tr><td rowspan="9">Class II
(Bike lanes)
(BDE Manual 2016)</td><td rowspan="2">Curbed streets without parking</td><td>Two-way curb and gutter section (one-way bike lane)</td><td>Min. 4 ft</td></tr>
<tr><td>Two-way monolithic curb and gutter section (one-way bike lane)</td><td>Min. 5 ft</td></tr>
<tr><td rowspan="2">Curbed streets with parking</td><td>Unmarked bike lane</td><td>Min. 13 ft</td></tr>
<tr><td>Marked bike lane</td><td>Min. 5 ft, parking 8 ft</td></tr>
<tr><td colspan="2">Bicycle lanes adjacent to bus lanes</td><td>Min. 5 ft</td></tr>
<tr><td colspan="2">One-way bike lane on shoulder</td><td>Min. 4 - 6 ft</td></tr>
<tr><td colspan="2">One-way bike lane on roadway</td><td>Min. 4 ft</td></tr>
<tr><td colspan="2">One-way bike lane cross structure</td><td>Min. 5 ft</td></tr>
<tr><td colspan="2">Shared lane on roadway</td><td>Min. 13 - 14 ft</td></tr>
<tr><td colspan="3">Class III (Bike route)</td><td>Minimum standards for highway lanes and shoulder</td></tr>
<tr><td colspan="3">Class IV (Shared roadway)</td><td>4 ft of paved roadway shoulder with 4 in. edge line</td></tr>
<tr><td colspan="4">Cross slope</td><td>Max. 2%, Min. 1%</td></tr>
<tr><td colspan="4">Shoulder width</td><td>Min. 2 ft (preferable 3 ft) with slope 2 - 5%</td></tr>
<tr><td colspan="4">Shy distance</td><td>Min. 2 ft on each side</td></tr>
<tr><td colspan="4">Separation width from pedestrian walkway</td><td>Min. 5 ft</td></tr>
<tr><td colspan="3" rowspan="2">Clear distance to obstruction from bike path</td><td>Horizontally</td><td>Min. 2 ft (preferable 3ft)</td></tr>
<tr><td>Vertically</td><td>Min. 8 ft across width and 7 ft over shoulder</td></tr>
<tr><td colspan="4">Ramp width</td><td>Same width of bicycle path with smooth transition between bicycle path and the roadway</td></tr>
<tr><td colspan="4">Paving width at crossings of roadway or driveway</td><td>Min. 15 ft</td></tr>
<tr><td colspan="4">Separation width of bike paths parallel & adjacent to streets and highway</td><td>Min. 5 ft plus shoulder width.</td></tr>
<tr><td colspan="2" rowspan="3">Posted speed limit</td><td colspan="2">Mopeds prohibited bike paths</td><td>20 mph</td></tr>
<tr><td colspan="2">Mopeds permitted bike paths</td><td>30 mph</td></tr>
<tr><td colspan="2">Bike paths on long downgrades (steeper than 4% and longer than 500 ft)</td><td>30 mph</td></tr>
</table>

Table 2-5. The minimum requirements of street components for bike ways (contd.)

Superelevation rate		Max. 2%
Horizontal Alignment	Radius of curvature with Superelevation rate	90 ft for 20 mph 160 ft for 25 mph 260 ft for 30 mph.
	Radius of curvature without Superelevation rate	100 ft for 20 mph 180 ft for 25 mph 320 ft for 30 mph.
Stopping sight distance		Min. 125 ft for 20 mph Min. 175 ft for 25 mph Min. 230 ft for 30 mph.
Grades		Min. 2%, Max. 5 %
Length of crest vertical curves		$L = 2S - \frac{1600}{A}$ when S > L $L = \frac{AS^2}{1600}$ when S < L where, L is minimum length of vertical curve in feet S is stopping distance in feet A is algebric grade difference
Lateral clearance on horizontal curves		$m = R\left[1 - \cos\left(\frac{28.65S}{R}\right)\right]$ where, m is minimum lateral clearance in feet S is stopping distance in feet R is radius of center of lane in feet
Lighting		Average illumination of 5 - 22 lux
Speed bumps, gates, obstacles, posts, fences, or other similar features intended to cause bicyclists to slow down		Not required
Entry control for bicycle paths		Required
Signing and delineation		MUTCD section 9B and 9C

2.3 COMPONENTS OF A TEMPORARY TRAFFIC CONTROL ZONE

The condition of available roadway features is changed due to the presence of a work zone, an incident zone, or a special event that requires defining an area termed as a Temporary Traffic Control (TTC) zone. Signs, channelizing devices, barriers, temporary pavement markings, and/or work vehicles are used to guide road users from start to end of a TTC zone. The TTC zone extends from the first warning sign to the END ROAD WORK sign or the last TTC device. As shown in Figure 2-1, a TTC zone is divided into four areas: a) advance warning area, b) transition area, c) activity area, and d) termination area (MUTCD 2009). Each area provides distinct information to road users. The length of each area is determined based on traffic volume, speed, construction activity, etc.

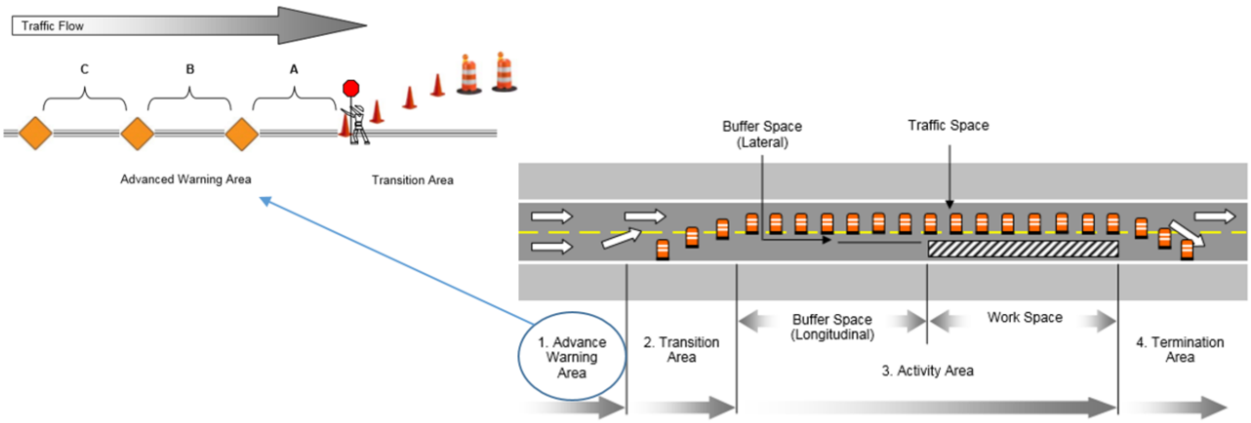


Figure 2-1. TTC zone components (MUTCD 2009, OSHA 2008)

Information about upcoming road changes is provided by placing various signs within the advance warning area. A single sign, a series of signs or high-intensity rotating, flashing, or strobe lights on a vehicle are used to inform road users about upcoming changes. The typical length of A, B, and C, distance among signs, are calculated using MUTCD (2009) Table 6C-1. However, these distances depend on the posted speed and road type. After crossing the advance warning area, road users enter the transition area. In the transition area, road users are redirected out of their normally traveled way. Usually channelizing devices, tapers and/or pavement markings are used in this area. Taper length (L, in feet) depends on width of offset (W, in feet) and posted speed (*or off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed*) (S, in mph) of the road, and is calculated using Equation 2-1 and 2-2. The subsequent area is the activity area. Usually, the activity area is prepared by using channelizing devices and temporary barriers to separate the non-motorized traffic and construction workers from motorized traffic. The activity area includes a buffer space, a traffic space, and a working space. Length of the buffer space depends on stopping distance which is a function of the posted speed, and is calculated using MUTCD (2009) Table 6C-2. The traffic space is used to route the road users while the workspace is reserved for the work zone staff, equipment, and materials. The termination area is the last component of a TTC zone in which road users return to their normal path with regular posted speed. An END ROAD WORK sign, regular posted speed, or the last TTC device is posted in this area. Typically, this area is 50-100 ft long.

For posted speed 40 mph or less, taper distance, $L \text{ (ft)} = WS^2/60$ (2-1)

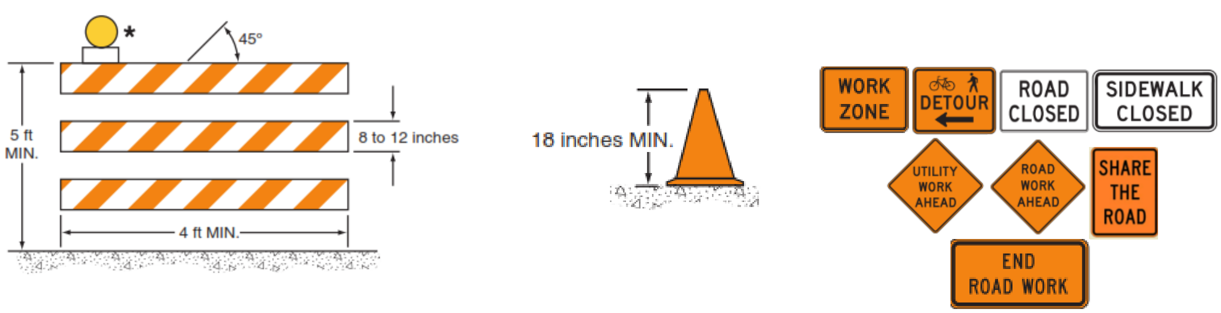
For posted speed more than 40 mph, taper distance, $L \text{ (ft)} = WS$ (2-2)

2.4 TTC DEVICES

TTC devices such as signs, signals, marking, and other devices are used to regulate, warn, or guide road users in order to ensure safe access through the work zone while ensuring the safety of workers, construction equipment, and material. The ultimate target of using such devices is to ensure uniform traffic flow and to minimize the occurrences of crashes. Prior to using TTC devices, a plan and guidelines need to be developed considering road geometry and roadside features. Design and application of TTC devices should satisfy five fundamental requirements listed in MUTCD (2009) Section 1A.02. These five requirements are i) fulfilling the need, ii) commanding attention, iii) conveying a simple and clear message, iv) commanding respect from road users, and v) giving adequate time for proper responses. In addition to the five requirements, installation of these devices on a street needs jurisdiction of authority from a public agency or official. The following TTC devices are used in a work zone:

- Regulatory, guide, and warning signs/devices
- Channelizing, barricades, cones, tubular markers, drum, vertical panel, lane separators, direction indicator barricades, longitudinal channelizing, and detectable edging devices
- Screen devices
- Lighting devices
- Arrow panels
- Pavement markings
- Portable changeable message signs
- Flaggers
- Crash cushion

A few TTC devices are presented in Figure 2-2.



a) Barricade b) Cone c) Signs

Figure 2-2. TTC devices (MUTCD 2009)

2.5 NON-MOTRIZED MOBILITY MANAGEMENT

Planning and managing a TTC zone requires considering work zone location, work duration, work type, highway type, geometry, road user volumes, road vehicle mix (buses, trucks, and cars), speed, vertical and horizontal alignment, and presence of intersections and interchanges (MUTCD 2009). Work duration, location, and work types become deciding factors for construction zones located in urban, suburban, and rural areas. The type of work is considered to evaluate space and construction activity requirements when developing a TTCMP. In most cases, presence of a work zone affects the existing pedestrian and cyclist facilities. Based on site specific conditions, highway agencies modify the typical application guidelines that are available in Section 6H of MUTCD (2009) to manage access to pedestrians. However, limited information is available in the MUTCD for managing cyclists. The temporary Traffic Control Technical Committee (TTCTC) in association with the Bicycle Technical Committee (BTC) (2013) provides additional guidelines and modified typical applications of MUTCD to manage access to cyclists within and around a work zone.

To provide a safe and convenient access to non-motorized traffic within and around a TTC zone, work duration and location, closure conditions, and construction activity are considered. These parameters are discussed in the subsequent sections.

2.5.1 Work Duration

Work duration is a major parameter for selecting the type of TTC zone. The work duration is categorized into five (5) categories as presented in Table 2-6 (MUTCD 2009). The work duration is considered to be long-term stationary when a job occupies a location more than 3 days, and other categories are defined for the work duration of less than 3 days.

Table 2-6. Work duration categories

Category	Work duration
Long-term stationary	Occupies a location for more than 3 days
Intermediate-term stationary	Occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 hour
Short-term stationary	Occupies a location for more than 1 hour within a single daylight period
Short duration	Occupies a location up to 1 hour
Mobile	Moves intermittently or continuously

2.5.2 Work Location

Work location affects the selection and installation methods of TTC devices. As an example, if the construction work closes pedestrian and cyclist facilities, large numbers of TTC devices are required to delineate designated temporary pathways for pedestrians and cyclists. Work location is classified into five (5) categories (MUTCD 2009) as presented below:

i) Outside of the shoulder

ii) On the shoulder with no encroachment

iii) On the shoulder with minor encroachment

iv) Within the median

v) Within a traveled way

2.5.3 Work Type and Activity

To acquire necessary space for managing a work zone (equipment, material, and construction activities), the sidewalk, shoulder, bike lane, traffic lane(s), or a combination thereof is closed. Roadway features that are affected due to construction activities are listed in Table 2-7. Transportation engineers need to consider alternatives to provide access to non-motorized traffic for different construction activities like demolition or excavation. The main objective of providing safe and convenient access to non-motorized traffic is to discourage the risk-taking behavior of pedestrian and cyclists resulting in a reduced possibility of injury and fatality. During demolition activity, a covered pathway is provided to pedestrians and cyclists. During an excavation perpendicular to a traveled way, providing a temporary bridge is preferred. Different practices are available to provide a safe access route due to different closure conditions and construction activities. The following alternatives are evaluated while developing plans for providing access to non-motorized traffic:

a) Protective barrier
b) Pathway on on-street parking lane
c) Temporary crosswalk
d) Covered pathway
e) Shared lane and extended bike lane
f) Temporary pathway
g) Temporary bridge
h) Detour

These solutions are discussed in the following sections.

Table 2-7. Roadway features affected by construction activities

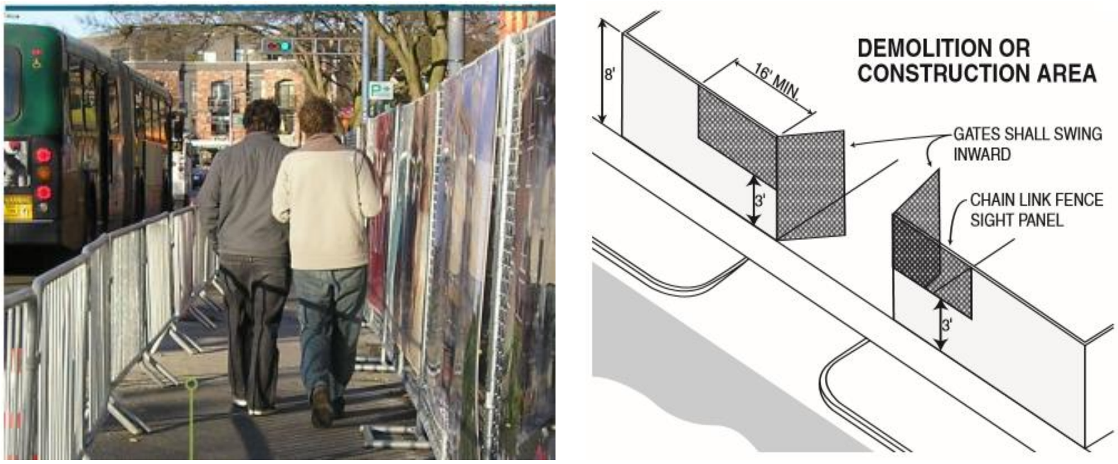
Affected roadway features
Sidewalk – SW
Bike lane – BL
Traffic lane(s) – TL
Sidewalk and bike lane – SWBL
Sidewalk and traffic lane(s) – SWTL
Sidewalk, bike lane, and traffic lane(s) – SWBLTL
Complete closure – CC

2.5.3.1 Protective Barrier

When a work zone is located on a traffic lane or by the side of a non-motorized facility, a protective barrier or a fence is installed to provide safe access. The factors that need to be considered for selecting a protective barrier to discourage pedestrian crossing over a protective barrier and jaywalking are presented below (Slcdocs 2017):

a) A work zone is located at a distance of 6 ft or more, but between ¼ to ½ of the height of construction.
b) Construction activity is performed at a height of 8 ft or more above the non-motorized facility.

Figure 2-3 shows a fence made of strong, non-bendable material (detectable for vision-impaired people) installed to protect non-motorized traffic (Turner 2006). Typically, an 8 ft tall fence is placed to prevent pedestrians from jumping over it. Depending on the construction activities and the proximity of the non-motorized path to the work zone, fences are installed with covered pathways. The criteria for selecting fences are presented in Table 2-8.



a) Pedestrian pathway separated from work zone and live traffic by using fences (Hawaii 2013)

b) A typical construction zone with tall fences (Slcdocs 2017)

Figure 2-3. Fence as a protective barrier

Table 2-8. Solution to accommodate the non-motorized mobility (Slcdocs 2017))

Height of the construction	**Distance between work zone and non-motorized facility**	**Provided protection**
8 ft or less	Less than 6 ft	Railing
	6 ft or more	None
More than 8 ft	Less than 6 ft	Fence and covered way
	6 ft or more, but not more than ¼ the height of the construction	Fence and covered way
	6 feet or more, but between ¼ to ½ the height of the construction	Fence
	6 feet or more, but exceeding ½ the height of the construction	None

Railing is used to prevent jaywalking and pedestrians entering a work zone when a work zone is located at a distance of 6 ft or less from sidewalk, and when material and equipment are not stored on site (Slcdocs 2017). As shown in Figure 2-4, a railing is placed to separate pedestrians from the work zone.

Figure 2-4. Railing as protective barriers (Google image)

2.5.3.2 Pathway on an On-street Parking Lane

When a sidewalk or a bike lane is closed and on-street parking lane is available, pedestrians and cyclists are accommodated within the on-street parking lane (Figure 2-5). Safety barriers are installed around the pathway to protect non-motorized traffic from live motorized traffic. Usually, on-street parking is prohibited temporarily in a construction work zone during active construction.

Figure 2-5. Pathway on on-street parking lane

2.5.3.3 Temporary Crosswalk

A temporary crosswalk is provided when a pedestrian and cyclist facility is discontinued due to a work zone located at an intersection or a mid-block. As shown in Figure 2-6, a temporary crosswalk is provided to westbound non-motorized traffic. However, northbound non-motorized traffic was detoured via the sidewalk available on opposite side of the road. This solution can be adopted at any phase of construction by satisfying the MUTCD (2009) requirements given below:

a) A temporary crosswalk should be marked at signalized intersection if it is relocated, and a curb ramp should be provided for pedestrians, cyclists, and people with special needs.
b) TTC devices including barricades, signs, signals, closure notification, audible information, and a flagger should be used for managing motorized traffic.
c) A pushbutton should be provided for a temporary crosswalk at mid-block.

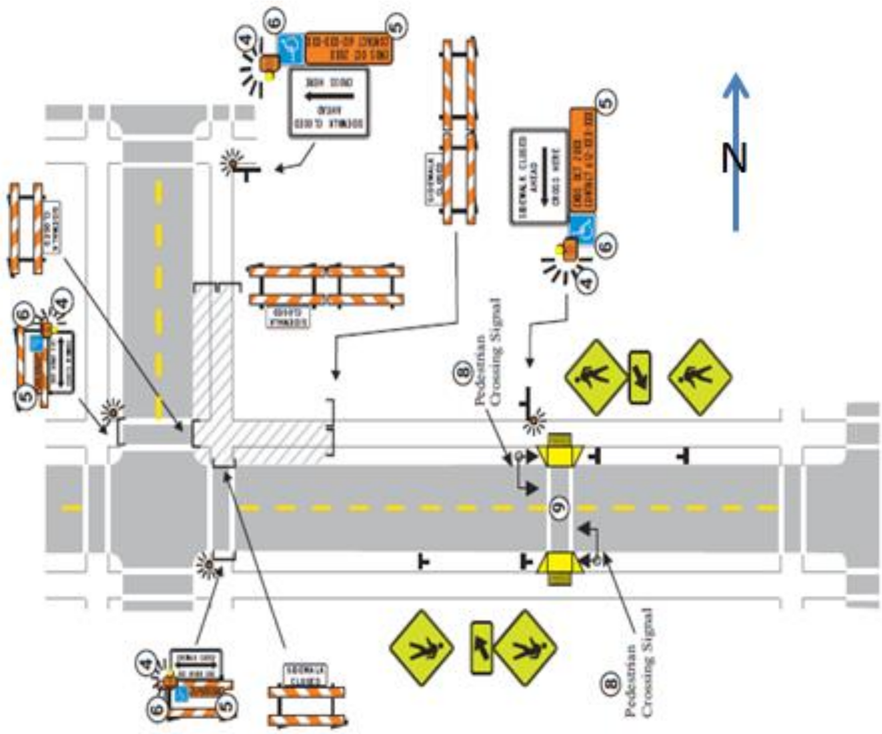


Figure 2-6. Temporary crosswalk (MN MUTCD 2015)

2.5.3.4 Covered Pathway

Instead of closing a pathway or detouring non-motorized traffic, a covered pathway is used during demolition and other construction activities to protect pedestrians and cyclists from falling debris. A covered pathway is a solution when a work zone is located at an intersection or at mid-block. As shown in Figure 2-7, a covered pathway is used during roadside building construction near an intersection. The need of a covered pathway is evaluated using the following conditions (Slcdocs 2017):

a) The work zone is located at a distance of 6 ft or more, but within ¼ of the height of construction.

b) Construction activity is performed at a height of 8 ft above the non-motorized facility.

Figure 2-7. Covered walkway (Raleighnc 2017)

Figure 2-8a and b show covered pathways made of scaffolding and wood, respectively. Sometimes, shipping containers can be used as covered pathways (Figure 2-8c). However, separated pathways for pedestrians and cyclists are desired if they are accommodated within the same covered pathway. Figure 2-9 shows accommodating pedestrians and cyclists in separate lanes during construction in Steglitz, Germany. A pushbutton can be provided in the covered pathway, if needed (Figure 2-10a). Openings are included in the design to provide emergency access (Figure 2-10b).

a) Covered way made of scaffolding for bicyclist (Sinclair 2017)

b) Covered way made of wood for pedestrians (Raleighnc 2017)

c) Covered pathway assembled using shipping containers

Figure 2-8. Covered pathway options (Slcdocs 2017)

Figure 2-9. Separate access for pedestrian and cyclist

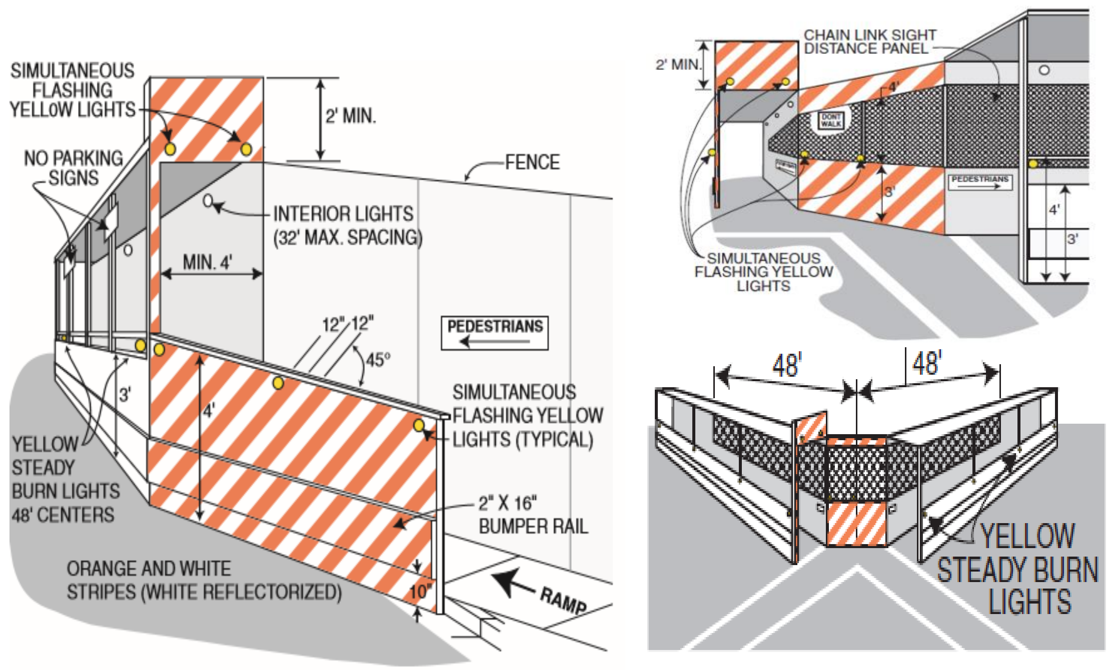
a) Pushbutton b) Opening is provided for emergency access

Figure 2-10. Pushbutton and emergency access

Typical dimensions and layout of a covered pathway are presented in Figure 2-11. Guidelines for providing a covered pathway are given in the MUTCD (2009) and several other publications. These guidelines are summarized below:

- Be made from strong material and constructed sturdily.
- Have adequate lighting for nighttime use and safety.
- Achieve a proper sight distance at intersections and crosswalks (Turner 2006).
- Have adequate resistance along the path for vehicles' impact on higher speed streets. Wooden railings, chain link fencing, and similar systems are not acceptable along the path (Turner 2006).
- Maintain unimpeded accessibility regards to emergency access. An opening on the wall of a covered pathway, a red light camera box, a pedestrian pushbutton (Hawaii 2013), and guidance signage can be provided for emergency access.

