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1.0 INTRODUCTION

1.1 INTENT & PURPOSE

Safe, convenient and well-designed facilities are essential to encourage bicycle and pedestrian use. The intent of this guide is to provide information on the design and development of facilities to enhance and encourage safe bicycle and pedestrian use. At the same time, this document is intended to provide consistent and recognizable features that are unique to the City of Billings. The design standards and recommended features in this document are based on a thorough "state-of-the-practice" review with the heritage and character of Billings in mind. This document is intended to provide a recognizable design consistency between facilities and to eliminate the need to start from scratch with each new bikeway or trail design.

1.2 RELATIONSHIP TO OTHER GUIDELINES

This guide is not intended to be a replacement for any of the applicable federal, state, or local guidelines. Rather it is intended as a synthesis of those documents providing an interpretation on how they may be applied in typical situations in the City of Billings.

Many states and localities have developed their own bicycle and pedestrian facility design manuals, many of which were researched and evaluated during the development of these guidelines.

The following bicycle and pedestrian facility design manuals were used in development of these guidelines and are recommended as additional resources:

- AASHTO Guide for the Development of Bicycle Facilities
- AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities
- ITE Recommended Practice "Design and Safety of Pedestrian Facilities"
- Manual on Uniform Traffic Control Devices (MUTCD)

1.3 POLICY STATEMENT

The decision not to accommodate bicyclists and pedestrians should be the exception, rather than the rule. "Due consideration" of bicycle and pedestrian needs should include, at a minimum, a presumption that bicyclists and pedestrians will be accommodated in the design of new and improved transportation and recreational facilities.

Bicycle and pedestrian facilities should be established in all new construction and reconstruction projects unless one or more of the following conditions are met:

- The law prohibits bicyclists and pedestrians from using the roadway.

- The cost associated with establishing the non-motorized facility would be excessively disproportionate to the demand or probable use.
- Where other factors, such as sparsity of population, indicate an absence of demand.

Design and development of all transportation and recreational facilities should improve conditions for alternate modes through the following additional steps:

- Addressing the need for bicyclists and pedestrians to cross corridors as well as travel along them.
- Getting exceptions approved at a senior level. Exceptions for the non-inclusion of bicycle and pedestrian facilities shall be approved by the City Engineer if the facility would be located within public right-of-way or by the Department of Parks, Recreation and Public Lands if the facility would be located within a park or greenway. The exception should be documented with supporting data that indicates the basis for the decision.

2.0 DEFINITIONS AND PRINCIPLES OF TRAIL AND BIKEWAY DESIGN

2.1 TYPICAL BICYCLE AND RIDER CHARACTERISTICS

For design of bicycle facilities, the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) have adopted the following classification system:

Group A: Advanced Bicyclists
Advanced bicyclists are experienced riders who can operate under most traffic conditions. They comprise the majority of the current users of collector and arterial streets. They are riding for convenience and speed and want direct access to destinations with minimum delay.

Group B: Basic Bicyclists
Basic bicyclists are casual or new adult and teenage riders who are less able to operate in traffic without provisions for bicycles and will typically avoid high speed, high volume roadways. They are comfortable riding on neighborhood streets and multi-use trails and prefer designated bike lanes or wide shoulders on busier streets. Some will develop greater skills and progress to the advanced level, but there will always be millions of basic bicyclists.

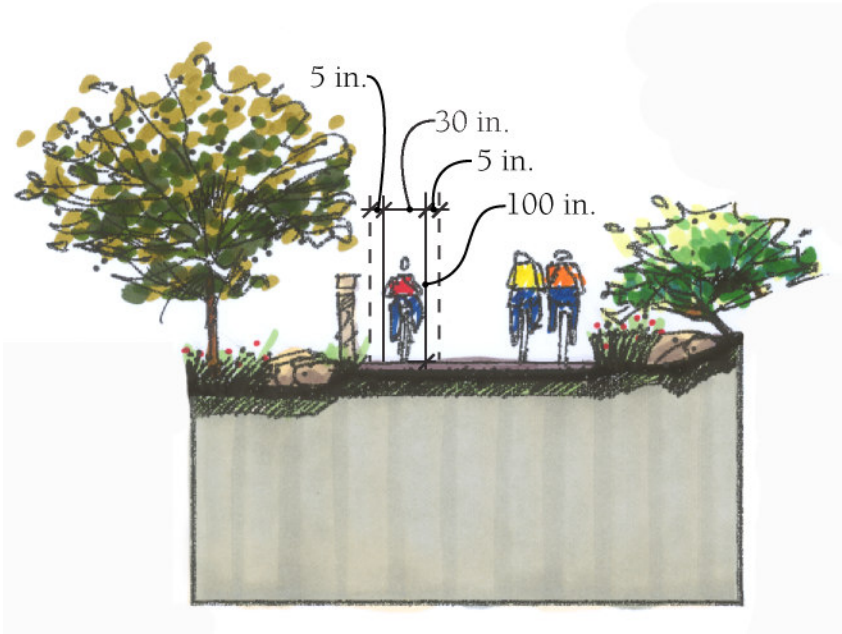
Group C: Children
This group consists of pre-teen riders whose roadway use is initially monitored by parents, but will eventually be allowed independent access to the road system. While they do not travel as fast or as confidently as their adult counterparts, children still require access to key destinations in the community, such as schools, convenience stores, and recreational facilities.

As shown in Figure 2.1.1, bicyclists require at least 40 inches of essential operating space. Although higher widths are recommended for various facilities throughout this document, the absolute minimum operating width of any facility designed for the exclusive or preferential use of bicyclists is 4 feet. The design bicyclist also requires approximately 100 inches of vertical operating space.

2.2 TYPICAL PEDESTRIAN CHARACTERISTICS

Designers should understand that there is no single "design pedestrian" and that the transportation system should accommodate a variety of users. In general, two people walking side-by-side or passing one another require 4 to 5 feet of space. Two people in wheelchairs need a minimum of 8 feet to pass one another. Accessibility requirements for individuals with disabilities will be further discussed in Section 11.0.

Figure 2.1.1. Bicyclist Operating Space



2.3 DESIGN ISSUES

The following issues need to be addressed in the design of all bicycle and pedestrian facilities:

- Safety
- Access
- Route Continuity (linkage to other facilities)
- Lighting
- Regulatory signing and pavement marking
- Wayfinding and directional signing
- Surfacing
- Terrain and grade
- Width and geometry
- Landscaping
- Related amenities (benches, water fountains, restrooms, interpretive signing)
- Roadway interface/intersections
- Sight distance
- Traffic control devices
- Bicycle parking
- Relationship of facilities to parking lots/on-street parking
- Easements and/or rights-of-way for a bicycle lane, sidewalk, or trail
- Setback and natural buffer requirements for multi-use trails
- Transit connections
- Compliance with goals and requirements of the Americans with Disabilities Act

3.0 ON-STREET BIKEWAYS

On-street bikeways are portions of paved roadway that safely separate bicyclists from vehicular traffic. They include bike routes and bike lanes. Bike routes are shared portions of the roadway that provide separation between vehicles and bicyclists, such as paved shoulders, and bike lanes are designated portions of the roadway for the preferential or exclusive use of bicyclists.

3.1 BIKE ROUTES

General Design Considerations

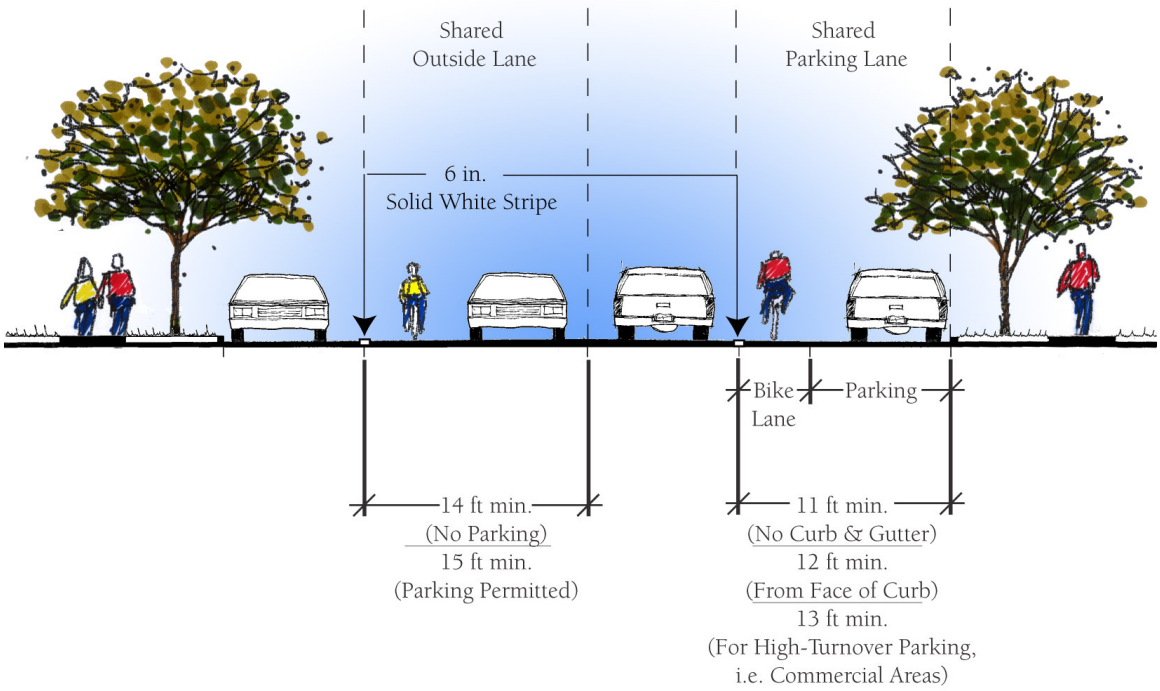
The addition of paved shoulders or the improvement of existing paved shoulders can often be the best way to accommodate bicyclists in more rural areas. In order to accommodate bicycle travel, paved shoulders should be at least 4 feet wide, not including the width of a gutter pan. Where 4-foot widths cannot be achieved, any additional shoulder width is better than none at all. If guardrail, curb, or any other roadside barrier is present, a shoulder width of 5 feet is recommended from the face of the barrier. Additional shoulder width is also recommended for areas with high motor vehicle speeds (> 50 mph) or a high percentage of trucks, buses, and recreational vehicles. In order to be usable by bicyclists, the shoulder must be paved.

Rumble strips are not recommended where shoulders are used by bicyclists unless there is a minimum clear path of 1 foot from the rumble strip to the traveled way, 4 feet from the rumble strip to the outside edge of the paved shoulder, or 5 feet to adjacent curb or guardrail.

Where paved shoulders are not provided, wide curb lanes for bicycle use are usually the preferred alternative. A curb lane wider than 12 feet can accommodate both bicycles and motor vehicles in the same lane. In general, 14 feet is the recommended usable lane width for shared use. Usable width is typically measured from the lane stripe to the edge stripe or from the lane stripe to longitudinal joint of the gutter pan. A 15-foot curb lane is preferred in areas where the usable lane width is reduced by on-street parking or in areas with steep grades, drainage grates, or raised reflectors. In situations where more than 15 feet of pavement width is available for the curb lane, a striped bike lane should be considered.

On-street parking significantly increases the potential for conflict between bicyclists and motor vehicles. The most common bicycle riding location on urban roadways is in the area between parked vehicles and the moving vehicles in the outside lane. Here, bicyclists are subjected to opening car doors, as well as vehicles entering and exiting on-street parking spaces. Parked vehicles can also obscure a bicyclist's view of intersecting traffic. Therefore, where this type of shared use is desirable, it is recommended that the combined bicycle travel and parking width be a minimum of 11 feet from the edge of pavement or 12 feet from the face of curb. An additional 1 to 2 feet of width is desirable in areas with high parking volumes or turnovers. Figure 3.1.1 shows a typical cross-section of a designated bike route for the various situations discussed above.

Figure 3.1.1. Typical Bike Route Cross-Section

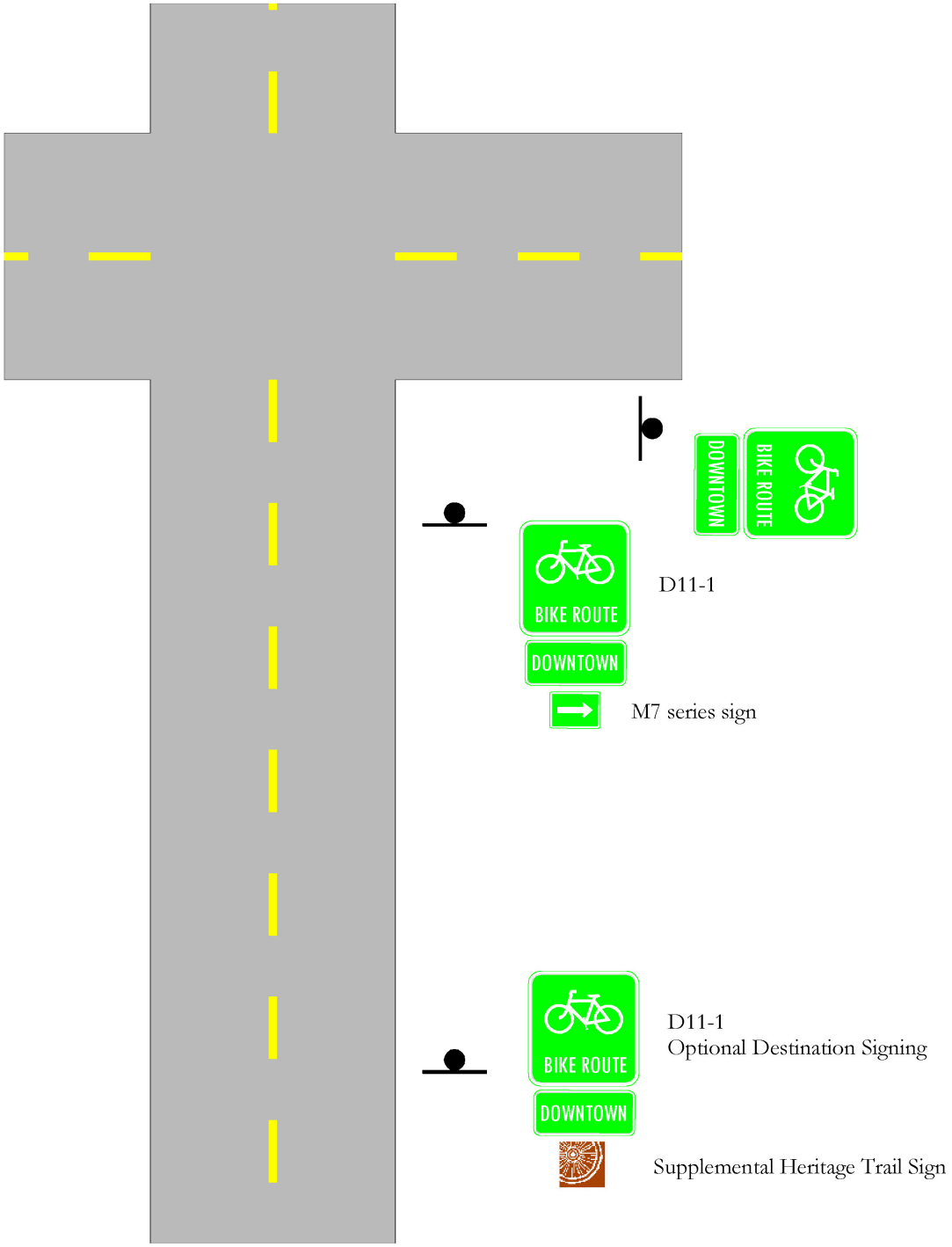


Signing

Bike route signage shows continuity to other bicycle facilities such as bike lanes and trails. Bike route signs indicate to bicyclists that there are advantages to using these routes over alternate routes. Bike route signs may also be used on trails or streets with striped bike lanes. Typical bike route signing is shown in Figure 3.1.2. The functionality of these signs can be increased by placing supplemental destination signs beneath them when located along routes leading to high demand destinations (i.e., "To Downtown"). It is recommended that bike route signs be placed at all transition points, including all turns, signalized intersections, and multi-use trail/roadway intersections.

The recommended signing practice from the Heritage Trail Plan is that all marked on-street bike routes be signed to show continuity to nearby bike lanes and multi-use trails. This can be accomplished through the use of a supplemental "Heritage Trail" sign, an example of which is shown in Figure 3.1.2.

Figure 3.1.2. Typical Bike Route Signing



Note:
Bike Route signs should be placed at all transitions points including all turns, signalized intersections, and multi-use trail/roadway intersections.

Source: AASHTO Guide for the Development of Bicycle Facilities

According to AASHTO *Guide for the Development of Bicycle Facilities,* the following criteria should be considered prior to signing a route:

- The route provides through and direct travel in bicycle-demand corridors.
- The route connects discontinuous segments of trails, bike lanes, and/or other bike routes.
- An effort has been made to adjust traffic control devices to give greater priority to bicyclists, as opposed to alternative streets.
- A smooth surface has been provided and utility covers and drainage grates are bicycle friendly.
- Shoulder or curb lane widths generally meet or exceed the width requirements discussed above.

3.2 BIKE LANES

General Design Considerations

The use of striped bike lanes is recommended when it is desirable to delineate available road space for the preferential use of bicyclists. Bike lane markings can increase a bicyclist's confidence by reducing the likelihood of a motorist drifting into their travel path. Likewise, passing motorists are less likely to swerve to the left to avoid bicyclists on their right.

Bike lanes should be one-way facilities that carry bicycle traffic in the same direction as the adjacent motor vehicle lane. Two-way bike lanes on one side of the roadway are not recommended because they often result in bicycles riding against the flow of motor vehicle traffic. Along the same lines, the use of contra-flow bike lanes located on the left side of the street adjacent to opposing traffic is not recommended unless they would substantially decrease the number of conflicts caused by right-turning vehicles.

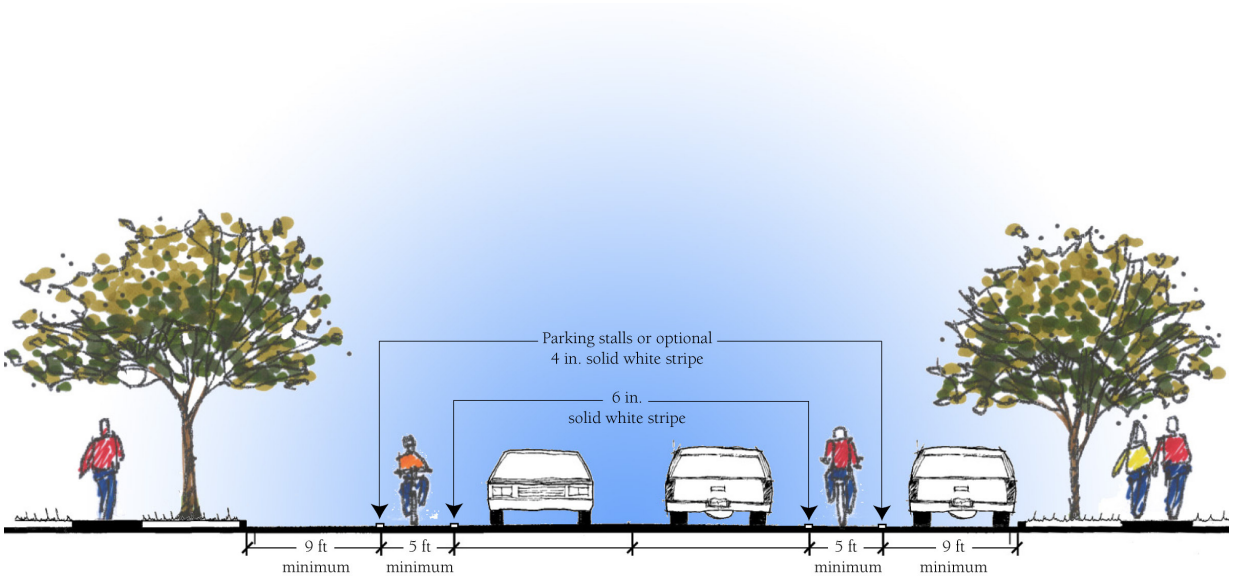
On one-way streets, bike lanes should generally be placed on the right side of the street because bike lanes on the left side are unfamiliar and unexpected to most motorists. Similar to two-way streets, bike lanes on the left side of one-way streets should only be considered when they would substantially decrease the number of conflicts, such as those caused by a high volume of right-turning vehicles.

