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SAFE ACCOMODATION OF BICYCLISTS ON HIGH-SPEED ROADWAYS IN MARYLAND

Final Report

by

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16. Abstract This study investigated bicycle infrastructure design options and treatments to facilitate safe accommodation of bicyclists on high-speed roadways. The bicycle safety research literature, design guidelines from federal, state, and international highway agencies, and interviews with experts and bicyclist groups were among the information sources used. A design called "rumble-buffered" bike lane was proposed and its application to example sites was described. The treatments presented in this report can help mitigate the inherent hazards to bicyclists associated with limited separation from motor vehicles where separated facilities are infeasible.			
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STUDY FINDINGS AND RECOMMENDATIONS

FINDINGS

This study investigated bicycle infrastructure design options and related treatments to facilitate safe accommodation of bicyclists on high-speed roadways in Maryland. High-speed roadways are defined here as having speed limits above 45 miles per hour (mph). The state-of-the-practice in the U.S. and best practices in designs and related treatments worldwide were explored. Both at-grade intersections and grade-separated interchanges, along with designs of dedicated and shared-use bike lanes adjacent to roadways and roadway shoulders, were studied. Inputs from government agencies, bicycle advocacy groups, researchers, and practitioners were reflected in the proposed design alternatives, developed with the aim of enhancing safe and efficient human interaction with the built environment.

Bicycle facilities (see Appendix 1.1 for definitions and illustrations) can be classified under one of six categories (Federal Highway Administration, 2015): (1) signed routes; (2) shared lane markings or "sharrows"; (3) on-street bike lanes; (4) on-street buffered bike lanes; (5) separated bike lanes, also referred to as cycle tracks or protected bike lanes; and (6) off-street trails or sidepaths. Study of the state-of-the-practice in the application of these design categories for high-speed roadways world-wide produced two key findings: (1) bicycles may not be permitted on high-speed roadways and (2) when permitted, a bicycle path separated from the motorized traffic is almost universally the recommended treatment. When bicycle traffic is permitted and separation is not a realistic option, some states recommend expanding the paved shoulder widths to 4 feet (5 feet where the speed limit exceeds 45 miles per hour).

Thirty states (see Appendix 2.2.1) in the U.S. have a statewide bicycle design guideline or a bicycle master plan. These guidelines and plans were reviewed and discussed with bicycle coordinators from various states. The design guidelines and discussions held with the bicycle coordinators revealed that bicyclists are permitted on Interstates and freeways in the following 16 states: Alaska, Arizona, California, Colorado, Idaho, Missouri, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. Most states allow bicycle traffic on other high-speed roadways unless specifically prohibited. In at least one design manual (Indiana) separated bike facilities are recommended for high-speed roadways. AASHTO (2012) provides general guidance on the design of shared-use bike paths adjacent to or within freeway right-of-way, as well as basic design principles for freeway interchanges. Considerations along the length of the path include wind blast effect from vehicular traffic and the need for separation, as well as shoulder-width requirements are discussed. The guidelines note the difficulties associated with cycling in the presence of two-lane ramps, flyovers, left-side ramps, and heavy traffic volumes. Design principles at these interchanges include: minimizing the occurrence of conflict areas, restraining speeds of motorized vehicles in conflict areas, increasing sight distances, and creating right-angle crossings. Grade-separated crossings at ramps are also recommended. Specific design considerations are presented for a single-point diamond interchange involving a signalized crossroad, free-flow merging and diverging ramp lanes.

Only 14 of the 50 states include special design considerations for bicycle safety on high-speed roadways in their design manuals. The Institute of Transportation Engineers (ITE) (Mitman & Rideway, 2014) also proposes numerous general design alternatives to accommodate bicyclists at interchanges. The ITE guide recommends geometric designs that slow traffic during turns and allow flexible weaving for bicyclists. For on-ramps, skip-striping and flexible merging lanes are recommended. For off-ramps, requiring vehicles to yield to bicyclists is recommended. However, free right-turn off-ramps can be safe for bicycles if the bicycle lane is perpendicular to the free-right turn lane and bicyclists are required to yield to turning traffic. Optional "sidewalk exit ramps" are suggested so that less confident or inexperienced bicyclists can enter the sidewalk before reaching the interchange and then cross as pedestrians.

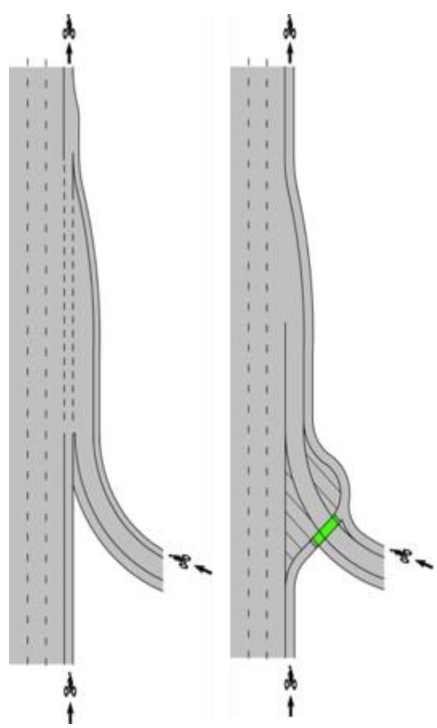
In addition to state and federal guidelines, there exists a considerable amount of literature on bicycle safety, but little pertains directly to high-speed roadways. Important insights, however, may be gained from reviewing it (see Appendix 2.1). First, several factors were identified as having signficant impact on bicycle safety, including the design and maintenance of the built environment, number of bicyclists, and details of treatment type, e.g. lane markings and colors. The majority of cyclist-motorist accidents occur at intersections where conflicts between bicyclists and motorists are most likely (Korve & Niemeier, 2002; Wachtel & Lewiston, 1994). Approaches, such as implementing cycle tracks that circumvent the use of intersections (by ending the cycle track before an intersection, locating cycle crossings within 3 meters from the parallel road, or grade separating crossings), and thus reduce or eliminate conflicts between bicycles and vehicles, are the focus of many studies (Thomas & DeRobertis, 2013). Results of statistical analyses reported in the literature indicate that buffered bike lanes provide distinct advantages compared to wider bike lanes (Fees & Engineer, 2015). Moreover, bicyclists tend to position themselves closer to parked vehicles or curb facilities as traffic and truck volumes increase. Rumble strips, often used on higher-speed roadways, can be a source of significant danger for bicyclists. It was noted in the literature (Moeur, 1999) that inclusion of 12 foot gaps at either 40- or 60-foot intervals in the rumble strips would be desirable for non-controlled access roadways.