- Provide a pushbutton for pedestrians when the relocated crosswalk is more than 10 ft away from the available crosswalk (SDOT 2017).
- Have a nonslip surface path, and smooth connections between joints or separations.
- Have curb ramps with geometry and alignment meeting the requirements of the ADAAG as listed in Table 2-2.
- Have top rails and handrails located at a minimum height of 3 ft 6 in. from grade (Hawaii 2013).
- Have wire screens covering the openings (Hawaii 2013).
- Have yellow warning lights (SDOT 2017).



a) Covered walkway at a mid-block b) Covered walkway at a corner

Figure 2-11. Covered walkway (Slcdocs 2017)

2.5.3.5 Shared Lane and Extended Bike Lane

When a sidewalk or a part of a bike lane is closed to meet space requirements for construction, the bike lane can be extended by taking a 2-3 ft wide strip from the adjacent traffic lane to manage pedestrians and cyclists on an extended bike lane. The width of the traffic lane can be reduced to 9 ft to 11 ft when the posted speed of the road is not greater than 65 miles/hour (Porter et al. 2016; MUTCD 2009). Several configurations can be developed to manage non-motorized traffic as discussed below:

a) Separated pathways are provided within an extended bike lane for pedestrians and cyclists (Figure 2-12a).
b) A path for cyclists is managed within the traffic lane by sharing the lane when a bike lane is affected for a short distance, the average daily traffic is low, and posted speed and differential speed between motorized traffic and cyclist speed is low (Figure 2-12b).
c) An alternate temporary bike lane is provided when the length of construction zone is long, and the average daily traffic and posted speed is high (Figure 2-12c).

A non-motorized pathway should be smooth, clear, clean, and free from the construction debris. Temporary signs should not be placed in the pathway, and a transition sloped area should be painted with retro-reflective orange color (City of Cambridge 2007), as shown in Figure 2-12c. The cyclists should not be accommodated on a sidewalk with pedestrians unless there is no other option.

a) Extended bike lane (Evans 2017) b) Shared lane (WABA 2015) c) Temporary bicycle lane

Figure 2-12. Shared and extended bike lanes

2.5.3.6 Temporary Pathway

When a sidewalk and bike lane are closed to meet space requirements for construction, non-motorized mobility can be managed with temporary pathways provided within and/or around the construction zone. Figure 2-13 shows a few example implementations. The following guidelines from the MUTCD (2009) can be considered when evaluating temporary pathways:

- Demonstrate clearly the temporary pathway by using continuous channelizing devices, barricades, cones, and advanced signs.
- Provide temporary signs and closure notifications as well as devices that provide audible information.
- Provide a minimum width of 48 in. The preferred width is 60 in. For narrow roads, 36 in. is acceptable.

- Provide a smooth surface with a 60 in. × 60 in. curb ramp at every 200 ft interval.
- Provide adequate lighting at night.
- Protect the pedestrians and bicyclists from live motorized traffic and work hazards like holes, cracks, debris, dust, and mud.
- Relocate bus stops, transit facility, and crosswalks when the work zone blocks access to such facilities.

a) A temporary pathway is provided around the construction zone in Greece town (Rochester, NY)

b) A travel lane used to provide access to pedestrians due to work on the sidewalk (Google image).

c) A traffic lane is used for both pedestrians and bicyclists (Google image).

d) A parking lane used for bicyclists (Google image).

Figure 2-13. Temporary pathways provided based on different site-specific conditions

2.5.3.7 Temporary Bridge

A temporary bridge with handrails can be used to provide access over an excavated area (Figure 2-14a). The bridge should be strong, stable, clear, and free of cracks and holes. An above grade crossing can be provided using temporary bridges (Figure 2-14b). This solution is adopted when the occupied area is large and pedestrian volume is high. A wheelchair accessible entrance and exit ramps need to be provided (SDOT 2017).

a) Prefabricated bridge (Sinclair 2017) b) Elevated bridge (Layher 2013)

Figure 2-14. Temporary bridge

2.5.3.8 Detour

When space is not available to provide a safe access route within or around the construction zone, non-motorized traffic is detoured using a designated shortest possible route with advance signing in accordance with the MUTCD (2009). As an example, pedestrians were detoured via the opposite side of the road during construction work in Washington DC (Figure 2-15). Signs should be placed to avoid blocking the path of pedestrians and bicyclists.

Figure 2-15. Non-motorized traffic is detoured via the nearest sidewalk

2.5.4 Public Outreach

It is necessary to develop and carryout a public outreach campaign to inform the public about upcoming projects, scheduled activities, schedule changes, and on-going activities. The other objectives of such campaigns are to get public input in order to find solutions to address their concerns and to notify them regarding the actions being undertaken to accommodate their needs. This purpose is fulfilled through creating and organizing a systematic process to deliver work zone information. Generally, the information should include the date/time of work, a brief description of work, staged traffic changes, emergency events/accidents, etc. The following are the most commonly used tools and methods for public outreach (FDM 2017):

- Media news release
- Public meetings or speaker forums
- Meetings with stakeholders and emergency response agencies
- Notices to the traveling public (Radio, TV, print media)
- Brochures and mailers.
- Paid advertising
- Special notification to targeted groups
- Telephone hotline
- Public information center
- Traveler information (GPS, WAZE, Temporary rumble stripes)
- Portable changeable message signs (PCMS)
- Dynamic message signs (DMS)
- Ground mounted signs
- Planned lane closure signs
- Portable work zone traveler information systems (ITS)
- Other methods including the Internet and social media (Facebook, Twitter etc.)

Special telephone lines or teleprinters (also called teletypewriters, TTYs) need to be used to accommodate people with special needs. Appropriate auxiliary aids and services are needed within TTC zones. Devices with audible messages are helpful for all road users (ATSSA 2012). Figure 2-16 shows a TTC device that is equipped with an audible message system. This TTC device includes a pushbutton with a locator tone to notify visually impaired people.

Figure 2-16. Audible information device (ATSSA 2012)

2.6 INFRASTRUCTURE FOR MANAGING NON-MOTORIZED MOBILITY

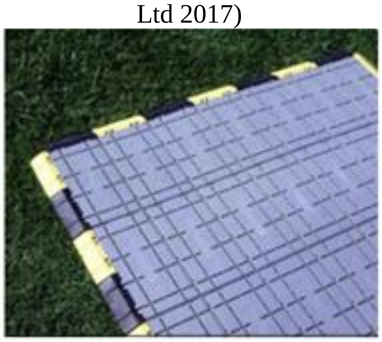
Depending on the closure of a single roadway feature or a combination of multiple roadway features, various solutions are adopted to manage non-motorized mobility. Typical solutions for providing access are temporary pathways, temporary bridges, detours, or a combination thereof. An open or covered pathway is a possible solution when a temporary pathway is provided within or around the construction zone. To provide access to pathways, temporary curve ramps and temporary rumble strips are installed for people with special needs. Providing a temporary pathway within and around a work zone brings an extra cost to the project. Instead of using well paved surfaces for temporary pathways, temporary, cost-effective, reusable, rapid installation products can used to reduce the economic impact of the project. Currently, various products are available in the market. A list of such products is provided in this section. When properly installed and maintained, the risk of tripping can be minimized, thus the contract documents need to include required inspection and maintenance clauses.

2.6.1 Flooring for Temporary Pathways

Several products are available to construct the riding surface of a temporary pathway. Few examples of such products are Supa-TracTM, Supa-TracTM LITE, CellPaveTM AP, Roal-TracTM ULTRA, GT Trax, of Groundtrax Systems Ltd (2017) and PERFO-EQ reinforcement tile of PERFO-UK 2017. Figure 2-17 shows the application of these flooring materials. Similar products can be used to cover a damaged sidewalk to enhance the safety of non-motorized traffic (Figure 2-18).

a) Supa-Trac™ and Supa-Trac™ LITE (Groundtrax Systems Ltd 2017)

b) CellPave™ (Groundtrax Systems Ltd 2017)



c) Rola-Trac™ ULTRA (Groundtrax Systems Ltd 2017)

d) GT Trax (Groundtrax Systems Ltd 2017)

e) PERFO-EQ Reinforcement Tile (PERFO-UK 2017)

Figure 2-17. Temporary flooring systems

a) Before b) After

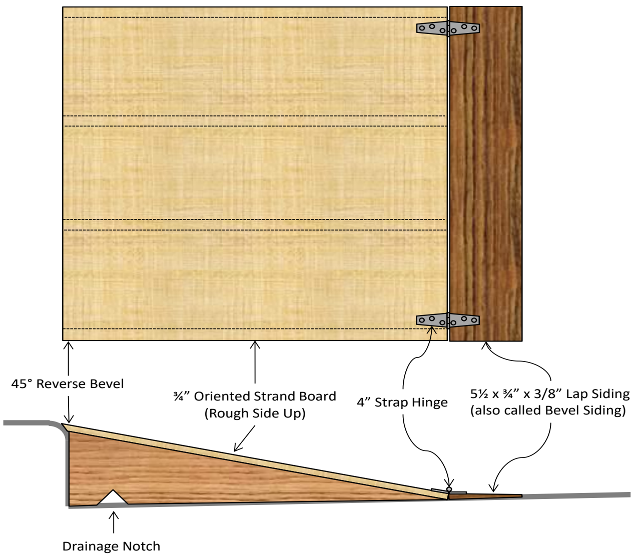
Figure 2-18. Sidewalk repair options (Handiramp 2017)

2.6.2 Temporary Ramps

Temporary ramps are needed to provide access for people with special needs. Longitudinal and transverse slopes of the ramps are maintained according to ADA guidelines. Figure 2-19 shows a few options available to maintain temporary ramps during construction.

a) A ramp made of plastic (Handiramp 2017)

b) A ramp made of concrete (Sinclair 2017)



c) A ramp made of wood (Sinclair 2017)

d) A ramp made of aluminum (Sinclair 2017)

Figure 2-19. Temporary ramps for providing access to people with special needs

2.6.3 Temporary Rumble Strips

Temporary rumble strips are used to alert motorized traffic (shown in Figure 2-20a) about road changes ahead (such as sharp curves, reduced lane widths, construction activities, etc.) that require reducing speed and cautious driving. Most of these strips are reusable and easy to install and remove. Similar strips can be used to mark pedestrian crossings and help people with sight disability to navigate through the crossings (Figure 2-20b).

a) For Motorized traffic (ATSSA 2013) b) For people with sight disability (Google image)

Figure 2-20. Temporary rumble strips

2.6.4 Pushbutton Activated Trolley System

A pushbutton activated trolley system can be installed to help mobility-disabled people access staircases. Figure 2-21 shows the implementation of a system in Prague, Czech Republic. This system can be incorporated when above grade facilities are provided to navigate through work zones.

a) Pushbutton to call platform b) Platform of trolley system

Figure 2-21. Pushbutton activated trolley system

2.7 ALTERNATIVE CONSTRUCTION METHODS AND TECHNOLOGIES

Construction work zones located in urban areas affect the existing pedestrian and cyclist facilities to meet space and activity requirements. To provide access, depending on the work duration, location, and type of construction, non-motorized mobility is accommodated within the construction zone or detoured via the shortest possible route. Often, pedestrians and cyclists are reluctant to add distance or travel out-of-the-way to reach their intended destinations. For this reason, instead of using the designated detour, they try to jaywalk and pass through the construction zone. Passing through the construction zone increases the risk of injury and fatality. As a result, alternatives need to be evaluated for providing safe access within or around construction zones. In addition to evaluating alternatives to provide access, another approach would be to develop projects with less-invasive construction methods and technologies directly incorporated into their design.

The use of less-invasive construction methods and equipment reduces the length of work zone and duration of work. Length and duration are two important parameters that increase accident risks. To evaluate the effect of length and duration of construction, Crash Modification Factors (CMFs) are provided in the Highway Safety Manual (HSM 2010) to describe the correlation among overall safety, physical length, and duration of a given work zone. As shown in equation 2-3 and 2-4, CMFs are calculated using percent increase in length and duration of work (HSM 2010, Savolainen et al. 2015). The coefficients used in the equations are calculated using historical data at a site prior to construction and an estimated amount of additional incidents due to a specific work zone configuration. As per the equations, reducing work zone length and construction duration would result in a lower risk of accidents. Even though the CMFs given in these equations have no direct relation to the pedestrian and cyclist injuries and fatalities, similar trends can be assumed until future research proves otherwise. In any case, it is obvious that work zone length and duration greatly impact the non-motorized mobility and performance of neighboring business (Yavuz et al. 2017). Thus, implementation of a wide array of innovative methods and technologies such as trenchless pipe technologies, pavement rehabilitation, pavement reconstruction, and accelerated bridge construction can be evaluated to reduce space and time requirements for construction activities and material and equipment storage.

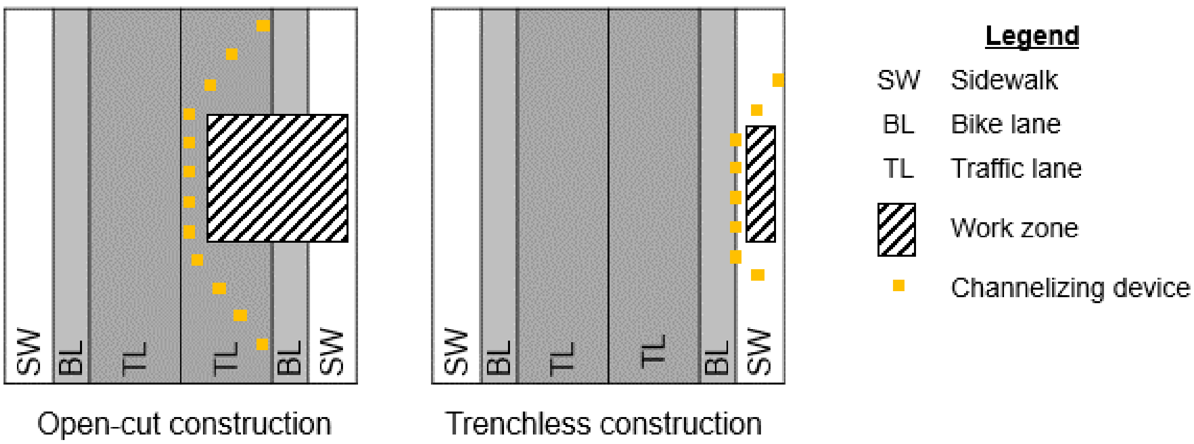
$$CMF = 1.0 + \frac{\%\, increase\ in\ length\ in\ miles \times 0.67}{100} \tag{2-3}$$

$$CMF = 1.0 + \frac{\%\, increase\ in\ duration\ from\ 16\ days \times 1.11}{100} \tag{2-4}$$

2.7.1 Trenchless Pipe Technologies

High volume excavation during repair and maintenance or new utility construction for long-term stationary work is amongst the most disruptive tasks that adversely affect non-motorized mobility (Figure 2-22a). Though more widely proliferated in rural settings, significant innovation has occurred in recent years to adapt trenchless technologies to urban applications. As shown in Figure 2-22b, trenchless pipe technology offers minimum excavation and maintains a higher level of services throughout construction because full removal and replacement of affected roadway features is no longer required. Trenchless pipe technologies also reduce the duration of activities resulting in a reduction of total work duration. Duration and space requirement of a work zone can be reduced from long-term stationary to intermediate-term or short-term stationary work zone within a closed auxiliary lane, and most of the impact on non-motorized mobility can be eliminated. Reduced duration and space requirements are capable of reducing the possibility of fatalities and increasing the overall safety of road users, including non-motorized traffic. According to Lord et al. (1998) 40% of all pedestrian accidents occur in construction zones located at intersection due to jaywalking as a result of restricting their turning movement. This highlights the need for reducing the duration and space requirements for construction. Cured-in-place pipe lining can be performed from entirely outside of roadway features (such as traffic, auxiliary, and parking lanes) allowing contractors to locate the TTC zone entirely out-of-the non-motorized travelled way. Reduced magnitude and near-grade construction allows use of smaller, space-saving channelizing devices to mitigate potential lane encroachment.

a) Traditional open-cut pipe replacement



b) Space requirement for open-cut and trenchless construction.

Figure 2-22. Typical space requirement with traditional and trenchless technology

Based on the condition of the existing pipe and other site constraints, trenchless pipe technologies can be used to rehabilitate or completely replace or upsize an existing system. Available methods and equipment of trenchless technologies include slip-lining, cured-in-place lining, spin-cast lining, joint sealing, directional boring, and pipe bursting (Figure 2-23). These methods are less-invasive and avow a 50 to 100-year design life. Construction using trenchless pipe technology generally requires removal of small sections of pavement at each end with a minimal excavation resulting in the preservation of existing roadway features. Trenchless technologies make TTC zones less noisy and dusty and can generally be situated without conflicting access to critical infrastructure (features like mass transit stops, bus stops, and fire hydrants).

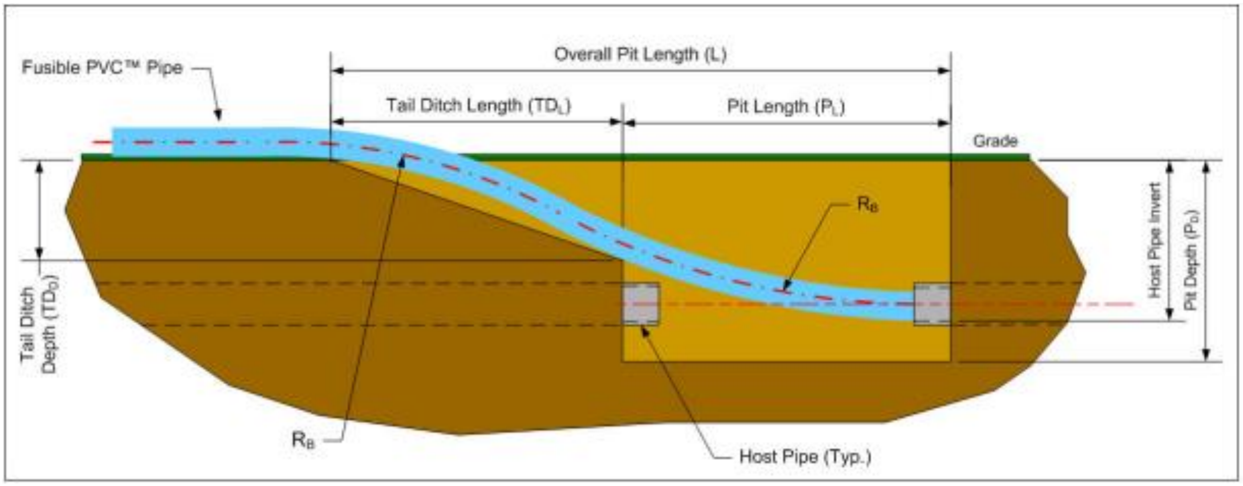


Figure 2-23. Typical sliplining, boring, and/or pipe bursting insertion/receiving pit (Underground Solutions 2016)

Trenchless pipe technologies must be evaluated for other environmental factors too. Many trenchless methods require bypassing of the flow in the existing facility, this may not work well on pipelines with severe deflections, and it may require careful monitoring of chemical agents to avoid potential downstream contamination. A notable limitation for directional boring, pipe bursting, and some sliplining applications is the required space for staging the new pipe material (Figure 2-24a). Sliplining offers a segmental approach (Figure 2-24b), in which space requirements are more localized and vertically-oriented (i.e. stockpile) than the continuous method of sliplining. In most applications, segmental sliplining does not require bypass flow control. Effort is required to summarize the method of application and limitations and to develop a decision-support tool for selecting appropriate trenchless technology based on work type and site constraints.

a) Significant space requirement of pipe bursting (IPR Great Lakes 2017)

b) Segmental sliplining (HOBAS Pipe 2017)

Figure 2-24. Space requirement of pipe bursting and segmental sliplining

A matrix for selecting appropriate trenchless technology for a given scope (type of work) and site-specific condition is developed and presented in Figure 2-25. To develop the matrix and present an appropriate selection criterion for each technology, numerous case studies and product brochures from a wide range of manufacturers' were reviewed and analyzed. The vertical axis shows trenchless methods and the horizontal axis (presented at the top) shows the project scope, maximum diameter of pipe, material type, and local constraints. In order to identify the most suitable option, the following steps need to be followed:

a) Identify the project scope (i.e. new pipe, structural rehabilitation, or non-structural rehabilitation).
b) Check if the selected pipe diameter is equal or less that the maximum diameter given in the chart.
c) Verify material type.
d) Identify and evaluate the other considerations specific to the site.

Example: A new water main valve consisting of a 96 in. diameter steel pipe is required to be installed in an urban environment and within an intersection with a high-volume of traffic. The alignment of the existing pipe changes along the length of the pipe. Therefore, a steerable trenchless technology is needed to perform the replacement of the water main valve. As presented in Figure 2-25, pipe bursting, horizontal directional drilling, and jack and bore methods are applicable for new pipe construction. Since the required pipe diameter is 96 in., only the jack and bore method is applicable. It is also noted that pipe bursting, however, requires bypass pumping (because the existing facility is taken out of service while new facility is installed), which is generally not feasible at an intersection. The existing water main pipe is made of steel, so the jack and bore method can be used. Since the alignment of the existing pipe is changing, this specific application requires a steerable method such as the jack and bore method. Therefore, the jack and bore method is determined to be the appropriate technology for this application. Aside from a short connection period, service remains uninterrupted with this method, and the replacement of the valve is completed without any major excavation in the intersection or undesirable detours, which mitigates the overall impact to road users, especially non-motorized mobility. Resources used for documenting the applications and limitations of the various trenchless technologies listed in Figure 2-25 are presented in Chapter 6 - References.

Trenchless Method	Project Scope	New Pipe	Structural Rehabilitation	Non-Structural Rehabilitation	Maximum Diameter (in.)	48	60	96	126	Material Type (End Product)	Concrete (Reinforced, Non-Reinforced)	High Density Polyethylene (HDPE)	Plastic (CPV, CPE, PVC)	Steel, Ductile Iron	Fiberglass Reinforced Plastic (FRP)	Polymers (Epoxy Resin, Polyurethane)	Considerations	Steerable[1]	Bypass Flow Control Required[2]	Sound Carrier Pipe Required[3]	Excavation for Laterals Required[4]	Environmental Considerations/Monitoring Req.[5]	Install Through Deflected Carrier Pipe[6]	Install Through Elliptical Carrier Pipe[6]	Pressurized Applications[7]
Pipe Bursting		✓				✓					✓	✓	✓	✓				✓	✓		✓	✓	✓	✓	✓
Cured In-Place Pipe				✓					✓							✓			✓			✓			✓
Spiral Wound Relining				✓					✓			✓	✓									✓	✓	✓	
Spin-Cast Lining				✓					✓		✓					✓		✓	✓	✓		✓	✓	✓	✓
Sliplining			✓						✓		✓	✓	✓	✓	✓				✓		✓	✓		✓	✓
Thermoformed			✓					✓				✓	✓						✓			✓	✓	✓	
Horizontal Directional Drilling		✓					✓					✓	✓	✓				✓	N/A	N/A		✓	N/A	N/A	✓
Jack and Bore		✓						✓			✓		✓	✓	✓			✓	N/A	N/A	✓	✓	N/A	N/A	✓
Joint Seal/Grout				✓					✓			✓	✓	✓				N/A	✓	✓	N/A		✓	✓	✓

1. Moveable steering head that can be controlled remotely to adjust vertical or horizontal alignments - recommended in critical utility zones.
2. Flow control is required to keep certain grouts, gels, and other materials dry and free of contamination during the curing process.
3. The condition of the existing pipe facility in which the trenchless technology is to be applied
4. Remote reinstatement of service connections from the new main pipe facility
5. Monitoring requirements may include the release of chemicals, grout, sand, heat and/or steam infiltration that may alter the physical and/or chemical makeup of the adjacent area. Refer to specific product Safety Data Sheets.
6. The shape of the existing pipe facility in which the trenchless technology is to be applied
7. Acceptability for typical pressurized applications, such as force mains, are based on proprietary product test data and/or empirical evidence (i.e. case studies).

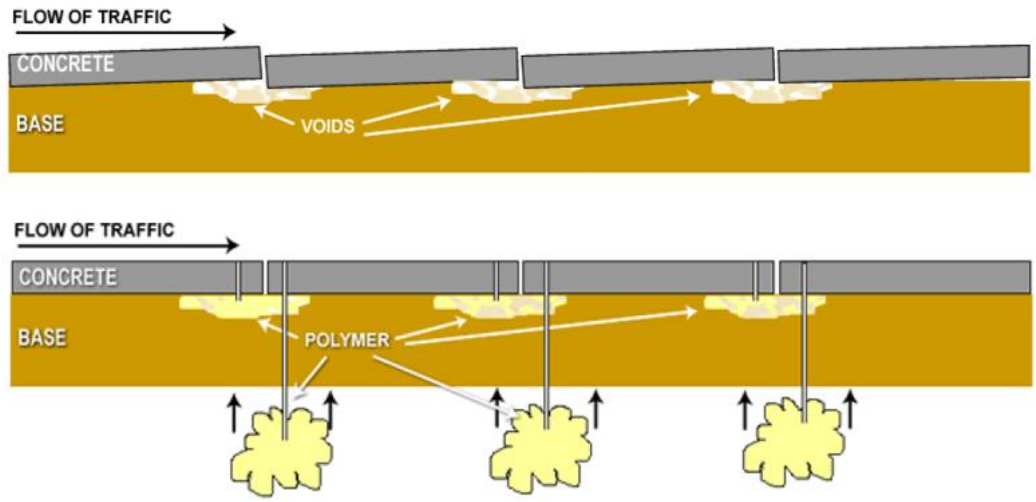
Figure 2-25. Trenchless technology selection matrix

2.7.2 Pavement Rehabilitation

2.7.2.1 Slab Jacking, Slab Stabilization, and Soil Densification

Innovative pavement rehabilitation methods were developed to minimize work duration and economic impact to a community and different road users. Traditionally, settlement remediation requires saw-cutting, removal, re-grading, and replacement of the affected pavement section and often occupies a location for more than 3 days. Recent innovations allow jacking/stabilization/densification to be performed on rigid, flexible, or composite pavements, and completion of work can be performed in nighttime and off-peak hours. Concrete slab jacking, slab stabilization, and soil densification can provide the same outcome that is expected through the traditional process, but with a reduced activity duration. Hence, concrete pavement rehabilitation work results in short-term stationary work zones. Pavement stabilization can be performed to meet owner-specified ride quality and Americans with Disabilities Act (ADA) requirements without excavating.