Bike lanes should never be placed between the parking lane and curb. This placement would prohibit bicyclists from making left turns, as well as create several obstacles for bicyclists from opening car doors and poor visibility at intersections and driveways.

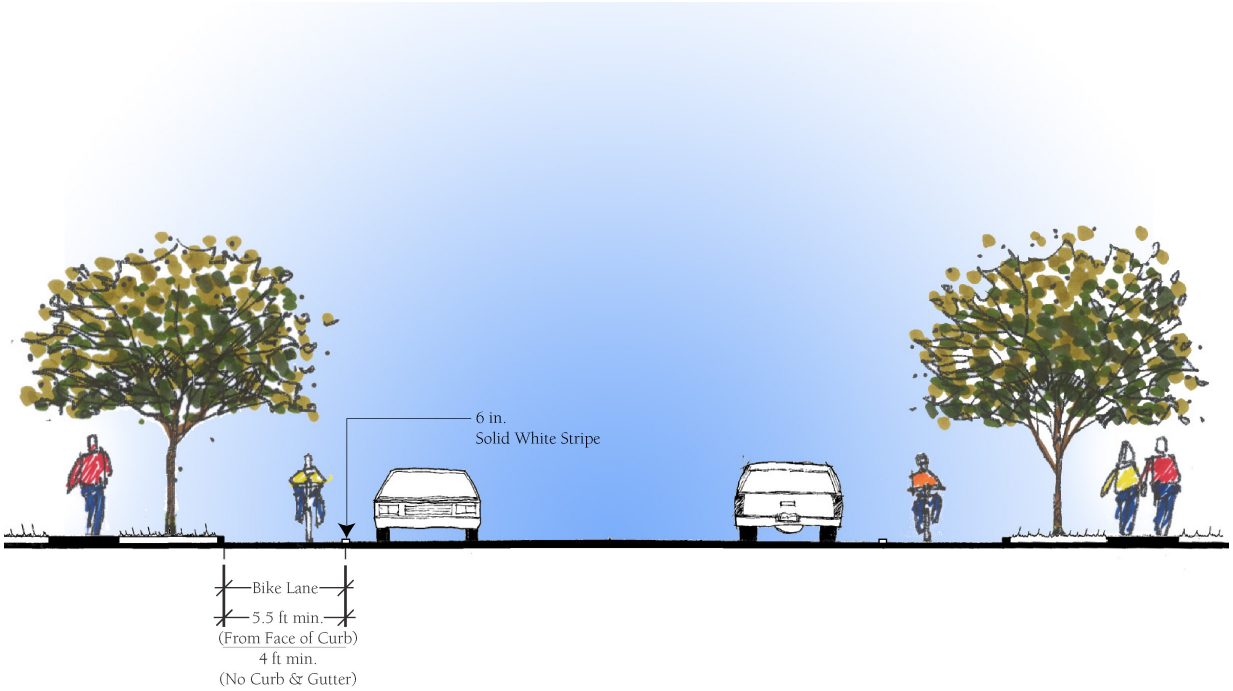
Bike Lane Widths

For roadways without curb and gutter, the minimum width of a bike lane should be 4 feet. Where parking is permitted, as shown in Figure 3.2.1, the bike lane should be placed between the travel lane and parking area with a minimum width of 5 feet. Where parking is allowed but there are no parking stripes or stalls, the shared parking area and bike lane should be a minimum of 12 feet from the face of curb or 11 feet from edge of pavement, as previously discussed. An additional 1 to 2 feet of width is desirable in areas with high parking volumes or turnovers.

Figure 3.2.1 Typical Bike Lane Cross-Sections



Parking Permitted



Parking Prohibited

AASHTO recommends a usable surface width of at least 4 feet for bicycle use and states that the width of the gutter pan can be included in the usable surface width if the longitudinal joint between the gutter pan and pavement surface is smooth. However, the

City of Billings standard is to place the finished street surface 1/4 inch ± 1/8 inch above the gutter pan. Therefore, for roadways with curb and gutter, the recommended width of a bike lane is 4 feet, measured from the bike lane stripe to the longitudinal joint between the gutter pan and pavement surface. For the City of Billings standard 1.5-foot wide gutter pan, this would mean that the bike lane stripe should be placed 5.5 feet from the face of curb. Bike lanes in excess of 6 feet wide are undesirable because they may be mistaken for a motor vehicle lane or parking area. Bike lane widths less than 5.5 feet from the face of curb may be approved by the City Engineer on a case-by-case basis only. Vehicle lanes adjacent to bicycle lanes should be at least 11 feet wide.

Signing and Pavement Markings

A bike lane should be delineated with a 6-inch solid white line adjacent to the motor vehicle traffic lane. An additional 4-inch solid white line can be placed between the parking lane and the bike lane. This second line will encourage parking closer to the curb and it can discourage motorists from using the bike lane as an additional through lane. Raised pavement markings and raised barriers are not recommended for delineating bicycle lanes because they can cause steering difficulties for bicyclists. It is recommended that all bicycle lane striping and symbols be marked with white traffic paint or white texturized tape.

Bike lanes should be painted with standard pavement symbols to inform bicyclists and motorists of the presence of the bike lane. These symbols should be painted on the far side of each intersection. Additional markings may be placed on long, uninterrupted sections of roadway. All pavement markings are to be white and reflectorized. The Preferential Lane Symbol (diamond) that has been used in some cities to show preferential use by different vehicle classes should no longer be used for bike lanes, due to confusion with the use of the diamond for High Occupancy Vehicle (HOV) lanes. Figure 3.2.2 shows recommended bike lane markings.

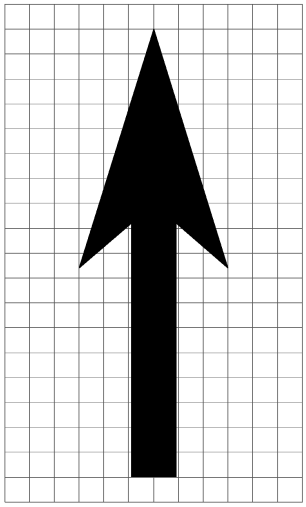
Examples of signs used for bike lanes are included throughout the following sections and additional guidance for pavement markings and signing of bike lanes is contained in the Manual on Uniform Traffic Control Devices (MUTCD).

Bike Lanes at Intersections

Bike lanes should not be striped across crosswalks and, in most cases, should not continue through street intersections. If there are no painted crosswalks, the bike lane striping should stop at the near side of the cross street and resume at the far side. The only exception to this rule may be the extension of dotted guidelines through a particularly complex intersection.

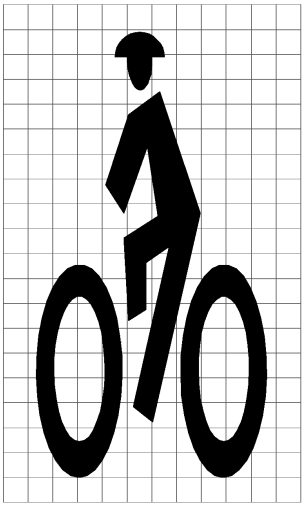
At intersections with a dedicated right-turn bay, the solid striping on the approach should be replaced with a broken line with 2-foot dashes and 6-foot spaces. The length of the broken section should correspond with the length of the entrance taper and is usually 50 to 200 feet. Similar striping should be used on minor intersections when there is a bus stop or heavy right-turn volume. Otherwise, the solid striping can continue all the way to the crosswalk on the near side of the intersection. The bike lane striping should resume at the outside line of the crosswalk on the far side of the intersection (see Figure 3.2.3). If a bus stop is located on the far side of the intersection, the solid bike lane line should be replaced with a broken line for a distance of at least 80 feet from the crosswalk on the far side.

Figure 3.2.2. Typical Bike Lane Markings

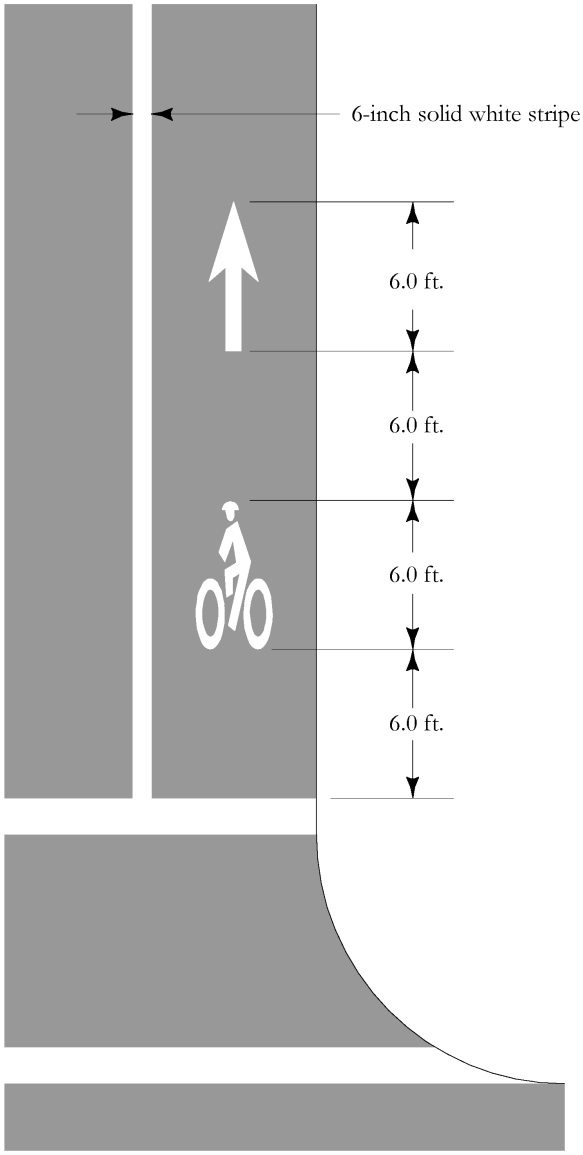


Directional arrow

= 4-inch x 4-inch



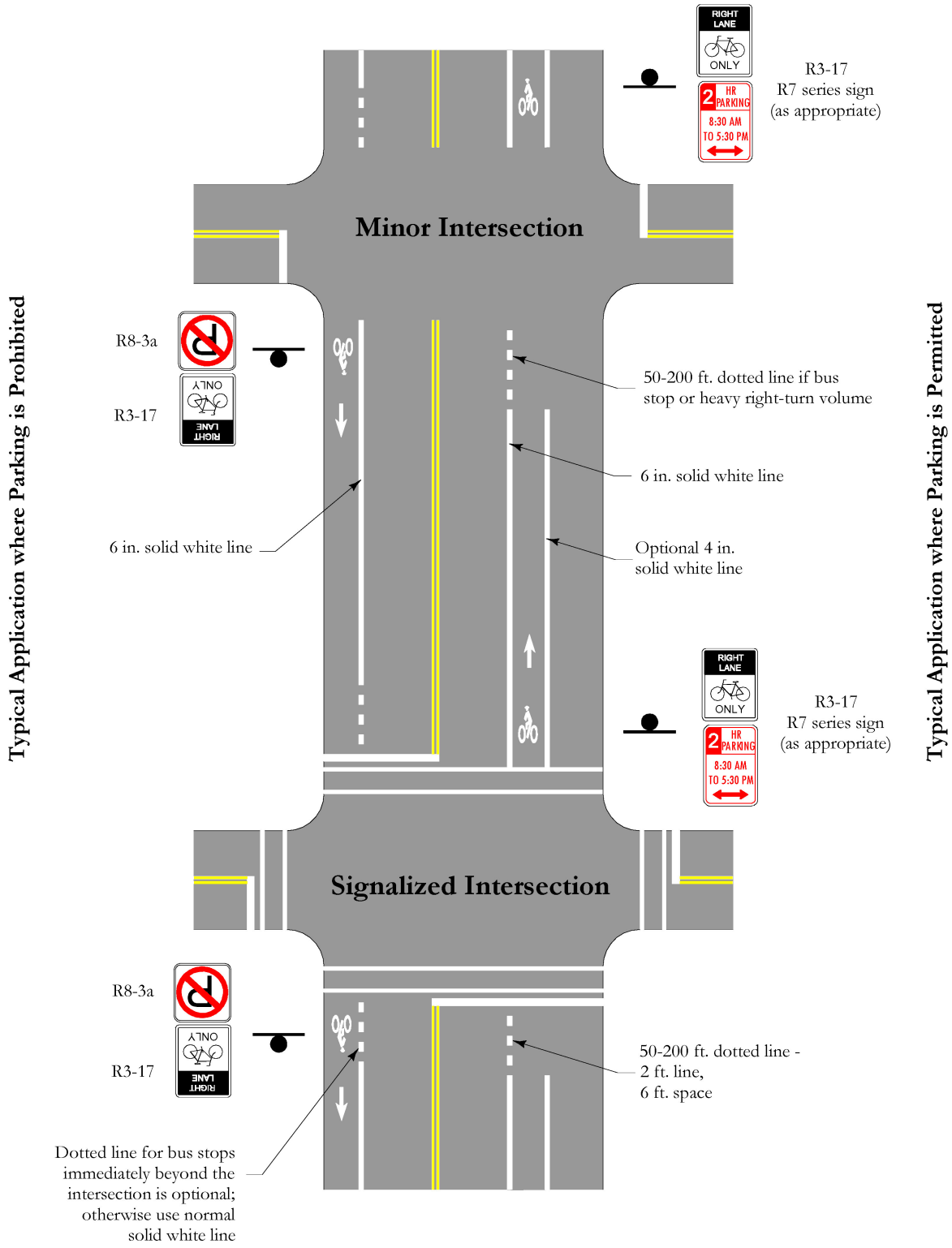
Preferred Symbols



Note:
Symbols should be painted
on the far side of each intersection.

Source: AASHTO Guide for the Development of Bicycle Facilities

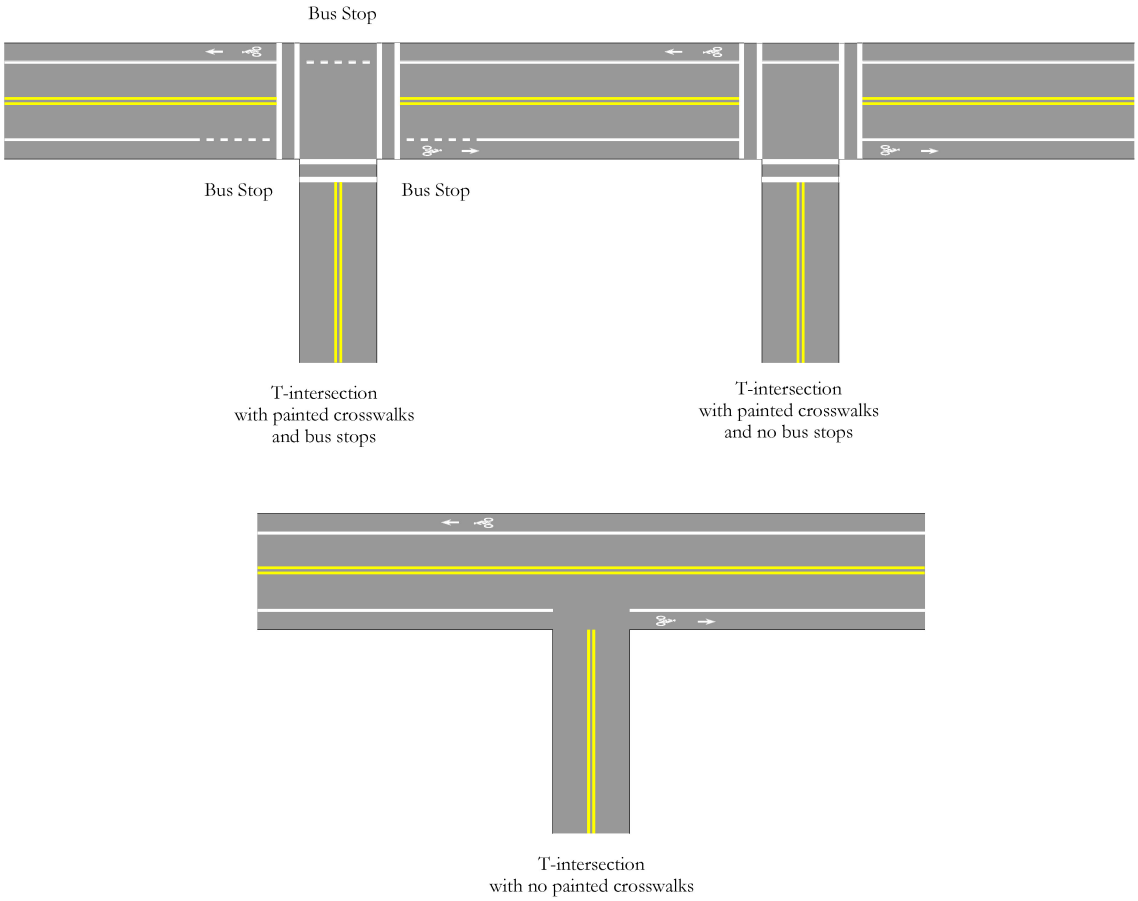
Figure 3.2.3. Typical Bike Lane Markings at Four-Way Intersections



Source: Manual on Uniform Traffic Control Devices (MUTCD)

At T-intersections with no crosswalks, the lane striping on the side across from the T-intersection approach should continue through the intersection area with no break. If there are painted crosswalks, the bike lane striping on this side should be discontinued only at the crosswalks. See Figure 3.2.4 for bike lane striping recommendations at T-intersections.

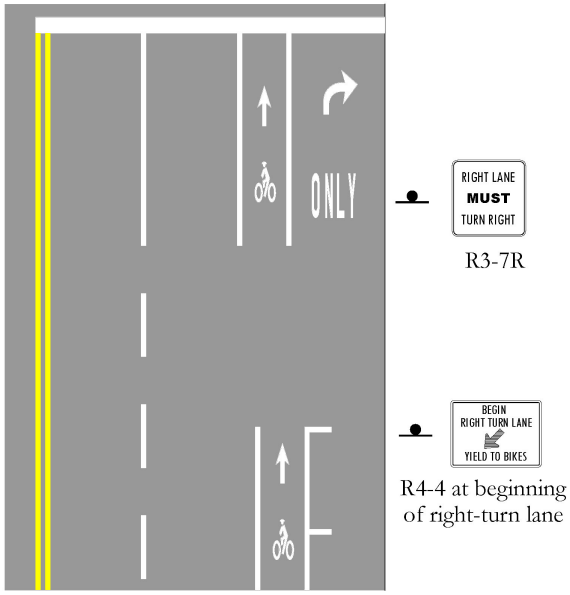
Figure 3.2.4. Typical Bike Lane Striping at T-Intersections



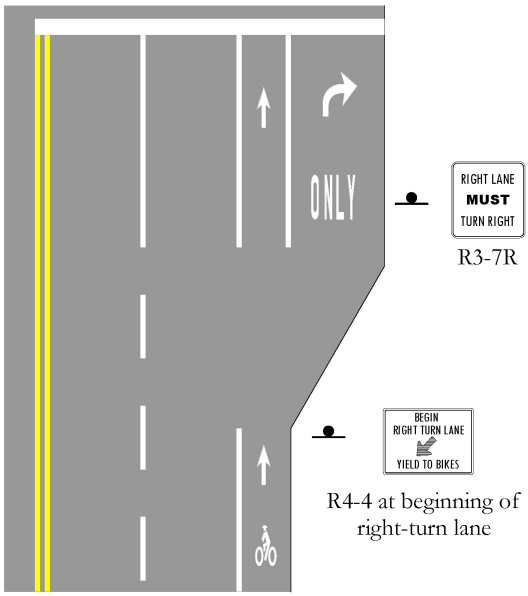
Source: AASHTO Guide for the Development of Bicycle Facilities

Bike lanes have a tendency to complicate turning movements for both bicyclists and motor vehicles. Because they encourage bicyclists to keep right and motorists to keep to the left, both are often discouraged from merging in advance of turns, resulting in conflicts. At intersections, bicyclists proceeding straight through and motorists turning right must cross paths. It is preferred that signing and striping configurations encourage merging in advance of the intersection. Some examples of signing and striping configurations used where a bike lane approaches a vehicle right-turn lane are shown in Figure 3.2.5. Where feasible, the approach shoulder width should be provided through the intersection to accommodate right-turning bicyclists or those that prefer to use the crosswalks to negotiate the intersection.