Bicycle advocacy groups contacted in 16 states (see Appendix 3.1) as part of this study were unanimous in their concerns about cycling along roadways with speed limits above 45 mph. They agreed that the method used for separating bicyclists from motor-vehicle traffic, whether a buffer, physical barrier or separated path, is very important. Some groups recommended cycle tracks with complete separation. Others suggested separated trails or side paths. For highways with business assets, such separation would reduce access and thus could be less desirable. These groups shared additional practical concerns and made several suggestions. These include that: (1) actual speeds are as important as posted speed limits; (2) the 3-feet-passing law should be enforced; (3) clear signage is needed; (4) colored pavements in conflict areas can be helpful; and (5) designs should account for the way how bicyclists use the facilities, e.g. that an experienced bicyclist will merge into the inside lane and turn left under low traffic volumes, but will make a two-stage left turn under high traffic volumes. Appendix 4.5.1further discusses the use of color in pavement marking.

Bicycle accomodation is also a concern internationally, where the concensus is that bicyclists should be separated from motor vehicles by cycle tracks, for example, when the speed limit exceeds 50 mph (see Appendix 2.2.2). More generally, review of current literature and practice strongly suggests cycle tracks as the most appropriate design approach for bicycle facilities for high-speed roadways. The separation of cycle tracks from motorways can be either vertical or horizontal (see Appendix 5.1 for more details on separation options). Common vertical barriers include, for example, concrete barriers, bollards and flexible posts (FHWA, 2015). The selection of separation type(s) should be based on the presence of on-street parking, overall street and buffer width, cost, durability, aesthetics, traffic speeds, emergency vehicle and service access, and maintenance (FHWA, 2015). If sufficient right of way is available, horizontal separation such as raised medians between cycle track and motorway may be preferable. Appropriate separation width depends on the speed of adjacent roadway traffic. At 50 mph, a minimum median width of 4.5 meters (14.76 feet) is recommended (6 meters (19.68 feet) is preferred), while at 62 mph, 10 meters (32.81 feet) is preferred (CROW, 2007). Raised medians may present a maintenance and snow clearing challenge. An additional challenge of vertical separation is emergency access. Flexible posts, raised medians, and parking stops are advantageous for this purpose.

Five states suggested specific treatments to accommodate bicyclists through interchanges along high-speed facilities. The two general approaches, designed for grade-separated, free-flow conditions, are depicted in Figure 1. For merging ramps, these five states and AASHTO (2012) recommended a curved bike lane to guide bicyclists across the merging ramp lane at a right angle to vehicular traffic (Type 2), but did not specify implementation details. Issues, such as motor vehicle and bike volumes, speeds, stopping-sight distance and sight distance for bicyclists looking up the ramp, should be carefully considered. For diverging ramps, the Type 1 treatment, recommended by AASHTO, Colorado, and Vermont, may be appropriate if signage is added to encourage motorists to yield to bicyclists. The benefits and detriments of each treatment type are described in Table 1.

Figure 1a Two treatments for merging ramps (Left: Type 1, Right: Type 2)



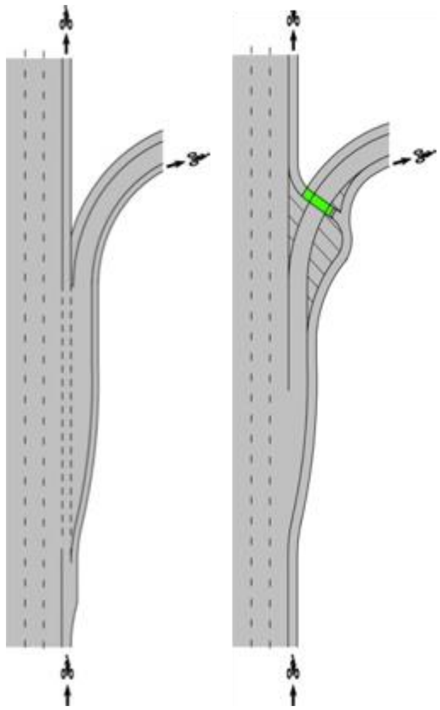


Figure 1b Two treatments for diverging ramps

(Left: Type 1, Right: Type 2)