Concrete slab restoration process is shown in Figure 2-26. This process involves drilling a series of small-diameter holes in the pavement and injecting grout into the underlying grade to fill voids and lift the pavement to the required elevation. The significant advantage of these technologies is that only a localized area surrounding the affected roadway features needs to be occupied during the work activity, which can resume functionality immediately after completion of work. Hence, pedestrians and cyclists are not exposed to unprotected excavations, other unsafe conditions, or lengthy and undesirable detours. Further, the injection process is very quiet and results in very little disruption to the surrounding communities, if the work is performed at night or off-peak hours in the urban environment. It is also noted that the traffic control and construction activities can be stopped and resumed in a matter of minutes, making the work zone receptive to emergency response activities.



a) Slab jacking, slab stabilization, and soil densification process (Barrette 2014)

b) Nighttime slab jacking, slab stabilization, and soil densification

Figure 2-26. Slab jacking, slab stabilization, and soil densification process

2.7.2.2 Concrete Pavement Panels

Similar benefits are also inherent to precast concrete pavement panels, which may be employed during emergency utility work to quickly replace a removed portion of a pavement. If an underground feature needs to be accessed below a roadway feature, removal of the existing pavement is performed and a precast slab may be set and grouted in place. The dimension of precast slab can be predetermined. Precast concrete panels allow the facility to be returned to use immediately after the completion of work; therefore, the duration of occupying space is minimal as these panels do not need to cure in place. However, traditional concrete patches require up to 72-hours of cure time before resuming functionality. Moreover, concrete pavement panels are only applicable to rigid pavements, and a significant amount of pre-planning and capital investment is required. Maintaining a stockpile of precast slabs may not be practical unless they are programmed into a large-scale maintenance project.

Figure 2-27. Precast concrete slab being lowered into place (Snyder 2012)

2.7.2.3 Asphalt Paving

Pavement rehabilitation with asphalt paving affects non-motorized mobility during paving operations. Asphalt paving can be a hindrance to urban non-motorized mobility for a few different reasons:

a) Bond coat, the thin coat of asphalt emulsion applied to the underlying pavement surface which is to be overlaid, is slippery when first applied and becomes sticky after it cures. Bond coat presents a slip hazard initially, and later tends to stick to shoes and "track" as pedestrians walk through it.
b) The paving operation as a whole is very lengthy, and crossing the TTC zone can be dangerous.
c) The asphalt mat behind the paver remains too hot to accommodate non-motorized access for several hours after the paving operation has been completed.

The recent proliferation of a low-tracking bond coat (LTBC) and a warm mix asphalt (WMA) has helped to mitigate these issues and increase the mobility of road users during asphalt paving activities. LTBC is a generic term for any of a variety of polymer-modified asphalt emulsions used as an asphalt bond coat. The main characteristic that makes this material 'low tracking' is a higher penetration grade of asphalt as the base binder. There are several variations of proprietary additives and blending methods that keep asphalt suspended in the emulsion and homogenous. LTBCs are typically trackless within twenty seconds. This is a significant improvement over traditional bond coats which usually take about an hour or more to "break", depending on ambient weather conditions.

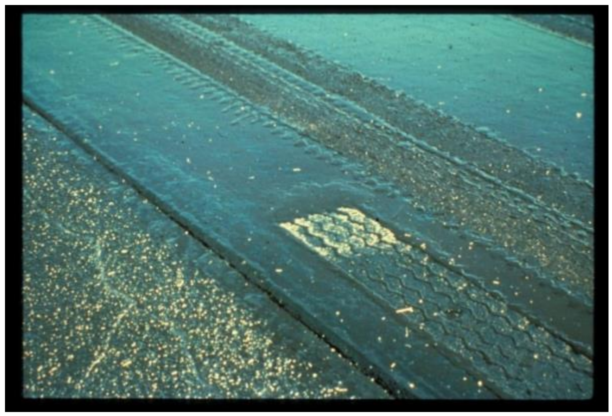
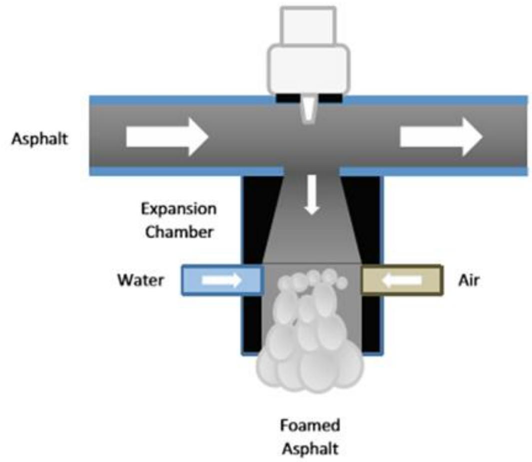


Figure 2-28. Traditional bond coat (Sherocman 2015)

Asphalt paving operations typically produce significant effects to the travelled way. Applying a "trackless" bond coat allows access to non-motorized mobility in a non-active part of the TTC zone without slip hazards or tracking until the mobile part of the operation is encountered. The paving area is closed completely from non-motorized mobility travel until the work activity has been completed during a dynamic paving operation. As a result, the overall TTC zone remains lengthy but becomes an effective work zone due to the reduced duration of work. The affected roadway feature(s) is essentially reduced from long-term stationary work to mobile operation. Due to a reduced duration of work, the CMFs shown in Equation 2-4 are decreased. WMA is generally 30 to 120°F cooler than the traditional hot mix asphalt (HMA) which allows for more rapid cooling of the pavement matrix during placement. This is done by adding water to the asphalt binder immediately before mixing with the aggregate, as shown in Figure 2-29a. When water is blended with the binder, the volume of the liquid asphalt greatly increases, which therefore increases the film thickness of the asphalt during production, transportation, and laydown. The asphalt mix behaves like a mix with very high asphalt content during placement. This allows a very easy compaction of the pavement to its desired level. The quicker reduction in temperatures allows the roller pattern to be "tightened" which expedites the dynamic portion of the activity in an affected location. WMA provides additional functionality for working during the night and off-peak hours by allowing for lower batching and placement temperatures, thus reducing the impact on motorized and non-motorized mobility. Lower design temperatures also create less odors, fumes, and smoke compared with traditional HMA. Therefore, WMA is more readily compliant with most local air quality restrictions.



a) Warm mix asphalt (WMA) foaming process (Newcomn et al. 2015)

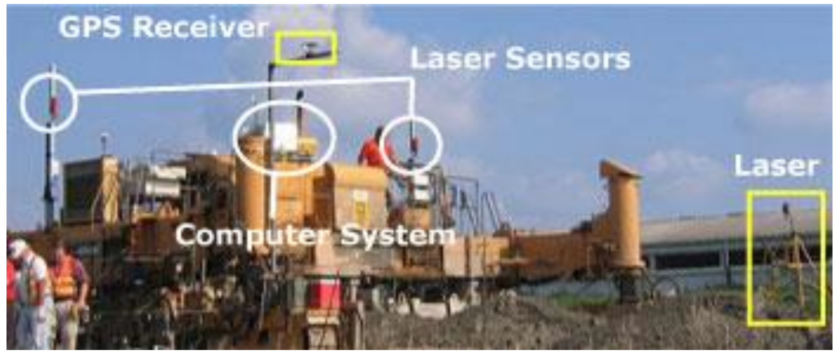
b) Hot mix asphalt (HMA) paving (Eddy's Construction 2016)

Figure 2-29. WMA and HMA paving

2.7.3 Pavement Construction

When complete removal and replacement of the pavement structure is required, stringless paving technologies have a potential impact on reducing the length of a work zone, decreasing work duration and increasing the safety of road users. Stringless paving can be performed for concrete pavement and curb work by using 3-dimensional computerized equipment (Figure 2-30), eliminating the need for on-paver sensing. Stringless technologies are not only able to reduce the work duration down to short-term stationary or mobile work, but they also accommodate on-site mobility, which is not possible with traditional paving practices. Stringless technology requires only an additional 4 ft on each side of the working space, which immensely reduces the length of work zone. The 3-dimensional modeling technologies are being adapted for other applications as well, such as asphalt paving and excavating.

a) Stringlines and on-paver sensors



b) Paver with GPS or total stations

Figure 2-30. Stringless paving repeats a 3D representation of the project to the paver via GPS or total stations (Cable et al. 2004)

2.7.4 Accelerated Bridge Construction

Accelerated bridge construction (ABC) is a term for a wide array of methods and technologies used in the rapid removal and replacement of bridge structures. The most common of the ABC technologies are the Slide-In Bridge Construction (SIBC), the Self-Propelled Modular Transporter (SPMT), the Precast Bridge Element System (PBES), and Launched Temporary Truss Bridge (LTTB) techniques. Out-of-service bridges have major implications for non-motorized mobility. However, the decision-making methodology for utilization of ABC techniques is generally beyond the consideration of non-motorized mobility, so further discussion on this topic is not warranted in this report. Additional information about ABC methods can be found in Aktan and Attanayake (2013), Aktan and Attanayake (2015), and Aktan and Attanayke (2017).

2.8 TECHNOLOGY TO ENHANCE NON-MOTORIZED MOBILITY

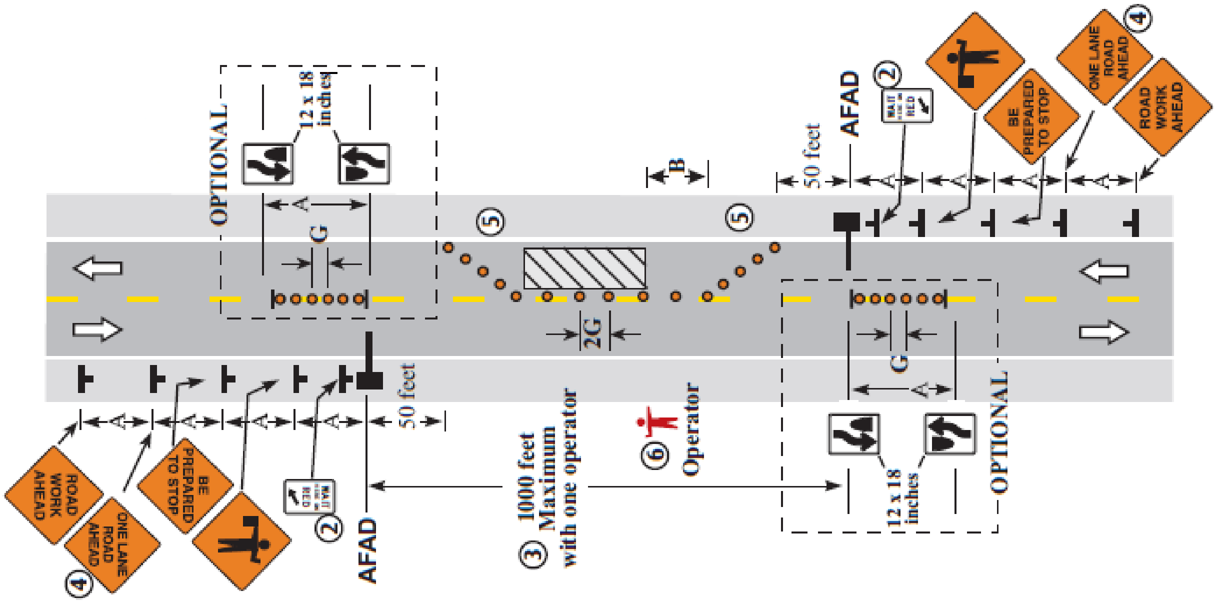
To promote mobility while ensuring safety for road users during construction is a concern for transportation engineers. Implementation of policies and guidelines, adequate training workshops, effective public outreach programs, and safety research programs are a priority of the highway agencies to ensure the safety of construction workers along with motorized and non-motorized traffic. These agencies have also developed or adopted new technologies and tools that can be used to enhance the safety of workers and road users. A few examples described in this report are the Automatic Flagger Assistance Device (AFAD), navigation systems using smartphone and Bluetooth technology, portable and non-intrusive advance warning devices, an in-vehicle work zone message system, a pedestrian warning system, the Blaxtair anti-collision camera, the Mobileye advanced driver assistance system, pedestrian switch pads, the Kapten plus pedestrian GPS, and Waze technology.

2.8.1 Automatic Flagger Assistance Device (AFAD)

Flagging is a critical operation during certain construction/maintenance activities or in emergency situations. For the duration of a project, flaggers are exposed to live traffic and weather conditions. In order to reduce the risks and hardship that the humans are exposed to while working as flaggers, Automatic Flagger Assistance Devices (AFAD) are developed to meet the operational requirement of MUTCD (2009) Section 6E (Terhaar 2014). One operator can easily manage two or more AFADs simultaneously by using a remote control while staying away from the live traffic and harsh weather conditions. Figure 2-31b shows an AFAD in action. Figure 2-31c shows a typical position of the flaggers in a construction site.

a) Traditional flagger person

b) AFAD machine in operation



c) Typical layout of using AFAD in two-lane two-way road

Figure 2-31. Picture of a traditional flagger, an automatic flagger assistant device, and a typical site layout showing the position of the flaggers (MN MUTCD 2014 and Terhaar 2014)

2.8.2 Navigation System Using Smartphone and Bluetooth Technologies

Providing safe passage for people with special needs is a challenge, especially for people with a sight disability or a hearing and sight disability. The University of Minnesota is developing an Android smartphone app that will automatically vibrate and send audible messages as pedestrian approaches a work zone or a designated space. A Bluetooth beacon will be attached to a barricade or traffic cones at decision points. The initial test result shows that smartphone app could successfully detect Bluetooth beacons within 15 feet, vibrate the phone for about one second, and send an audible message to provide navigation information. The functioning of the app is accomplished by using GPS signals, Bluetooth technology, a text to speech (TTS) interface, and a digital compass available in the smart phone. In addition, a digital map integrated in the app as well as Bluetooth beacons installed near a work zone provide the necessary data and signal for functioning the app (Liao 2014).

2.8.3 Portable and Non-Intrusive Advance Warning Devices

A technologically advanced drum line system, shown in Figure 2-32, has been developed and implemented in construction work zones to improve safety by drawing drivers' attention using audible and visual warning message as they approach the work zone. The drums are placed in an advanced warning area and at 1-3 ft away from the shoulder. The process of the system starts when the first drum's sensors detect a vehicle's speed and distance. This information is transmitted to the second and third drums using a wireless communication sub-system. If a vehicle exceeds the posted speed, both drums activate visual warning systems. When the high speed vehicle is closer to the second and third drums, the drums activate an air horn to warn the driver (Hourdos, 2012). The developers of this system have not explained the complications due to presence of multiple vehicles and the impact of the distraction generated by the noise of the air horn. Further, it is not clear what advantages (other than the air horn) that this system offers compared to using a typical digital speed limit sign. Hence, before adopting this technology, it is vital to address the aforementioned concerns through additional research.

Figure 2-32. Intelligent drum line system (Hourdos 2012)

2.8.4 In-Vehicle Work Zone Messages

An in-vehicle work zone messaging system can be used to send a message through the driver's smartphone to alert the driver who might not pay attention to the posted signs (Craig et al. 2017). The in-vehicle messaging smartphone is either mounted on the dashboard or placed in the passenger seat. A GPS sensor on the smartphone monitors the location of the vehicle and, as the vehicle moves toward the beginning of a work zone, Bluetooth service initiates a continuous scan and sends an audible message and/or a visual message. As shown in Figure 2-33a, when the driver is one and quarter (1.25) miles away from work zone, an introductory message appears in the driver's smartphone to signify upcoming changes to driving conditions. When the driver is one (1) mile away, an audio message is sent to the driver's smartphone requesting to a reduction in speed as the driver enters the work zone ahead (Figure 2-33b). When the driver enters the work zone, an audio-visual message is sent to alert the driver about the presence of the work zone and suggesting a reduction in speed (Figure 2-33c). Typically, several variable-message signs (VMS), similar to what is shown in Figure 2-33d, are required to use to inform drivers about upcoming road changes. This message system can eliminate the use of such VMS to reduce the projected cost. However, the impact of the driver distraction due to this messaging system needs to be evaluated before implementing such a system.

In-vehicle message alert system

Message Placement

Mile Marker 1.25

Introductory Drive (Before Transition Zone)

a) A text message is sent to the driver when the driver is 1.25 miles away from the site.

Audio-Only Message

"Work Zone Ahead"
"1 Mile"
"Reduce Speed"

b) An audio message is sent to the driver when the driver is one mile away from the site.

Audio-Visual Message (Icon)

c) An audio-visual message is sent to the driver when the driver enters a work zone.

VMS

REDUCE SPEED
WORK ZONE
1 MILE

d) Typically used variable-message signs (VMS)

Figure 2-33. In-vehicle message alert system and VMS to alert drivers about upcoming road changes (Craig et al. 2017)

2.8.5 Pedestrian Warning Systems

Work sites are very busy and the equipment used for construction related activities are large. This increases accident risks when non-motorized traffic is allowed within or around work zones. Most of the accidents occur when pedestrians or cyclists are unaware of an approaching vehicle, distracted, or unfamiliar with the work site, especially in busy and noisy environments. There are different types of alert and warning systems that can be used to enhance the safety in work zones or any other busy and dangerous areas.

2.8.5.1 Crossing Alert-Pedestrian Warning System

The crossing alert-pedestrian warning system developed by ZoneSafe (2017) helps to separate site traffic and pedestrians through audible warning messages. These messages help to alert pedestrians as well as the construction equipment operators and drivers. In order to make the system work, a ZoneSafe tag is attached to the construction equipment. Then, a Zonesafe unit is installed at a blind corner or on the wall just to emit a 360° detection zone (The distance of the detection zone can be adjusted from 9.8 ft to 29.5 ft.). When the equipment with the tag enters the detection zone, an audible visual alarm is set off by warning the people in that area. Once the equipment leaves the detection zone the alarm stops. Figure 2-34 illustrates the application of the system.

Figure 2-34. Crossing alert-pedestrian warning system (ZoneSafe 2017)

2.8.5.2 Walkway Alert–Approaching Vehicle Warning

The walkway alert-approaching vehicle warning system developed by Zonesafe (2017) works in a similar fashion to the crossing alert pedestrian warning system. As shown in Figure 2-35, the only difference is that this system is using multiple ZoneSafe units in the walkway.

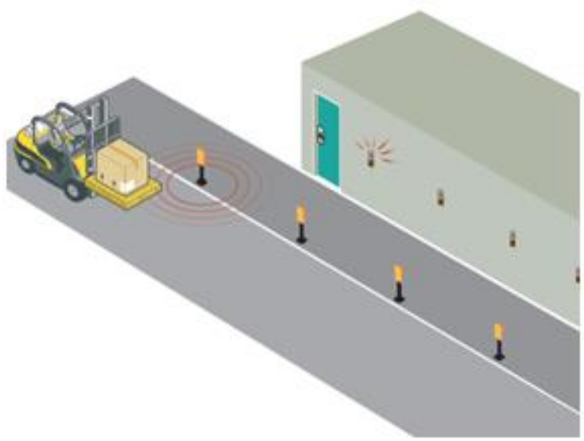


Figure 2-35. Walkway alert-approaching vehicle warning system (Zonesafe 2017)

2.8.6 Blaxtair Anti-Collision Camera

Equipment and vehicles used for construction are large, and it is very hard for operators and drivers to effectively detect people around them without the help of technology. The Blaxtair anti-collision camera shown in Figure 2-36 can be used to help construction equipment operators and drivers to observe their surroundings (Blaxtair 2017). The Blaxtair is a smart camera with an image processing capability that helps to distinguish a person from another obstacle in real time and alert the operator of upcoming danger. It is composed of a camera, calculator, and an LCD screen. The Blaxtair sensors scan blind areas around the equipment or vehicles and reconstruct their environment in 3D showing the nature of the obstacle based on powerful video recognition algorithms. If a person is detected in the danger zone, Blaxtair gives off a visual and provides an audible warning message to alert the driver. A control screen in the cabin allows the driver to judge the critical nature of the situation.

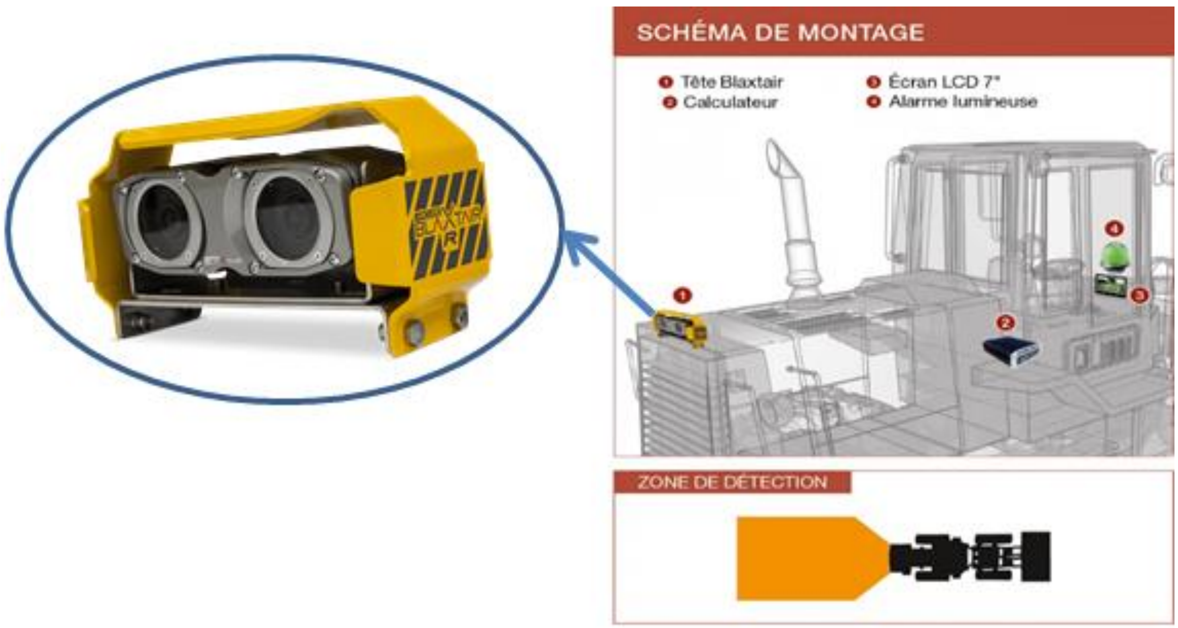


Figure 2-36. Blaxtair anti-collision camera (Blaxtair 2017)

2.8.7 Mobileye Advanced Driver Assistance System

Mobileye assistance systems can warn drivers when pedestrians, bicyclists, and other cars are close to the vehicle. As an example shown in Figure 2-37, Mobileye warns drivers showing a pedestrian sign on their smartphones when the pedestrian is closer to the car. Also, this system can read traffic signs and alert the drivers if their vehicle is out of the lane.

Figure 2-37. Mobileye advance driver assistance system (Swallow 2012)

2.8.8 Pedestrian Switch Pads

The tactile pad is a thin layer that can be installed onto an existing surface to detect the presence of pedestrians, cyclists, and/or cars. It functions when a load is placed on the surface. This technology can be used for pedestrian crosswalks, vehicle entry and exit locations, or pedestrian and cyclist ramps (Figure 2-38). When combined with other technologies, the pad can be used as a switch to activate audible and/or visual message systems to alert pedestrian and cyclists navigating through or around construction zones.

Figure 2-38. Tactile pad (Swallow 2012)

2.8.9 Kapten Plus Pedestrian GPS

Kapten Plus, a voice controlled GPS unit, is designed for sight-impaired pedestrians to navigate cities, locate intersections, and reach the destinations (Swallow 2012). Figure 2-39 shows a Kapten plus pedestrian GPS.

a) Kapten plus pedestrian GPS

b) Person with sight disability is using Kapten

Figure 2-39. Kapten plus pedestrian GPS (Google image)

2.8.10 Waze Technology

Waze is a GPS navigation software that works on smartphones and tablets with GPS support and provides real-time information about traffic and road features. Data needed for app operation is entered and verified by the users.

2.9 SUMMARY

Enhancing safety of non-motorized mobility is a significant concern of many transportation engineers and highway agencies. Providing safe access to non-motorized mobility within and around construction zones needs to be prioritized since the casualty figures are significant. National and international agencies have provided policies and guidelines to accommodate non-motorized traffic within and around work zones, and ADA/ADAAG/PROWAG provides minimum requirements of street components to provide access to people with special needs. Policies, guidelines, and minimum requirements of street components from national and international agencies for pedestrians and cyclists are documented and presented. TTC devices used to separate the road users from the work zone must be installed at the site during construction to provide information to road users about upcoming changes of the roads. A list of TTC devices used to manage non-motorized traffic is documented and presented. MUTCD provides basic principles and shows design, application, installation, and maintenance of the various types of TTC devices. However, selection and installation of TTC devices depend on the work type, work duration, work location, road geometric, intersections, interchanges, road user volumes, and the road user speeds. To alert people about work and upcoming construction activities, public outreach tools and methods are used; these include media, meetings, brochures, mailers etc. During construction work, different solutions are adopted to accommodate non-motorized traffic within or around construction zones, as needed; these include fences, open and covered pathways, shared or extended bike lanes, temporary bridges and pathways, and detours. A list of available infrastructures and products is presented and their benefits are described; this should prompt officials to use them when a temporary pathway must be provided during an alternative closure of roadway features. Most of these products are cost-effective, easy and quick to install and can be used several times. However, the use of these materials, due to different site-specific conditions, depends on the sincere response of contractors to the policies and guidelines. Moreover, by planning to provide a safe access route, the impact on mobility can be reduced by using less-invasive construction methods and technologies to reduce space and construction activity requirements. Less-invasive construction methods and equipment can be directly incorporated into a design. A list of less-invasive construction methods and equipment are presented. Also presented is a list of efficient equipment and tools that can be used to enhance safety of workers and road users.