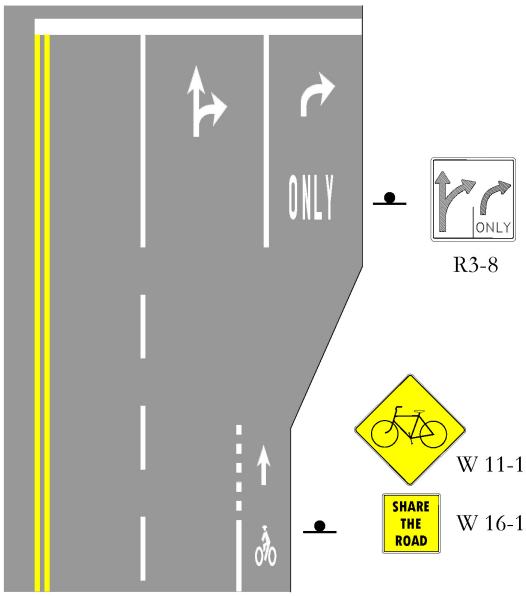
Figure 3.2.5. Bike Lane Options at Right-Turn-Only Lanes



a. Parking lane into right-turn-only lane



b. Right-turn-only lane



c. Optional right/straight and right-turn-only lane

Source: AASHTO Guide for the Development of Bicycle Facilities

Another conflicting movement is that of left-turning bicyclists; however, most vehicle codes allow the bicyclist the option of making either a "vehicular style" left turn (bicyclist merges to vehicle left-turn lane) or a "pedestrian style" left turn (bicyclist proceeds straight through intersection, then proceeds across the intersection again on the cross street).

3.3 ADDITIONAL ON-STREET DESIGN CONSIDERATIONS

Pavement Surface Quality

The comfort and safety of bicyclists are directly related to the smoothness and uniformity in width of the riding surface. Wide cracks, holes, drop-offs, or other obstacles in bicyclists' traveled way can cause loss of control or can cause bicyclists to swerve into the path of motor vehicle traffic. As pavements age, it may be necessary to fill joints or cracks, adjust utility covers or even overlay the pavement in some cases to make it suitable for bicycling. Adequate drainage should be provided to prevent ponding, washouts, debris accumulation and other potentially hazardous situations for bicyclists. Frequent maintenance is necessary to keep bike routes clear of debris.

Drainage Inlet Grates

Drainage inlet grates and utility covers are potential obstructions to bicyclists. Drainage inlet grates with slots parallel to the roadway, or a gap between the frame and grate, can trap the front wheel of a bicycle and cause loss of control. Therefore, bicycle-safe grates should be used, and grates and covers should be located where they will minimize severe or frequent maneuvering by the bicyclist. Drainage inlet grates and utility covers should be placed or adjusted to be flush with the adjacent pavement surface. When immediate replacement is not possible, a temporary correction is to weld steel cross straps or bars perpendicular to the parallel bars at 4-inch center-to-center maximum spacing to provide a maximum safe opening between straps. When new highway facilities are constructed, curb-opening inlets should be considered to minimize the number of potential obstructions.

3.4 MINIMUM BICYCLE COMPATIBILITY INDEX (BCI) CRITERIA

The Bicycle Compatibility Index (BCI) can be used to evaluate the capability of a specific roadway to accommodate the efficient operation of both bicyclists and motorists, based on the bicyclists' level of comfort. The BCI is an empirically derived model recently developed at the Federal Highway Administration's Turner-Fairbanks Highway Research Center. The goal of the BCI model is to give traffic engineers, transportation planners, and bicycle coordinators a means to evaluate how well a roadway can accommodate efficient operation of both bicycles and motor vehicles. The BCI is an effective tool for establishing minimum criteria for the design of new roadways.

Development of the BCI Model

The BCI model was developed by having bicyclists view numerous roadway segments on videotape and rate how comfortable they would be riding on the street under the existing conditions. This surveying methodology allowed the participants to be able to rank the same stretch of roadway under the same traffic conditions without having to be exposed to dangerous riding conditions. Over 200 participants ranked 80 different roadway segments

using a scale from *one* to *six*. A *one* indicated that the individual would be "extremely comfortable" riding in the shown conditions, while a *six* indicated that the individual would be "extremely uncomfortable" riding in the shown conditions.

Based on the results, a model was established using linear regression to predict a cyclist's comfort level on any stretch of roadway from the following eight geometric and operational characteristics:

- Presence of a bicycle lane
- Bicycle lane width
- Curb lane width
- Type of development along the roadside (residential or other)
- Curb lane traffic volumes during the peak hour conditions
- Motor vehicle speed
- Presence of on-street parking

- Adjustment factor which accounts for the following three operational conditions:
    1. Percent of heavy vehicles on the roadway,
    2. Number of vehicles turning right into driveways
    3. Number of vehicles pulling into or out of on-street parking spaces

The model accurately predicts the overall comfort level ranking of each roadway segment for urban and suburban roadways. The basic model (excluding the adjustment factor) has an R^2-value of 0.89, indicating that 89 percent of the variance in comfort level of the bicyclist is based on the eight variables included in the model. The BCI is applicable to through-corridors or mid-block locations that are exclusive of major intersections. Table 3.4.1 shows the BCI model, variable definitions, and adjustment factors.

Bicycling Level of Service

The *2000 Highway Capacity Manual (HCM2000)* defines level-of-service (LOS) as "a qualitative measure that characterizes operational conditions within a traffic stream and the perception of these conditions by motorists and passengers." While the *HCM2000* does not define LOS for bicyclists, the concept of basing the LOS on the user's perceptions of the operational conditions applies just as well to bicyclists as it does to motorists. The BCI reflects the comfort levels of bicyclists based on observed geometric and operational conditions and creates a numerical output.

In order to remain consistent to the *HCM2000*, six LOS designations from A to F were defined. Each letter designation corresponds to a range of numerical values. Based on the responses of all types of cyclists, the roadway segment with the best rating had a mean value of 1.24 and the roadway segment with the worst rating had a mean value of 5.49. Those two extreme values were considered to indicate the conditions in which *all* cyclists would feel comfortable riding in or all cyclists would feel uncomfortable riding in, respectively. The upper and lower boundaries for the LOS designations were established around the two extreme values. Table 3.4.2 gives the numerical equivalents for each LOS designation.

Table 3.4.1. Bicycle Compatibility Index (BCI) Model

$$\mathbf{BCI} = 3.67 - 0.966\mathbf{BL} - 0.125\mathbf{BLW} - 0.152\mathbf{CLW} + 0.002\mathbf{CLV} + 0.0004\mathbf{OLV} + 0.035\mathbf{SPD} + 0.506\mathbf{PKG} - 0.264\mathbf{AREA} + \mathbf{AF}$$

Where:

BL = presence of a bicycle lane or paved shoulder ≥ 3.0 ft
no = 0
yes = 1

BLW = bicycle lane (or paved shoulder) width
ft (to the nearest tenth)

CLW = curb lane width
ft (to the nearest tenth)

CLV = curb lane volume
vph in one direction

OLV = other lane(s) volume – same direction
vph

SPD = 85th percentile speed of traffic
mph

PKG = presence of a parking lane with more than 30% occupancy
no = 0
yes = 1

AREA = type of roadside development
residential = 1
other = 0

$\mathbf{AF} = f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes *(see below)*

f_p = adjustment factor for parking turnover *(see below)*

f_{rt} = adjustment factor for right-turn volumes *(see below)*

Adjustment Factors

Hourly Curb Lane Large Truck Volume[1]	f_t	Parking Time Limit (min)	f_p
≥ 120	0.5	≤ 15	0.6
60 – 119	0.4	16 – 30	0.5
30 – 59	0.3	31 – 60	0.4
20 – 29	0.2	61 – 120	0.3
10 – 19	0.1	121 – 240	0.2
< 10	0.0	241 – 480	0.1
		> 480	0.0

Hourly Right-Turn Volume[2]	f_{rt}
≥ 270	0.1
< 270	0.0

[1] Large trucks are defined as all vehicles with six or more tires.
[2] Includes total number of right turns into driveways or minor intersections along roadway segment.
Source: FHWA Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual

Table 3.4.2. BCI & LOS Designations

LOS	BCI Range	Compatibility Level
A	≤ 1.50	Extremely High
B	1.51 – 2.30	Very High
C	2.31 – 3.40	Moderately High
D	3.41 – 4.40	Moderately Low
E	4.41 – 5.30	Very Low
F	> 5.30	Extremely Low

Source: FHWA Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual

Evaluating Proposed Facility Designs Using the BCI

New roadway designs and roadway re-designs or retrofits should also be evaluated in order to determine their level of bicycle compatibility. Planned geometric and operational parameters can be used as inputs to determine the BCI value and bicycle LOS that can be expected on the roadway. If the roadway does not meet the desired LOS, necessary design changes should be made. For new roadway designs or redesigns, *The Billings Urban Area 2000 Transportation Plan* establishes LOS C as the minimum acceptable level for motor vehicle traffic operations. Similar to the acceptable LOS for motor vehicles, bicycle compatibility should also have a minimum LOS C for newly constructed roadways or retrofits. BCI and BCI LOS should be calculated for all new designs and retrofits of existing arterial and collector streets.

In cases where certain data is not available, adjustments and assumptions should be made in accordance with the *Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual* (FHWA-RD-98-095). For example, 85th percentile speeds should be assumed to be 9 mph above the posted speed limit and the percentage of heavy vehicles should be assumed to be 3.5% for principal arterials, 2% for minor arterials, 1.5% for collectors, and 0% for local streets.

The BCI and LOS criteria have been incorporated into a Microsoft Excel workbook to simplify the use of the model for real-world applications. The workbook includes three separate worksheets that are linked together to provide BCI and LOS calculations and results. The three worksheets include Data Entry, Intermediate Calculations, and BCI and LOS Computations. The workbook, along with various BCI publications, can be downloaded from www.hsrc.unc.edu/research/pedbike/bci/.

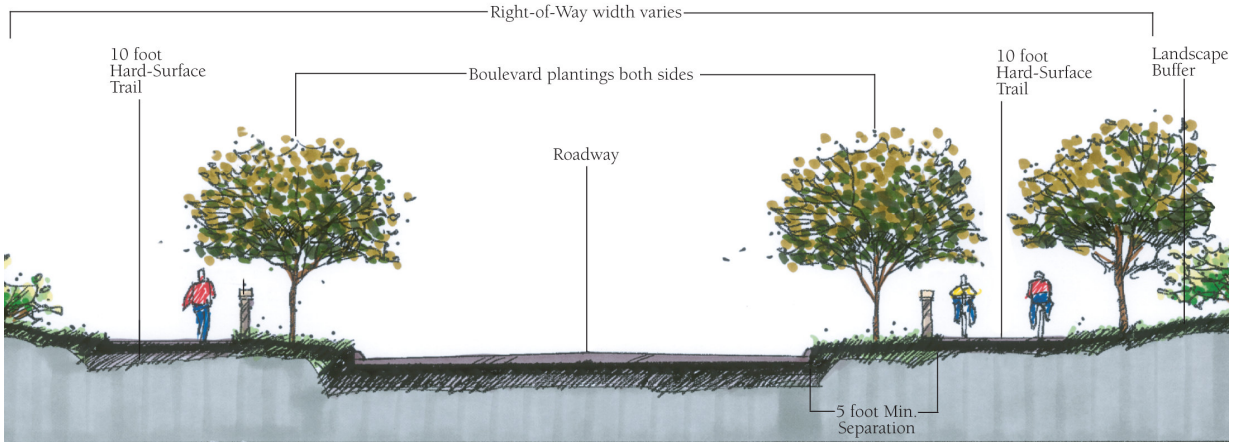
4.0 HARD-SURFACE MULTI-USE TRAILS

Hard-surface multi-use trails include Connector Trails and Park Trails, as designated in the *Heritage Trail Plan*. Connector trails are multipurpose trails that emphasize safe travel to and from destinations throughout the community and park trails are multipurpose trails located within greenways, parks, or natural resource areas.

4.1 CROSS SECTIONS

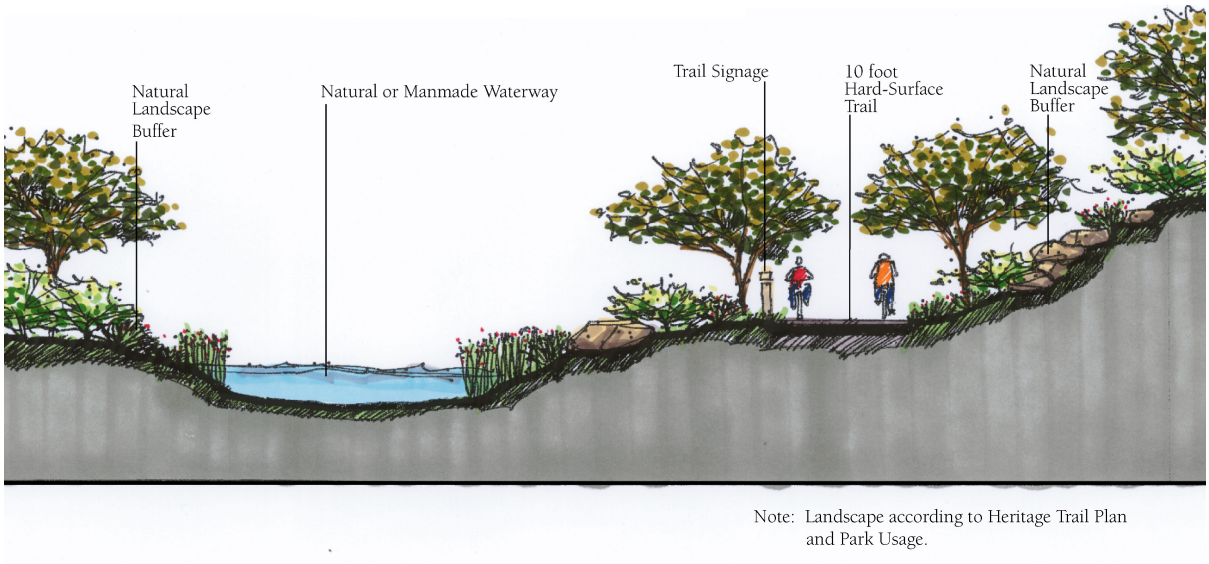
The focus of connector trails is as much on transportation as it is on recreation. In general, connector trails are located within existing road rights-of-way and utility easements or along artificial drainage ways. Connector trails are typically designed to accommodate heavy use patterns and can be developed for multiple, separated, and/or directional lanes. Connector trails can be developed on one or both sides of a roadway. Figure 4.1.1 shows an example of a connector trail cross-section.

Figure 4.1.1. Typical Connector Trail Cross-Section



Park trails are multipurpose trails located within greenways, parks, or natural resource areas. The focus of this type of trail is primarily on recreational value and interaction with the natural environment. Abandoned railroad beds, utility rights-of-way, and scenic and historic routes provide the greatest opportunity for park trails. Figure 4.1.2 shows an example of a hard-surface park trail cross-section.

Figure 4.1.2. Typical Hard-Surface Park Trail Cross-Section



4.2 GENERAL DESIGN CONSIDERATIONS

When connector trails are located adjacent to a roadway, wide separation between the trail and the roadway is desirable, preferably 10 feet or more. This will demonstrate to the trail user, as well as to motorists, that the trail functions as an independent facility. The absolute minimum width of separation between roadways and connector trails should be 5 feet. When a wide separation is not feasible and the distance between the edge of the shoulder and the trail is less than 5 feet, a suitable physical barrier is recommended. Where used, the barrier should be a minimum of 42 inches high, but should not impair sight distance at intersections and should be designed to not be a hazard to passing vehicles.

Two primary design considerations of shared use facilities are paved width and operating width (discussed under *Horizontal Clearances* below). The recommended pavement width for a two-directional shared use trail is 10 feet. Under certain circumstances it may be necessary or desirable to increase the width to 12 or 14 feet, due to heavy use by multiple non-motorized modes, use by larger than average maintenance vehicles, and/or steep grades.

For certain connector or park trails, a reduced pavement width of 8 feet may be acceptable, but shall be approved by the City Engineer on a case-by-case basis. This reduced width would only be adequate when the following conditions exist: (1) peak day or peak hour bicycle traffic is expected to be low, (2) only occasional pedestrian use is expected, (3) safe and frequent passing opportunities are provided through good horizontal and vertical alignments, and (4) the trail will not be subjected to potentially damaging loading conditions during normal maintenance activities.

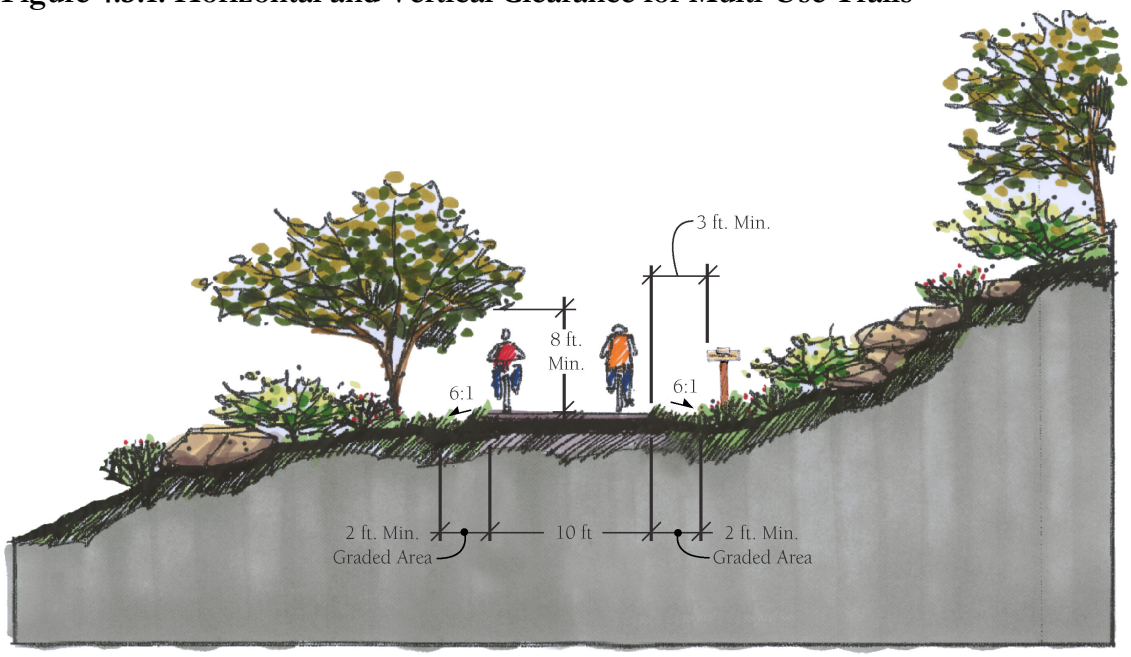
Because of enforcement difficulties, it should be assumed that all shared use trails will be used as two-way facilities by both pedestrians and bicyclists. In the rare occasion where

effective measures can be taken to assure one-way operation, the minimum width should be 6 feet.