Table 1. Benefits and detriments of treatments

	Pros	Cons
Merging Type 1	• Bicyclists have more flexibility to choose their own merging, weaving, and crossing maneuvers, flexibility that is favored by advanced bicyclists	• Acute angle reduces visibility • Accelerating motor vehicle may fail to yield to bicyclists • Large speed differential
Merging Type 2	• Short crossing distance for bicyclists, at close to a right angle • Improved sight distance and lower traffic speed as compared to further downstream • Drivers may be distracted from focusing on merging with other vehicles • Plowable, as most manuals show the triangular area between the ramp and the road to be paved	• Bicyclists must wait for the gap in merging traffic, causing them extra delay; • Bicyclists need to stop and accelerate again if stop control used for them, reversing the yielding relationships that would apply if the other approach used
Diverging Type 1	• Bicyclists can continue straight through the interchange area • Motorists should yield to bicyclists when entering the dedicated right turn lane or exit ramp	• Acute angle reduces visibility • Amateur bicyclists may not have the skills or confidence to use this kind of facility • Not appropriate in rural interchanges where diverging vehicles' speeds are comparatively high
Diverging Type 2	• Short crossing distance for bicyclists, at close to a right angle • Improved sight distance and lower traffic speed compared to further upstream • Drivers are not distracted by other motor vehicles • Plowable if the triangular area between the ramp and the road is paved	• Bicyclists must travel a longer distance before re-entering the bike lane • Bicyclists must wait for a gap in exiting traffic causing them extra delay • Bicyclists must stop and accelerate again if stop control implemented, causing them extra inconvenience

For at-grade signalized intersections, current guidance in the literature (see Appendix 4.3) includes several left turn options for bicyclists (CALTRANS, 2006):

1. Vehicular style: cyclist merges left and makes a left turn from the inside or left lane. This technique seems to be favored by experienced bicyclists.
2. Two-stage left: cyclist crosses one leg of the intersection and then waits to cross second leg to complete the left turn.
3. Bike boxes: this treatment is intended to allow bicyclists to position themselves ahead of queuing traffic during a red signal phase. It is currently used in many U.S. cities, according to the Urban Bikeway Design Guide (2014).

Current guidance from the literature for right turns (see Appendix 4.4) for at grade intersections often includes right-turn slip lanes for bicyclists. In terms of passing through an interchange, the California Highway Design Manual notes that shoulder widths should not be reduced through interchange areas (CALTRANS 2006).

As noted by the representatives of various bicycle advocacy groups, the safety of any bikeway (see Appendix 4.5.1) depends on the details of its design, including the colored markings and signage. In this context, Brady et al. (2011) studied the effectiveness of lane markings in bike routes and concluded that in addition to reducing unsafe bicyclist behavior, motorist behavior also improved as a result of the specific treatment under study. An example application in Austin, Texas is presented in Figure 2. The colored pavement used in Figures 2a and 2b increased the yielding behavior by motorists in experiments conducted in Portland, Oregon and South Burlington, Vermont (Hunter et al., 2000; Sadek et al., 2007). It currently has FHWA interim approval.

Figure 2a Colored Bike Lane West Bound Exit from Interstate 35 in Austin, Texas

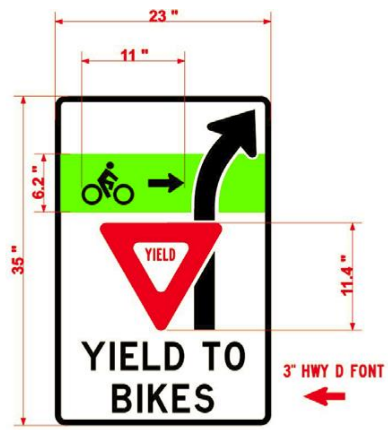


Figure 2b Sign Detail Westbound Exit from Interstate 35 in Austin, Texas

Various performance measures can be considered in the evaluation of new projects and design alternatives for enabling bicyclist use of high-speed roads. The performance measures recommended in this study are shown in Figure 8b. Most of the measures (including right-of-way, construction and operation costs, accident costs, pollution savings and energy savings) can be translated into monetary terms and aggregated into general cost-effectiveness measures such as the benefit/cost ratio or net present value.

The main conclusion of this study is that bicyclists on high-speed roads (above 45 mph) face serious risks unless sufficiently separated from the motor-vehicle traffic. The treatments presented in the project report, if prudently implemented, can help mitigate such risks where separated facilities are not an option. This study also found that available data on accidents involving bicyclists are inadequate for quantitatively comparing the merits of design alternatives and treatments.

PROPOSED SOLUTION: RUMBLE-BUFFER

A treatment, referred to as a “rumble-buffered” bike lane or Rumble-Buffer is proposed and depicted in Figure 3. The suggested minimum rumble-buffer width is 5 ft. The desirable bike travel lane width is 5 ft, in accordance with the *Urban Bikeway Design Guide* (National Association of City Transportation Officials, 2014). The minimum total width for the rumble-buffered bike lane is 10 feet, which may be difficult to provide in dense urban areas. The reasearch team suggested to use the available paved shoulder (widening the paved shoulder may be needed if the paved shoulder width is less than 10 feet) to construct the rumble-buffered bike lane.