To develop safe and convenient pathways within or around a construction zone, policies, guidelines, and minimum requirements of street components must be followed. Sometimes, even with these policies and guidelines, the safety and accessibility of non-motorized mobility is compromised. To better understand the application process of policies and guidelines, a direct survey was conducted with transportation engineers of green, walk-friendly, and bike-friendly cities. These cities have performed extensive work to manage non-motorized mobility within and around construction zones. Objectives and outcomes of the survey are presented in Chapter 3.

3 SURVEY OF TRANSPORTATION ENGINEERS

3.1 OVERVIEW

Efforts are made to provide safe access to non-motorized traffic within or around construction zones. Policies and guidelines from national and international agencies were reviewed and documented in Chapter 2. Most of these policies and guidelines are primarily based on the MUTCD (2009). However, there are a large number of green, bike-friendly, and walk-friendly cities. These cities have conducted extensive work to manage non-motorized traffic during construction work. Several of these cities were selected and surveyed to understand the application of the guidelines in accordance with site-specific conditions. This chapter presents a list of cities identified for the survey, the survey questionnaire, policies and guidelines (other than the MUTCD) used in those cities, public outreach tools and methods, and case studies of managing non-motorized mobility within or around construction zones.

3.2 CITIES SELECTED FOR SURVEY

A list of top ranked green, walk-friendly, and bike-friendly cities in the United States of America (USA) and other parts of the world was prepared and presented in Table 3-1 and Table 3-2.

The green city ranking is based on the use of renewable sources for electricity, the use of public transportation or carpooling, the number of buildings certified by the US Green Building Council, and available green space like public parks and nature preserves. Walk-friendly cities are ranked based on walkable neighborhoods with access to public transit, better commutes, and proximity to the people and places that are the key to a happier, healthier, and more sustainable lifestyle. Bike-friendly cities are ranked based on the total miles of bike lanes available in the city and comparing the percentage of females or population least likely to take the risk of cycling to the total number of commuters.

Table 3-1. Green, walk-friendly, and bike-friendly cities in USA

Green cities (City, State)	Walk-friendly cities (City, State)	Bike-friendly cities (City, State)
Albuquerque, New Mexico	Boston. Massachusetts	**Austin, Texas**
Burlington, Vermont	Chicago. Illinois	**Boulder, Colorado**
Chicago, Illinois	Denver, Colorado	Cambridge, Massachusetts
Fargo, North Dakota	**Long Beach, California**	Chicago. Illinois
Fort Collins, Colorado	Miami, Florida	Denver, Colorado
Garland, Texas	New York, New York	**Fort Collins, Colorado**
Grand Rapids, Michigan	Oakland, California	Indianapolis, Indiana
Healdsburg, California	Philadelphia. Pennsylvania	**Madison, Wisconsin**
Honolulu, Hawaii	Portland, Oregon	Minneapolis, Minnesota
Middleburg Heights, Ohio	San Francisco, California	New York, New York
Portland, Oregon	**Seattle, Washington**	Philadelphia, Pennsylvania
Poultney, Vermont	Washington D.C.	**Salt Lake City, Utah**
Roanoke, Virginia		San Francisco, California
San Francisco, California		**Seattle, Washington**
Seattle, Washington		Washington, DC

Source: Wired (2017), Dille (2016), Mulliner, (2017), and the Mysterious World (2017)
Note: Bold text indicates the survey participants (see Section 3.4).

Table 3-2. Green, walk-friendly, and bike-friendly cities located outside of the USA

Green cities (City, Country)	**Walk-friendly cities (City, Country)**	**Bike-friendly cities (City, Country)**
Amsterdam, Netherlands	Buenos Aires, Argentina	Amsterdam, Netherlands
Copenhagen, Denmark	Dubrovnik, Croatia	Antwerp, Belgium
Curitiba, Brazil	Florence, Italy	Barcelona, Spain
Helsinki, Finland	Marrakech, Morocco	Berlin, Germany
London, England	Melbourne, Australia	Bordeaux, France
Oslo, Norway	Paris, France	Copenhagen, Denmark
Reykjavik, Iceland	**Vancouver, Canada**	Hamburg, Germany
Stockholm, Sweden	Vientiane, Laos	**Helsinki, Finland**
Vancouver, Canada		Ljubljana, Slovenia
		Malmö, Sweden
		Montreal, Canada
		Munich, Germany
		Nantes, France
		Oslo, Norway
		Paris, France
		Seville, Spain
		Strasbourg, France
		Tokyo, Japan
		Utrecht, Netherlands
		Vienna, Austria
Source: Wired (2017), Dille (2016), Mulliner, (2017), and The Mysterious World (2017)		

Contact information from transportation engineers was documented primarily from their cities' respective websites. When contact information was not available, a representative employee of the agency was contacted to access relevant information or appropriate contacts.

3.3 SURVEY QUESTIONNAIRE

The objective of the survey was to identify (i) agency specific policies and guidelines other than the MUTCD, (ii) special provisions in contract documents for managing non-motorized mobility within and/or around construction zones, (iii) considerations on ADA/ADAAG/PROWAG criterion to provide access to people with special needs, and (iv) public outreach tools and methods used for informing the public about planned and ongoing construction activities. In order to accomplish the objectives, the following questionnaire was formulated:

1. Do you have agency specific policies and guidelines for managing non-motorized mobility within and/or around construction zones?
2. What are the special provisions that are included in your contract documents to accommodate/manage non-motorized mobility?
3. Other than your own manuals/guides/specifications (if any), what other resources are you using for selecting and specifying signage, managing motorized and non-motorized traffic, and accommodating emergency responders (ambulance, firefighters, and towing trucks)?
4. What public outreach tools or methods do you implement during planning and construction phases?

Once these questions were formulated, the survey was conducted with transportation engineers, and survey outcomes were documented. As needed, responses were followed up with additional questions for clarification and to acquire case studies.

3.4 SUMMARY OF SURVEY RESULTS

Only 8 agencies located in the US responded to the survey: Austin, TX; Boulder, CO; Fort Collins, CO; Honolulu, HI; Long Beach, CA; Madison, WI; Salt Lake City, UT; Seattle, WA. Out of these 8 agencies, 3 agencies (Fort Collins, CO; Honolulu, HI; Seattle, WA) represent green cities, 2 agencies (Long Beach, CA; Seattle, WA) represent walk-friendly cities, and 6 agencies (Austin, TX; Boulder, CO; Fort Collins, CO; Madison, WI; Salt Lake City, UT; Seattle, WA) represent bike-friendly cities. Unfortunately, none of the international agencies responded to the survey. Hence, policies and guidelines of those cities were documented in Chapter 2 through a web search. Practices of several cities located outside the United States were documented by the project team and presented in this chapter (see section 3.4.4.3).

3.4.1 Policies and Guidelines

Policies and guidelines for managing non-motorized mobility are quite similar among the US Departments of Transportation (DOTs) and the local agencies. Primarily, the DOTs have adopted MUTCD with or without amendments. The title of the adopted version is denoted by placing one or two letters of the state name in front of the original manual name - MUTCD. As an example, Michigan adopted MUTCD and renamed the manual as MMUTCD. DOTs use various indicators to highlight state specific amendments. For example, an image of the Michigan map is placed along the left border and next to each amended section of the MMUTCD. Italics, Bold text, or underlining is used by the other agencies for highlighting the amendments.

To meet the ADA requirements, DOTs refer to ADA/ADAAG/PROWAG guidelines. Few DOTs have written their own manuals by duplicating and amending MUTCD and ADA/ADAAG/PROWAG guidelines. As an example, Washington State DOT developed the Pedestrian Facility Guidebook after considering MUTCD and ADA requirements. Green, walk-friendly, and bike-friendly cities located in the US follow respective state specific MUTCD, their own manuals, and ADA/ADAAG/PROWAG guidelines. Each state DOT that responded to the survey has adopted MUTCD with some minor changes and ADA/ADAAG/PROWAG guidelines to meet ADA requirements. The cities that responded to the survey use their DOT's manuals.

As mentioned earlier, none of the international agencies responded to the survey. A web search was performed to find international publications and manuals. International publication and manuals of 4 cities listed in Table 3-2 (Oslo, Norway; Helsinki, Finland; London, England; and Vancouver, Canada) were reviewed and documented. All these 4 cities are considered green cities. Vancouver, Canada is also a walk-friendly city. Oslo, Norway and Helsinki, Finland are bike-friendly cities. In addition, two manuals (Guidance for the Control and Management of Traffic at Road Works; National Cycle Manual) published by the Department of Transport and Transport Authority of Ireland were also reviewed. Officials of these cities are managing non-motorized mobility by following policies and guidelines that are quite similar to MUTCD. However, the minimum requirements of street components used by those cities are slightly conservative compared to the ADA guidelines. As an example, the typical practice in the above stated cities is to use 3 ft wide pedestrian paths whereas the suggested minimum width in the PROWAG guideline is 4 ft.

The Victorian Transport Policy Institute published *Pedestrian and Bicycle Planning – A Guide to Best Practices for the City of Vancouver, Canada* (Litman et al. 2016). Primary references of this guide include the MUTCD, ADA, AASHTO (1999), State of Washington manuals and guides, and publications by several other US agencies. Hence, a majority of their guidelines are quite similar to the guidelines used by the US agencies.

3.4.2 Public Outreach Tools and Methods

Initially, a literature search was conducted to identify commonly used public outreach tools and methods. The result of the literature search is presented in Chapter 2, Section 2.5.2. The survey included a question related to public outreach tools. However, the findings are similar to what is already document in Chapter 2, except the city of Boulder, Colorado who uses Waze and Google Maps as additional public outreach tools. Since there was no response from the agencies outside the U.S., the public outreach tools and methods used by such agencies are not documented in this chapter.

3.4.3 Case Studies

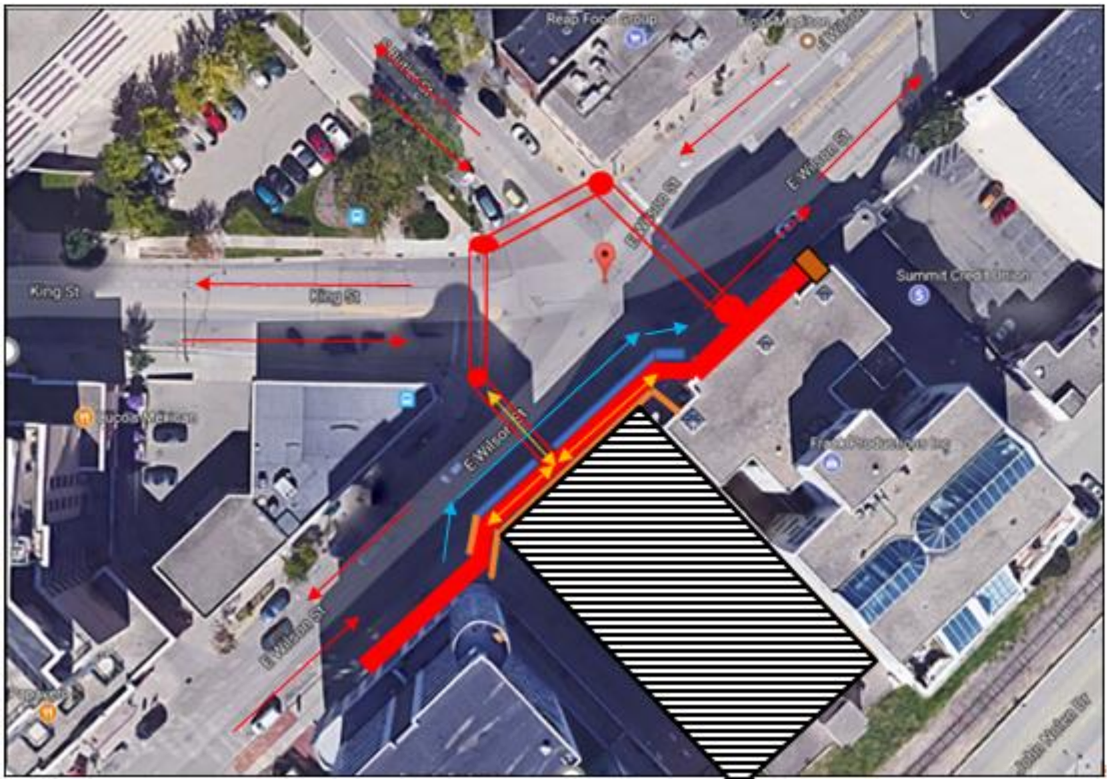
Three case studies submitted by Madison, Wisconsin and Austin, Texas are presented here to demonstrate the approaches taken by transportation engineers to manage non-motorized mobility within or around construction zones. Throughout the survey, transportation engineers from contacted cities were generous to share their experience. In addition, practices by several cities located in Europe are presented.

3.4.3.1 Case Study of Madison, Wisconsin

Two case studies from a survey of Madison, Wisconsin are shown in Figure 3-1 and Figure 3-2. As shown in Figure 3-1, a sidewalk was occupied to meet the space requirement for construction activities of the site located at the intersection of E Wilson Street and King Street. In order to provide safe access for non-motorized traffic, a 4 ft wide temporary pathway was provided by taking space from the traffic lane. Available space was adequate to shift the traffic to the middle of the road while maintaining the traffic in the opposite direction unaltered. All the safety precautions such as Jersey barriers and fences were in place. Also, all the crosswalks were left operational. Hence, jaywalking was discouraged and the risk of accident was reduced.

Figure 3-2 shows the non-motorized and motorized traffic management plan during the construction activities at the intersection of S Hancock Street and E Wilson Street. Space was adequate to provide a 5-ft wide protected walkway and a 5-ft wide bike lane after removing a 21-

ft parking and turning lane during construction activities. Signs were placed at the E Main Street and S Hancock Street intersection to guide pedestrians to use the available sidewalk of S Hancock Street located on the opposite side of the construction zone.



Legend:

Construction zone	Construction fence
Crosswalk	Jersey barrier
Crosswalk landing	Pedestrian & Cyclist direction
Protected path	Off ramp
Normal traffic direction	Diverted traffic direction

Notes:

Jersey barriers are located 14 ft out from the curb.

Detour path is 4 ft width.

Construction fence is located 8 ft from the curb.

Figure 3-1. Work zone located at the intersection of E Wilson St and King St, Madison, Wisconsin (43.074651, -89.378442)

Legend:

	Construction zone		Construction fence
	Crosswalk		Jersey barrier
	Crosswalk landing		Pedestrian & Cyclist direction
	Protected path		Bike path
	Channelizing barrels		Sidewalk Closed sign
	Off ramp		Right Lane Ends sign
	Arrow board		Normal traffic direction
	Diverted traffic direction	-	-

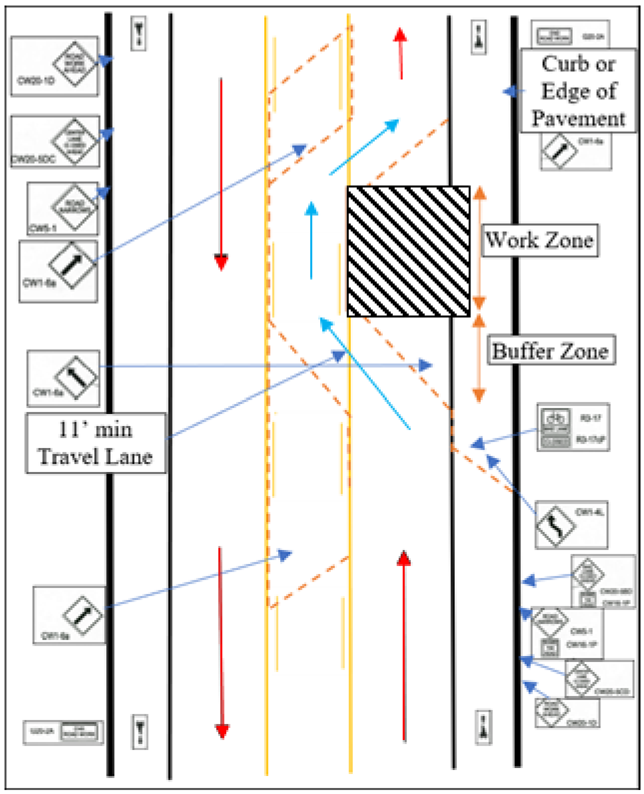
Notes:

Additional CLOSED SIDEWALK signs are deployed north of the area shown in the figure.
Additional warning signs are deployed further east on E. Wilson Street (not shown in the figure).
Construction fence on S Hancock Street is 12 ft away from the Eastern curb.
Protected walkway is 5 ft wide.
Bike lane is 5 ft wide.

Figure 3-2. Work zone located at the intersection of S Hancock St and E Wilson St, Madison, Wisconsin (43.075262, -89.377526)

3.4.3.2 Case Study from Austin, Texas

As shown in Figure 3-3, this two-way road has three traffic lanes and two bike lanes on both sides of the street. The three lanes include one traffic lane in each direction and a turning lane. There is no sidewalk on this street. The work zone occupied the northbound traffic lane and part of the adjacent bike lane. At the construction site, a new lane was defined by taking space from the turning lane. The new lane accommodated traffic and the cyclists. However, accommodating traffic and cyclists requires defining this as a shared lane with adequate space for such a lane. This new lane width is not adequate for a shared lane. Also, the shared lane was created without repainting the shared lane sign. Hence, cyclists might face challenges when merging with traffic increasing the risk of accidents.



Legend:

Construction zone

Bike path

Normal traffic direction

Diverted traffic direction

Channelizing barriers

Figure 3-3. Case study from Austin, Texas

3.4.3.3 Case Studies from European Cities

Figure 3-4 shows alternatives used for managing non-motorized mobility within and around construction zones in Steglitz and Berlin, Germany. These alternatives are securely arranged and maintained. However, in certain instances, uneven surface conditions that can increase the risk of tripping and falling are observed (Figure 3-4e). Figure 3-5 shows a situation in Berlin, Germany. Vehicle access is provided through a temporary lane that occupies a non-motorized path. With this situation, pedestrians and cyclists pass through the same lane provided for vehicle access increasing the risk of accidents. Figure 3-6 shows the implementation of temporary bicycle lanes and walkways for managing non-motorized mobility in Bremen, Germany. Figure 3-7 shows the closure of a building front for renovation activities in Bremen, Germany. Due to lack of space available for non-motorized mobility, pedestrians navigate through the space available between traffic lanes and bus/tram shelters while cyclists use traffic lanes. Figure 3-8 shows a few examples from Hanover, Germany. Figure 3-8d shows improper maintenance of a safety barrier/fence that becomes a tripping hazard. Figure 3-9 shows a complete closure of a street for construction activities in Sofia, Bulgaria. Non-motorized mobility parallel to the street is maintained using protected space between the construction zone and the buildings located along the street (Figure 3-9b). However, a designated path in front of the construction zone for non-motorized traffic is not provided (Figure 3-9c). As a result, pedestrians are exposed to a greater risk due to conflict of their movements with the construction vehicles moving in and out of the construction site (Figure 3-10a and b). On-street parking for building residents is allowed in many cities due to space constraints. Figure 3-10c shows the vehicles parked on a street that is parallel to the street closed for construction. This hinders access to emergency responders.

a) Covered bicycle lane and walkway (Steglitz, Germany)

b) A bicycle lane protected with a fence and a designated shy distance (Berlin , Germany)

c) Cyclist share the lanes while pedestrians are provided a protected temporary walkway (Berlin , Germany)

d) A temporary bicycle lane and a protected walkway (Berlin , Germany)

e) A temporary walkway with an uneven surface condition (Berlin , Germany)

Figure 3-4. Non-motorized mobility management during construction activities in Steglitz and Berlin cities in Germany

a) A crane occupying a street

b) A pedestrian standing next to the crane and waiting to pass through the construction zone

c) A cyclist travelling through the lane provided for vehicles

Figure 3-5. Vehicle and non-motorized traffic conflicts due to construction activities in Berlin, Germany

a) A temporary bicycle lane and a walkway

b) A shared temporary bicycle lane and a walkway

c) A close up view of the walkway surface condition

Figure 3-6. Managing non-motorized mobility during construction activities in Bremen, Germany

a) A work zone designated for a building renovation project

b) Pedestrians travel between the bus/tram shelter and the traffic lanes

c) Pedestrians navigating through a bus/tram shelter and cyclists using traffic lanes

Figure 3-7. Vehicle and non-motorized traffic conflicts due to construction activities in Bremen, Germany

a) Pedestrian and cyclist shared lane

b) A lane occupied for construction activities and storage

c) Protected bicycle lane and walkway using a fence

d) Improper management of fences/barriers

e) Part-width construction

f) Use of a temporary bridge

Figure 3-8. Managing non-motorized mobility during construction activities in Hanover, Germany

a) Complete street closure due to construction activities (non-motorized access parallel to the street is provided using the walkways located between the buildings and the work zone)

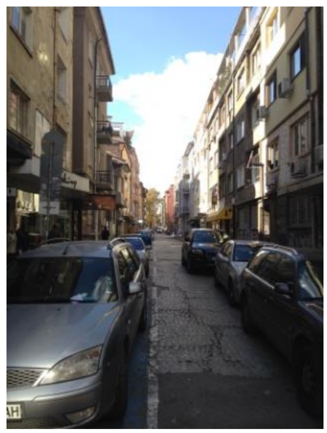
b) Access for non-motorized traffic

c) Unprotected non-motorized access provided in front of the work zone entrance

Figure 3-9. Non-motorized mobility management during construction activities in Sofia, Bulgaria

a) Pedestrians crossing the road in front of the work zone

b) Mobility impact due to construction vehicles



c) Vehicles parked on parallel streets hindering access to emergency responders

Figure 3-10. Impact of construction activities on non-motorized mobility and access to emergency responders in Sofia, Bulgaria

3.5 SUMMARY

Policies and guidelines, minimum requirements of street components, and practices are documented in Chapter 2. Besides having policies and guidelines from MUTCD and minimum requirements of street components from ADA/ADAAG/PROWAG, safety and accessibility of pedestrians and cyclists are still compromised. To understand the application of policies, guidelines, and the minimum requirements of street components, a direct survey was conducted with transportation engineers of top ranked green, walk-friendly, and bike-friendly cities. Transportation engineers of the contacted cities were requested to provide responses to four fundamental questions regarding practices and specifications of the intended city. The survey yields that green, walk-friendly, and bike friendly cities inside the USA follow MUTCD policies and guidelines, and minimum requirements of street components meet following

ADA/ADAAG/PROWAG standards. Unfortunately, none of the international agencies responded to the survey. However, practices of several cities located outside the United States were documented by the project team and presented in this chapter. International publications and manuals were reviewed via web search and documented in Chapter 2. Based on national and international publications, manuals, and survey outcomes, possible solutions for managing non-motorized traffic were developed and presented in subsequent chapters.

4 ALTERNATIVES FOR MANAGING NON-MOTORIZED MOBILITY

4.1 OVERVIEW

Providing safe routes for non-motorized mobility during construction activities in urban, rural, and congested cities is a challenge. As a result of decreasing the level-of-service (LOS), the risk-taking behavior of pedestrians and cyclists increases. Hence, it is necessary to identify alternatives for providing safe access to non-motorized traffic and evaluating them to identify the most suitable alternative for a site. To develop a list of safe passage alternatives to manage non-motorized traffic, national and international publications and manuals, a number of case studies, best practices, policies and guidelines, and minimum requirements of street components were reviewed. A survey was conducted to understand the application of policies and guidelines and to identify additional documents including policies and guidelines, public outreach tools and methods, and case studies of managing non-motorized mobility within or around construction zones located in green, walk-friendly, and bike-friendly cities. As a result, a risk-based decision support framework for identifying the most viable alternatives for managing non-motorized mobility during construction activities was developed. This chapter presents a work zone and mobility management framework, space management for construction, level-of-service considerations, alternatives for managing non-motorized mobility within or around construction zone, a risk-based decision support framework, and alternatives to provide access to different facilities.

4.2 WORK ZONE AND MOBILITY MANAGEMENT FRAMEWORK

With the introduction of the complete street policies, highway and city officials evaluate alternatives for managing non-motorized traffic for projects with long-term stationary work duration. Agencies pay little or no attention to managing non-motorized mobility when the work duration is less than or equal to 3 days. However, the overall impact of nearby projects and congestion, delay, and safety issues may demand developing a plan for managing motorized and non-motorized mobility even if the construction duration is not more than 3 days. Based on the literature review, case studies, and the survey, a framework was developed to guide a decision maker through a systematic process to evaluate work zone and mobility management needs. Figure 4-1 shows the framework. As shown in the figure, the decision process starts with the project duration. Even if the overall impact of nearby projects is not significant, identifying construction technologies and methods along with an assessment of activities to minimize the construction impacts is still needed. When the project duration is greater than 3 days, the impact of nearby projects and congestion, delay, and safety issues needs to be evaluated. The next two steps include identifying construction technologies and methods as well as space management techniques for material and construction equipment storage. Activity management includes slurry/material transport, hazardous material handling, historic/aesthetic value preservation, and developing a schedule to manage work during regular working hours, off-peak hours, nighttime, or as phase construction. The schedule needs to be developed considering the access to local businesses, nearby facilities (such as schools, offices, transit facilities, etc.), and special events in the area (such as shows at a theater, games at a stadium, etc.). The next few steps include managing motorized and non-motorized mobility, emergency responder access, and pollution due to construction activities.