4.3 HORIZONTAL CLEARANCES

As illustrated in Figure 4.3.1, the operating width for shared use facilities should include a minimum 2-foot wide graded area with maximum 6:1 slopes along both sides of the trail. However, 3 feet or more is desirable to provide clearance from trees, poles, walls, fences, guardrail, or other lateral obstructions.

Figure 4.3.1. Horizontal and Vertical Clearance for Multi-Use Trails



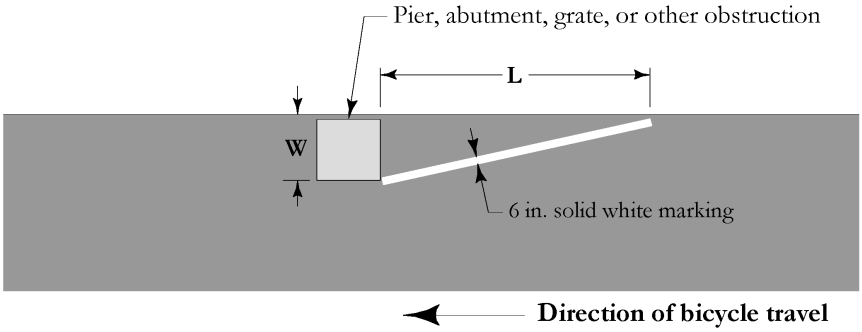
Where the trail is adjacent to a canal, ditch, or slope steeper than 3:1, a wider separation should be considered. A minimum 5-foot separation from the edge of pavement to the top of the slope is desirable. When a 5-foot separation is not feasible, a physical barrier, such as dense shrubbery or a railing should be provided. Railings or barriers should be 54 inches (4.5 feet) high and should include smooth rub rails attached at handlebar height, 42 inches (3.5 feet). Railing ends should be flared away from the trail at either end of the railing to prevent trail users from catching on the railing. See Section 9.1 for additional guidelines on railing placement.

Depending on character and location, the areas adjacent to many trails will need to be mowed regularly during spring and summer months. Therefore, where mowing is expected, it is important to construct ditch sections with slopes flat enough that a large mower can easily traverse them. Typically, a 4:1 foreslope (beyond the 2-foot minimum graded area) and backslope are reasonable. However, the ability of a mower to traverse a ditch will also

depend on the depth and width of the bottom of the ditch. The bottom of a flat bottom ditch should be a minimum of 6 feet wide for mowing. Backslopes steeper than the standard 4:1 adjacent to trails where mowing will be necessary shall be approved by the City Engineer and the department director responsible for their maintenance on a case-by-case basis.

When barriers and obstructions, such as bridge abutments or piers, cannot be placed outside the recommended horizontal clearance for multi-use trails, they should be clearly marked. This treatment should only be used when the obstruction is absolutely unavoidable, and is by no means a substitute for horizontal clearance recommendations. Signs, reflectors, pavement markings, or other treatments may be appropriate to alert bicyclists to obstructions. Figure 4.3.2 shows an example of an obstruction marking.

Figure 4.3.2. Obstruction Markings



L = WV, where V is bicycle approach speed (mph)

Source: Manual on Uniform Traffic Control Devices (MUTCD)

4.4 VERTICAL CLEARANCES

Also shown in Figure 4.3.1 above, the vertical clearance from overhead obstructions, such as trees or signs, should be a minimum of 8 feet. However, where it is desirable to provide access for maintenance and emergency vehicles, vertical clearance may need to be greater. For underpasses and tunnels, 10 feet is desirable for adequate vertical clearance.

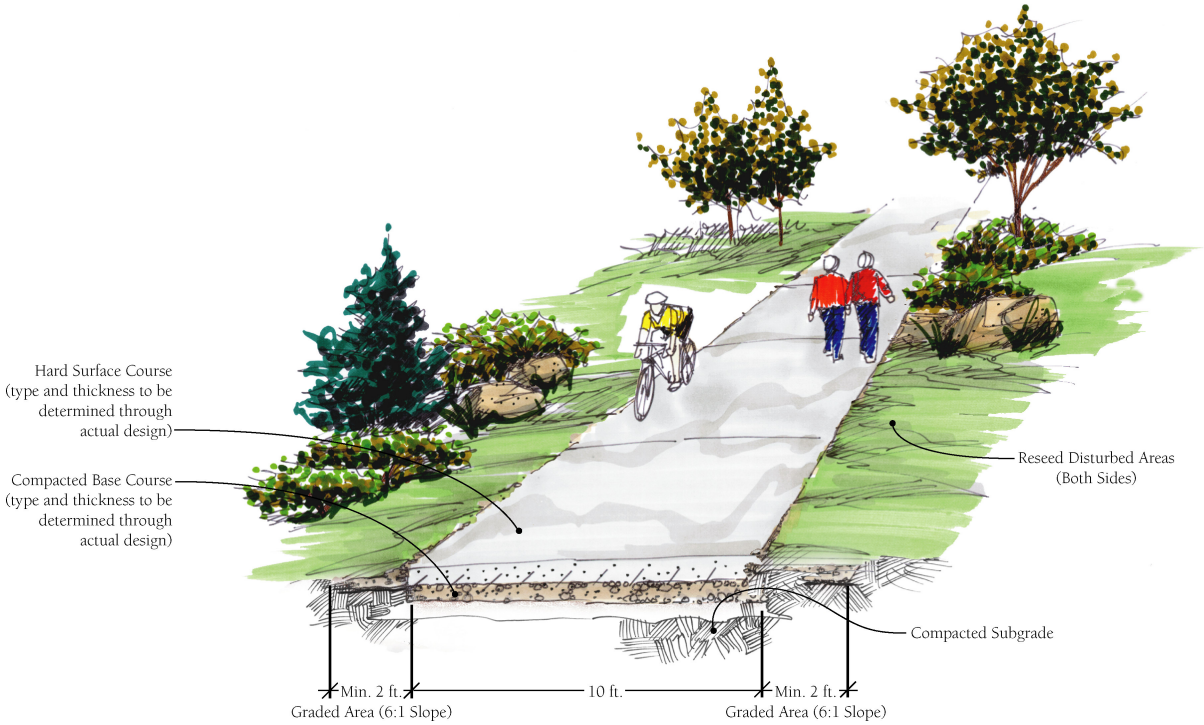
4.5 SURFACING

Paved surfaces are generally preferred over those of crushed aggregate or stabilized earth because they are accessible to more types of users and require less maintenance. A typical hard-surface trail cross-section is shown in Figure 4.5.1. Because of variations in soils, loads, materials, and construction practices, it is not practical to recommend specific pavement structural sections that will be universally applicable. Actual pavement and subbase thicknesses should be determined during the design process.

A parallel soft-surface path or wider graded area with a 2% cross slope on one or both sides of the trail can serve as a separate, softer surface for runners. The optimal width for this graded area is 3 to 4 feet to accommodate runners; although the minimum 3-foot horizontal clearance from lateral obstructions should be provided from the outside edge of this graded area. Where practical, the use of a planted strip should be considered to separate the two surfaces and prevent the surfacing material from being carried between the trail and adjacent path.

www.cityofseattle.net/parks/BurkeGilman/bgtrail.htm

Figure 4.5.1. Typical Hard-Surfacing Cross-Section



Good quality pavement structures can be constructed of asphalt or portland cement concrete. The following criteria should be considered when deciding which surface material would be more appropriate for a specific trail:

- Initial cost
- Life cycle cost (including maintenance)
- Source of funding
- Availability of maintenance funding
- Wheel-loads of maintenance and emergency vehicles
- Useful lifespan
- Site characteristics (water table, existing soil, etc.)
- Trail characteristics
- Subsoils and subgrade preparation
- Availability of material and labor
- Site clearance for construction machinery
- Access for disabled users
- Aesthetics
- Safety

Table 4.5.1 lists some general advantages and disadvantages of portland cement concrete and asphalt surfacing and the following sections provide specific design recommendations for each.

Table 4.5.1. Hard-Surfacing Options – Advantages and Disadvantages

Surface Material	Advantages	Disadvantages
Portland Cement Concrete	▪ Durable and long-lasting (30-50 years) ▪ Resists freeze-thaw ▪ Can be graded and formed into curves more precisely than asphalt ▪ Low maintenance ▪ Edges hold up over time ▪ Will withstand periodic small flooding ▪ Spot repairs can be made flush to the surface	▪ High installation cost
Asphalt	▪ Runners prefer asphalt because it's a softer surface and easier on their joints ▪ Less expensive to install ▪ Will hold up well over time with a good quality subgrade ▪ The darker color melts snow faster ▪ In-house repair capability	▪ Shorter life expectancy (15-30 years) ▪ Freeze-thaw can crack surface ▪ Susceptible to root eruptions ▪ Edges can crumble over time reducing the pavement width

Portland Cement Concrete (PCC) Surfacing

The sustainability of a concrete trail is most directly related to the concrete mix and the way the concrete is handled. The mix must be precise; the concrete cannot be excessively handled in the forms; and it must be cured correctly or the surface will deteriorate. The use of reinforcing steel is necessary only when the trail is subject to frequent vehicular traffic (such as driveway crossings), on concrete-surfaced bridges, and over exceptionally poor or wet subgrades. When reinforcing steel is used, it should be 6 x 6 x 10 gauge wire mesh unless otherwise specified.

On PCC surfaces, the transverse joints, necessary to control cracking, should be saw cut to provide a smooth ride. Expansion joints should be placed in the trail at intervals of no more than 500 feet and contraction joints should be placed at 10-foot intervals and should be constructed to a depth equal to ¼ the slab thickness. Contraction joints should be saw cut 1/8 inch wide as soon as concrete has hardened sufficiently to permit sawing without excessive raveling. Transverse joints shall be constructed by sawing to a minimum depth of ¼ of the slab thickness and a maximum width of 3/8 inch.

Although it is important to provide a smooth riding surface, skid resistance qualities should not be sacrificed. A transverse light broom finish is preferred. In addition to the above guidelines, the trail must meet all applicable Montana Public Works (MPW) specifications as modified by the City of Billings for placement of PCC pavement.

Asphalt Surfacing

The best condition for sustainable asphalt paths is to have a dry subgrade of well-draining soils topped by a well-draining base course free of clays and other materials that expand when wet. Mixing a small amount of lime into the base course further increases base course stability. Both the subgrade and base course should be compacted to a percentage of maximum density obtained at optimum moisture as specified during the design process. As with concrete surfacing, placement of asphalt surfacing should meet all applicable MPW specifications as modified by the City of Billings.

An ideal location for an asphalt trail would be on a dry rocky south-facing slope with a subgrade of bedrock and clean sharp sands with no clay or plastic materials. An inappropriate location would be on a clay-silt subgrade in an area with a high water table and a lot of trees with aggressive root systems (i.e., willow, cottonwood, or aspen). In addition, if sprinklers regularly irrigate the area surrounding the trail, summertime heaving from water vapor and temperature differentials in the base course could eventually damage the surface.

If the existing soil does not provide a well-draining subgrade, it will need to be excavated and replaced with a layer of river run (pit run) topped with a suitable base course. The cost of the subgrade replacement may raise the total initial cost of the asphalt to a level comparable to that of concrete. Even asphalt on the best foundation requires much more frequent and extensive maintenance. Unlike asphalt roads, the surface of an asphalt trail has a tendency to dry out because it doesn't have the heavy live loads to circulate the oils inside the asphalt mat. Therefore, asphalt trails need to be sealed more often than asphalt roads.

4.6 DESIGN SPEEDS

Hard-surface multi-use trails should be designed for a speed that is at least as high as the preferred speed of the fastest mode, in this case assumed to be the bicycle. The speed a bicyclist travels is dependent on several factors, including the physical condition of the bicyclist, type and condition of the bicycle, condition and grade of the trail, and the number of other users on the trail. In general, a minimum design speed of 20 mph should be used. Although bicyclists can travel faster than this, it is typically inappropriate to do so in a mixed-use setting. Traffic control devices can be used to deter excessive speeds or faster bicyclists can be encouraged to use the roadway system instead of the trail. The prevention of excessive speeds should not be attempted by arbitrarily selecting lower design speeds. For downgrades greater than 4 percent, a design speed of 30 mph is recommended.

4.7 HORIZONTAL ALIGNMENT AND SUPERELEVATION

Due to the generation of centrifugal force, a bicyclist must lean while cornering to keep from falling outward. If a bicyclist is traveling too fast and has to lean too far, the pedal will strike the ground. Although pedal heights vary, the pedal will generally strike the ground when the lean angle reaches about 25 degrees. However, because most bicyclists are not comfortable at high lean angles, 15 to 20 degrees is generally considered the maximum lean angle. The following equation can be used to determine the minimum radius of curvature for any combination of design speed and lean angle:

$$R = \frac{0.067\ V^2}{\tan \theta}$$

Where:
R = Minimum radius of curvature (ft)
V = Design speed (mph)
θ = Lean angle from vertical (degrees)

Based on design speeds ranging from 12 to 30 mph and a maximum lean angle of 15 degrees, the minimum radius of curvature for a hard-surface multi-use trail can be selected from Table 4.7.1.

Table 4.7.1. Desirable Minimum Radii for Paved Trails Based on 15° Lean Angle

Design Speed, V (mph)	Minimum Radius, R (ft)
12	36
20	100
25	156
30	225

Source: AASHTO Guide for the Development of Bicycle Facilities

However, when the lean angle approaches 20 degrees, the superelevation rate and the coefficient of friction must also be considered when calculating the minimum radius of curvature. The following formula should be used for this situation:

$$R = \frac{V^2}{15(e/100 + f)}$$

Where:
R = Minimum radius of curvature (ft)
V = Design speed (mph)
e = Rate of bikeway superelevation (%)
f = Coefficient of friction

The Americans with Disabilities Act (ADA) guidelines require a maximum cross slope of 2 percent to avoid the severe difficulties that greater cross slopes can create for people using wheelchairs. Thus, the maximum superelevation rate for hard-surface multi-use facilities should be 2 percent. When transitioning between two horizontal curves with 2 percent superelevation, a minimum 25-foot transition distance should be provided between the end of the first curve and the beginning of the next.

The coefficient of friction is dependent on speed, the condition of the tires, type and condition of the surface, and whether the surface is wet or dry. Extrapolating from values used in highway design, design friction factors for hard-surface multi-use trails can be assumed to vary from 0.31 at 12 mph to 0.21 at 30 mph.

Where a lean angle of 20 degrees can be tolerated, the minimum radii of curvature for a 2 percent superelevation rate and various design speeds of 12 to 30 mph can be taken from Table 4.7.2.

Table 4.7.2. Minimum Radii for Paved Trails Based on 2% Superelevation Rates and 20° Lean Angle

Design Speed, V (mph)	Friction Factor, f (paved surface)	Minimum Radius, R (ft)
12	0.31	30
20	0.28	90
25	0.25	155
30	0.21	260

Source: AASHTO Guide for the Development of Bicycle Facilities

When a lean angle of 20 degrees is used, it will be necessary to provide additional width because the bicyclist taking the curve will take up more horizontal space. In this case, it is also recommended that a centerline be placed down the middle of the trail.

When curve radii smaller than those shown in Table 4.7.2 must be used because of limited right-of-way, topographical features or other considerations, standard curve warning signs and supplemental pavement markings should be installed in accordance with the MUTCD.

4.8 GRADES

On multi-use trails, grades should be kept to a minimum, especially on long inclines. For paved surfaces, grades steeper than 5 percent should be avoided because they are difficult for many bicyclists and wheelchairs to climb, and descending them may cause some users to exceed the speeds at which they feel comfortable. On some trails, where terrain dictates, the recommended maximum grade of 5 percent may need to be exceeded. As a general guide, the grade restrictions and grade lengths shown in Table 4.8.1 are suggested.

Table 4.8.1. Grade Restrictions & Lengths

Grade	Length
5-6%	for up to 800 ft
7%	for up to 400 ft
8%	for up to 300 ft
9%	for up to 200 ft
10%	for up to 100 ft
11+%	for up to 50 ft

Source: AASHTO Guide for the Development of Bicycle Facilities

The following options should be considered when grades steeper than 5 percent cannot be avoided:

- Provide an additional 4 to 6 feet of width for slower speed bicyclists or those who choose to get off their bike and walk.
- Provide signing that alerts bicyclists to the maximum percent of grade and/or the recommended descent speed.
- Provide more than adequate stopping sight distances, horizontal clearances, and recovery areas.

4.9 SIGHT DISTANCE

A multi-use trail should be designed with adequate stopping sight distances to provide bicyclists with an opportunity to see and react to unexpected objects in their path. The distance required to bring a bicycle to a full stop is dependant on the bicyclist's perception and brake reaction time, the initial speed of the bicycle, the coefficient of friction between the tires and the pavement, and the braking ability of the bicycle.

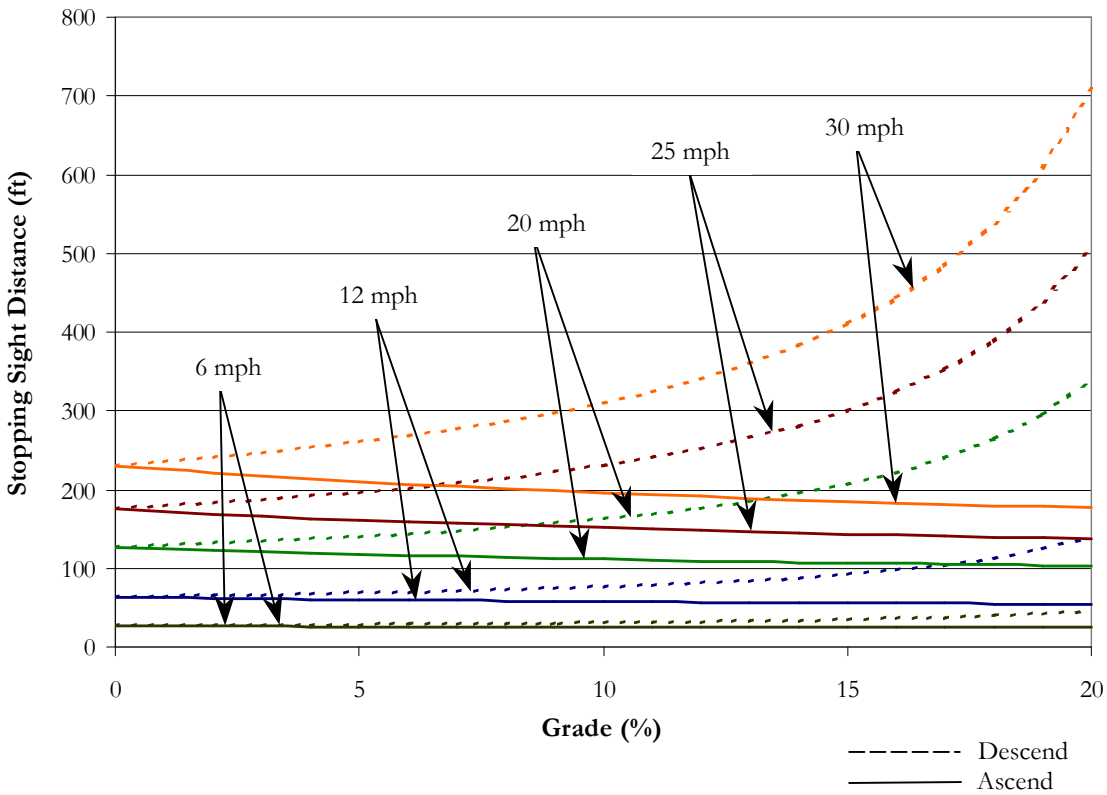
Figure 4.9.1 shows the minimum stopping sight distance for various grades and design speeds and is based on the following equation:

$$S = V^2/[\,30\,(f \pm G)] + 3.67V$$

Where S = Stopping Sight Distance (ft)
V = Velocity (mph)
f = Coefficient of Friction (Assume 0.25)
G = Grade (ft/ft) (rise/run)

This figure is based on a total reaction time of 2.5 seconds and a coefficient of friction of 0.25 for wet pavement. For multi-use trails, the sight distance for a descending bicyclist, that is where the grade is negative, will control the design.