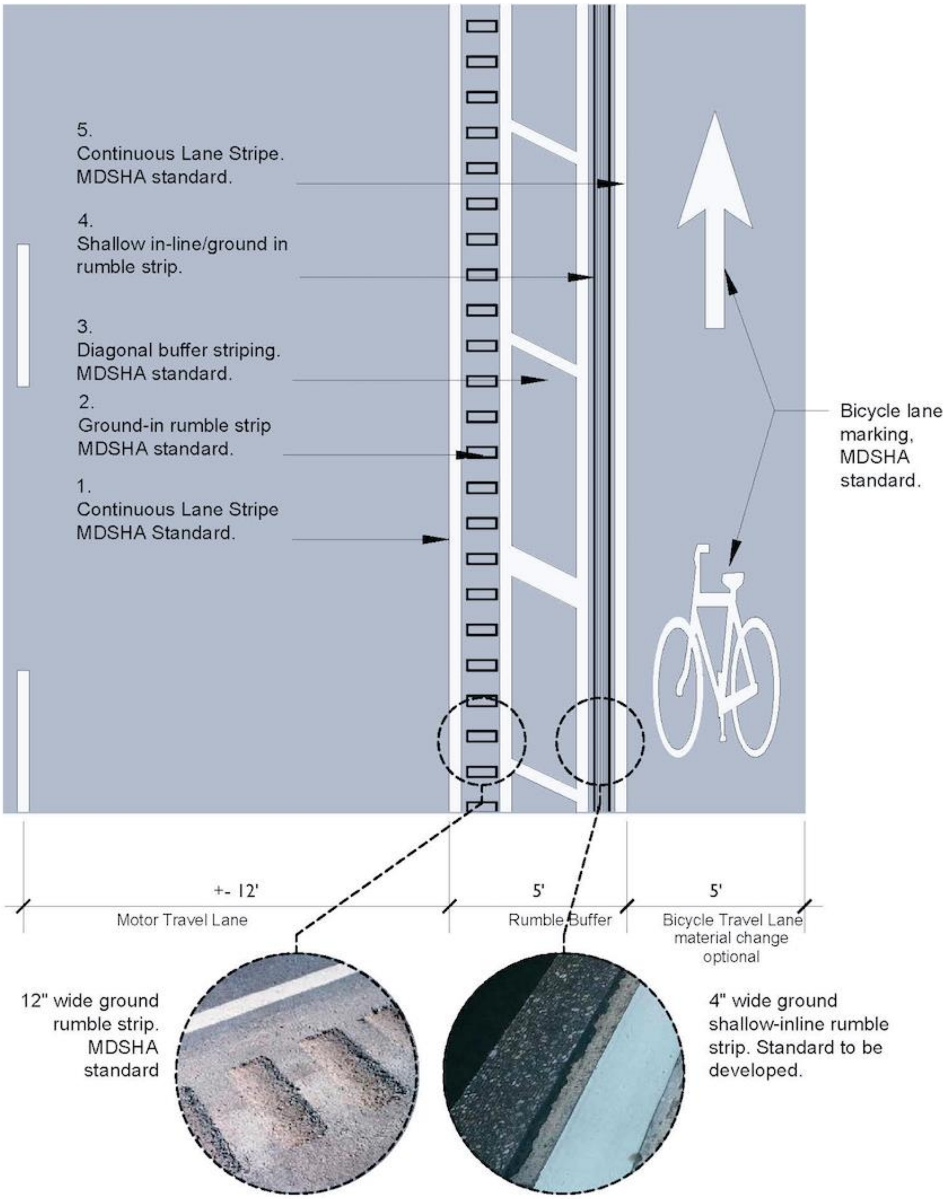


Figure 3 Rumble-buffered bike lane design

A “Rumble Buffer” on a 10 ft wide shoulder consists of:

1. Standard painted diagonal buffer striping defining the right side of the first motor vehicle travel lane;
2. Standard 12” wide ground-in rumble strip to further define and announce the right edge of the motor vehicle lane with possible breaks at intervals required to allow bicyclists’ turning movements, with a 12-ft gap every 40 feet to 60 feet, as recommended by Moeur (1999) ;
3. Standard painted buffer striping;
4. Shallow in-line/ground-in rumble strip to define and announce the left edge of the bike lane. Item #5 is based on a rumble strip example implemented in Minneapolis, Minnesota. Assessment of the safety and effectiveness of this component is required before design implementation.
5. Standard painted continuous edge line defining the left side of the bike lane.

The “Rumble Buffer” design has numerous advantages, including that it:

1. provides buffer separation between motor and cycling vehicles;
2. allows emergency travel or stopping space for each mode;
3. discourages cyclists from entering the buffer area without the hazard presented by standard rumble strips designed for motor vehicles;
4. allows ready access for routine maintenance and snow removal; and
5. requires only a modest increase in shoulder width.

Testing of the overall design and of the effectiveness and safety of its individual features, especially the in-line ground-in strip, as well as cost analysis of the complete design is recommended before wide-spread implementation.

The implications of the proposed Rumble Buffer are explored at five intersections: MD 32 at MD 18, US 29 at MD 216, US 40 at MD 66, US 40 at MD 18, and US 29 at Greencastle Road. These applications are illustrative of commonly encountered conditions in Maryland, but are not intended to provide needed specifications for implementation, nor to recommend specific changes at those particular intersections.

The AASHTO Guide for the Development of Bicycle Facilities 1999 (pp. 37-39) recommends minimum radii for paved shared use paths. Assuming a lean angle of maximum 20 degrees and a design speed of 10 mph, the AASHTO guide recommends a minimum radius of approximately 20 ft. This criterion is intended for separate shared-use paths but may be applied to repurposed shoulders if the available right-of-way is sufficient. The minimum path radii in the following implementation studies are taken as approximately 20 ft.