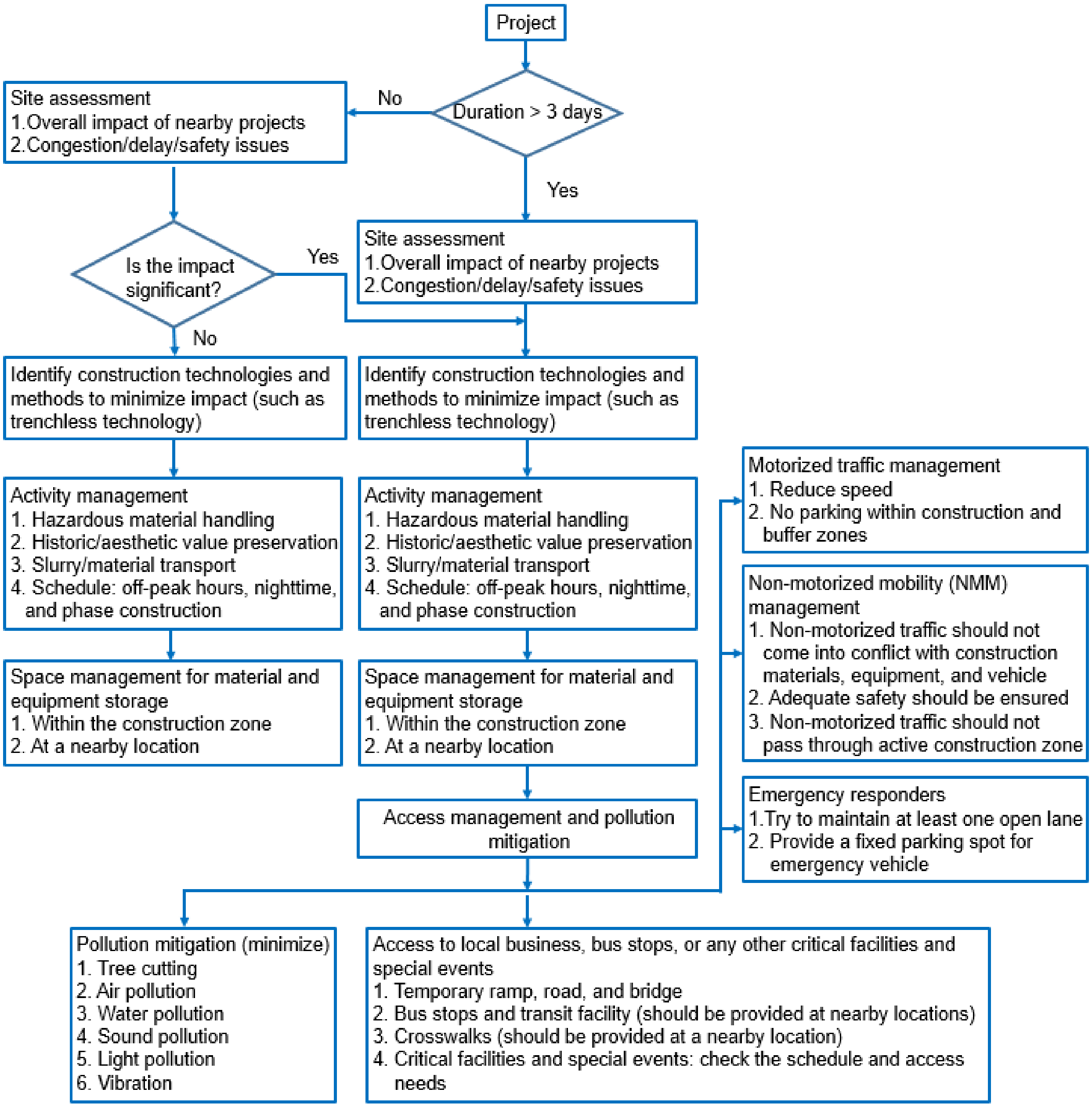


Figure 4-1. Work zone and mobility management framework

4.3 SPACE MANAGEMENT FOR CONSTRUCTION

To acquire necessary space for managing construction activities, sidewalks, shoulders, bike lanes, traffic lanes, or a combination thereof are closed. Roadway features that are affected by construction activities are listed in Table 4-1. Alternatives for managing non-motorized traffic need to be developed after considering space availability due to closure conditions.

Table 4-1. Roadway features affected by construction activities

Affected roadway features
Sidewalk – SW
Bike lane – BL
Traffic lane(s) – TL
Sidewalk and bike lane – SWBL
Sidewalk and traffic lane(s) – SWTL
Sidewalk, bike lane, and traffic lane(s) – SWBLTL
Complete closure – CC

4.4 PEDESTRIAN AND CYCLIST FACILITY LEVEL-OF-SERVICE (LOS)

The level-of-service (LOS) of non-motorized traffic measures the degree of accommodation of pedestrians and cyclists in a transportation corridor (Dixon 1996, Litman et al. 2016). LOS is used to evaluate the performance rating of an existing non-motorized facility. This tool can be used to assess the LOS of a non-motorized traffic facility during the construction work.

To meet construction space and activity requirement, sidewalks, bike lanes, traffic lanes or a combination thereof are closed resulting in a discontinuous pathway for non-motorized mobility. As a result, the LOS is reduced. LOS also decreases due to many other reasons such as reduced functional width, an uneven surface, large cracks, and potholes. As the LOS decreases, the risk-taking behavior of non-motorized traffic increases, thus the risk of injuries and fatalities. At least reinstating LOS by managing non-motorized traffic with proper facilities is a potential solution to reduce risk-taking behavior. As an example, when a sidewalk is closed due to construction and a temporary pathway is not provided for pedestrians, pedestrians exhibit risk-taking behavior such as using traffic lanes, jaywalking, or passing through areas with active construction. If a safe and convenient temporary pathway is provided for pedestrians within or around a work zone, the LOS would increase, and the risk-taking behavior of pedestrian would decrease. Hence, it is expected that cities would increase or at least reinstate the LOS of non-motorized traffic facility during construction.

LOS for a pedestrian and/or cyclist facility is measured based on assigned points on six categories. The provision of basic facilities, conflicts, amenities, motor vehicle LOS, maintenance, and transportation demand management (TDM) and multimodal provisions are the categories considered for measuring LOS for pedestrians. Designated basic facility, conflicts, speed differential, motor vehicle LOS, maintenance, and provision of TDM programs or intermodal links are the categories considered for evaluating LOS for cyclists. These categories and associated criteria with respective points are presented in Table 4-2. As shown in Table 4-2, a pathway is assigned points for each criterion under each category. The summation of all the points is the segment score. Then, a pathway score is calculated by multiplying the segment score with the segment weight, where segment weight is the ratio of segment length over pathway length. Finally, the pathway score is used to select performance rating (A, B, C, D, E, or F) and the corresponding performance level as shown in Table 4-3. The performance level in Table 4-3 is defined as the LOS.

Table 4-2. LOS evaluation matrix for pedestrian and cyclist facilities (Dixon 1996, Litman et al. 2016)

	Pedestrian		Cyclist	
Category	**Criterion**	**Points**	**Criterion**	**Points**
Facility (Max. value = 10)	Not continuous or non-existent	0	Outside lane 12 ft	0
	Continuous on one side	4	Outside lane 12-14 ft	5
	Continuous on both sides	6	Outside lane > 14 ft	6
	Min. 5 ft wide and barrier free	2	Off-street/parallel alternative facility	4
	Sidewalk width > 5 ft	1		
	Off-street/parallel alternative facility	1		
Conflicts (Max. value = 4)	Driveways and sidestreets	1	Driveways and sidestreets	1
	Pedestrian signal delay 40 sec or less	0.5	Barrier free	0.5
	Reduced turn conflict implementation	0.5	No on-street parking	1
	Crossing width 60 ft or less	0.5	Medians present	0.5
	Posted speed ≤ 35 mph	0.5	Unrestricted sight distance	0.5
	Medians present	1	Intersection implementation	0.5
Amenities (Max. value = 2)	Buffer not less than 3 ft 5 in.	1		
	Benches or pedestrian scale lighting	0.5		
	Shade trees	0.5		
Speed differential (Max. value = 2)			> 30 mph (posted speed > 45mph)	0
			25 – 30 mph (posted speed 40 - 45mph)	1
			15 – 20 mph (posted speed 30 - 35 mph)	2
Motor vehicle LOS (Max. value = 2)	LOS = E, F, or 6+ travel lanes	0	LOS = E, F, or 6+ travel lanes	0
	LOS = D, & < 6 travel lanes	1	LOS = D, & < 6 travel lanes	1
	LOS = A, B, C, & < 6 travel lanes	2	LOS = A, B, C, & < 6 travel lanes	2
Maintenance (Max. value = 2)	Major or frequent problems	-1	Major or frequent problems	-1
	Minor or infrequent problems	0	Minor or infrequent problems	0
	No problems	2	No problems	2
TDM/Multi Modal (Max. Value = 1)	No support	0	No support	0
	Support exists	1	Support exists	1
Calculation	Segment score[1]	21	Segment score	21
	Segment weight[2]	1	Segment weight	1
	Pathway score[3]	21	Pathway score	21

1. Segment score is the sum of point of six categories.
2. Segment weight is ratio of segment length over corridor length.
3. Pathway score is product of segment score and segment weight.

Table 4-3. Performance rating system (Dixon 1996, Litman et al. 2016)

Performance rating	Points	Performance level
A	> 17 but ≤ 21	A performance level well above average and may be expected in locations such as college campuses, downtowns, tourist centers, and activity centers
B	≥ 14 but < 17	
C	≥ 11 but < 14	An average performance level acceptable in most urban streets
D	≥ 7 but < 11	
E	≥ 3 but < 7	An unacceptable performance rating
F	≤ 3	

4.4.1 Pedestrian Facility LOS

For a pedestrian facility, a maximum of 10 points can be scored. A maximum of 6 points are assigned to the facility if the facility is continuous on both sides of the road. The facility earns 2 points if the functional width is at least 5-ft, and the pathway is barrier free. To be qualified as a barrier free facility, the pedestrian facility and ramp near an intersection must meet the ADA accessibility guidelines for width and slope. The facility earns 1 point if the pathway is at least 5 ft wide. The facility earns 1 point if it is located within 0.25 miles of the roadway segment and includes, but is not limited to, rail-trails, greenways, and pedestrian plazas.

When evaluating conflicts associated with the pedestrian facilities, a maximum of 4 points can be scored depending on the degree of conflicts created or alleviated due to visibility, pedestrian convenience, pedestrian exposure times, and motor-vehicle turning movements. One (1) point is assigned if access points (driveways and sidestreets) are located 245 ft apart which reduces the possibility of conflict with motorized traffic. A facility earns 0.5 point if delay time is 40 sec or less. Pedestrian impatience and risk-taking behavior increases after 30 secs of delay; therefore a 30 sec delay is considered as an acceptable average value (Kaiser 1994). Considering LOS of motorized traffic, a delay time of 40 secs is suggested for Table 4-2. To receive points for reduced turn conflict implementation criterion, a facility must be free of obstruction, and a crosswalk must be provided. In addition, the segment must have one of the two specifications: i) protected left-turn signal phasing on the majority of signals within the segment and ii) exclusive pedestrian phase, restricted right turn on red, or a grade-separated crossing. A facility earns points when the crossing width of a crosswalk is 60 ft or less. Pedestrians feel comfortable when the posted speed of the road is approximately 35 mph or less, so 0.5 point is assigned if the posted speed is 35 mph or less. Presence of a median reduces left-turn conflict and facility earns one (1) point.

The amenities category can earn a maximum of 2 points. A facility earns a point if the buffer is not less than 3 ft 5 in. Presence of benches or pedestrian scale lighting earns 0.5 points. Also, the presence of shade trees earns 0.5 points.

The posted speed is usually higher for 6 - lane streets and less comfortable for pedestrians. Pedestrians feel highly uncomfortable when the motor vehicle LOS decreases. Hence, when the number of lanes is less than 6 and the motor vehicle LOS is at A, B, or C, the facility earns 2 points. As the congestion increases, the points that can be earned by a facility decrease. The other two categories considered for a pedestrian facility include maintenance and presence of TDM along with multimodal provisions.

4.4.2 Cyclist Facility LOS

A maximum of 10 points are earned by a facility. A maximum of 6 points is assigned when the outside lane width is greater than 14 ft. A facility earns 4 points if cyclists are separated from motorized traffic.

When evaluating conflicts associated with a cycle facility, a maximum of 4 points can be scored. One (1) point is assigned if the access points of cyclists (driveways and sidestreets) are located at 245 ft apart, which reduces the possibility of conflict with motorized traffic. A cyclist facility earns 0.5 points if the facility is free from physical barriers. A facility earns 1 point if on-street parking is not available. On-street parking increases the possibility of conflicts. A facility earns 0.5 points due to a presence of a median, unrestricted sight distance, or an intersection with a proper right turn facility.

A facility can earn a maximum of 2 points based on the speed differential between cyclists and the posted speed for motorized vehicles. Figure 4-2 is a guidance graph published by the Ireland National Transport Authority in their National Cycle Manual (NCM 2011). As shown in Figure 4-2, posted motorized vehicle speed and traffic volume are two main parameters that can be used to define the level of comfort that a cyclist feels when moving with the vehicles. Cyclists feel very comfortable using shared lanes when the volume of traffic is low and the posted speed is less than 20 mph. However, as the posted speed increases more than 40 mph, use of a separate bike way makes cyclists to feel safe. According to Table 4-2, a facility scores 2 points when the speed differential ranges from 15 mph to 20 mph with the posted speed at 30 - 35 mph. The other scoring categories include motor vehicle LOS, maintenance, and presence of TDM along with multimodal provisions. Scoring procedure for those categories is same as that of pedestrian facilities.

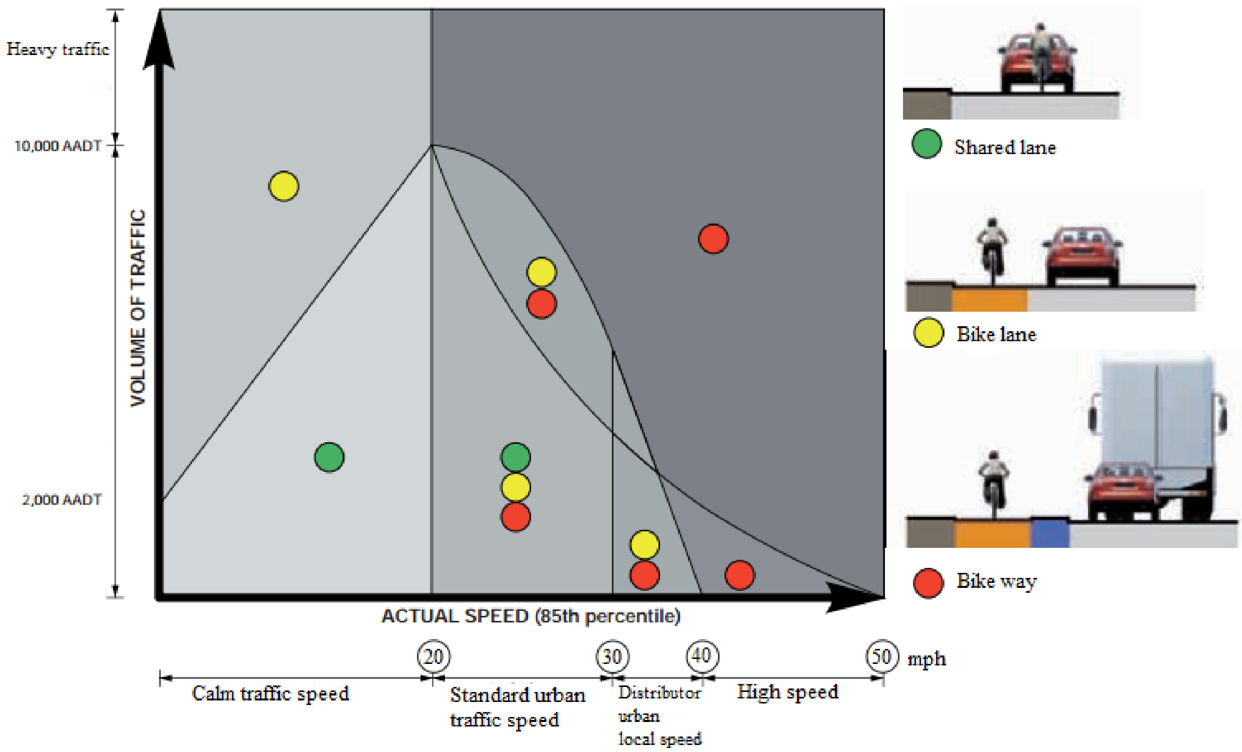


Figure 4-2. Guidance graph: volume of traffic vs actual speed diagram (NCM 2011)

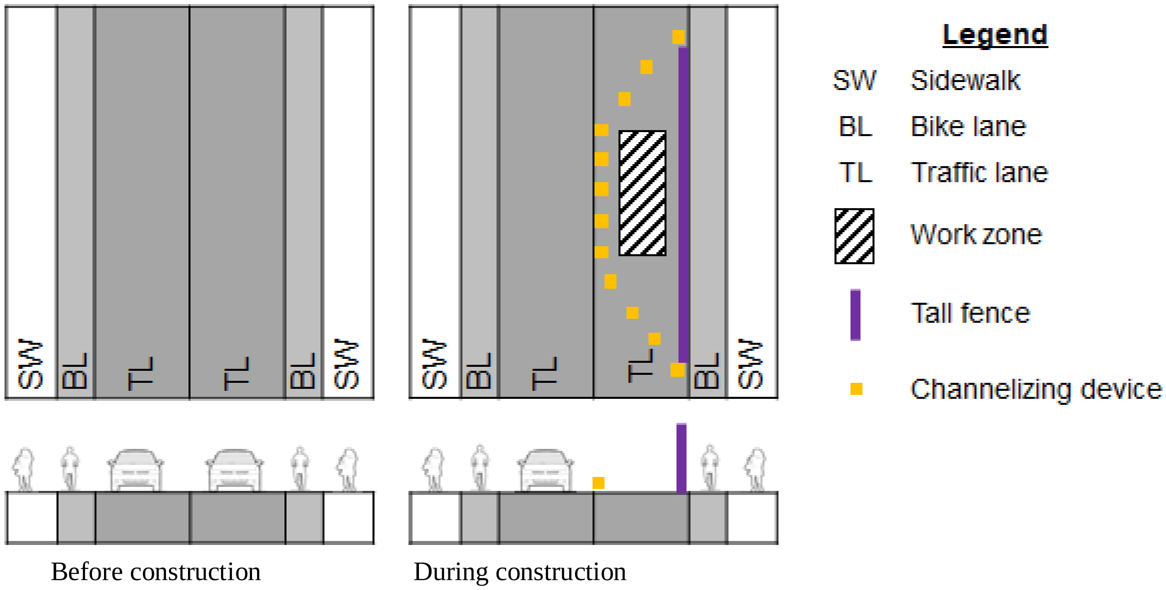
4.5 ALTERNATIVES FOR MANAGING NON-MOTORIZED MOBILITY

LOS decreases when an available pathway is disrupted due to the work zone and when a safe and convenient pathway is not provided. With the decrease in LOS, pedestrians and cyclists undertake risk. Risky behavior includes jaywalking, crossing busy highways during peak hours, climbing barriers to cross roads, and walking on the barriers as a short cut or for amusement (Bilton 2012). Risks can be reduced by increasing or at least reinstating LOS and performance rating by providing continuous accommodation of non-motorized traffic through or around the work zone, clear advance warning signage, adequate surface conditions, vehicle speed control, and proper signing and marking of detours and alternate routes (Ellis et al. 2008). The following is a list of 9 alternatives that can be implemented to manage non-motorized mobility during construction activities. A single or a combination of multiple alternatives can be implemented to provide a reasonably safe, convenient, and accessible pathway within and around construction zone.

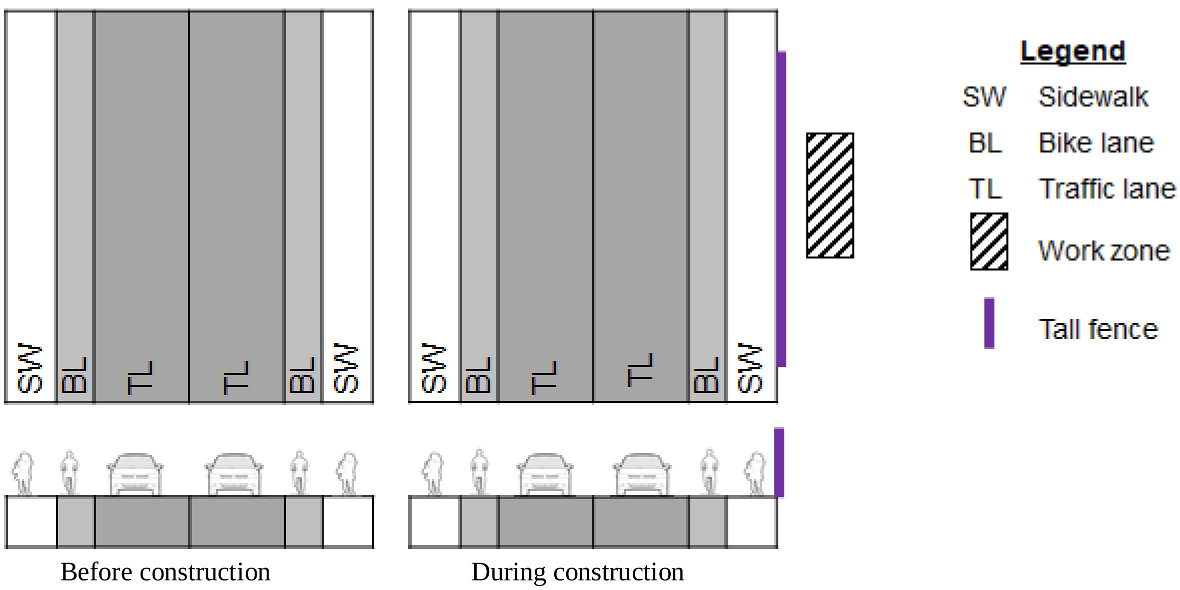
a) Tall fencing
b) Pathway on an on-street parking lane
c) Temporary crosswalk
d) Covered pathway
e) Pathway on extended bike lane
f) Pathway on traffic lane
g) Temporary pathway
h) Temporary bridge
i) Detour

4.5.1 Tall Fencing

When it is required to occupy a traffic lane(s) for managing construction activities, motorized traffic can be accommodated within the construction zone or detoured via a designated route. To ensure safety of non-motorized traffic and reinstate the LOS, a tall fence is suggested to erect separate the work zone from the non-motorized traffic facility, as shown in Figure 4-3a. However, minimum height of the fence depends on the construction activity and height of work above non-motorized facility. As an example, a 4-ft tall fence is suggested between a work zone and non-motorized facility when the work zone is located in a traffic lane. A tall fence can be installed when the work zone is located outside of a sidewalk and when the distance between the work zone and sidewalk is less than 15 ft, as shown in Figure 4-3b.



a) Work zone is located within a traffic lane



b) Work zone is outside of the shoulder/sidewalk

Figure 4-3. Implementation examples of a tall fence

4.5.2 Pathway on On-street Parking Lane

When a sidewalk or a bike lane is closed and an on-street parking lane is available, non-motorized traffic can be accommodated within the on-street parking lane, as shown in Figure

4-4. Usually, on-street parking is prohibited temporarily in a construction work zone during active construction.