Figure 4.9.1. Minimum Stopping Sight Distance vs. Grade for Various Design Speeds



Source: AASHTO Guide for the Development of Bicycle Facilities

Table 4.9.1 can be used to select the length of vertical curve necessary to provide the desired stopping sight distance on crest vertical curves and is based on the following equations:

When S>L, $L = 2S - 900/A$

When S<L, $L = AS^2/900$

Where L = Minimum Length of Vertical Curve (ft)
A = Algebraic Grade Difference (%)
S = Stopping Sight Distance (ft)

The eye height of a bicyclist is assumed to be 4.5 feet and the object height is assumed to be at pavement level. The shaded area represents the stopping sight distance being equal to the length of the crest vertical curve and the minimum length of vertical curve is 3 feet.

Table 4.9.1. Minimum Length of Crest Vertical Curve (L) Based on Stopping Sight Distance

A	S = Stopping Sight Distance (ft)														
(%)	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
2												30	70	110	150
3								20	60	100	140	180	220	260	300
4						15	55	95	135	175	215	256	300	348	400
5					20	60	100	140	180	222	269	320	376	436	500
6				10	50	90	130	171	216	267	323	384	451	523	600
7				31	71	111	152	199	252	311	376	448	526	610	700
8			8	48	88	128	174	228	288	356	430	512	601	697	800
9			20	60	100	144	196	256	324	400	484	576	676	784	900
10			30	70	111	160	218	284	360	444	538	640	751	871	1000
11			38	78	122	176	240	313	396	489	592	704	826	958	1100
12		5	45	85	133	192	261	341	432	533	645	768	901	1045	1200
13		11	51	92	144	208	283	370	468	578	699	832	976	1132	1300
14		16	56	100	156	224	305	398	504	622	753	896	1052	1220	1400
15		20	60	107	167	240	327	427	540	667	807	960	1127	1307	1500
16		24	64	114	178	256	348	455	576	711	860	1024	1202	1394	1600
17		27	68	121	189	272	370	484	612	756	914	1088	1277	1481	1700
18		30	72	128	200	288	392	512	648	800	968	1152	1352	1568	1800
19		33	76	135	211	304	414	540	684	844	1022	1216	1427	1655	1900
20		35	80	142	222	320	436	569	720	889	1076	1280	1502	1742	2000
21		37	84	149	233	336	457	597	756	933	1129	1344	1577	1829	2100
22		39	88	156	244	352	479	626	792	978	1183	1408	1652	1916	2200
23		41	92	164	256	368	501	654	828	1022	1237	1472	1728	2004	2300
24	3	43	96	171	267	384	523	683	864	1067	1291	1536	1803	2091	2400
25	4	44	100	177	278	400	544	711	900	1111	1344	1600	1878	2178	2500

Source: AASHTO Guide for the Development of Bicycle Facilities

Table 4.9.2 shows the recommended lateral clearance that should be used on horizontal curves to avoid line of sight obstructions, based on the following equation:

$$M = R[1 - \cos(28.65S/R)]$$

Where S = Stopping Sight Distance (ft)
R = Radius of Centerline of Lane (ft)
M = Distance from Centerline of Lane to Obstruction (ft)

The formula only applies when the stopping sight distance is equal to or less than the length of curve. The line of sight is assumed to be 2.3 feet above the centerline of the inside lane at the point of obstruction.

Table 4.9.2. Minimum Lateral Clearance (M) for Horizontal Curves

R	S = Stopping Sight Distance (ft)														
(ft)	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
25	2.0	7.6	15.9												
50	1.0	3.9	8.7	15.2	23.0	31.9	41.5								
75	0.7	2.7	5.9	10.4	16.1	22.8	30.4	38.8	47.8	57.4	67.2				
95	0.5	2.1	4.7	8.3	12.9	18.3	24.7	31.8	39.5	48.0	56.9	66.3	75.9	85.8	
125	0.4	1.6	3.6	6.3	9.9	14.1	19.1	24.7	31.0	37.9	45.4	53.3	61.7	70.6	79.7
155	0.3	1.3	2.9	5.1	8.0	11.5	15.5	20.2	25.4	31.2	37.4	44.2	51.4	59.1	67.1
175	0.3	1.1	2.6	4.6	7.1	10.2	13.8	18.0	22.6	27.8	33.5	39.6	46.1	53.1	60.5
200	0.3	1.0	2.2	4.0	6.2	8.9	12.1	15.8	19.9	24.5	29.5	34.9	40.8	47.0	53.7
225	0.2	0.9	2.0	3.5	5.5	8.0	10.8	14.1	17.8	21.9	26.4	31.3	36.5	42.2	48.2
250	0.2	0.8	1.8	3.2	5.0	7.2	9.7	12.7	16.0	19.7	23.8	28.3	33.1	38.2	43.7
275	0.2	0.7	1.6	2.9	4.5	6.5	8.9	11.6	14.6	18.0	21.7	25.8	30.2	34.9	39.9
300	0.2	0.7	1.5	2.7	4.2	6.0	8.1	10.6	13.4	16.5	19.9	23.7	27.7	32.1	36.7
350	0.1	0.6	1.3	2.3	3.6	5.1	7.0	9.1	11.5	14.2	17.1	20.4	23.9	27.6	31.7
390	0.1	0.5	1.2	2.1	3.2	4.6	6.3	8.2	10.3	12.8	15.4	18.3	21.5	24.9	28.5
500	0.1	0.4	0.9	1.6	2.5	3.6	4.9	6.4	8.1	10.0	12.1	14.3	16.8	19.5	22.3
565		0.4	0.8	1.4	2.2	3.2	4.3	5.7	7.2	8.8	10.7	12.7	14.9	17.3	19.8
600		0.3	0.8	1.3	2.1	3.0	4.1	5.3	6.7	8.3	10.1	12.0	14.0	16.3	18.7
700		0.3	0.6	1.1	1.8	2.6	3.5	4.6	5.8	7.1	8.6	10.3	12.0	14.0	16.0
800		0.3	0.6	1.0	1.6	2.2	3.1	4.0	5.1	6.2	7.6	9.0	10.5	12.2	14.0
900		0.2	0.5	0.9	1.4	2.0	2.7	3.6	4.5	5.6	6.7	8.0	9.4	10.9	12.5
1000		0.2	0.5	0.8	1.3	1.8	2.4	3.2	4.0	5.0	6.0	7.2	8.4	9.8	11.2

Source: AASHTO Guide for the Development of Bicycle Facilities

4.10 DRAINAGE

For hard-surface multi-use trails, the recommended minimum cross slope is 2 percent, which would adequately provide for drainage. Sloping in one direction is preferred over crowning, which will simplify drainage, as well as surface construction. A smooth pavement surface is crucial to prevent water ponding and ice formation.

When a trail is constructed along the side of a hill, a ditch or swale should be placed on the uphill side to intercept the hillside drainage. An additional option would be to provide catch basins with drains that would carry the intercepted water under the path. All drainage grates should be kept out of the travel path of trail users. Culverts and piping should extend to the outside of the 3-foot recommended clearance interval on either side of a trail. To assist in preventing erosion in the area adjacent to the trail, the design should include considerations for preserving the natural ground cover. Seeding, mulching and sodding of adjacent slopes, swales and other erodible areas should be included in the project plans.

If a trail is located within a waterway drainage area, it should be designed and constructed to handle a minimum 2-year design flood frequency without over-topping. However, a 5-year design flood or above is preferred. Bridges should be designed to allow the passage of the

10-year flood, with the 5-year flood as the absolute minimum, or in accordance to local flood regulations.

4.11 LIGHTING

Fixed-source lighting allows trail users to see the path direction, surface conditions and obstacles. Lighting should be considered where night usage is expected, such as paths serving college students or commuters, at highway intersections, and when nighttime security could be an issue. Lighting should also be considered through underpasses or tunnels.

Depending on the location, various levels of illumination are recommended as shown in Table 4.11.1. Where special security problems exist, higher illumination levels may be considered. Light poles should meet or exceed the recommended horizontal and vertical clearances. Luminaires and poles should be at a scale appropriate for pedestrians. Table 4.11.1 shows recommended lighting levels for various facilities.

Table 4.11.1. Recommended Lighting Levels

Location	Footcandles (fc)
Sidewalks/Trails along roadways:	
Commercial Areas	0.9
Intermediate Areas	0.6
Residential Areas	0.2
Sidewalks/Trails Distant from Roadways	0.5
Tunnels/Underpasses	0.4

Source: FHWA Course on Bicycle and Pedestrian Transportation

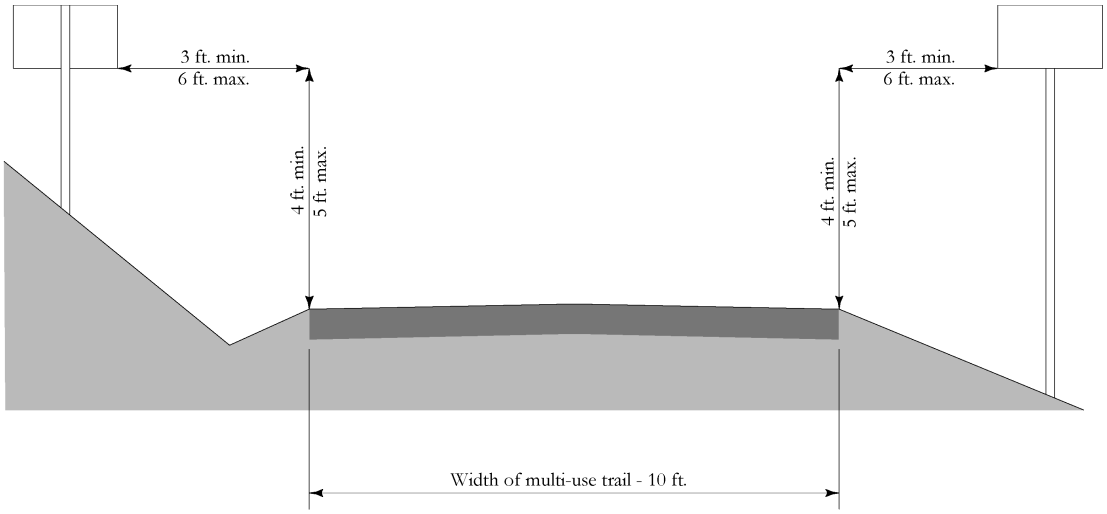
4.12 SIGNING AND MARKING

Adequate signing and marking are essential on trails and at trail-roadway intersections. This section provides general recommendations for the signing and marking of trail segments, while recommendations for trail-roadway intersections are included in Section 6.5. Additional guidance on signing and marking is provided in the MUTCD.

Signing and markings can be used to alert bicyclists and pedestrians to potential conflicts. Three types of signs should be used on multi-purpose trails: regulatory, warning, and guidance. Regulatory signs give operational requirements and are used for traffic control, such as stop signs, yield signs, and speed limit signs. Warning signs, typically used near intersections, point out existing or potentially hazardous conditions on or near the trail and warn users to reduce speeds. Warning signs should also be used in areas where recommended criteria cannot be met due to physical constraints. Guide signs provide trailside information including: directions, destinations, distances, route numbers and names of crossing streets. Signing can also be helpful to encourage users to share the trail and follow trail user etiquette such as giving audible signals before passing on the left.

Reduced versions (18" x 18") of typical highway signs should be used for trails and should be placed in a clear area so they are not obscured by vegetation and do not create a hazard. Post-mounted signs should be 4 to 5 feet tall and should be placed 3 to 6 feet from the edge of the trail surface, depending on the width of the unpaved shoulder. Figure 4.12.1 shows recommended sign placement from the MUTCD.

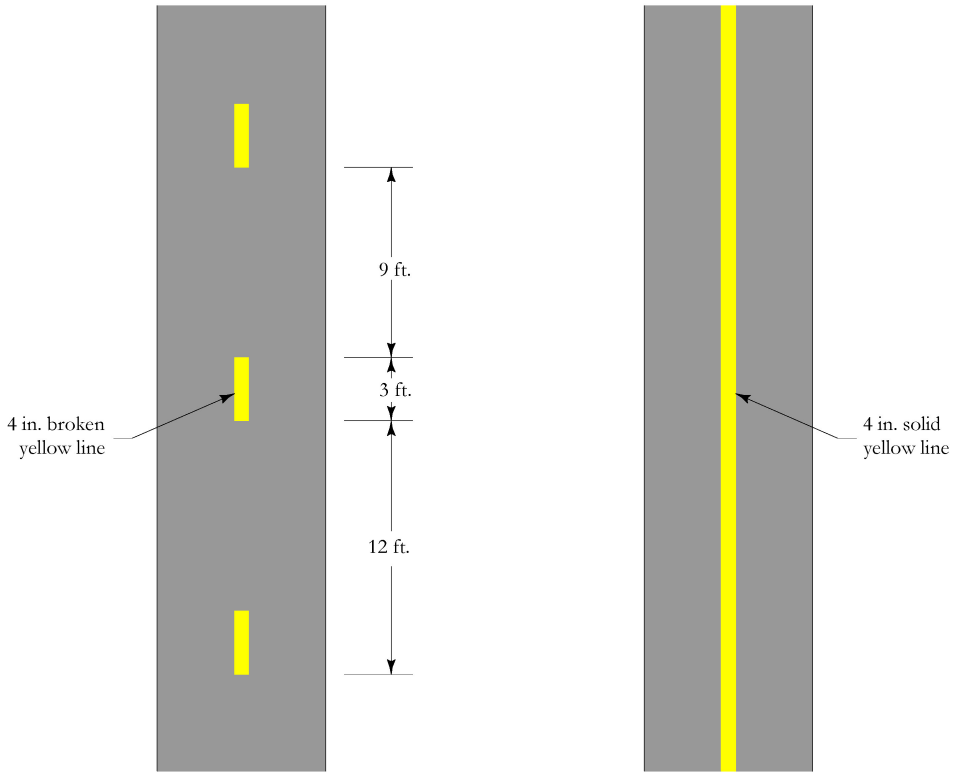
Figure 4.12.1. Sign Placement on Multi-Use Trails



Source: Manual on Uniform Traffic Control Devices (MUTCD)

In most cases, centerlines are not required on shared-use facilities. However, they should be considered for trails with high user volumes, on curves with restricted sight distance, on unlighted trails where nighttime riding is expected and at intersection approaches. As shown in Figure 4.12.2, a solid 4-inch wide yellow centerline stripe can be used to separate opposite directions of travel where passing is not permitted, and a broken yellow line may be used where passing is permitted. Broken yellow lines used on trails should have the standard 1-to-3 segment-to-gap ratio (3-foot segment, 9-foot gap).

Figure 4.12.2. Centerline Markings for Multi-Use Trails



Passing Permitted **Passing Prohibited**

Source: Manual on Uniform Traffic Control Devices (MUTCD)

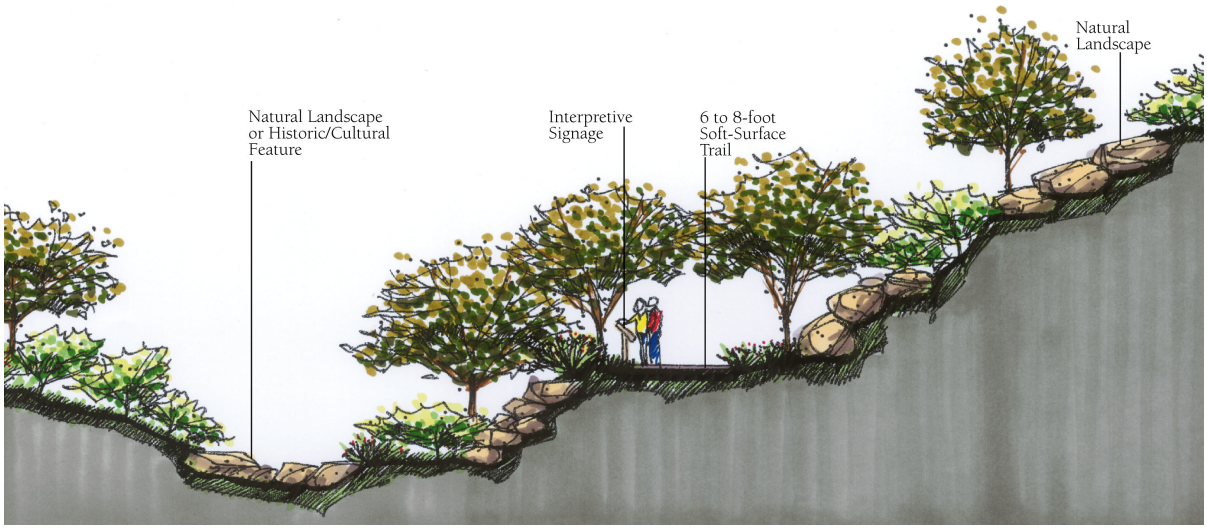
5.0 SOFT-SURFACE TRAILS

Soft-surface trails include Park Trails (Nature Trails), All-Terrain Bike Trails, Cross-Country Ski Trails, and Equestrian Trails as designated in the *Heritage Trail Plan.*

5.1 CROSS SECTIONS

Soft-surface trails will be constructed in varying widths, typically 6 to 8 feet. A typical soft-surface park trail cross-section is shown in Figure 5.1.1.

Figure 5.1.1. Typical Soft-Surface Park Trail Cross-Section



5.2 GENERAL DESIGN CONSIDERATIONS

It is usually not desirable to mix equestrian and bicycle traffic on the same shared use trail. Bicyclists are often not aware of the need for slower speeds and additional operating space near horses. Horses can be startled easily and may be unpredictable if they perceive approaching bicyclists as a danger. In addition, pavement requirements for bicycle travel are not suitable for horses. For these reasons, a bridle trail separate from the shared use trail is recommended to accommodate horses. However, it may also be desirable to develop trails specifically for horseback riding.

http://www.railtrails.org/benefits/recreation/horseback.asp

In some instances, cross-country ski trails provide an opportunity for horseback riding during the summer. During winter months, it is possible that there would not be sufficient bicycle traffic to justify plowing snow. In this case, managers of shared use trails may allow them to be used by cross-country skiers.

Cross-country skiing trails come in a variety of types and widths to accommodate two different styles: diagonal or traditional and skate-ski. Diagonal style requires a set track, while skate-ski style requires a wider packed and groomed surface. Since quality and safety are important to all skiers, a few well-groomed trails are preferable to extensive but poorly maintained ones. Trail design should coincide with the standards developed by regional park agencies and state resource agencies.

5.3 HORIZONTAL AND VERTICAL CLEARANCES

Standard horizontal clearance for soft-surface trails is 2 feet on either side of the trail. Vertical clearance should be 8 feet for pedestrian use only and 10 feet where bicyclists or equestrians are permitted. Cross-country skiing trails may require additional vertical clearance (up to 16 feet), depending on expected snowfall.

5.4 SURFACING

Soft-surface trails should be constructed with materials that provide stability and remain relatively firm when wet. Figure 5.4.1 shows a typical cross-section of a soft-surface trail and Table 5.4.1 provides a summary of the advantages and disadvantages associated with the different soft-surfacing options. Equestrian trails are usually grass or woodchip surfaced.

5.5 DESIGN SPEEDS

On unpaved paths, where bicyclists tend to ride more slowly, a lower design speed of 15 mph can be used.

5.6 HORIZONTAL ALIGNMENT AND SUPERELEVATION

Since bicycles have a higher tendency to skid on unpaved surfaces, horizontal curvature design should take into account lower coefficients of friction. Although there are no data available for unpaved surfaces, it is suggested that the friction factors for paved surfaces be reduced by 50 percent for soft-surfaces to allow a sufficient margin of safety. Curves with a radius of 50 feet or less should be avoided whenever possible except at switchbacks, intersections, and other slow zones. Warning signs should be used in situations where sharp curves are unavoidable because of right-of-way considerations or the need to retain certain trees or other vegetation.