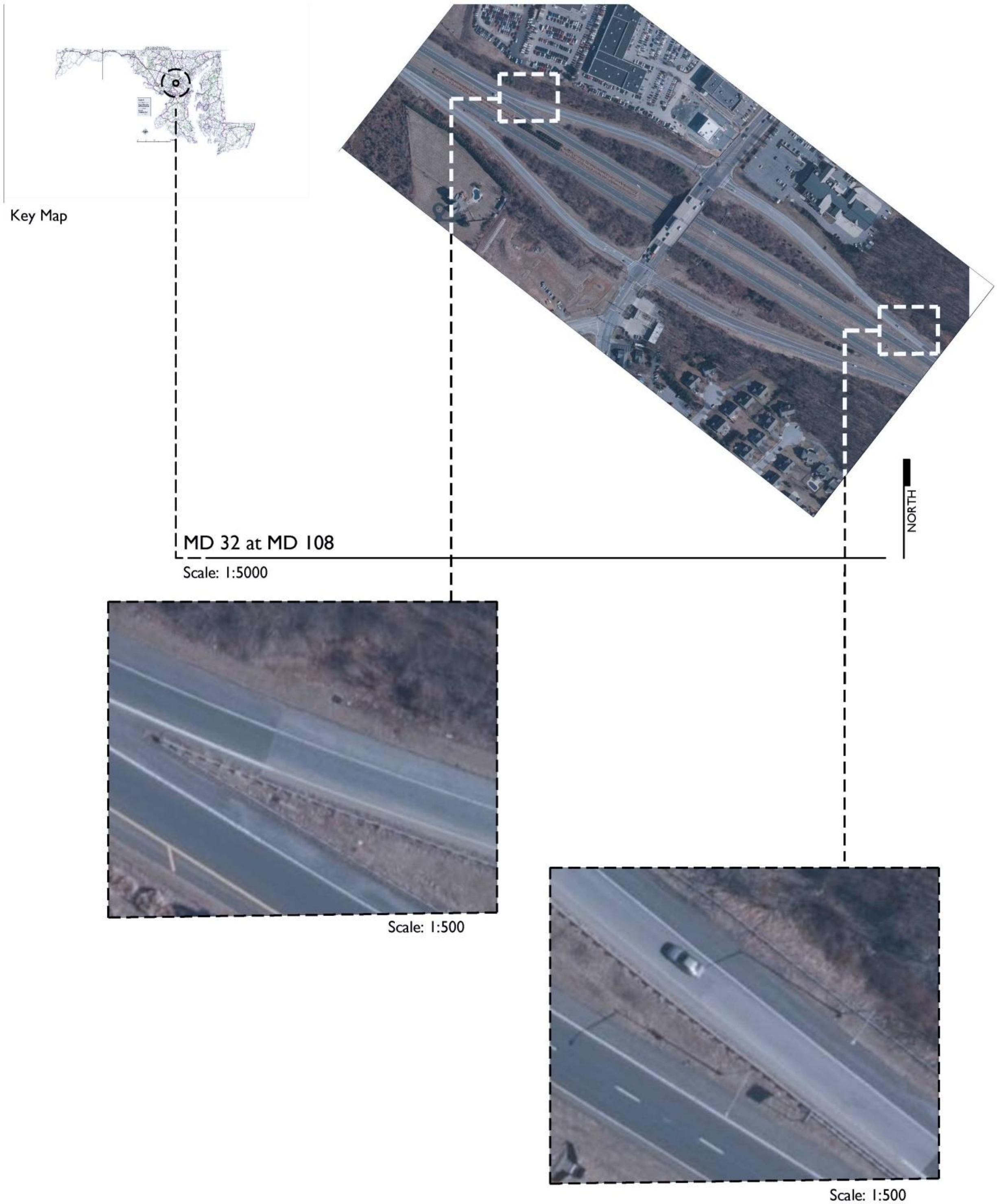


Figure 4 The Grade-Separated Intersection of MD 32 at MD 108 - Existing Conditions