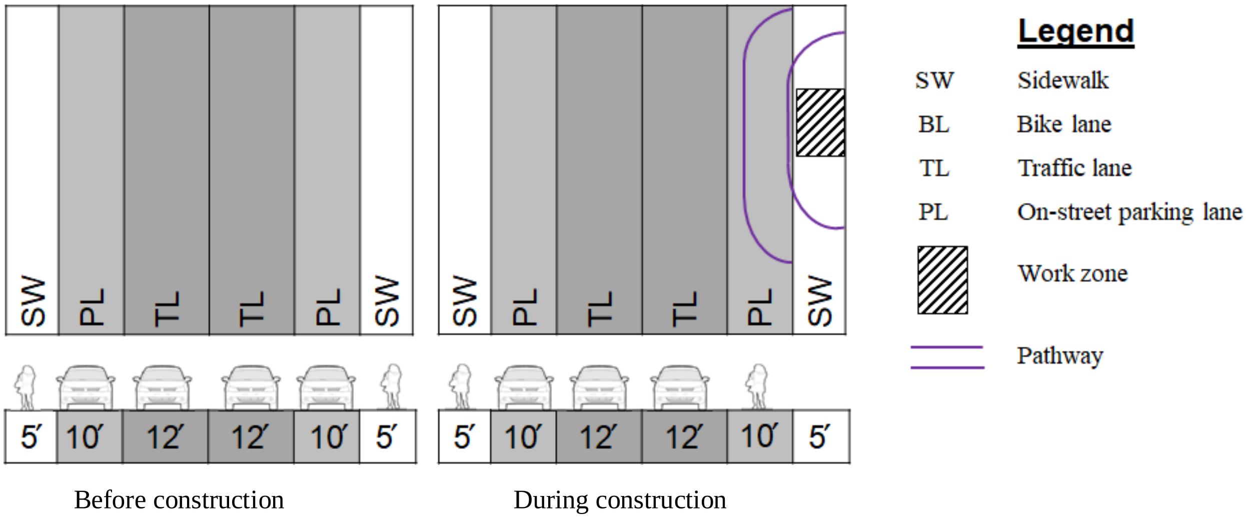
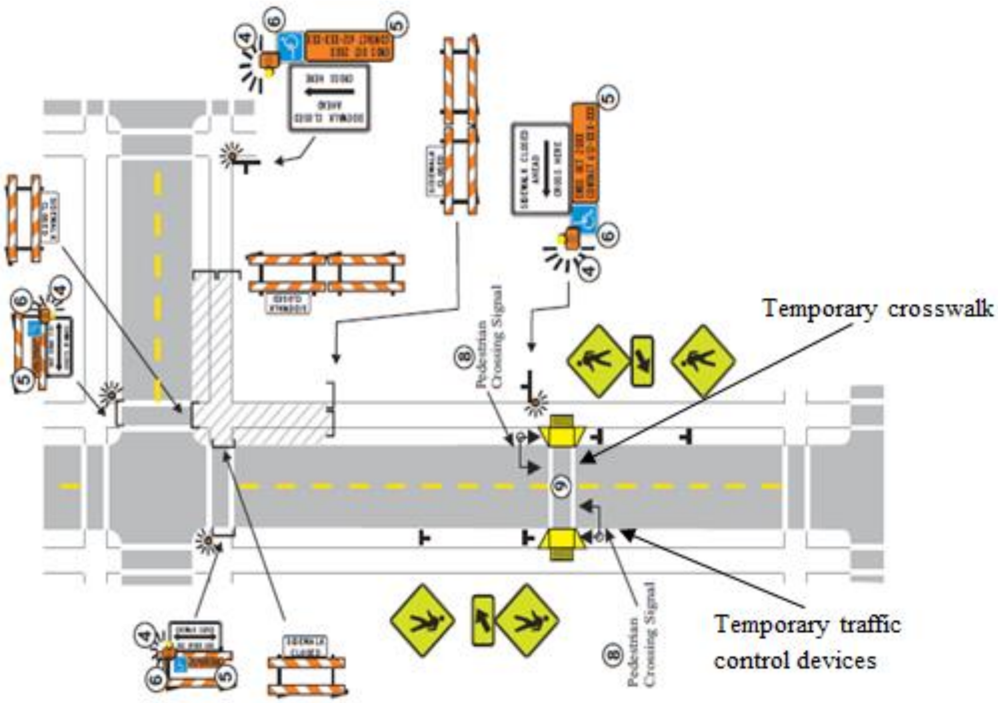


Figure 4-4. Non-motorized pathway located within an on-street parking lane

4.5.3 Temporary Crosswalk

Non-motorized facilities are closed when a work zone is located at a corner of an intersection or at mid-block. In order to move the non-motorized traffic safely across a road to available facilities, temporary crosswalks can be provided before the beginning of the work zone (Figure 4-5a). This type of solution can be adopted at any phase of the construction. When it is necessary to manage motorized traffic, an automated flagger assistance device (AFAD) (shown in Figure 4-5b) or a flagger person can be used.



a) Temporary crosswalk (MN MUTCD 2015)

b) Temporary traffic control devices

Figure 4-5. Temporary crosswalk (MN MUTCD 2015)

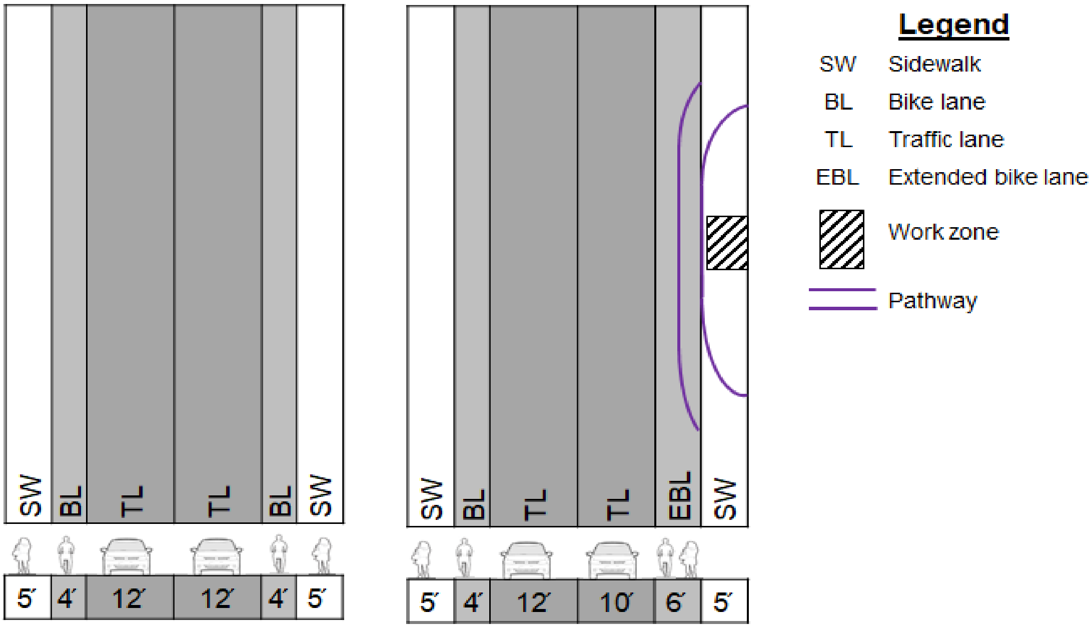
4.5.4 Covered Pathway

A covered pathway is provided underneath scaffolding to accommodate non-motorized traffic. This alternative is appropriate when the height of scaffolding is about 10-ft. A separate path can be provided for pedestrians and cyclists, if needed. As shown in Figure 4-6, pedestrian and cyclist access was provided during above-ground construction activities in Stagliz, Germany. A covered pathway is possible with all other construction activities except during demolition or excavation.

Figure 4-6. Covered pathway with separate pedestrian and cyclist access

4.5.5 Pathway on Extended Bike Lane

When a sidewalk is closed and a bike lane is available on the same side of the road, the bike lane can be extended to accommodate pedestrians as well as cyclists, as shown in Figure 4-7. The width of a traffic lane can be reduced to 9 ft when the posted speed of the road is no more than 65 miles/hour (Porter et al. 2016, MUTCD 2009). When there is a possibility to take a 2 to 3 ft wide strip from the adjacent traffic lane, the bike lane can be extended to accommodate pedestrians as well as cyclists. As an example, if a 4 ft wide bike lane is available, a 2 ft wide strip can be taken from the adjacent traffic lane to have a 6 ft wide extended bike lane. A minimum width of 4 to 6 ft is required to develop an extended bike lane to accommodate pedestrians and cyclists (ILMUTCD 2014).

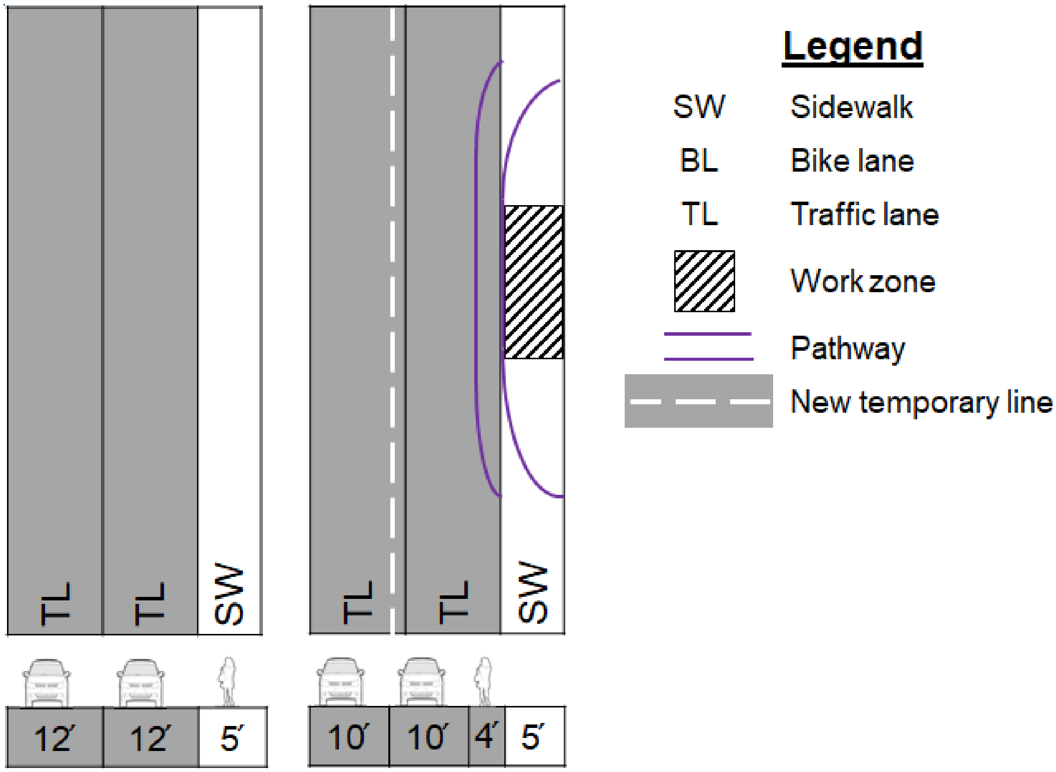


Before construction During construction

Figure 4-7. Pathway on an extended bike lane

4.5.6 Pathway on Traffic Lane

When a sidewalk (or a non-motorized path) is closed due to construction, the width of traffic lanes can be reduced to provide space for accommodating pedestrians. According to Porter et al. (2016) and MUTCD (2009), the width of a traffic lane can be reduced to 9 ft when the posted speed of the road is no more than 65 miles/hour. Figure 4-8 shows an example where the traffic lane widths are reduced to 10 ft to provide a 4 ft wide pathway.



Before construction During construction

Figure 4-8. Pathway on a traffic lane

4.5.7 Temporary Pathway

When a sidewalk (or a non-motorized path) is closed due to construction, a temporary pathway that is a minimum of 4 ft wide (5 ft preferable) can be provided without interfering with the traffic lanes (Figure 4-9). This requires the availability of space by the side of the road. However, additional space in excess of 4 ft is required for placing and arranging channelizing devices.

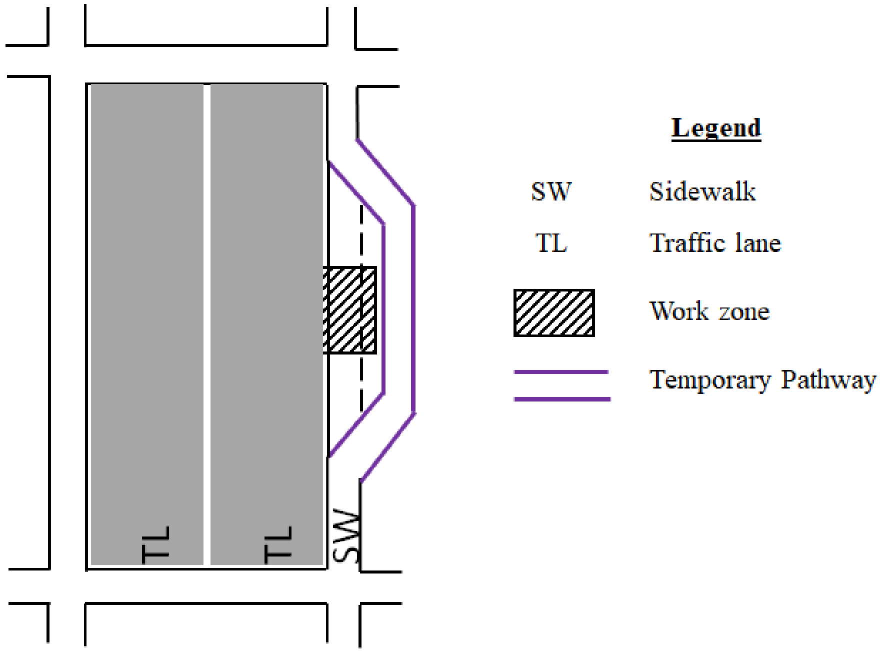


Figure 4-9. Temporary pathway

4.5.8 Temporary Bridge

Excavation at a side in a direction perpendicular to the travelled way compromises mobility. Non-motorized mobility can be restored using prefabricated temporary bridges (Figure 4-10). Use of temporary bridges is possible with all other construction activities except during active demolition or excavation.

Figure 4-10. Prefabricated bridge (Sinclair 2017)

4.5.9 Detour

When space is not available to provide a safe access route within or around the construction zone, non-motorized traffic can be detoured via designated shortest possible routes. As an example, pedestrians were detoured via the opposite side of the road during building construction activities in Washington DC (Figure 4-11). However, long detours should be avoided as they decrease LOS and promote risk-taking behaviors.

Figure 4-11. Non-motorized traffic is detoured via the nearest sidewalk (Washington DC)

4.5.10 Typical Layout and Signage of a Construction Site

Figure 4-12 presents a typical layout and signage that can be adopted to maintain safe access to non-motorized traffic. The construction zone is divided into an advanced warning area, transition area, buffer space, work space, and termination area. The minimum length of an advanced warning area and spacing of advanced warning signs is determined using MUTCD guidelines. Advanced warning signs include Road Work Ahead (W20-1), Right Lane Closed Ahead (W20-5), Work Zone Begins (R5-18c) or any other signs depending on the TTC zone requirements. A lighted arrow panel and speed limit sign (R2-1) should be placed at the beginning of a transition area. The minimum length of a transition area is calculated according to MUTCD guidelines using width of offset and posted speed limit. The length of buffer space is calculated using MUTCD guidelines and the posted speed and location of the road. The work space is the area where construction work is being conducted. The termination area is usually 50-100 ft long. An 8 to 10 ft wide emergency entrance and an exit door for an emergency crew is suggested based on the shortest accessible location of a fire hydrant; fire hydrants are typically placed at a spacing of 400-500 ft (NFPA 1999). However, a 6 ft wide door is recommended for medical emergency crews with a stretcher, and a 10 ft wide door is suitable for an emergency vehicle. A parking space of 10 ft by 20 ft is provided for emergency responders and is located in proximity to the emergency door. An END ROAD WORK sign (G20-2) should be provided after the parking space provided for an emergency vehicle. The pedestrian pathway needs to be at least 4 ft wide (5 ft preferable). The minimum height of 80 in. needs to be maintained for a covered pathway. Channelizing devices should be placed between the pathway and live traffic. Ramps of 5 ft in length and width, with no greater than 1:50 side slope and 1:12 cross slope, should be provided at the entrance and exit of a pathway. The minimum requirements for street components are given in Appendix-B. When a temporary path includes stairs or a significant elevation difference, a trolley with a controller can be incorporated to help mobility-disabled people. Temporary rumble strips can be installed on the sidewalk closer to the temporary pathway to make visually-impaired pedestrians aware of the impeding changes. Audio devices can be attached to the temporary traffic control device to make road users aware of upcoming changes. The University of Minnesota developed a mobile app that can alert sight and/or hearing impaired people through vibration and audio message (Liao 2014). A Bluetooth beacon is attached to the temporary traffic control device placed near transition area to activate the application.

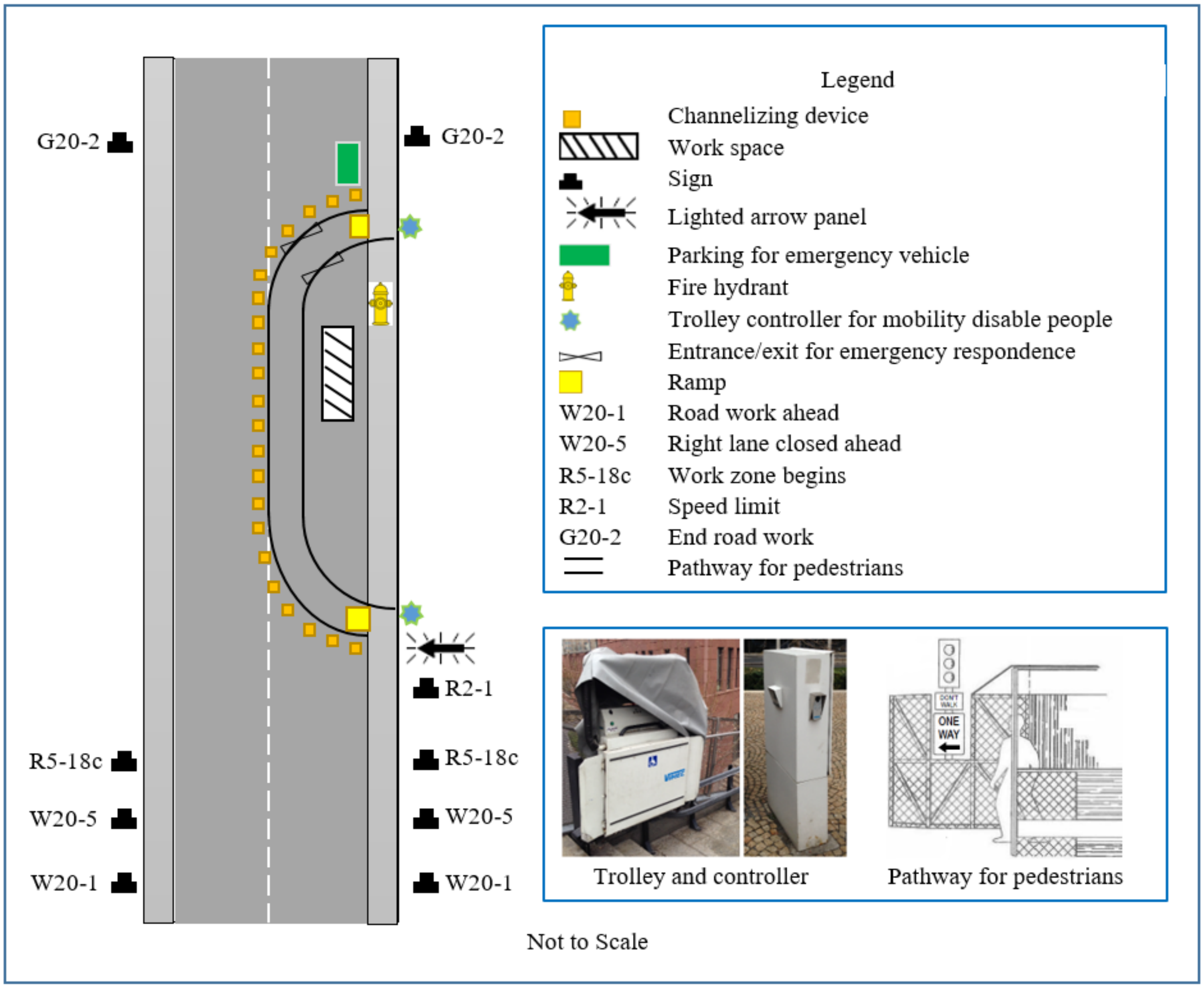


Figure 4-12. Typical layout and signage of a construction site

4.6 RISK-BASED DECISION-SUPPORT FRAMEWORK FOR MANAGING NON-MOTORIZED MOBILITY

A risk-based decision-support framework for identifying the most viable alternative for managing non-motorized mobility during construction activities is presented in Figure 4-13. The vertical axis (on the right side) represents the roadway features affected due to construction activities. The horizontal axis represents the alternatives for managing non-motorized mobility. An alternative is selected based on the affected roadway feature(s) during construction, the construction activity, and the location of work zone (corner or mid-block). The affected roadway features represent closure of sidewalks, bike lanes, traffic lanes, or a combination thereof (as shown in Table 4-1). The symbol "‖" represents demolition or excavation parallel to the travelled way and within roadway features or outside of sidewalk (but within 15 ft from sidewalk). Excavation activity performed perpendicular to the travelled way is denoted by "⊥".

Other construction activities are denoted by "O". Mid-block and a corner of an intersection are considered as construction zone locations. To promote mobility and discourage risk-taking behaviors, the 9 alternatives listed in Section 4.5 are listed along the horizontal axis of the diagram shown in Figure 4-13. The most preferred alternative is located at the leftmost column and preference is increasing from right to left. The preference is defined based on the policy that requires accommodating non-motorized traffic with greater safety and a minimum disruption to mobility. To select the most viable solution, users of the decision-support framework need to perform following tasks:

(a) Calculate LOS using Table 4-2 and evaluate performance rating of the existing facility before construction activities using Table 4-3.
(b) Identify affected roadway feature(s), construction activity, and construction location.
(c) Develop a list of possible solutions using Figure 4-13 for the affected roadway feature(s), construction activity, and location.
(d) Calculate LOS using Table 4-2 and evaluate performance rating using Table 4-3 for the leftmost alternative. If the performance level of the alternative is greater than or equal to the performance rating of the existing facility (calculated in step (a)), select the alternative as the most viable solution. Otherwise, repeat step (d) for the next possible alternative until an alternative is identified to manage non-motorized mobility.

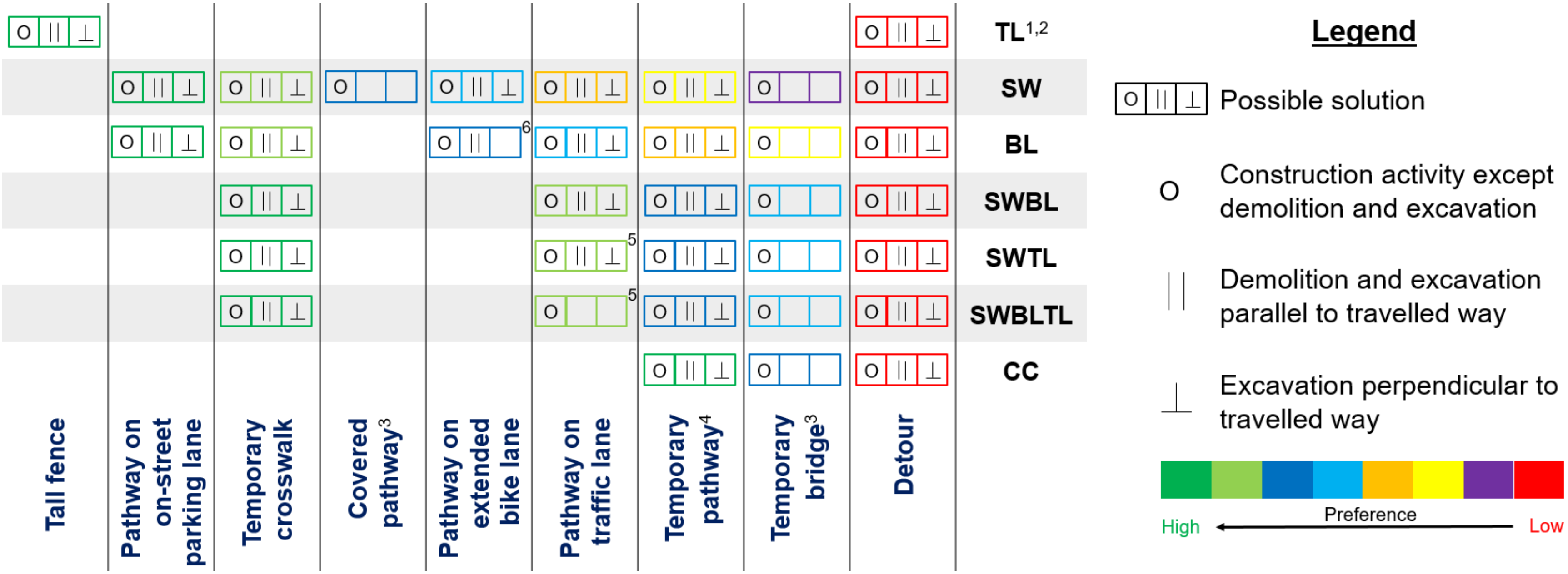
As an example, a pathway on an on-street parking lane can be provided as the most viable solution when a sidewalk is closed during excavation parallel to a travelled way, and the work zone is located at a corner of an intersection. The performance rating of providing pathway on an on-street parking lane is similar to the performance rating of the existing facility. If an on-street parking lane is not available, providing a temporary crosswalk is the next preferred alternative as it can reinstate the performance rating.

The following examples are taken from chapter 3 to demonstrate the application of the risk-based decision-support framework for evaluating non-motorized mobility management options:

Example 1: The sidewalk was closed during construction activities at the intersection of E Wilson Street and King Street. Motorized traffic was shifted to provide space for managing non-motorized mobility. On-street parking and a bike lane are not available on that street. Providing a temporary crosswalk is not necessary because pedestrians and cyclists can use the existing crosswalk at the signalized intersection. To reinstate the LOS and performance rating as the most viable solution, a 4 ft wide temporary pathway was provided on the traffic lane.

Example 2: A non-motorized facility was closed during construction activities at the intersection of S Hancock Street and E Wilson Street. Motorized traffic was shifted and an on-street parking lane was available on the street. A 5-ft wide protected walkway and a 5-ft wide bike lane were provided on the 21-ft parking and turning lane to reinstate LOS and performance rating. This is the most viable solution for providing non-motorized mobility access when an on-street parking lane is available. The sidewalk of S Hancock Street closer to the construction zone was also closed. Signs were placed at the E Main Street and S Hancock Street intersection to guide pedestrians to use the sidewalk on the opposite side of the construction zone and along S Hancock Street. At the intersection of E Wilson Street and King Street, a temporary crosswalk was provided for pedestrians coming through S Hancock Street to the protected walkway and bike lane. Providing a temporary crosswalk to reinstate the performance rating is another viable solution when a non-motorized traffic facility is interrupted.

Example 3: According to the case study from Austin, Texas, a sidewalk is not available but a bike lane is available. A northbound traffic lane and bike lane were occupied to meet the space requirement for construction. Northbound traffic and cyclists were accommodated on the turning lane. Use of a shared lane increases conflicts and risk of accidents when there is a higher speed differential and decreased LOS which results in a lower performance rating. Moreover, shared lane signage was not provided. However, LOS and performance rating could be improved by reducing the width of the southbound traffic lane to 10 ft and providing a 4-ft wide protected bike lane on the turning lane. Adopting this solution would reinstate the performance rating.