Figure 5.4.1. Typical Soft-Surface Cross-Section

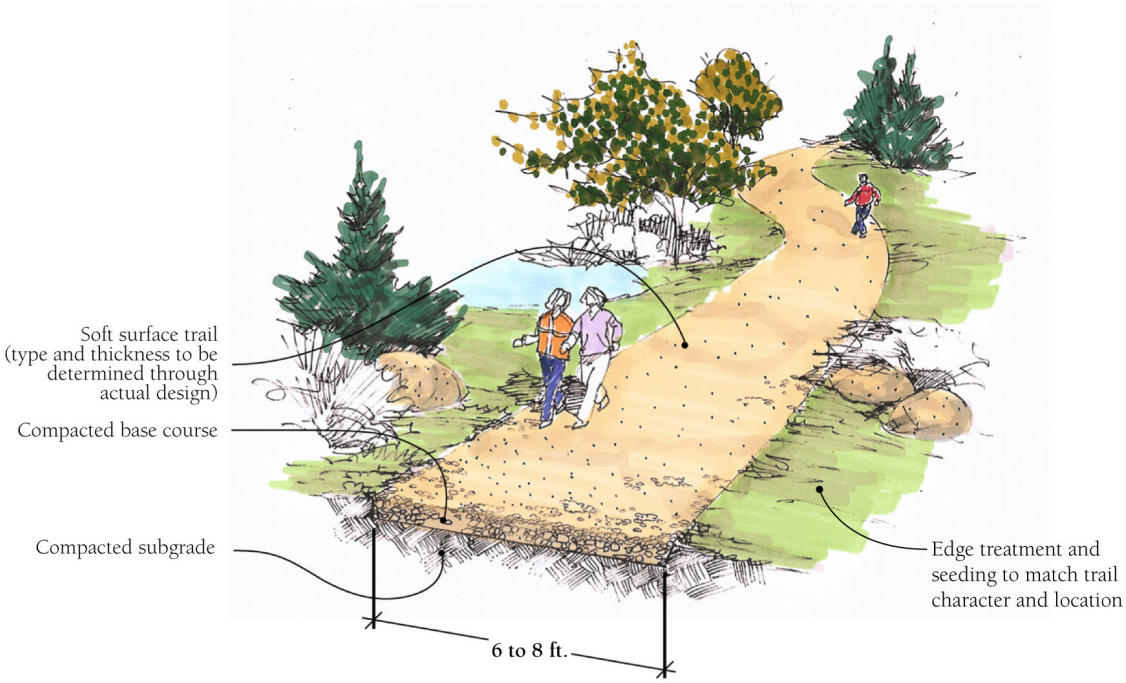


Table 5.4.1. Soft-Surfacing Options – Advantages and Disadvantages

Surface Material	Advantages	Disadvantages
Soil Cement	Uses natural materials, more durable than native soils, smoother surface, low cost	Surface wears unevenly, not a stable all-weather surface, erodes, difficult to achieve correct mix
Granular Stone	Soft but firm surface, natural material, moderate cost, smooth surface, accommodates multiple users	Surface can rut or erode with heavy rainfall, regular maintenance to keep consistent surface, replenishing stones may be a long-term expense, not for steep slopes
Native Soil	Natural material, lowest cost, low maintenance, can be altered for future improvements, easiest for volunteers to build and maintain	Dusty, ruts when wet, not an all-weather surface, can be uneven and bumpy, limited use, not accessible
Wood Chips	Soft, spongy surface – good for walking and horseback riding, moderate cost, natural material	Decomposes under high temperatures and moisture, requires constant replenishment, not typically accessible, limited availability
Recycled Materials	Good use of recyclable materials, surface can vary depending on materials	High purchase and installation cost, life expectancy unknown.

Source: Trails Design and Management Handbook, Pitkin County, CO

5.7 GRADES

A soft-surface multi-use trail designed to be accessible by users with disabilities should not be steeper than 3 percent. In addition, grades steeper than 3 percent may not be practical for soft-surface trails because of the possibility of erosion. Where terrain dictates and grades steeper than 3 percent cannot be avoided, it is recommended that concrete surfacing be considered for the sections with steep grades. Another option is to provide 5-foot level areas every 30 to 50 feet or pull-off rest areas.

For all-terrain bike trails, the trail grade should not exceed half of the grade of the hillside or sideslope that the trail is traversing. For example, when building across a hillside with a sideslope of 20 percent, the trail grade should not exceed 10 percent. There are limitations to this half rule because a trail cannot be indefinitely steep. There can be short, steep sections of trail, but the maximum grade should be limited to 15 percent. Trail grades can be steeper on solid rock, but earthen sections between rocks need to be stabilized to prevent soil erosion.

5.8 SIGHT DISTANCE

Some mountain bikers can travel almost as fast on natural surfaces as they do on hard surfaces. They should be given ample time to see ahead and slow down without skidding or losing control. Table 5.8.1 shows recommended sight distances for various speeds. In general, the design speed for soft-surface trails should be 15 mph. Therefore the sight distance should be within the range corresponding to 15 mph.

Table 5.8.1. Recommended Sight Distance for Soft-Surface Trails

Speed	Sight Distance
20 mph	130 to 200 feet
15 mph	85 to 130 feet
10 mph	35 to 60 feet

Source: Trails Design and Management Handbook, Pitkin County, CO

Whenever possible, curves should be avoided on grades because the combination of speed and limited sight distance may lead to accidents. If a trail must curve on a grade, a long sight distance should be provided. Where this cannot be achieved, trail signs should warn users of the curve ahead. A "Slow" sign may also be used for particularly blind curves.

5.9 DRAINAGE

On soft-surface multi-use trails, particular attention should be paid to drainage to avoid erosion. The key to successful trail drainage is to provide water with a lower place to flow than the trail itself. As previously discussed, the trail grade should not exceed half of the grade of the hillside or sideslope that the trail is traversing. If the grade does exceed half the

sideslope, it is considered a fall-line trail and water will flow down the trail rather than sheet across it.

As the trail contours across a hillside, soft-surface trails should slope away from the hillside. This cross slope, also called outslope, ensures that water will sheet across the trail. A well-built contour trail should also have grade reversals, which are subtle left or right turns that create rolls or undulations. These grade reversals will also help divert water off the trail. A contour trail on a steep slope may need grade reversals every 20 to 50 feet, depending on soil type and rainfall. Steeper grades should have more grade reversals that flatter grades.

6.0 TRAIL-ROADWAY INTERSECTIONS

Intersections between trails and roadways are often the most critical issue in shared-use trail design. Due to the potential conflicts at these intersections, careful design is of paramount importance to the safety of trail users and motorists. The recommendations provided in this section should be considered guidelines, not absolutes. Each intersection is unique and will require sound engineering judgment as to the appropriate design.

There are three basic categories of trail-roadway intersections: mid-block, adjacent, and complex. The following sections provide guidance for each category. Each of these intersection types may cross any number of roadway lanes, with or without a median, with varying traffic speeds and volumes, and may be controlled or uncontrolled. Grade separated crossings are also addressed in this section.

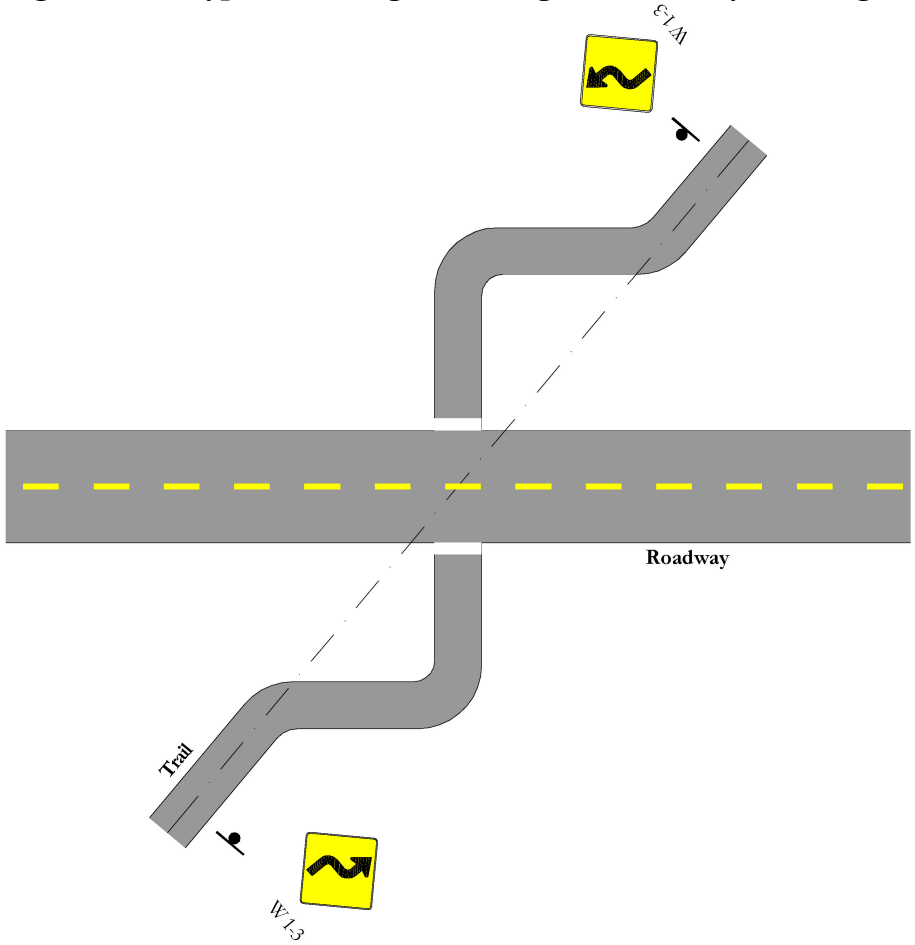
6.1 MID-BLOCK CROSSINGS

Due to safety concerns, mid-block crossings should be avoided whenever possible and bicycle and pedestrian traffic should be diverted to nearby intersections. Diverting trail users from a mid-block crossing to an intersection is difficult because many users will attempt the mid-block crossing even if it is more dangerous, simply because it is more convenient. Diverting the trail far enough back from the road in order to visually break the connection will ease the transition to the roadway intersection. Landscaping, fencing, or other visual or physical barriers may also be used.

If it is not feasible to divert trail users to a nearby intersection, crosswalk signalization or appropriate warning and stop signs for motorists and cyclists at the mid-block intersection are necessary. Mid-block crossings should be far enough away from existing roadway intersections to be clearly separate from the activity that occurs at these intersections. There are many other variables to consider when designing this type of intersection, including right-of-way assignment, sight distance for both trail users and motorists, the use of refuge islands (see Section 6.6), access control, and traffic control devices and pavement markings (see Section 6.5). The specific geometry of a mid-block crossing shall be approved by the City Engineer on a case-by-case basis.

Another important consideration for mid-block crossings is the treatment for a skewed intersection. Figure 6.1.1 depicts a path realignment to achieve a 90-degree crossing. A crossing of any angle less than 90 degrees shall be approved by the City Engineer on a case-by-case basis.

Figure 6.1.1. Typical Redesign of a Diagonal Roadway Crossing



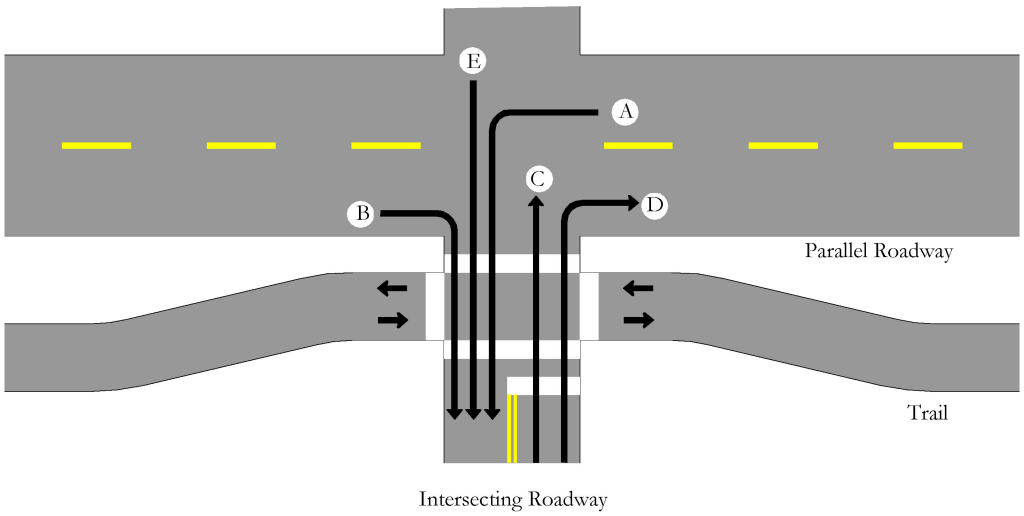
Source: AASHTO Guide for the Development of Bicycle Facilities

6.2 ADJACENT TRAIL CROSSINGS

Adjacent trail crossings occur when a trail crosses a roadway at an existing intersection between two roadways. The intersection between the two roadways can be either a T-intersection (including driveways) or a simple four-legged intersection, as shown in Figure 6.2.1. It is recommended that this type of crossing be installed near the roadway intersection to allow motorists and trail users to recognize each other as intersecting traffic. At this type of intersection, the trail user is faced with potential conflicts with motor vehicles turning left (A) and right (B) from the parallel roadway, and from the perpendicular roadway (C,D,E).

The major road may be either the parallel or the perpendicular roadway. Right-of-way assignment, traffic control devices, and separation distance between the roadway and trail are important factors that greatly affect the design of this type of intersection. The situation can be further complicated by the possibility of the conflicts being unexpected by trail users or motorists. Therefore, adequate sight distance across all corners is especially important.

Figure 6.2.1. Adjacent Trail Intersection



Source: AASHTO Guide for the Development of Bicycle Facilities

At crossings where the roadway intersection is signalized and the trail is controlled by a "walk/don't walk" signal in phase with the parallel roadway, conflict with turning vehicles are particularly unexpected. The trail user may be given a false sense of security by the "walk" signal while turning vehicles from the parallel roadway have a green signal at the same time.

Trail users with their backs to the turning vehicles are even more susceptible to unexpected conflict. As shown in Figure 6.2.1, trail users moving left to right are more vulnerable to vehicles turning right from the parallel roadway (Type B), and those moving right to left are more exposed to a Type A turning movement.

The conflict caused by a Type A turning movement may be mitigated by prohibiting permissive left turns on a high-volume parallel roadway and high-use trail crossings. Instead, a protected left turn can be provided with a "don't walk" signal for trail users. For turning movement Type B, curb radii should be minimized to reduce the speeds of turning motor vehicles. For Type C and D movements, conflicts can be avoided by prohibiting right-turns-on-red and placing a stop bar in advance of the trail crossing. To account for vehicle movement Type E, an all-red phase may be implemented to protect trail users.

To heighten awareness on the trail a yellow warning sign saying to "Watch for Turning Vehicles" can be used. On the intersecting roadway, bicycle and pedestrian advance crossing signs should be installed to warn approaching vehicles of potential conflicts. An option for warning vehicles on the parallel roadway is the use of a modified advance railroad crossing sign (W10-2 in MUTCD).

6.3 COMPLEX INTERSECTION CROSSINGS

Complex intersection crossings include all other intersections between a trail and roadway or driveway. They may include a variety of configurations, such as where a trail crosses directly through an intersection between two or more roadways where there may be any number of vehicle turning movements.

Improvements to complex intersection crossings shall be considered on a case-by-case basis. Some suggested treatments include: (1) move the crossing, (2) install a signal, (3) change signalization timing, or (4) provide a refuge island and make a two-step crossing for trail users. It is critical that each situation be treated as a unique challenge that requires creativity as well as sound engineering judgment. Throughout the design process, the primary goal should be the safe passage of all modes through the intersection.

6.4 SIGHT DISTANCE

Stopping sight distances at trail/roadway intersections should be consistent with the criteria presented in Section 4.9. Adequate warning signs should be placed in advance of the intersection to allow cyclists to stop before reaching the intersection, especially on downgrades.

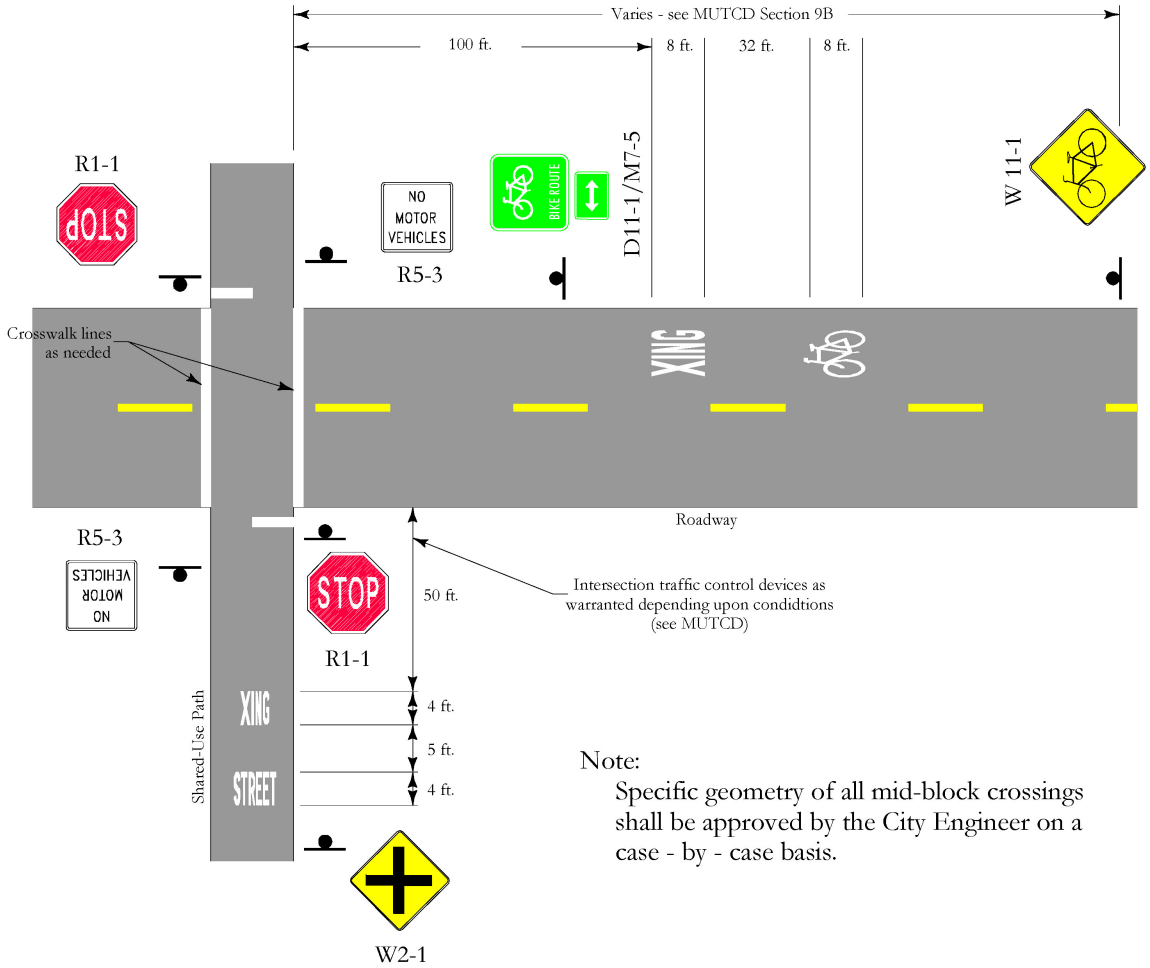
6.5 SIGNING AND MARKING

Pavement markings at a crossing should accomplish two things: channel trail users to cross at a clearly defined location and provide a clear message to motorists that this particular section of the road must be shared with other users.

For the trail user, stop signs, stop bar pavement markings, yield signs, caution signs or other devices should be used as applicable. Intersection warning signs should be located at least 400 feet before an intersection and sight distances leading to the intersection should be unobstructed.