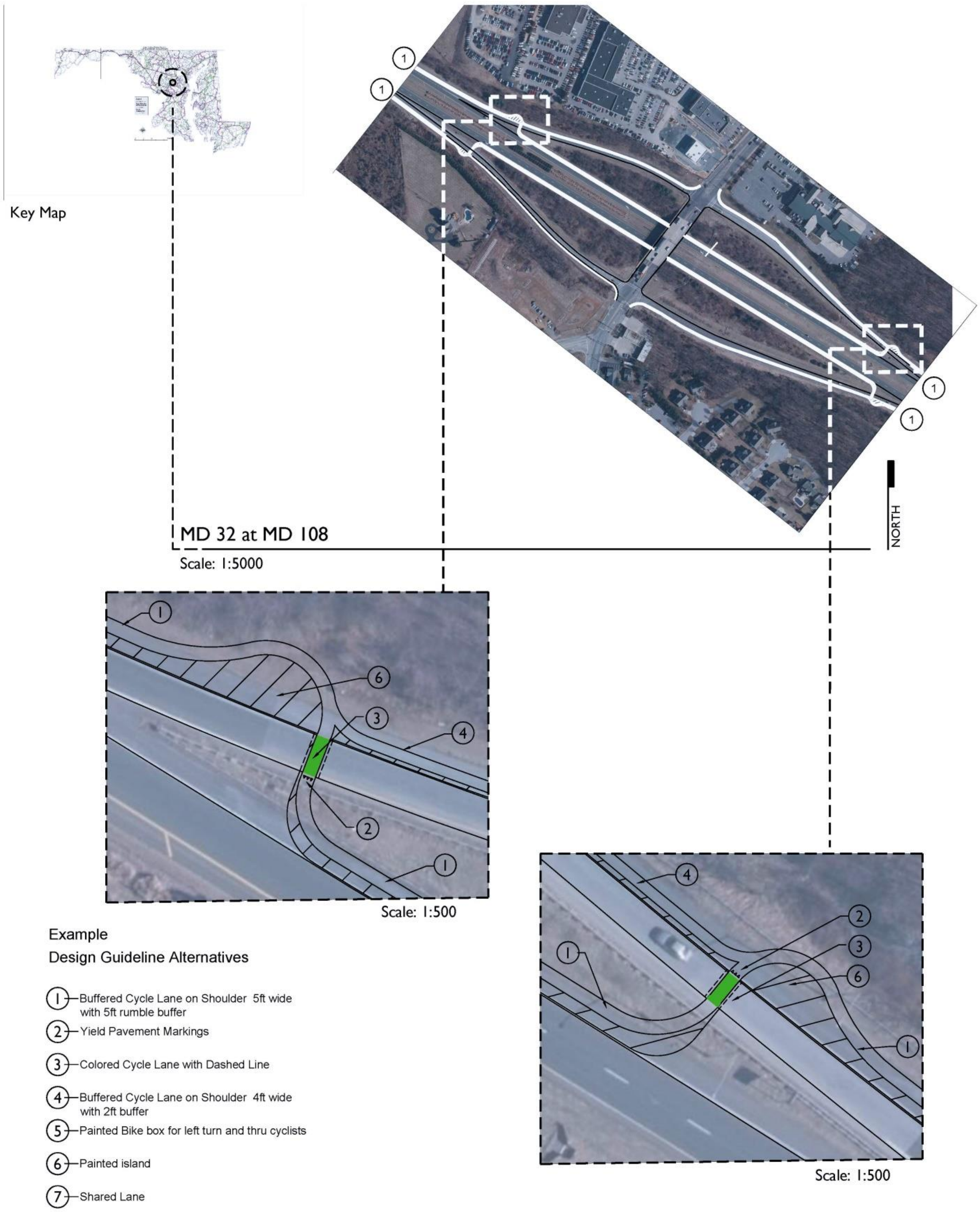


Figure 4b Implementation Study of the Grade-Separated Intersection of MD 32 at MD 108

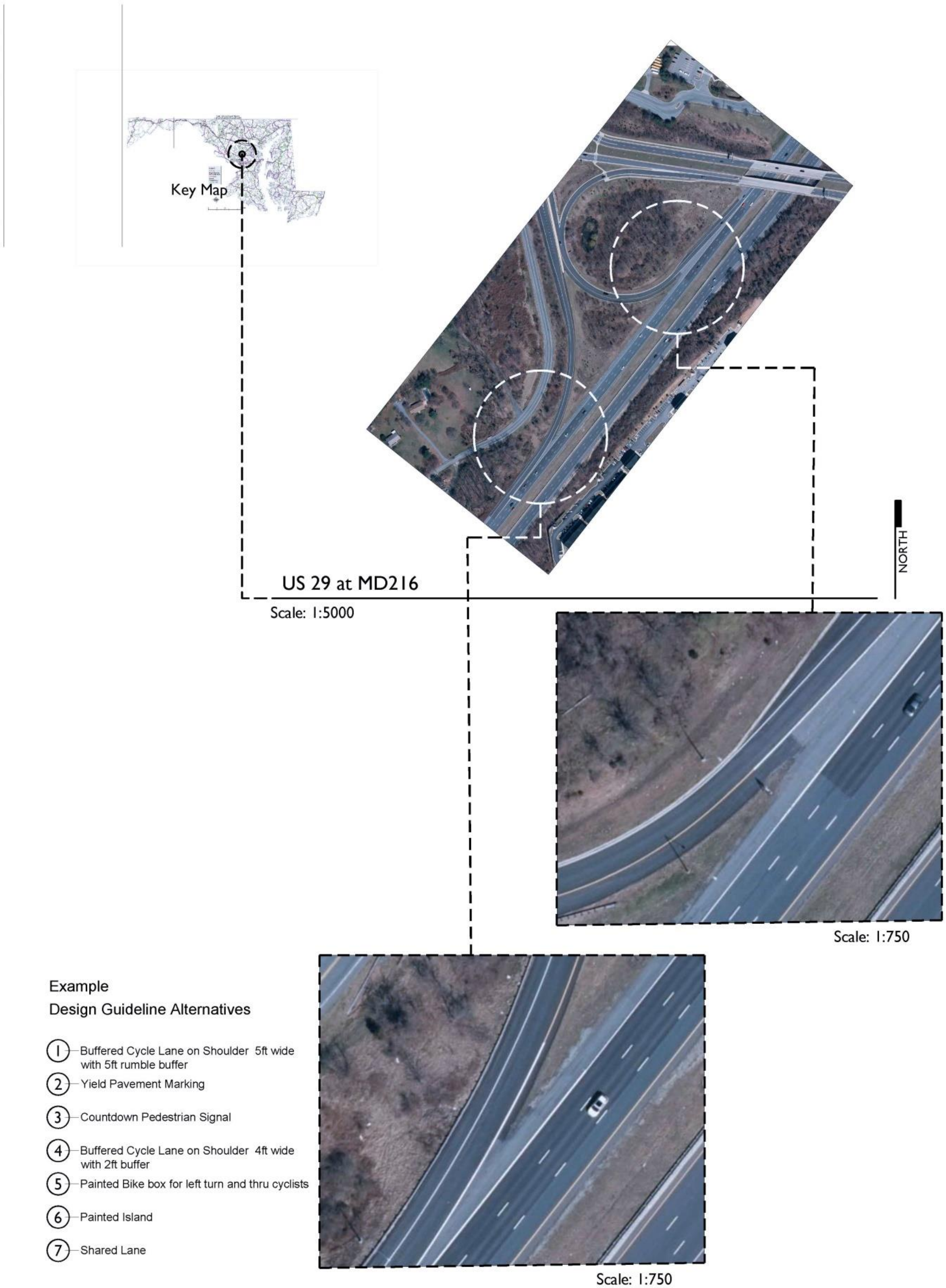


Figure 5a The Grade-Separated Intersection of US29 at MD 216 - Existing Conditions