1. TL represents closure of traffic lane. Similarly, closure of roadway features represented by SW – sidewalk, BL – bike lane, SWBL – sidewalk and bike lane, SWTL – sidewalk and traffic lane, SWBLTL – sidewalk, bike lane, and traffic lane, and CC – complete closure of street.
2. Possible solutions for closure of a traffic lane (TL) can be used when the work zone is outside of sidewalk and the distance between work zone and sidewalk is less than 15 ft.
3. A covered pathway or a temporary bridge is possible with all other construction activities except during demolition or excavation.
4. A temporary pathway is possible at a corner of an intersection when adequate space is available.
5. A pathway on traffic lane is possible for SWTL and SWBLTL at corner of an intersection, when
   a) number of lanes is more than 2
   b) number of lanes is 2 with motorized traffic detoured
6. A pathway on an extended bike lane is possible with partial closure of BL when at least 4 ft is available after taking 2-3 ft from an adjacent traffic lane.

Figure 4-13. Risk-based decision-support framework for managing non-motorized mobility

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4.7 ALTERNATIVES TO PROVIDE ACCESS TO DIFFERENT FACILITIES

Construction work impairs access to local businesses, commercial and residential buildings, crosswalks, bus stops, nearby shops, recreation centers, senior centers, schools, special events, and stadiums. The solutions to reinstate LOS and performance rating by providing access to different facilities are discussed below.

4.7.1 Access to Local Business and Commercial and Residential Buildings

When access to local businesses and commercial and residential buildings is affected by construction activities, it is preferred to have at least one lane kept open during the entire construction duration. If it is not possible to maintain at least one open lane, nighttime work, off-peak hour work, or phase construction needs to be considered. A typical layout and signage for providing access to a business is shown in Figure 4-14. Channelizing devices near the business place can be removed temporarily during peak business hours to provide access.

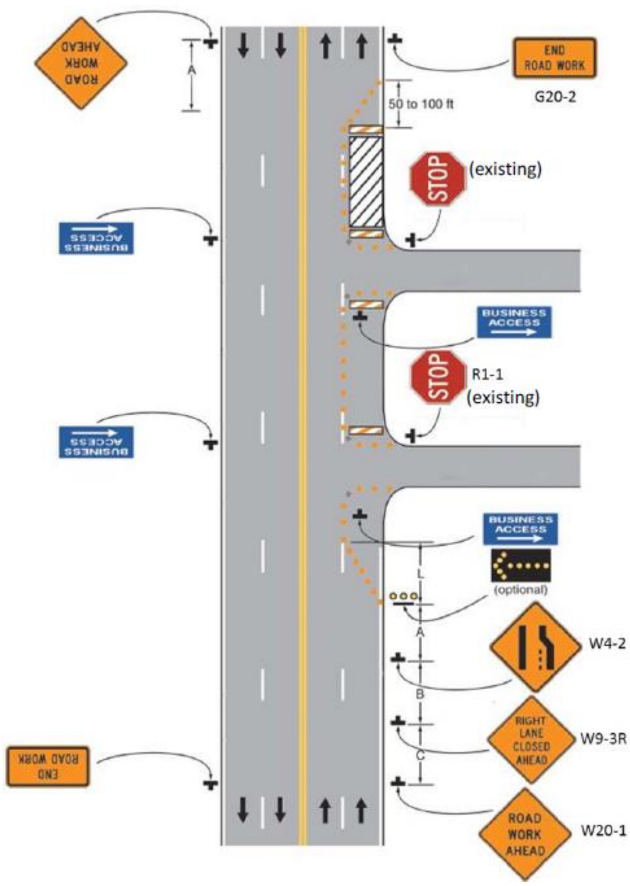

Figure 4-14. Alternatives to provide access to businesses during construction (Porter et al. 2016)

4.7.2 Access to Crosswalk

Sometimes, crosswalks become inaccessible due to work zones located near or at an intersection. In this situation, a temporary crosswalk should be provided at the nearest possible location (Figure 4-15). Temporary traffic control devices like AFAD can be incorporated to control the traffic when a temporary crosswalk is to be provided.

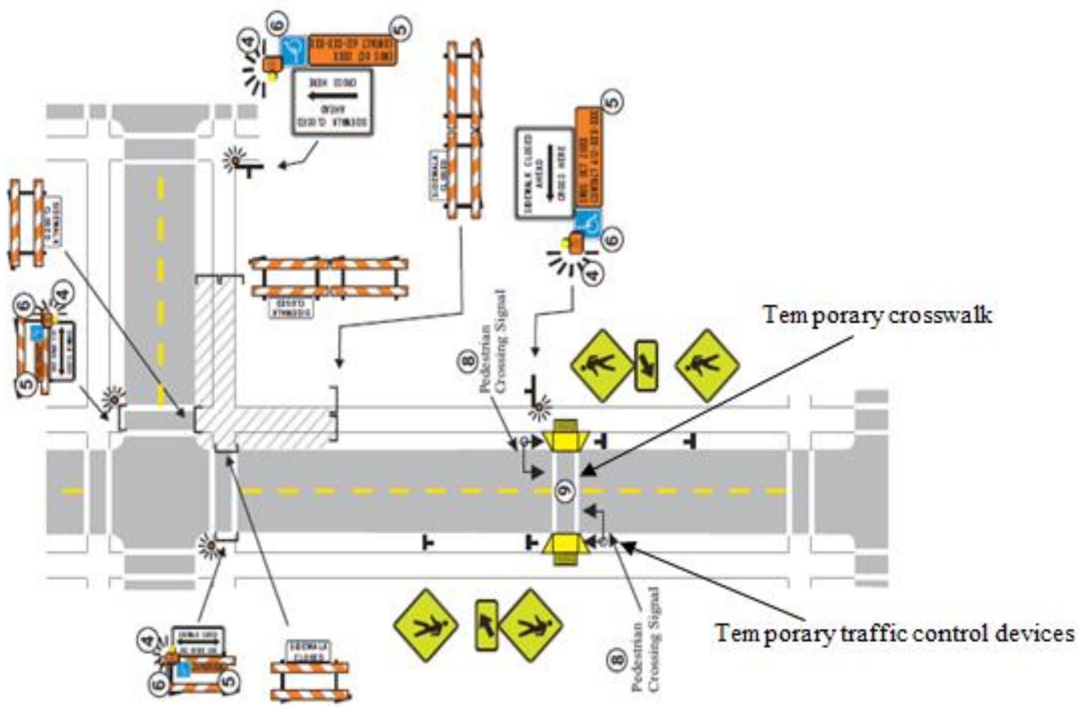

Figure 4-15. Temporary crosswalk (MN MUTCD 2015)

4.7.3 Access to Transit Facility and Bus Stops

Non-motorized traffic volumes are higher near transit facilities and bus stops. Sometimes transit facilities and bus stops become inaccessible due to construction activities. Bus stops and transit facilities need to be relocated to the nearest possible location. A relocated temporary transit facility and a bus stop are shown in Figure 4-16a and b.

a) Relocated transit facility with a temporary shelter

b) Rerouted bus stop

Figure 4-16. A temporary bus stop and a transit facility (Sinclair 2017)

4.7.4 Access to Other Facilities and Special Events

It is preferred to maintain at least one open lane to provide access to shops, recreation centers, senior centers, schools, hospitals, special events, and stadiums. If maintaining an open lane is not possible, performing activities during nighttime or off-peak hours is preferred. Another option is to implement phase construction (Figure 4-17a). Depending on the construction type and activity, access can sometimes be provided using a temporary prefabricated bridge (Figure 4-17b).

a) Phase construction was performed to provide access to shop

b) Use of a temporary prefabricated bridge

Figure 4-17. Phase construction and use of a temporary prefabricated bridge to provide access (Sinclair 2017)

4.8 SUMMARY

A sidewalk, bike lane, traffic lane, or a combination thereof is closed during construction activities to maintain space requirements. Disrupted and discontinued non-motorized facilities decrease LOS and performance rating and promote risk-taking behaviors. Seven closure conditions of roadway features are possible that impair non-motorized mobility and access to facilities. To promote mobility and reduce risk-taking behavior, it is desired to at least reinstate the performance rating of a facility. The performance rating can be reinstated by providing continuous access and accommodating non-motorized traffic within or around a construction zone. Nine alternatives are developed to provide continuous facilities. A risk-based decision support tool for selecting the most viable solution is developed and presented. The procedure to use the tool for selecting the most viable alternative is also demonstrated. A typical site layout and signage is presented. This can be used when a temporary pathway is to be provided for managing non-motorized mobility within or around a construction zone. It is recommended to provide a 10 ft wide door on the fence/wall of temporary pathway and a 10 ft × 20 ft parking space for emergency responders. The parking space needs to be located closer to the nearest fire hydrant. Finally, possible solutions for providing access to local business, commercial and residential buildings, and access to different facilities to maintain similar performance rating are demonstrated.

5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSIONS

Managing non-motorized mobility by providing safe access routes due to closure of different roadway features during construction activities is a challenge for transportation engineers and highway agencies. The space for managing construction activities is acquired by closing sidewalks, shoulders, bike lanes, traffic lanes, or a combination thereof. This increases congestion and delay, and compromises safety of road users. Further, work zones impair access to local businesses, bus stops, nearby facilities, etc., while hindering mobility of pedestrians, cyclists, and emergency responders. On the other hand, emergency response teams need the fastest access to a location or a facility. Typically, temporary traffic control management plans (TTCMPs) are developed to accommodate motorized traffic within construction zones with reduced speed limits and safety cautions or detour via designated routes. Detouring motorized traffic increases the vehicle operating cost, value of time cost, accident rate, and environmental pollution due to burning more fuels. The emphasis on non-motorized mobility varies significantly when TTCMPs are developed for small cities. Hence, managing non-motorized mobility becomes the contractors' responsibility. Due to lack of specific instructions and the potential liability issues, contractors tend to completely close access to non-motorized traffic without providing alternate routes within or around work zones or detouring them through unfamiliar territories. Typically, pedestrians and cyclists are reluctant to add distance or travel out-of-the-way to their destination. Hence, instead of using a detour, they tend to pass through the construction zone or jaywalk, which greatly increases the risk of accidents that could result in injuries and fatalities. As a result, it is necessary to find means and methods of providing safe and convenient non-motorized access within or around construction zones.

Non-motorized mobility can be promoted if best practices around the world, innovative technologies, infrastructure, and less-invasive construction methods are implemented to enhance safety and mobility. Less-invasive construction methods help to reduce work duration and work zone length. These methods, when combined with appropriate technologies, can enhance safety and mobility. State-of-the-art literature was reviewed, and innovative technologies, infrastructure, and less-invasive construction methods were documented. To synthesize best practices and the minimum requirements of street components, a comprehensive review of national and international publications, manuals, policies and guidelines were reviewed. To understand the application process of policies, guidelines, and the minimum requirements of street components, a direct survey was conducted with transportation engineers of top ranked green, walk-friendly, and bike-friendly cities. Transportation engineers were requested to provide responses to four fundamental questions regarding practices and specifications of the intended city. Only 8 agencies located in the U.S. responded to the survey. As per the survey results, green, walk-friendly, and bike friendly cities in the U.S. follow the Manual on Uniform Traffic Control Devices (MUTCD) policies and guidelines and the minimum requirement of street components given in the Americans with Disabilities Act (ADA), Americans with Disabilities Act Accessibility Guidelines (ADAAG), and Public Right-Of-Way Accessibility Guidelines (PROWAG). Unfortunately, none of the international agencies responded to the survey. However, practices of several cities located outside the U.S. were documented by the project team. Publications and manuals of international agencies located in five countries were reviewed via a web search. The overseas cities and countries include Oslo, Norway; Helsinki, Finland; London, England; Vancouver, Canada; and Dublin, Ireland.

Based on the literature review and survey results, a work zone and mobility management framework, a list of possible alternatives for managing non-motorized traffic within and around a construction zone, and a risk-based decision-support framework for identifying the most viable alternative for managing non-motorized mobility during construction activities were developed. Application of the risk-based decision-support framework was demonstrated. In addition, strategies to manage access to emergency responders, local businesses, commercial and residential buildings, and various other facilities are also presented. The following specific conclusions are derived from this study:

1) The policies, guidelines, and the minimum requirement of street components used by many agencies are primarily based on the MUTCD, ADA, ADAAG, and PROWAG. Slight modifications are made to the content of such publications and adopted to develop agency specific publications.
2) With the introduction of the complete street policies, highway and city officials evaluate alternatives for managing non-motorized traffic for projects with long-term stationary work durations. However, agencies pay little or no attention to managing

non-motorized mobility when the work duration is no more than 3 days. Hence, managing non-motorized mobility becomes the contractors' responsibility. Due to lack of specific instructions and the potential liability issues, contractors tend to completely close access to non-motorized traffic without providing alternate routes within or around work zones.

3) Trespassing and jaywalking are promoted when available non-motorized facilities are closed and alternate safe routes are not provided within or around construction zones. Trespassing increases the risk of encountering with construction activities and equipment. Jaywalking promotes conflict between non-motorized traffic and live motorized traffic. Accident risk to cyclists increases when adequate space is not provided to navigate and maneuver. In addition the lack of regulated space for non-motorized mobility and the presence of uneven surface conditions increases the risk of accidents due to tripping and falling leading to injuries and fatalities.
4) Less-invasive construction methods and technologies can be implemented to reduce the space requirements for construction activities. Trenchless technology is one such innovative method. The trenchless technology selection matrix presented in this report can be used to identify the most suitable technology for a given site.
5) The work zone and mobility management framework presented in this report can be used as a preplanning tool, irrespective of the duration of project.
6) The guidance graphs in the National Cycle Manual published by the National Transport Authority, Dublin, Ireland (NCM 2011) can be used as a decision tool for selecting shared lanes, bike lanes, or bike ways for a given road segment.
7) The risk-based decision-support framework presented in this report for managing non-motorized mobility and the level-of-service (LOS) evaluation matrix with the performance rating system presented by Dixon (1996) can be used to identify the most suitable alternative for managing non-motorized mobility within or around a construction zone.

5.2 RECOMMENDATIONS

The following implementation and future research recommendations are derived from this study:

- Appendix B presents a summary of policies, guidelines, and the minimum requirements of street components documented from national and international manuals, ADA, ADAAG, and PROWAG guidelines. Highway agencies can utilize the information in Appendix B to evaluate their practices and make changes to improve safety and mobility, as needed.
- Several implementation ready tools were identified/developed through this research – work zone and mobility management framework; trenchless technology selection matrix; guidance graph for selecting shared lanes, bike lanes, or bikeways; level-of-service (LOS) evaluation matrix and performance rating system for pedestrian and bicycle facilities; the risk-based decision-support framework for managing non-motorized mobility, and a typical site layout showing facilities allocated for emergency responders. These tools are presented in Appendix C as a set of non-motorized mobility planning tools. Highway agencies can integrate all of the tools, or a subset to support their decision making process.
- Appendix D presents a list of advanced technologies that the highway agencies can integrate into their current practice to enhance safety and mobility.
- As a future research project, the information in Appendix B and C can be integrated into a software module that the highway agencies can use as a planning and decision-support tool.

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APPENDIX A: ABBREVIATION

A

AASHTO	American Association of State Highway and Transportation Officials
ABC	Accelerated bridge construction
AFAD	Automatic Flagger Assistance Devices
ADA	Americans with Disabilities Act
ADAAG	Americans with Disabilities Act Accessibility Guidelines

B

BTC	Bicycle Technical Committee

C

CMF	Crash Modification Function/Factor

D

DMS	Dynamic message signs
DOT	Department of Transportation

F

FDM	Facility Development Manual

H

HDM	Highway Design Manual
HMA	Hot Mix Asphalt
HSM	Highway Safety Manual

I

ILMUTCD	Illinois Manual on Uniform Traffic Control Devices

L

LOS	Level-of-service
LTBC	Low-Tracking Bond Coat
LTTB	Launched Temporary Truss Bridge

M

MUTCD	Manual on Uniform Traffic Control Devices
MMMUTCD	Michigan Manual on Uniform Traffic Control Devices
MN MUTCD	Minnesota Manual on Uniform Traffic Control Devices

N

NCUTCD	National Committee on Uniform Traffic Control Devices
NFPA	National Fire Protection Association
NHTSA	National Highway Traffic Safety Administration

P

PBES	Prefabricated Bridge Elements Systems
PCMS	Portable Changeable Message Signs
PROWAG	Public Right-Of-Way Accessibility Guidelines

S

SDOT	Seattle Department of Transportation
SIBC	Slide-In Bridge Construction
SPMT	Self-Propelled Modular Transporter

T

TDM	Transportation Demand Management
TTC	Temporary Traffic Control
TTCMP	Temporary Traffic Control Management Plan
TTCTC	Temporary Traffic Control Technical Committee
TTS	Text To Speech

U

USDOT	U.S. Department of Transportation

V

VMS	Variable-Message Signs

W

WABA	Washington Area Bicycle Association
WMA	Warm Mix Asphalt

APPENDIX B: POLICIES, GUIDELIENS, AND MINIMUM REQURIEMENTS OF STREET COMPONENTS

B.1 PEDESTRIAN ACCESS AND MOBILITY MANAGEMENT

Table B- 1. Policies and guidelines regarding pedestrians

Policies[1]

- *The various TTC provisions for pedestrian and worker safety set forth in MUTCD Section 6D shall be applied by knowledgeable (for example, trained and/or certified) persons after appropriate evaluation and engineering judgment.*
- *Advance notification of sidewalk closures shall be provided by the maintaining agency.*
- *If the TTC zone affects the movement of pedestrians, adequate pedestrian access and walkways shall be provided. If the TTC zone affects an accessible and detectable pedestrian facility, the accessibility and detectability shall be maintained along the alternate pedestrian route.*

Guidelines

MUTCD (2009)[1]

- *Pedestrians should not be led into conflicts with vehicles, equipment, and operations.*
- *Pedestrians should not be led into conflicts with vehicles moving through or around the worksite.*
- *Pedestrians should be provided with a convenient and accessible path that replicates as nearly as practical the most desirable characteristics of the existing sidewalk(s) or footpath(s).*
- *Pedestrians should be separated from the worksite by appropriate devices that maintain the accessibility and detectability for pedestrians with disabilities.*
- *Pedestrians should not be exposed to unprotected excavations, open utility access, overhanging equipment, or other such conditions.*
- *Pedestrian detours should be avoided since pedestrians rarely observe them and the cost of providing accessibility and detectability might outweigh the cost of maintaining a continuous route. Whenever possible, work should be done in a manner that does not create a need to detour pedestrians from existing routes or crossings.*

Litman et al. (2016)[2]

- *Barricades and pylons can be used to create a temporary passageway for pedestrians. This is particularly important in urban areas. Sidewalk closures should be avoided or minimized as much as possible. Passageway should be wide enough to accommodate a wheel chair, and should have ramps where there are height changes.*
- *Construction signs should not obstruct bicycle and pedestrian paths. Where this is unavoidable, do not block more than half the path or sidewalk.*
- *Bus stops must remain accessible to pedestrians. Where necessary, bus stops may be relocated provided clear and noticeable signs are provided.*
- *Additional lighting may be required at night to identify hazards.*

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Table B- 2. The minimum requirements of street components for pedestrian facilities

Design elements[1, 2]		**Criteria**
Pedestrian access route	Width	Min. 4 ft (preferable 5 ft)
	Grade	Matching street grade, where feasible max. 5%
	Cross slope	Max. 2%
	Surface	Firm, stable, and slip resistant
	Vertical discontinuity	Max. 0.5 in.
	Horizontal opening	Max. 0.5 in.
	Flangeway gaps	Max. 2.5 in. for non-freight track
		Max. 3.0 in. for freight track
	Passing space	Min. 5 × 5 ft at interval of max. 200 ft
Perpendicular curb ramp	Width	Min. 4 ft
		Min. 3 ft between handrail
	Rise	Max. 2.5 ft
	Grade breaks	Perpendicular to the direction of the ramp (not permitted on the ramp runs, turning spaces)
	Cross slope	Max. 2%
	Counter slope	Max. 5%
	Turning space	Min. 4 × 4 ft, at the top of the curb ramp
	Running slope	Min. 5% and max. 8.3%
	Running slope (turning space)	Max. 2%
	Slope (flared sides)	Max. 10%
Parallel curb ramp	Width	Min. 4 ft
		Min. 3 ft between handrails
	Rise	Max. 2.5 ft
	Grade breaks	Perpendicular to the direction of the ramp (not permitted on the ramp runs, turning spaces)
	Cross slope	Max. 2%
	Counter slope	Max. 5%
	Turning space	Min. 4 × 4 ft at the bottom of the curb ramp
	Running slope	Min. 5% and max. 8.3%
	Running slope (turning space)	Max. 2%

Table B- 2. The minimum requirements of street components for pedestrian facilities (contd.)

Blended transitions	Width	Min. 4 ft
	Grade breaks	Perpendicular to the direction of the ramp (not permitted on the ramp runs, turning spaces)
	Cross slope	Max. 2%
	Counter slope	Max. 5%
Transit stops	Clear length	Min. 8 ft, perpendicular to the street
	Clear width	Min. 5 ft, parallel to the street
	Grade (parallel street)	Same as the street
	Grade (perpendicular street)	Max. 2%
	Surface	Firm, stable, and slip resistant
Landings	Slope	Any direction
	Width	Min. the widest ramp
	Length	Min. 5 ft
	Direction change	Min. 5 × 5 ft
	Surface	Firm, stable, and slip resistant
	Handrails	Required
Lighting[3]	Surface of Route	One foot-candle (one lumen per square foot or 10.764 lux)
Stairway[3]	Width	Min. 5 ft for public and 4.5 ft for private
	Treads	Min. 11 in.
	Riser indoor depth	Min. 7.5 in.
	Risers outdoor depth	Between 4.5 in. and 7 in.
	Tread (T) to riser (R) ratio	2R + T = 26 to 27 in.
	Height between landings	Max. 12 ft
	Landing length	Min. 5 ft

1. PROWAG (2011). Public Right-Of-Way Accessibility Guidelines. <https://www.access-board.gov/guidelines-and-standards/streets-sidewalks/public-rights-of-way/proposed-rights-of-way-guidelines> (Last accessed December 31, 2017).
2. Sinclair, K. (2017). "Designing for Pedestrian & Bike Safety in Work Zones", U. S. Department of Transportation, Federal Highway Administration, 1200 New Jersey Ave, SE, Washington, D. C. 20590, USA.
3. WSDOT (1997). Pedestrian Facilities Guidebook. 310 Maple Park Ave., SE Olympia, Washington, 98504, USA.

B.2 CYCLIST ACCESS AND MOBILITY MANAGEMENT

Table B- 3. Policies and guidelines regarding cyclists

Policies

MUTCD (2009)[1] Section 6G.11

If the TTC zone affects the movement of bicyclists, adequate access to the roadway or shared-use path shall be provided (MUTCD (2009) Section 6G.11).

NCUTCD (BTC) (2013)[2] Section 6G.05

The minimum TTC sign and plaque sizes for shared-use paths shall conform to those shown in Table 9B-1 of MUTCD (2009). The minimum TTC sign and plaque sizes for on-street bikeways shall conform to MUTCD (2009) Chapter 6F (NCUTCD (BTC) (2013) Section 6G.05).

Guidelines

MUTCD (2009)[1] Section 6G.05

- *If a designated bicycle route is closed because of the work being done, a signed alternate route should be provided. Bicyclists should not be directed onto the path used by pedestrians*.
- *Where bicycle usage is high, the typical applications should be modified by giving particular attention to the provisions set forth in Section 6D of MUTCD (2009), Section 6G, Section 6F.74 of MUTCD (2009) , and in other Sections of Part 6 related to accessibility and detectability provisions in TTC zones.*
- *Bicyclists should not be exposed to unprotected excavations, open utility access, overhanging equipment, or other such conditions.*

NCUTCD (BTC) (2013)[2] Section 6G.05

- *The continuity of a bikeway should be maintained through the TTC zone, if practical.*
- *If a bikeway detour is unavoidable, it should be as short and direct as practical*.
- *On-road bicyclists should not be directed onto a path or sidewalk intended for pedestrian use except where such a path or sidewalk is a shared-use path, or where no practical alternative is available (such as might be the case on a bridge in the course of a rehabilitation project*.
- *If a portion of a bikeway is to be closed due to construction activities and the detoured bikeway follows a complex path not in the original bikeway corridor, then a full detour plan should be developed and implemented. The TTC for the detour of the bikeway should include all necessary advance warning (W21 series) signs, detour (W4-9 series) signs, and any other TTC devices necessary to guide bicyclists along the detour route.*

Litman et al. (2016)[3]

- *Construction signs should not obstruct bicycle and pedestrian paths. Where this is unavoidable, do not block more than half the path or sidewalk.*
- *Additional lighting may be required at night to identify hazards.*

1. MUTCD (2009). Manual on Uniform Traffic Control Devices for Streets and Highways. U. S. Department of Transportation, Federal Highway Administration, 1200 New Jersey Ave, SE, Washington, D. C. 20590, USA.
2. NCUTCD (BTC) (2013). Accommodating Bicyclists Through Temporary Traffic Control Zones. Temporary Traffic Control Technical Committee (TTCTC) in association with Bicycle Technical Committee (BTC), 17200 West Bell Road, 1135 Surprise, Arizona 85374, USA.
3. Litman, T., Blair, R., Demopoulos, B., Eddy, N., Fritzel, A., Laidlaw, D., Maddox, H., and Forster, K. (2016). Pedestrian and Bicycle Planning - A Guide to Best Practices. Victoria Transport Policy Institute, 1250 Rudlin Street, Victoria, BC, V8V 3R7, Canada.