For the roadway user, a clear message must be presented in a location where that user will see it. Traditional treatments have included a bicycle crossing sign (W11-1), the pedestrian crossing sign (W11-2), the pedestrian crosswalk lines (double 6-inch lines spaced at least 6 feet apart), or flashing yellow beacons at the crosswalk. Trail crossing signs should be placed at least 250 feet prior to the trail on urban streets and at least 750 feet on more rural streets with higher speeds. All signs and crosswalk markings should be installed in accordance with MUTCD. Figure 6.5.1 shows an example of mid-block crossing signing and striping. If the trail crosses a street with curb and gutter, a curb cut and ramp should be constructed to the same width of the trail.

Figure 6.5.1. Typical Signing and Striping for Mid-block Trail Crossing

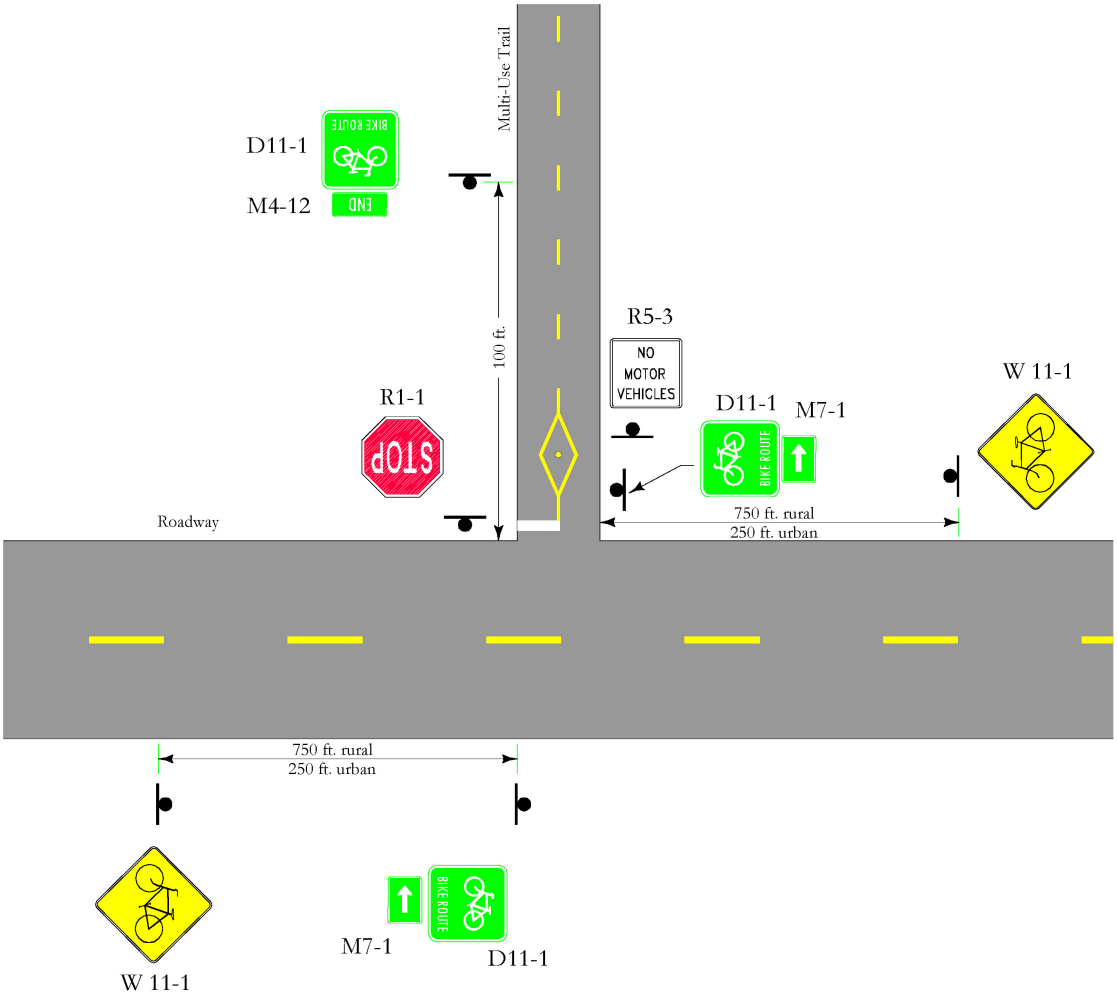


Source: Manual on Uniform Traffic Control Devices (MUTCD)

Figure 6.5.2 shows recommended signing and striping for a multi-use trail that terminates at an existing roadway. At trail ending intersections with roadways, trail users will be making the shift from the trail to the roadway system. In addition, many trail users will be using the roadway to access the trail. The design of the junction should accommodate their needs and provide for seamless transitions. Appropriate signing is necessary to warn and direct both bicyclists and motorists regarding these transition areas.

In recent years, new applications have been developed, which may be suitable for urban and suburban settings. For added visibility, the crosswalk area may be marked with white diagonal lines at a 45-degree angle to the typical crosswalk line or with white longitudinal lines parallel to the flow of traffic. The diagonal or longitudinal lines should be 12 to 24 inches wide and spaced 12 to 60 inches apart. Another new application is that of raised platform crosswalks, which can be useful to define roadway space for non-motorized users and stress the need for motorists to yield to that space. Mid-block neck-downs or intersection curb-bulbs at the crossing to reduce crossing distance are also becoming popular crosswalk treatments.

Figure 6.5.2. Typical Signing and Striping for Trail Ending Intersection with Roadway



Source: Manual on Uniform Traffic Control Devices (MUTCD)

6.6 REFUGE ISLANDS

Refuge islands should be considered for path-roadway intersections in which one or more of the following apply: (1) high volumes of roadway traffic and/or speeds create unacceptable conditions for trail users, (2) roadway width is excessive given the available crossing time, or (3) the crossing will be used by a number of people who cross more slowly, such as the elderly, schoolchildren, persons with disabilities, etc. Refuge islands make it possible for trail users to cross half of the street safely before crossing the remaining lanes.

Photo by Engineering, Inc.

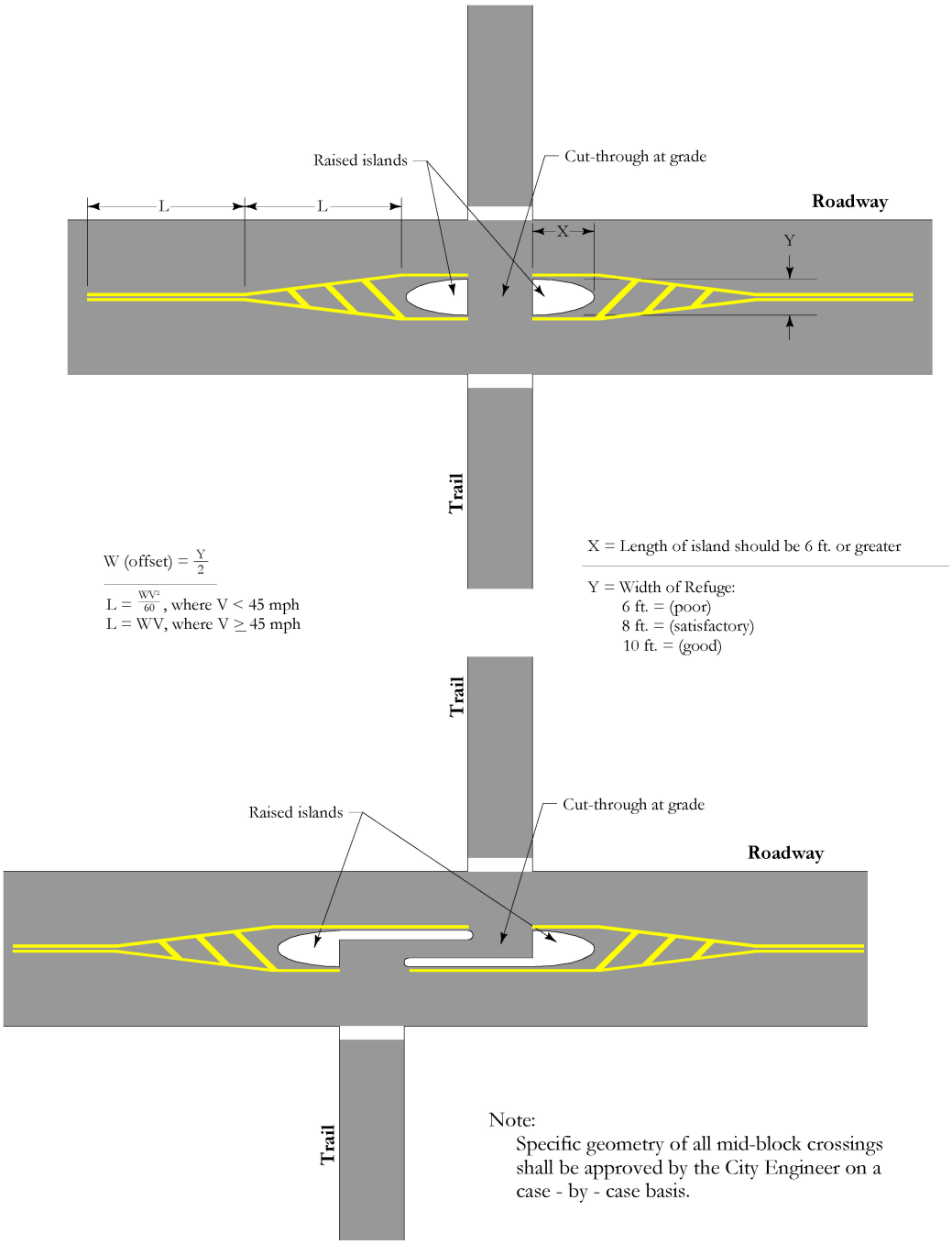
The refuge area should be large enough to accommodate platoons of users, including groups of pedestrians, groups of bicyclists, individual tandem bicycles (which are considerably longer that standard bicycles), wheelchairs, people with baby strollers and equestrians (if this is a permitted trail use). The area may be designed with the storage aligned across the island or longitudinally (see Figure 6.6.1). Adequate space should be provided so that those in the refuge area do not feel threatened by passing motor vehicles while waiting to finish the crossing.

6.7 GRADE-SEPARATED CROSSINGS

When a trail intersects with a street with high volumes or high speeds, a grade-separated crossing is an important design consideration. In general, wider streets are associated with higher volumes and higher speeds. The following guidelines have been developed for the City of Billings on the use of grade-separated crossing. However, all grade-separated crossing locations and designs shall be approved by the City Engineer.

The City of Billings suggests that grade-separated crossings be considered where bike and pedestrian facilities cross any major arterial or any other street with a speed limit of 45 mph or greater. Additional situations that may warrant grade-separated crossings include: a road crossing with four or more lanes of traffic; more than 100 trail users per hour; and crossings with poor sight distance for motorists or trail users.

Figure 6.6.1. Typical Refuge Area for Mid-block Crossings



Source: AASHTO Guide for the Development of Bicycle Facilities

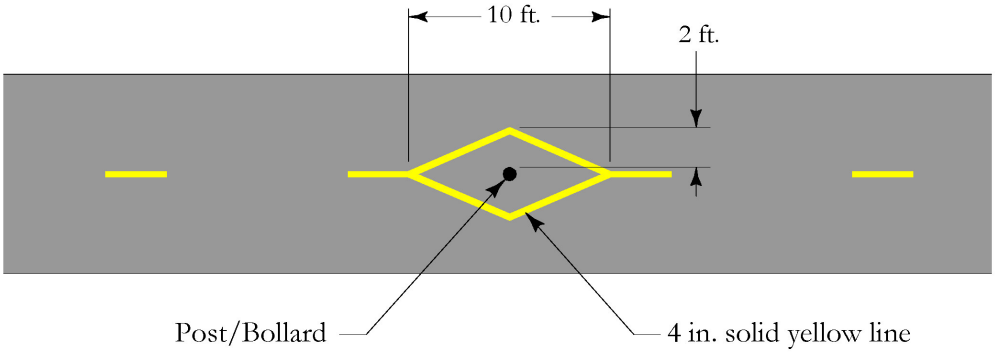
As part of the grade-separated design plan, a physical barrier should be considered to prohibit at-grade crossing of the roadway. Topography of the site should minimize changes in elevation for users of overpasses and underpasses and to help ensure that construction costs are not excessive. Elevation change is a factor that may inconvenience users and may even prevent them from using the facility. The needs of disabled users should also be

considered in the design of grade-separated crossings. See Section 9.0 for additional design recommendations for grade-separated crossing structures.

6.8 RESTRICTION OF MOTOR VEHICLE TRAFFIC

Shared use trails may need some form of physical barrier at highway intersections to prevent unauthorized motor vehicles from using the facilities. Provisions can be made for a lockable, removable (or reclining) barrier post to allow entrance by authorized vehicles. Past experience with lockable bollards has shown that locks have a tendency to freeze during winter months. Therefore, a reclining or swinging-type bollard would be more appropriate for Billings and surrounding areas. Posts or bollards should be at least 3 feet tall and should be set back beyond the clear zone on the crossing highway or be of a breakaway design. The post should be permanently reflectorized for nighttime visibility and painted a bright color for improved daytime visibility. Striping an envelope around the post is recommended as shown in Figure 6.8.1. When more than one post is used, an odd number of posts at 5-foot spacing is desirable. Wider spacing can allow entry to motor vehicles, while narrower spacing might prevent entry to some trail users such as bicyclists with trailers or wheelchair users.

Figure 6.8.1. Barrier Post Striping



Source: Manual on Uniform Traffic Control Devices (MUTCD)

An alternate method of restricting entry of motor vehicles is to split the entryway into two 5-foot sections separated by low landscaping. Emergency vehicles can still enter if necessary by straddling the landscaping. The higher maintenance costs associated with landscaping should be acknowledged before this alternative method is selected.

6.9 OTHER INTERSECTION DESIGN ISSUES

Regardless of the type of trail-roadway intersection, the following issues should also be considered during the design process:

Traffic Signals/Stop Signs

Whether it be stop signs or a traffic signal, some form of regulatory traffic control should be installed at all trail-roadway intersections. As with intersections between two roadways, MUTCD warrants and sound engineering judgment should be used when determining the type of traffic control device appropriate for the trail-roadway intersection.

Where trail stop signs are used, they should be placed as close to the intended stopping point as possible and should be supplemented with a stop bar. Four-way stops at trail-roadway intersections are not recommended because they may cause confusion about right-of-way rules. Yield signs may be acceptable at some locations, such as low-volume, low-speed neighborhood streets. Care should be taken to ensure that multi-use trail signs are placed in a location that will not confuse motorists, and that roadway signs are placed in a location that will not confuse trail users. Sign type, size and location shall be in accordance with the MUTCD.

Under certain circumstances, a traffic signal may also be appropriate control for a trail-roadway intersection. Although signal warrants for trail crossings are not addressed in the MUTCD, bicycle and pedestrian traffic may be functionally classified as vehicular traffic and the signal warrants for roadway intersections may be applied accordingly.

Another option is a manually operated signal, where trail users activate the signal through the use of a push button. These push buttons should be located in a position that is easily accessible from the trail and 4 feet above the ground, so that bicyclists will not have to dismount to activate the signal. Another method of activating the signal is to provide a detector loop in the trail pavement. However, since the loop detector will not respond to pedestrians, this must be supplemented with a push button. If a manually operated signal is used on a divided roadway, an additional push button should be located in the median to account for those trail users who may have been trapped in the refuge area.

Approach Treatments

All multi-use trail intersections and approaches should be on relatively flat grades. Stopping sight distance should be evaluated and necessary warning signs should be placed in advance of the intersection to allow bicyclists enough distance to stop, especially on downgrades. An approach to a soft-surface multi-use trail should include a paved apron that extends a minimum of 10 feet from the paved roadway surface.

Ramp Widths

Curb ramps at trail-roadway intersections should be at least the same width as the multi-use trail. Curb cuts and ramps should provide a smooth transition between the trail and the roadway. A 5-foot radius or flare may be considered to facilitate right-turn transitions for bicycles.

7.0 TRAFFIC SIGNALS

At signalized intersections where bicycle traffic is anticipated, it is important to consider the timing of the traffic signal, the method of detecting the presence of the bicyclists, and whether the signal heads are visible from a bicycle in the expected roadway position.

7.1 SIGNAL TIMING

In mixed traffic flow, bicyclists normally cross the intersection under the same signal phase as motor vehicles. The greatest risk to bicyclists at signalized intersections occurs during the clearance interval and during the actuated phases during periods with low traffic volumes. Signals should be designed to provide an adequate clearance interval for bicyclists who enter at the end of the green interval. They should also provide a total crossing time (minimum green plus clearance interval) long enough to accommodate bicyclists starting up on a new green interval.

The length of the yellow change interval typically depends on the speed of the approaching vehicles. Generally, a yellow interval that is adequate for motor vehicles (3 to 6 seconds) will also be adequate for bicyclists. The all-red interval can also be used to give a bicyclist additional time to clear the intersection. The all-red interval typically ranges from 1 to 2 seconds. The total clearance interval, yellow plus all-red, can be calculated from the following equation:

$$Y + AR \geq t_r + v/2b + (w + l)/v$$

Where Y = Yellow interval (sec)
AR = All-red interval (sec)
t_r = Reaction time (1.0 sec)
v = Bicyclist speed (mph)
b = Bicyclist braking deceleration (4 to 8 ft/s^2)
w = Width of crossing (ft)
l = Bicycle length (6 ft)

Bicycle speeds (v) should be based on field observations, if available. Otherwise, 98 percent of bicyclists should be able to clear an intersection with a signal timed for the following speeds:

- 12 mph (17.6 ft/sec) for Group A bicyclists
- 8 mph (12.0 ft/sec) for Group B bicyclists
- 6 mph (9.1 ft/sec) for Group C bicyclists.

Approximately 85 percent of bicyclists will be able to clear and intersection with a signal timed for speeds 20 percent higher than those listed above. When it isn't practical to use the

clearance interval calculated from the above equation, the longest all-red clearance interval consistent with City of Billings standards should be used.

When an approach receives a green signal, a bicyclist needs enough time to start up, accelerate, and clear the intersection. The minimum green time for bicyclists can be calculated using the following equation:

$$G + Y + AR \geq t_{cross} = t_r + v/2a + (w + l)/v$$

Where G = Minimum green (sec)
Y, AR = Yellow and all-red clearance intervals actually used
t_{cross} = Time to cross the intersection (sec)
t_r = Reaction time (2.5 sec)
v = Bicycle speed (ft/s)
a = Bicycle acceleration (1.5 to 3 ft/s^2)
w = Width of crossing (ft)
l = Bicycle length (6 ft)

As with all signalized intersections, field observations should be performed before making final adjustments to the calculated minimum green or clearance intervals.

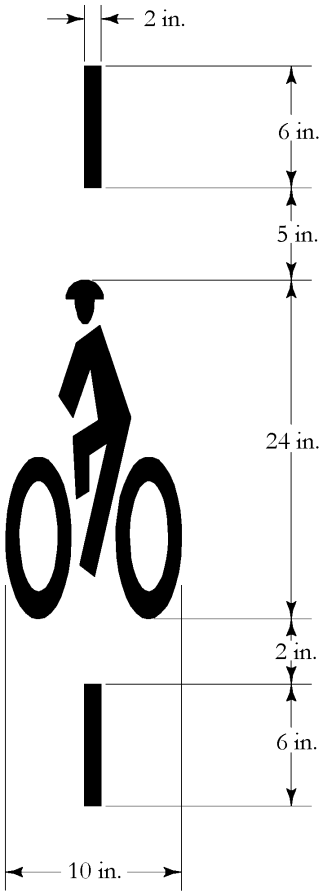
7.2 DETECTING THE PRESENCE OF BICYCLISTS

Numerous advances have been made in the detection of bicycles at actuated traffic signals. Quadrupole and diagonal-type loop detectors are examples of induction loops that provide bicycle detection. If the sensitivity of the detector is adjusted, dipole and rectangular loops can also detect the presence of bicycles. If existing detection devices are not capable of detecting bicyclists, the following options should be considered:

- Installing more bicycle-sensitive loop systems
- Marking current loops that detect bicycles
- Adjusting systems that do not detect bicycles
- Converting to new technology (i.e., infrared or video detection)

Bicycle detectors should be located in the bicyclist's expected path, including shoulders and bicycle lanes. It would also be helpful to the bicyclist if pavement markings were used to show the optimum location for detection. Figure 7.2.1 shows the standard pavement symbol used for this purpose.