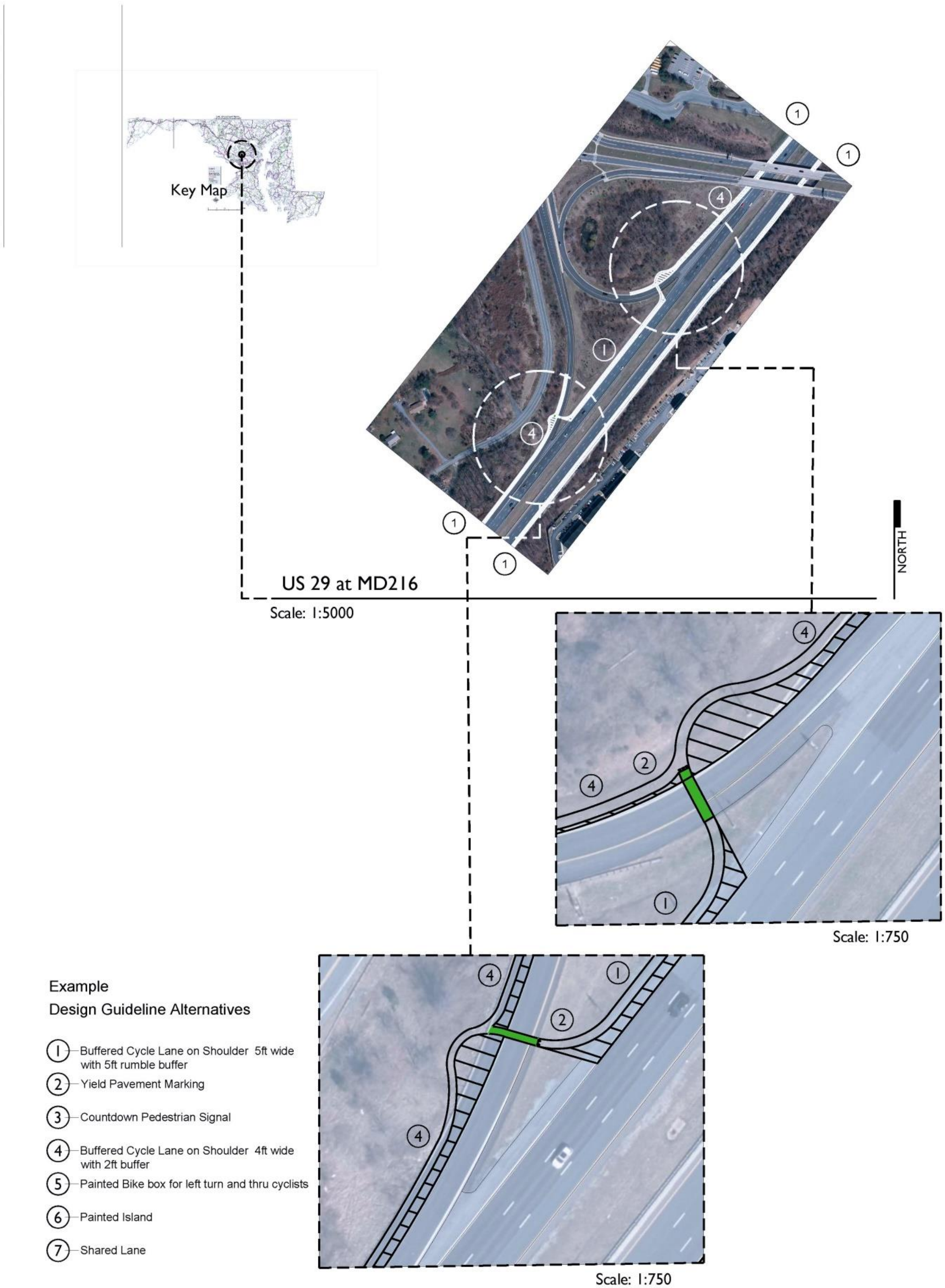


Figure 5b Implementation Study of the Grade-Separated Intersection of US29 at MD 216