Table B- 4. The minimum requirements of street components for bike ways

Design elements[1]				**Criteria**
Width of bikeway	Class I (Bike paths)	Two-way		Min. 8 ft is preferred 10 ft or 12 ft for heavy cyclist volume
		One-way		Min. 5 ft
		Bike path on structure (bridge and overpass)		Min. 10 ft
	Class II (Bike lanes) (BDE Manual 2016)[2]	Curbed streets without parking	Two-way curb and gutter section (one-way bike lane)	Min. 4 ft
			Two-way monolithic curb and gutter section (one-way bike lane)	Min. 5 ft
		Curbed streets with parking	Unmarked bike lane	Min. 13 ft
			Marked bike lane	Min. 5 ft, parking 8 ft
		Bicycle lanes adjacent to bus lanes		Min. 5 ft
		One-way bike lane on shoulder		Min. 4 - 6 ft
		One-way bike lane on roadway		Min. 4 ft
		One-way bike lane cross structure		Min. 5 ft
		Shared lane on roadway		Min. 13 - 14 ft
	Class III (Bike route)			Minimum standards for highway lanes and shoulder
	Class IV (Shared roadway)			4 ft of paved roadway shoulder with 4 in. edge line
Cross slope				Max. 2%, Min. 1%
Shoulder width				Min. 2 ft (preferable 3 ft) with slope 2 - 5%
Shy distance				Min. 2 ft on each side
Separation width from pedestrian walkway				Min. 5 ft
Clear distance to obstruction from bike path			Horizontally	Min. 2 ft (preferable 3ft)
			Vertically	Min. 8 ft across width and 7 ft over shoulder
Ramp width				Same width of bicycle path with smooth transition between bicycle path and the roadway
Paving width at crossings of roadway or driveway				Min. 15 ft
Separation width of bike paths parallel & adjacent to streets and highway				Min. 5 ft plus shoulder width.
Posted speed limit		Mopeds prohibited bike paths		20 mph
		Mopeds permitted bike paths		30 mph
		Bike paths on long downgrades (steeper than 4% and longer than 500 ft)		30 mph

Table B- 4. The minimum requirements of street components for bike ways (contd.)

Superelevation rate		Max. 2%
Horizontal Alignment	Radius of curvature with Superelevation rate	90 ft for 20 mph 160 ft for 25 mph 260 ft for 30 mph.
	Radius of curvature without Superelevation rate	100 ft for 20 mph 180 ft for 25 mph 320 ft for 30 mph.
Stopping sight distance		Min. 125 ft for 20 mph Min. 175 ft for 25 mph Min. 230 ft for 30 mph.
Grades		Min. 2%, Max. 5 %
Length of crest vertical curves		$L = 2S - \frac{1600}{A}$ when S > L $L = \frac{AS^2}{1600}$ when S < L where, L is minimum length of vertical curve in feet S is stopping distance in feet A is algebric grade difference
Lateral clearance on horizontal curves		$m = R\left[1 - \cos\left(\frac{28.65S}{R}\right)\right]$ where, m is minimum lateral clearance in feet S is stopping distance in feet R is radius of center of lane in feet
Lighting		Average illumination of 5 - 22 lux
Speed bumps, gates, obstacles, posts, fences, or other similar features intended to cause bicyclists to slow down		Not required
Entry control for bicycle paths		Required
Signing and delineation		MUTCD section 9B and 9C

1. California HDM (2016). California Highway Design Manual. California Department of Transportation (CADOT), 1120 N Street, Sacramento, California 95814, USA.
2. BDE Manual (2016). Bureau of Design and Environment Manual-Chapter 17: Policy & Procedures Section. Illinois Department of Transportation (IDOT), 2300 South Dirksen Parkway, Room No. 330 Springfield, Illinois 62764, USA.

APPENDIX C: NON-MOTORZIDE MOBILITY PLANNING TOOLS

C.1 WORK ZONE AND MOBILITY MANAGEMENT FRAMEWORK

A work zone and mobility management framework is presented in Figure C-1. Please refer to Section 4.2 of the report for additional information on the use of this framework.

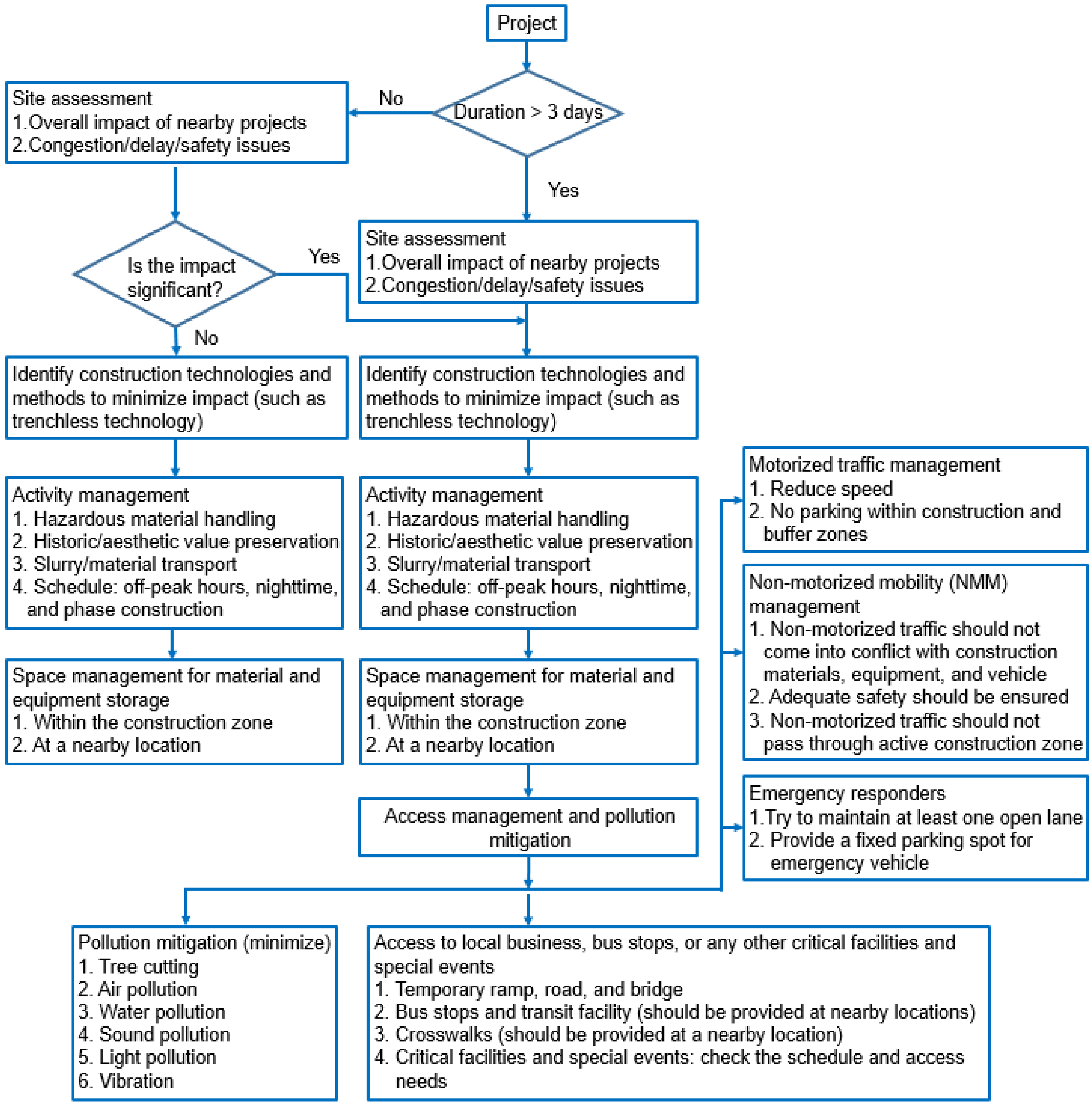


Figure C- 1. Work zone and mobility management framework

C.2 TRENCHLESS TECHNOLOGY SELECTION MATRIX

A matrix for selecting appropriate trenchless technology for a given scope (type of work) and site specific condition is presented in Figure C-2. Please refer to Section 2.7.1 of the report for additional information

Trenchless Method	Project Scope	New Pipe	Structural Rehabilitation	Non-Structural Rehabilitation	Maximum Diameter (in.)	48	60	96	126	Material Type (End Product)	Concrete (Reinforced, Non-Reinforced)	High Density Polyethylene (HDPE)	Plastic (CPV, CPE, PVC)	Steel, Ductile Iron	Fiberglass Reinforced Plastic (FRP)	Polymers (Epoxy Resin, Polyurethane)	Considerations	Steerable[1]	Bypass Flow Control Required[2]	Sound Carrier Pipe Required[3]	Excavation for Laterals Required[4]	Environmental Considerations/Monitoring Req.[5]	Install Through Deflected Carrier Pipe[6]	Install Through Elliptical Carrier Pipe[6]	Pressurized Applications[7]
Pipe Bursting		✓				✓					✓	✓	✓	✓				✓	✓		✓	✓	✓	✓	✓
Cured In-Place Pipe				✓					✓							✓			✓			✓			✓
Spiral Wound Relining				✓					✓			✓	✓									✓	✓	✓	
Spin-Cast Lining				✓					✓		✓					✓		✓	✓	✓		✓	✓	✓	✓
Sliplining			✓						✓		✓	✓	✓	✓	✓				✓		✓	✓		✓	✓
Thermoformed			✓					✓				✓	✓						✓			✓	✓	✓	
Horizontal Directional Drilling		✓					✓					✓	✓	✓				✓	N/A	N/A		✓	N/A	N/A	✓
Jack and Bore		✓						✓			✓		✓	✓	✓			✓	N/A	N/A	✓	✓	N/A	N/A	✓
Joint Seal/Grout				✓					✓			✓	✓	✓				N/A	✓	✓	N/A		✓	✓	✓

1. Moveable steering head that can be controlled remotely to adjust vertical or horizontal alignments - recommended in critical utility zones.
2. Flow control is required to keep certain grouts, gels, and other materials dry and free of contamination during the curing process.
3. The condition of the existing pipe facility in which the trenchless technology is to be applied
4. Remote reinstatement of service connections from the new main pipe facility
5. Monitoring requirements may include the release of chemicals, grout, sand, heat and/or steam infiltration that may alter the physical and/or chemical makeup of the adjacent area. Refer to specific product Safety Data Sheets.
6. The shape of the existing pipe facility in which the trenchless technology is to be applied
7. Acceptability for typical pressurized applications, such as force mains, are based on proprietary product test data and/or empirical evidence (i.e. case studies).

Figure C- 2. Trenchless technology selection matrix

C.3 GUIDANCE GRAPH

Figure C-3 shows guidance graph for selecting shared lanes, bike lanes, or bike ways depending on average daily traffic and poster speed. For more information, please refer to Section 4.4.2 of the report.

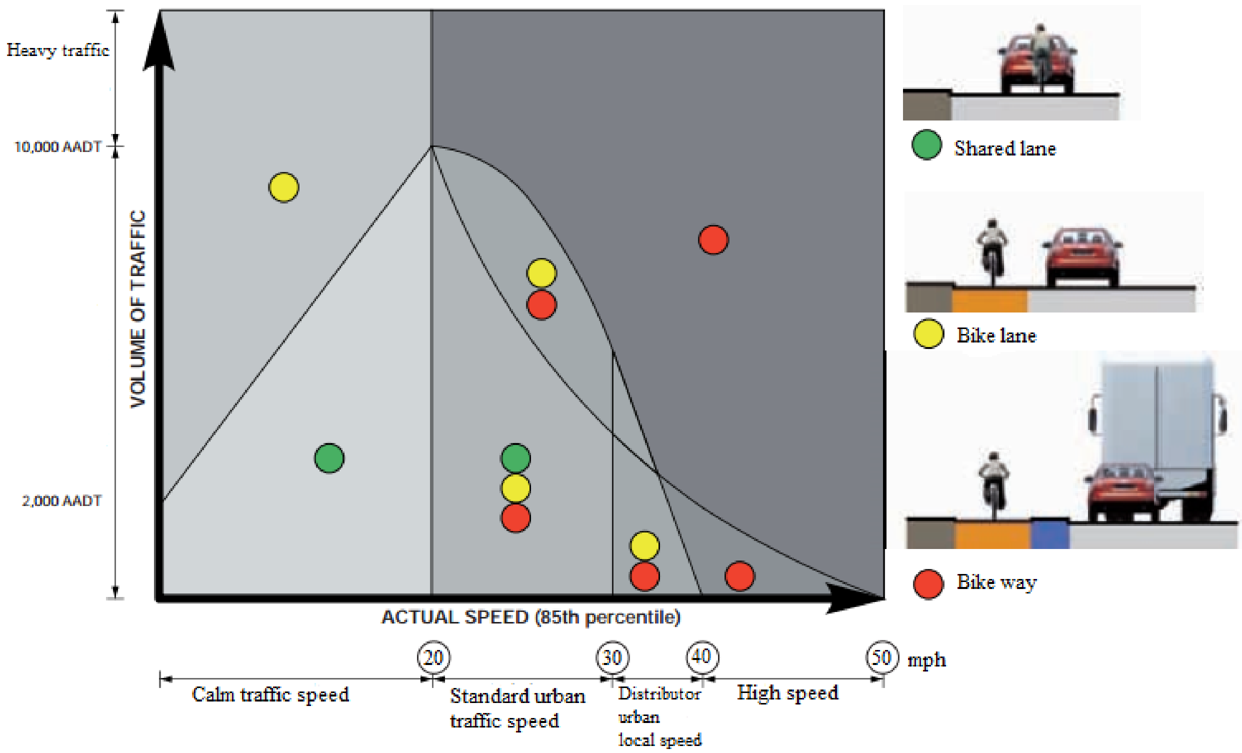


Figure C- 3. Guidance graph: volume of traffic vs actual speed diagram (NCM 2011)

C.4 LEVEL-OF-SERVICE (LOS) EVALUATION MATRIX AND PERFORMANCE RATING SYSTEM FOR PEDESTRIAN AND CYCLE FACILITIES

Table C-1 shows LOS evaluation matrix with six categories and associated criteria with respective points. Table C-2 shows performance rating system from A to F. For more information, please refer to Section 4.4 of the report.

Table C- 1. LOS evaluation matrix for pedestrian and cyclist facilities (Dixon 1996, Litman et al. 2016)

	Pedestrian		Cyclist	
Category	**Criterion**	**Points**	**Criterion**	**Points**
Facility (Max. value = 10)	Not continuous or non-existent	0	Outside lane 12 ft	0
	Continuous on one side	4	Outside lane 12-14 ft	5
	Continuous on both sides	6	Outside lane > 14 ft	6
	Min. 5 ft wide and barrier free	2	Off-street/parallel alternative facility	4
	Sidewalk width > 5 ft	1		
	Off-street/parallel alternative facility	1		
Conflicts (Max. value = 4)	Driveways and sidestreets	1	Driveways and sidestreets	1
	Pedestrian signal delay 40 sec or less	0.5	Barrier free	0.5
	Reduced turn conflict implementation	0.5	No on-street parking	1
	Crossing width 60 ft or less	0.5	Medians present	0.5
	Posted speed ≤ 35 mph	0.5	Unrestricted sight distance	0.5
	Medians present	1	Intersection implementation	0.5
Amenities (Max. value = 2)	Buffer not less than 3 ft 5 in.	1		
	Benches or pedestrian scale lighting	0.5		
	Shade trees	0.5		
Speed differential (Max. value = 2)			> 30 mph (posted speed > 45mph)	0
			25 – 30 mph (posted speed 40 - 45mph)	1
			15 – 20 mph (posted speed 30 - 35 mph)	2
Motor vehicle LOS (Max. value = 2)	LOS = E, F, or 6+ travel lanes	0	LOS = E, F, or 6+ travel lanes	0
	LOS = D, & < 6 travel lanes	1	LOS = D, & < 6 travel lanes	1
	LOS = A, B, C, & < 6 travel lanes	2	LOS = A, B, C, & < 6 travel lanes	2
Maintenance (Max. value = 2)	Major or frequent problems	-1	Major or frequent problems	-1
	Minor or infrequent problems	0	Minor or infrequent problems	0
	No problems	2	No problems	2
TDM/Multi Modal (Max. Value = 1)	No support	0	No support	0
	Support exists	1	Support exists	1
Calculation	Segment score[1]	21	Segment score	21
	Segment weight[2]	1	Segment weight	1
	Pathway score[3]	21	Pathway score	21

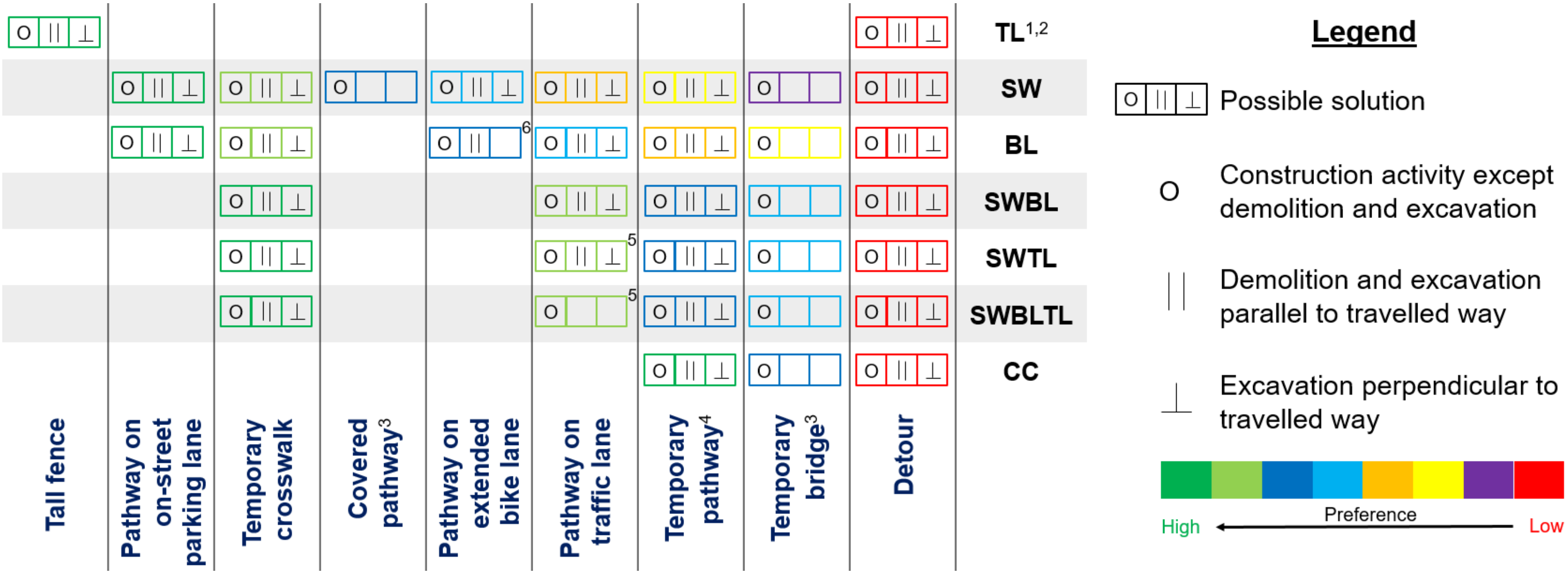
1. Segment score is the sum of point of six categories.
2. Segment weight is ratio of segment length over corridor length.
3. Pathway score is product of segment score and segment weight.

Table C- 2. Performance rating system (Dixon 1996, Litman et al. 2016)

Performance rating	Points	Performance level
A	> 17 but ≤ 21	A performance level well above average and may be expected in locations such as college campuses, downtowns, tourist centers, and activity centers
B	≥ 14 but < 17	
C	≥ 11 but < 14	An average performance level acceptable in most urban streets
D	≥ 7 but < 11	
E	≥ 3 but < 7	An unacceptable performance rating
F	≤ 3	

C.5 RISK-BASED DECISION-SUPPORT FRAMEWORK FOR MANAGING NON-MOTORIZED MOBILITY

A risk-based decision-support framework for identifying the most viable alternative for managing non-motorized mobility during construction activities is presented in Figure C-4. Please refer to Section 4.6 of the report for additional information.



1. TL represents closure of traffic lane. Similarly, closure of roadway features represented by SW – sidewalk, BL – bike lane, SWBL – sidewalk and bike lane, SWTL – sidewalk and traffic lane, SWBLTL – sidewalk, bike lane, and traffic lane, and CC – complete closure of street.
2. Possible solutions for closure of a traffic lane (TL) can be used when the work zone is outside of sidewalk and the distance between work zone and sidewalk is less than 15 ft.
3. A covered pathway or a temporary bridge is possible with all other construction activities except during demolition or excavation.
4. A temporary pathway is possible at a corner of an intersection when adequate space is available.
5. A pathway on traffic lane is possible for SWTL and SWBLTL at corner of an intersection, when
   a) number of lanes is more than 2
   b) number of lanes is 2 with motorized traffic detoured
6. A pathway on an extended bike lane is possible with partial closure of BL when at least 4 ft is available after taking 2-3 ft from an adjacent traffic lane.

Figure C- 4. Risk-based decision-support framework for managing non-motorized mobility

C.6 A TYPICAL SITE LAYOUT AND ACCESS MANAGEMENT FOR EMERGENCY RESPONDERS

Figure C-5 presents a typical layout and signage that can be adopted to maintain safe access to non-motorized traffic and emergency responders. For more information, please refer to Section 4.5.10 of the report.

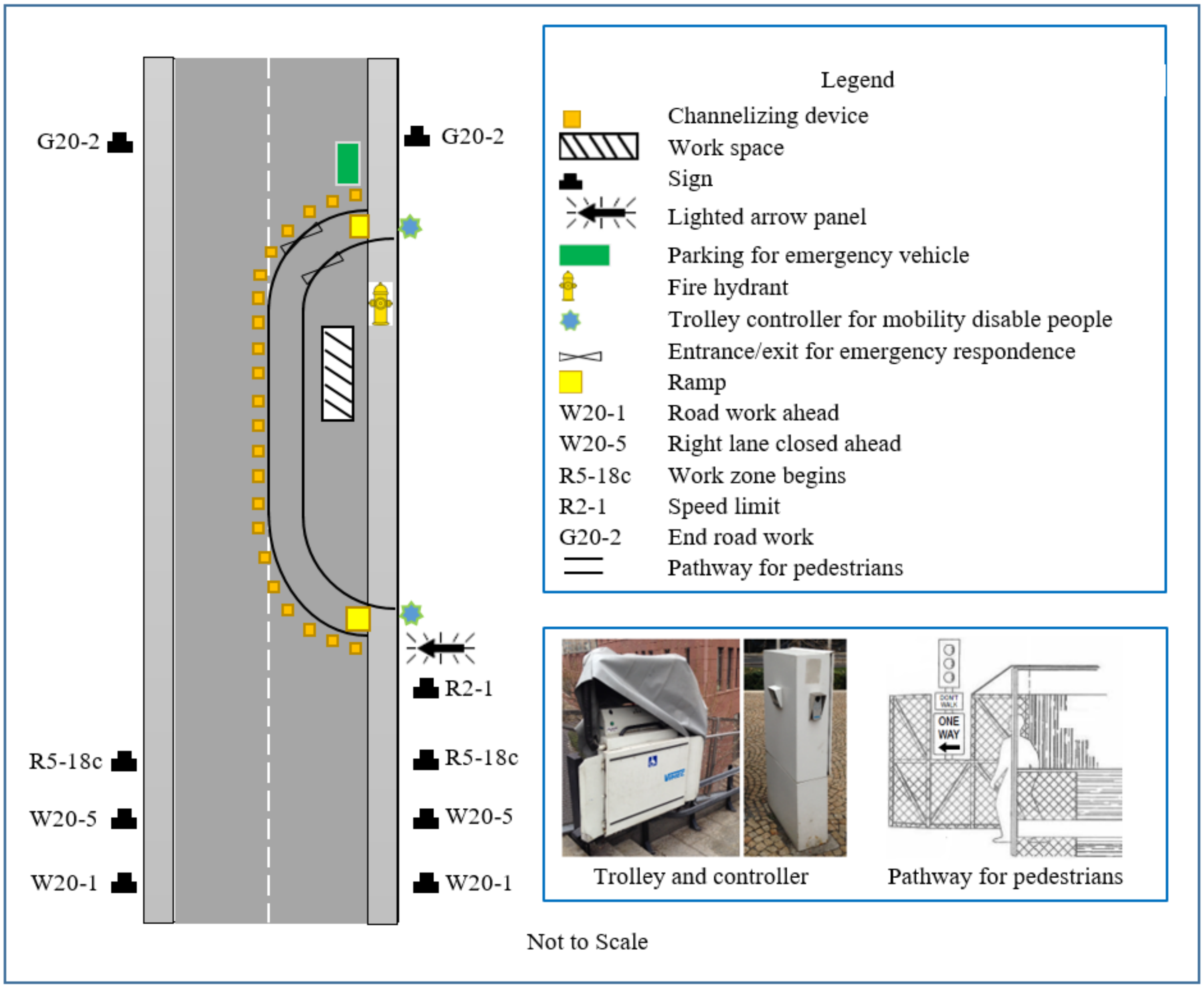


Figure C- 5. A typical site layout and access management for emergency responders

APPENDIX D: ADVANCED TECHNOLOGIES

Table D-1 shows advanced technologies that can be adopt to enhance safety and mobility. For additional information, please refer to Section 2.8 of the report.

Table D- 1. Advanced technologies

Devices	Apps
• Temporary bridges (at grade and above ground) • Platform system for mobility disabled people • Automatic Flagger Assistance Device (AFAD) • Portable and non-intrusive advance warning devices • Pedestrian warning system • Blaxtair anti-collision camera • Pedestrian switch pads • Kapten plus pedestrian GPS	• Navigation system using smartphone and Bluetooth technology • In-vehicle work zone message system • Mobileye advanced driver assistance system • Waze technology