Figure 7.2.1. Bicycle Detector Pavement Symbol



Source: AASHTO Guide for the Development of Bicycle Facilities

7.3 ADJUSTING SIGNAL HEADS FOR BICYCLISTS

Since bicyclists are expected to obey traffic signals, they should be able to see them from their recommended roadway position. Adjusting signal heads, especially those that are designed to have a finite field of view, involves having someone stand in a location where bicyclists may be expected to wait and attempt to read the signal indication. The appropriate locations will generally be within a bicycle lane or near the right-hand edge of the roadway. If signals cannot be aimed to serve the bicyclists, then separate signal heads shall be provided.

8.0 BICYCLES AT MODERN ROUNDABOUTS

Bicyclists are vulnerable users of roundabouts and consideration should be given for their accommodation. In general, bicyclists are accommodated in roundabouts either in mixed flow with vehicular traffic, or along separate bicycle or multi-use trail facilities. It is not recommended that bicycles be accommodated through the use of bicycle lanes along the outside diameter of roundabouts.

In low-speed (15 to 18 mph), single-lane roundabouts, few negative safety impacts have been observed when bicycles are mixed in the traffic stream. Because of the small speed differential, bicyclists can be expected to circulate in the traffic lane at approximately the same speed as vehicles. When bike lanes lead to this type of roundabout, it is preferable to discontinue them 35 to 65 feet before reaching the roundabout, rather than continuing the lane through the roundabout. As shown in Figure 8.1.1, "Bike Lane Ends" signs should accompany pavement markings.

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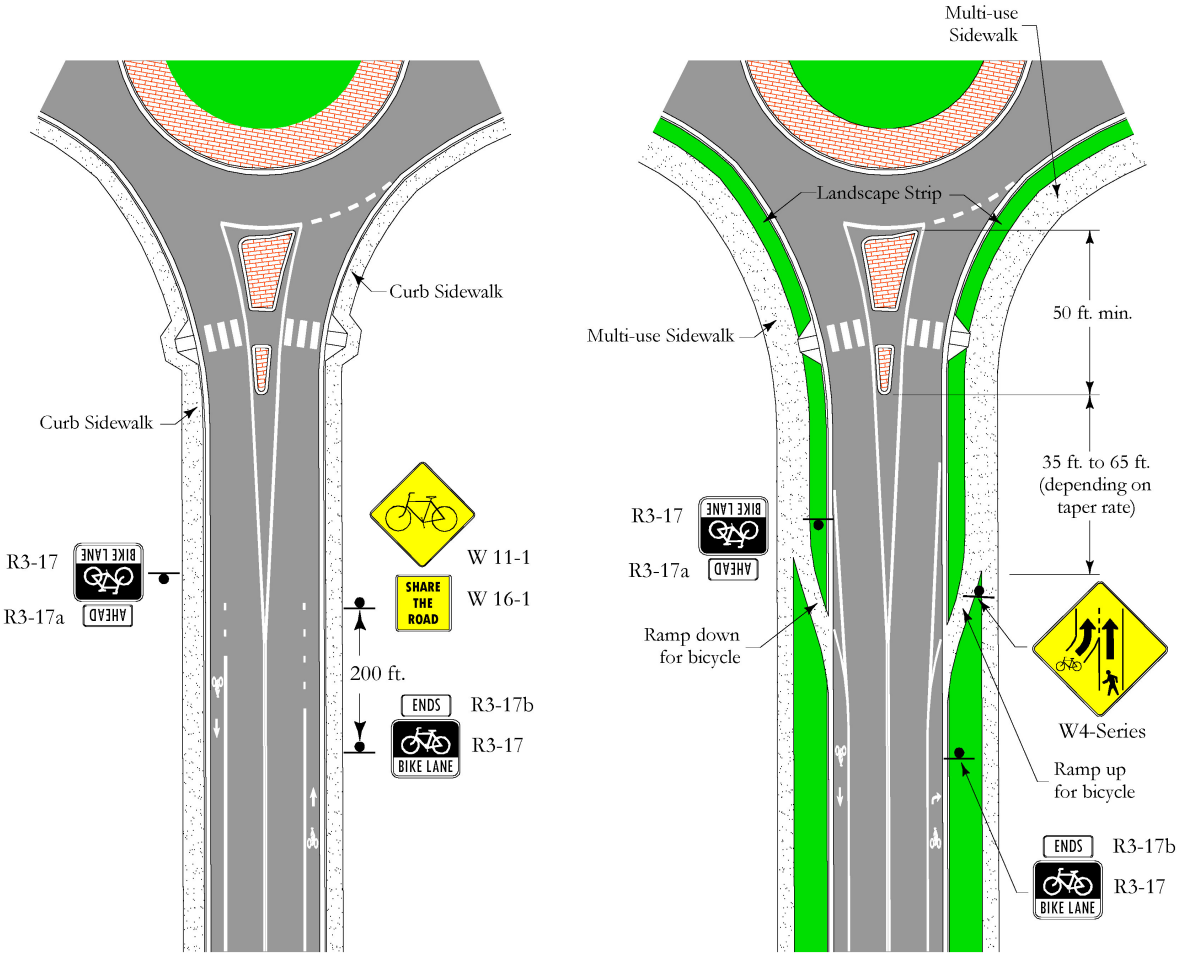
Bicycle safety tends to deteriorate at higher speed, multi-lane roundabouts. At these roundabouts, special solutions should be sought when warranted by bicycle volumes. Among the possible solutions is separate bikeways, shared use of pedestrian facilities, separate bike routing through other intersections, or grade separation for vulnerable modes. Two options for the accommodation of bicyclists in roundabouts are shown in Figure 8.1.1. However, all specific designs of bicycle treatments at roundabouts shall be approved by the City Engineer on a case-by-case basis.

The majority of bicycle crashes at roundabouts involve entering vehicles and circulating bicycles. This reinforces the need to reduce entering speeds by providing ample deflection, to maintain good visibility for entering traffic, and to enforce yield conditions for entering traffic. Like other vehicles, bicyclists must yield to vehicles already in the circulating roadway prior to entering the intersection. It is important for bicyclists to avoid getting into the position where they could be cut off by a right-turning vehicle.

Roundabouts also provide additional protection for pedestrian movements at the intersection. Crosswalks generally run through the "splitter islands," which are designed to deflect vehicle movements entering and exiting a roundabout. The "splitter island" essentially acts as a refuge island for crossing pedestrians, which means they only have to cross one lane of traffic at a time.

Figure 8.1.1. Bicycle Lane Treatment Options at Modern Roundabouts



9.0 STRUCTURES

9.1 BRIDGES

Although each bridge design is site specific, safety should always be the primary concern. As a general rule, bridges should be designed to carry at least the same live load that the rest of the trail has been designed to support (i.e., maintenance vehicle), as well as the dead load made up of all the bridge components. AASHTO's Standard Specifications for Highway Bridges provides additional information on bridge design. However, the designer should keep in mind that these guidelines were developed for highway bridges and can result in an "over designed" and costly multi-use trail bridge. Pre-fabricated bridges should also be considered as an option for multi-use trails.

On all new structures, the minimum width should be the same as the approach trail plus the recommended horizontal clear zone (minimum 3 feet on either side). Carrying the clear zone across the structure provides the minimum shy distance from the railing or barrier and it provides needed maneuvering space to avoid conflicts with other trail users. If significant pedestrian traffic is expected, or if users are likely to stop on the bridge to view the scenery, extra width should be considered. Access by emergency and maintenance vehicles should be considered in establishing the design clearances of bridges on multi-use trails. Bridges should be placed and bridge approaches should be designed so that there is no sharp curves or deflections. Users should not have to initiate turning movements while on or directly adjacent to a bridge.

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Railings along a bike trail structure should be a minimum of 54 inches (4.5 feet) above the bridge deck surface. A second horizontal rail at a height of 42 inches (3.5 feet) is required by AASHTO to serve as a bicycle handlebar rub rail. This rub rail should protect a wide range of handlebar heights and should be made of smooth metal or a similar material. This rail can also serve as a handrail for pedestrians. Finally, for aesthetic balance, a third horizontal rail can be provided at 15 to 18 inches above the bridge deck.

For safety reasons, vertical or diagonal members should typically accompany the horizontal railings. Additional horizontal railings can also be used. AASHTO requires that railing elements be spaced such that a 6-inch sphere will not pass through any opening below the rail located 42 inches above the bridge deck. An 8-inch sphere should not be able to pass through any opening between the top two required horizontal rails.

Railings along bridges that are expected to have pedestrian traffic only should be at least 42 inches (3.5 feet) high. Approach railings should extend 15 feet from each end of the bridge and should be flared away from the trail to prevent cyclists and pedestrians from catching on the railing.

9.2 TUNNELS AND UNDERPASSES

Like bridges, tunnels and underpasses are site specific and therefore difficult to address in general terms. Many multi-use trails will require a tunnel or underpass to provide a grade-separated crossing below a high volume roadway. Most tunnels are constructed with corrugated metal culverts or precast concrete culverts. Tunnels must be at least 10 feet in width and height, with a 14-foot width as the preferred alternative. Tunnels and underpasses should always be at least as wide as the approach trail surface.

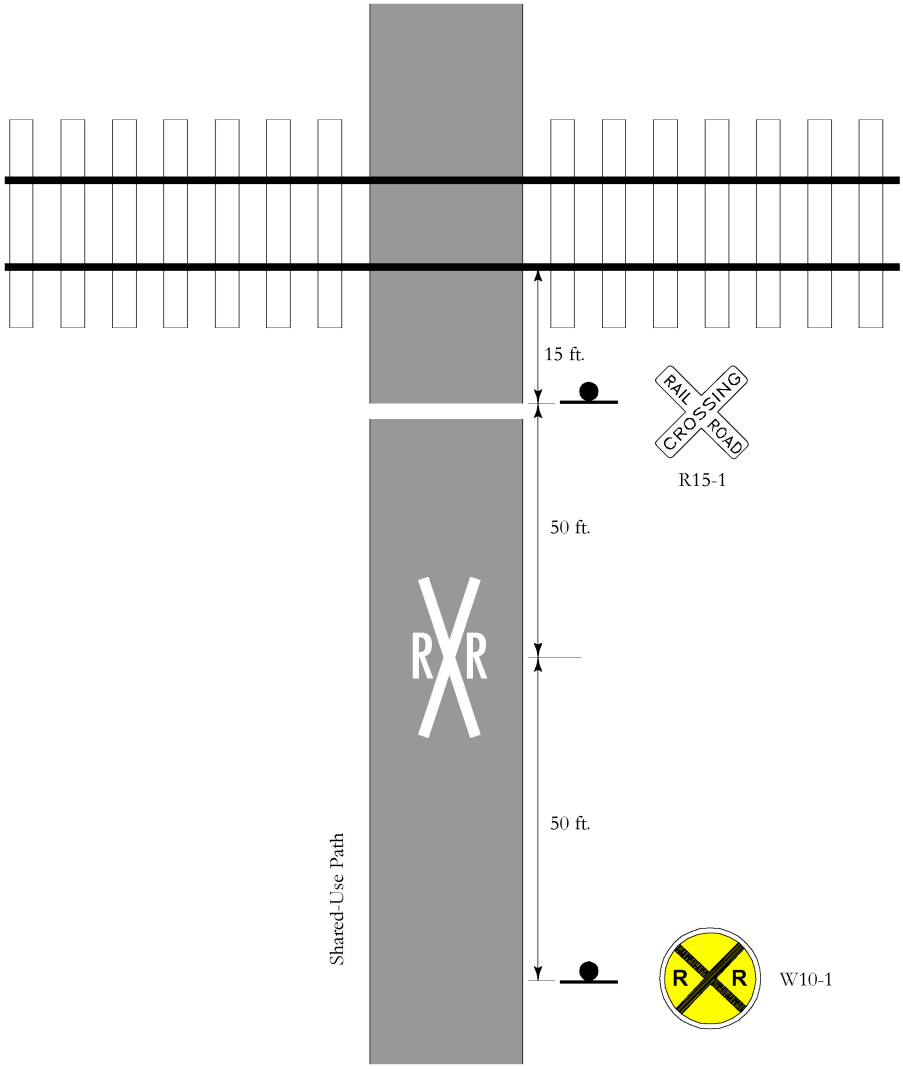
Photo by Engineering, Inc.

Underpass approaches should have excellent visibility; exiting bicyclists should be able to see approaching bicyclists, and vice versa. In addition, bicyclists entering one end should be able to see all the way through the underpass for personal security reasons. For safety and security reasons, lighting should be added to all dark tunnels in any urban or suburban location.

10.0 RAILROAD CROSSINGS

Streets and highways should ideally cross railroads at a right angle. On-street bikeways and multi-use trails should also cross railroads at a right angle. For on-street bikeways, this can be accomplished by providing a wider shoulder or a path separated from the roadway. The more a crossing angle deviates from 90 degrees, the greater the bicyclist's chance of having their front wheel caught in the flangeway, causing loss of control. Where less than 90-degree crossings cannot be avoided, and where train speeds are low, compressible flangeway fillers may be used. Consideration should be given to the crossing surface materials and to the flangeway depth and width. Rubber or concrete crossing materials would last longer and be easier to maintain than other materials such as asphalt or wood. Whenever possible, abandoned tracks should be removed. Warning signs and pavement markings should be installed in accordance with the MUTCD, as shown in Figure 10.1.1.

Figure 10.1.1. Typical Signing of Railroad Crossings



Source: Manual on Uniform Traffic Control Devices (MUTCD)

11.0 ACCESSIBILITY REQUIREMENTS

The Americans with Disabilities Act (ADA) of 1990 is a civil rights legislation that prohibits discrimination against people with disabilities. It guarantees the right to participate fully and equally in all aspects of life. Providing accessibility to transportation systems requires usable facilities for the highest number of users possible. There are approximately 50 million Americans with disabilities and 70 percent of all Americans will have a temporary or permanent disability at some point in their lives. People may have mobility, visual, or cognitive disabilities that affect how usable a facility may be for them.

ADA requirements are an important consideration in bicycle and pedestrian facility design. Well-designed, ADA compliant facilities are usually more functional for all users, with and without disabilities. However, it is understood that outdoor facilities may have certain limitations that may make it difficult to build fully accessible trails. These limitations include those that:

- Cause harm to significant cultural or historical characteristics or landmarks
- Alter the fundamental experience of the setting or intended purpose of the trail
- Require construction methods that are prohibited by federal, state, or local regulations
- Involve terrain characteristics (i.e., slopes, soils, geologic, or aquatic) that prevent compliance with the technical provision.

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Understanding how people with various disabilities function in the transportation system is an important factor in determining the best way to accommodate their needs.

Wheelchair Users

Many wheelchair users have a difficult time pushing uphill and maintaining control going downhill. Therefore, grades should not be steeper than 5 percent, with 3 percent preferred. When terrain dictates and grades steeper than 5 percent cannot be avoided, adequate signing should be placed at all trail access points to warn wheelchair users of steep grades. Where grades greater than 5 percent cannot be avoided, it is recommended that a five-foot level area or pull-off rest area be provided every 30 to 50 feet.

Steep cross slopes also cause problems when maneuvering a wheelchair. The greater the cross slope, the more difficult it is to avoid turning into the slope. Therefore, cross slopes should not be greater than 2 percent. Compound slopes can also cause maneuvering difficulties for wheelchair users and should therefore be avoided.

Amenities, such as phones and water fountains, need to be placed no higher than 4 feet from the ground level. The buttons on actuated signals should also be placed at a maximum height of 4 feet and should have large buttons that are easier to push for those with limited mobility of their hands or arms. The buttons also need to be placed within a wheelchair accessible travel path.

Visually Impaired

Curb ramps are typically thought of as an accommodation for wheelchair users or bicyclists, but they can also provide a transition warning between sidewalk or trail and street for the visually impaired. If the ramp grade is too low, a visually impaired person may have a difficult time detecting it. Therefore, it may be necessary to place detectable warnings and contrasting colors at the bottom of the ramp. All ramp designs should be in accordance with current City of Billings guidelines for contrasting colors and detectable warnings.

Cognitive Disabilities

Children under the age of 12 often do not think about the rules of the road, even though they have learned them. Their ability to perceive the roadway environment and make quick decisions may not be fully developed. Therefore, this issue must be considered during the design phase, especially if the facility is a school route. Adults with cognitive disabilities may also benefit from easy-to-interpret signs.

12.0 BICYCLE PARKING FACILITIES

Providing bicycle-parking facilities is an essential element in an overall effort to promote bicycling, because people have a tendency to be discouraged from bicycling when adequate parking is not available. Bicycle-parking facilities should be provided at all destinations and should offer protection from theft and damage. The wide variety of parking facilities can generally be grouped into two classes, short-term and long-term.

12.1 SHORT-TERM FACILITIES

Short-term facilities provide a means of locking the bicycle frame and wheels, but do not provide security for components or accessories. Unless they are covered, short-term facilities typically don't provide protection from the elements. Short-term facilities should be located where they are visible and convenient to building entrances. Short-term bicycle parking facilities should be:

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- Well distributed (i.e., it's likely better to have four or five racks spread out along one city block rather than a group of four or five racks mid-block)
- Visible to the cyclist
- Visible to passers-by to promote usage and enhance security

12.2 LONG-TERM FACILITIES

Long-term facilities provide a high degree of security and protection from the weather. They are intended for situations where bicycles are left unattended for long periods of time. They are appropriate for destinations such as apartment complexes, colleges and universities, places of employment and transit stops. These facilities are usually lockers, fenced in areas, or individual rooms within a building.

Bicycle lockers provide a higher level of security than bicycle racks. They are the preferred option where long-term security is more important than short-term convenience. Unlike racks, lockers provide protection for a bike's components, as well as the user's other belongings. Each locker unit is divided diagonally to allow separate storage for two bicycles.

www.cycle-safe.com/Photos.html

12.3 DESIGN AND PLACEMENT RECOMMENDATIONS

The following issues should be considered in the design and placement of bicycle parking facilities:

- Supports the frame of the bicycle and not just one wheel
- Allows the frame and one wheel to be locked to the rack when both wheels are left on the bike
- Allows the frame and both wheels to be locked to the rack if the front wheel is removed
- Accommodates all types of bike locks on the market, including the high-security U-shaped lock
- Is securely anchored
- Is usable by bikes without a kickstand
- Is usable by bikes with water bottle cages
- Is usable by a wide variety of sizes and types of bicycles
- Is easily accessible from the street, but well protected from motor vehicles.
- Has as few moving parts as possible and does not bend or damage any bicycle parts.
- Is made of square-channel tubing, which is more difficult to cut than round tubing.

Bicycle parking facilities should be able to accommodate a wide variety of bicycle shapes and sizes and they should be simple to operate. If necessary, signs depicting how to operate the facility should be posted.

The rack area should be located along a major building approach line and be clearly visible from the approach. The rack area should be no more than a 30-second walk (120 feet) from the entrance it serves and should preferably be within 50 feet. New commercial development should be required to provide convenient bicycle parking with the furthest bicycle parking rack no further away from the building entrance than the nearest car parking space.

13.0 PARKING LOT DESIGN

According to the *FHWA Course on Bicycle and Pedestrian Transportation*, parking lots with 50 or more spaces should be divided into separate areas with walkways in between that are at least 10 feet in width. These pedestrian paths should be designed with minimal direct contact with traffic. Parking areas should be kept away from the side of the building that would generate the most pedestrian access.

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