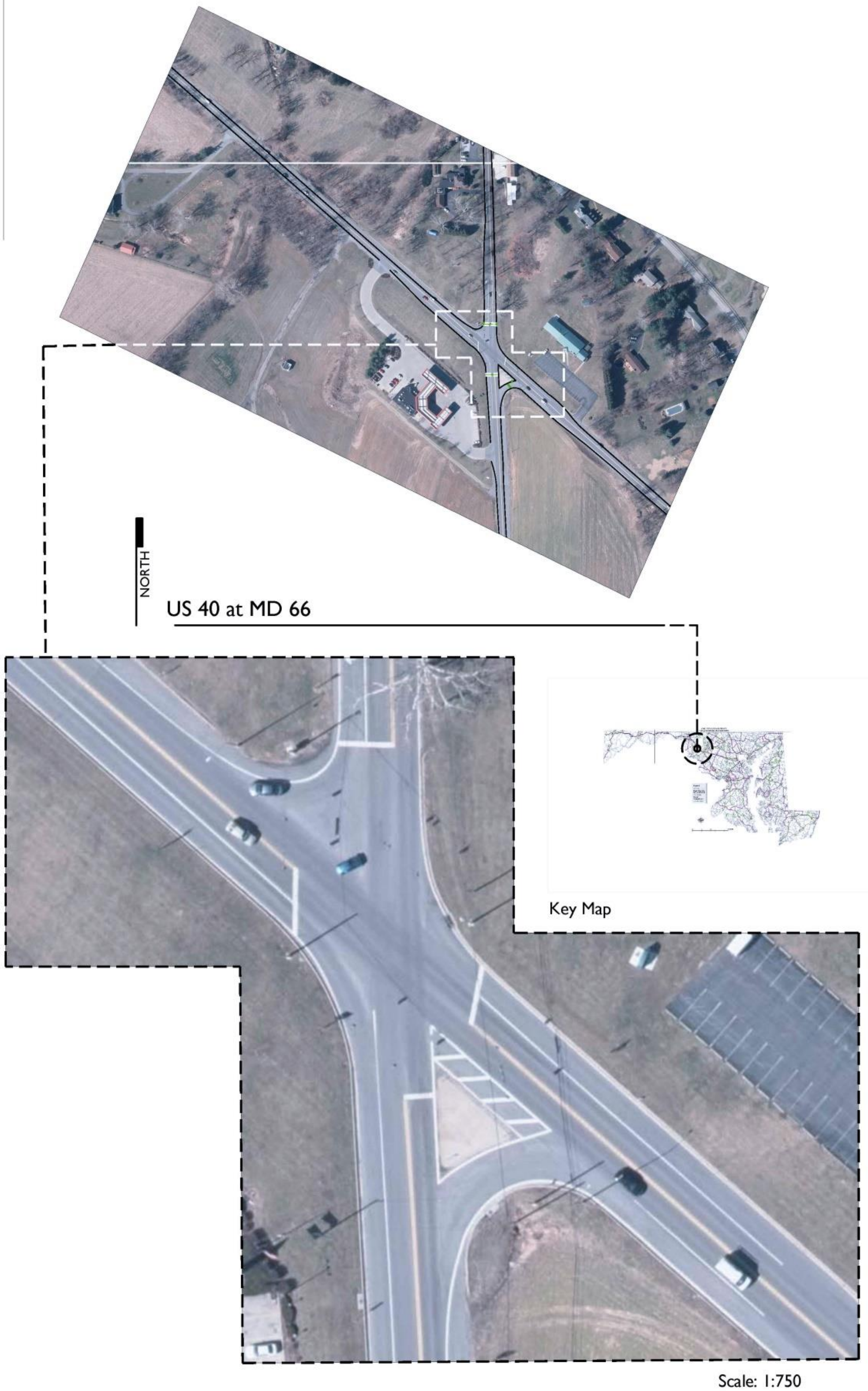


Figure 6a The At-Grade Intersection of US 40 at MD 66 - Existing Conditions

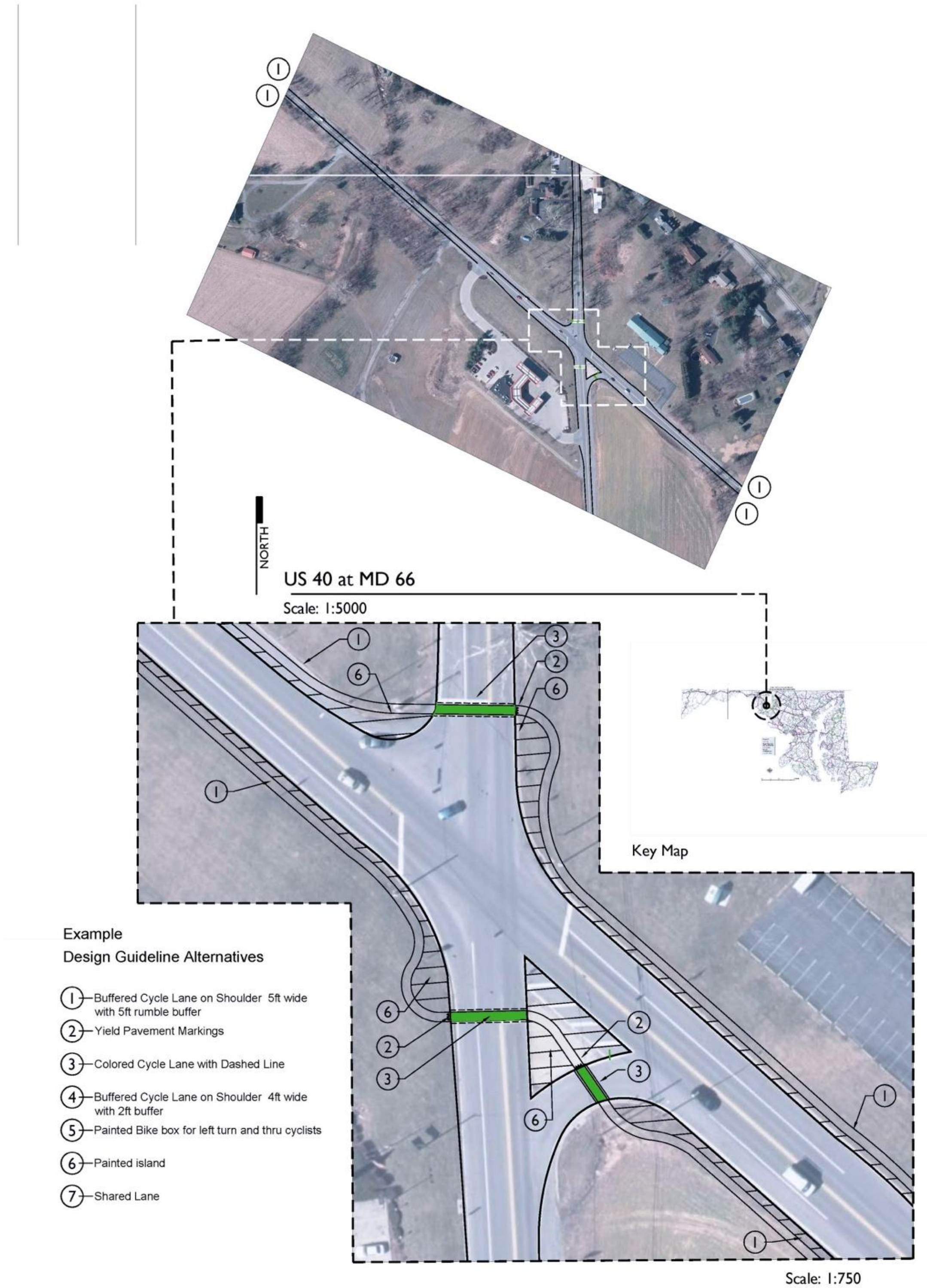


Figure 6b Implementation Study of the At-Grade Intersection of US 40 at MD 66

** Such design would require extra pavement at the intersection and the environmental permitting would be another challenge.*

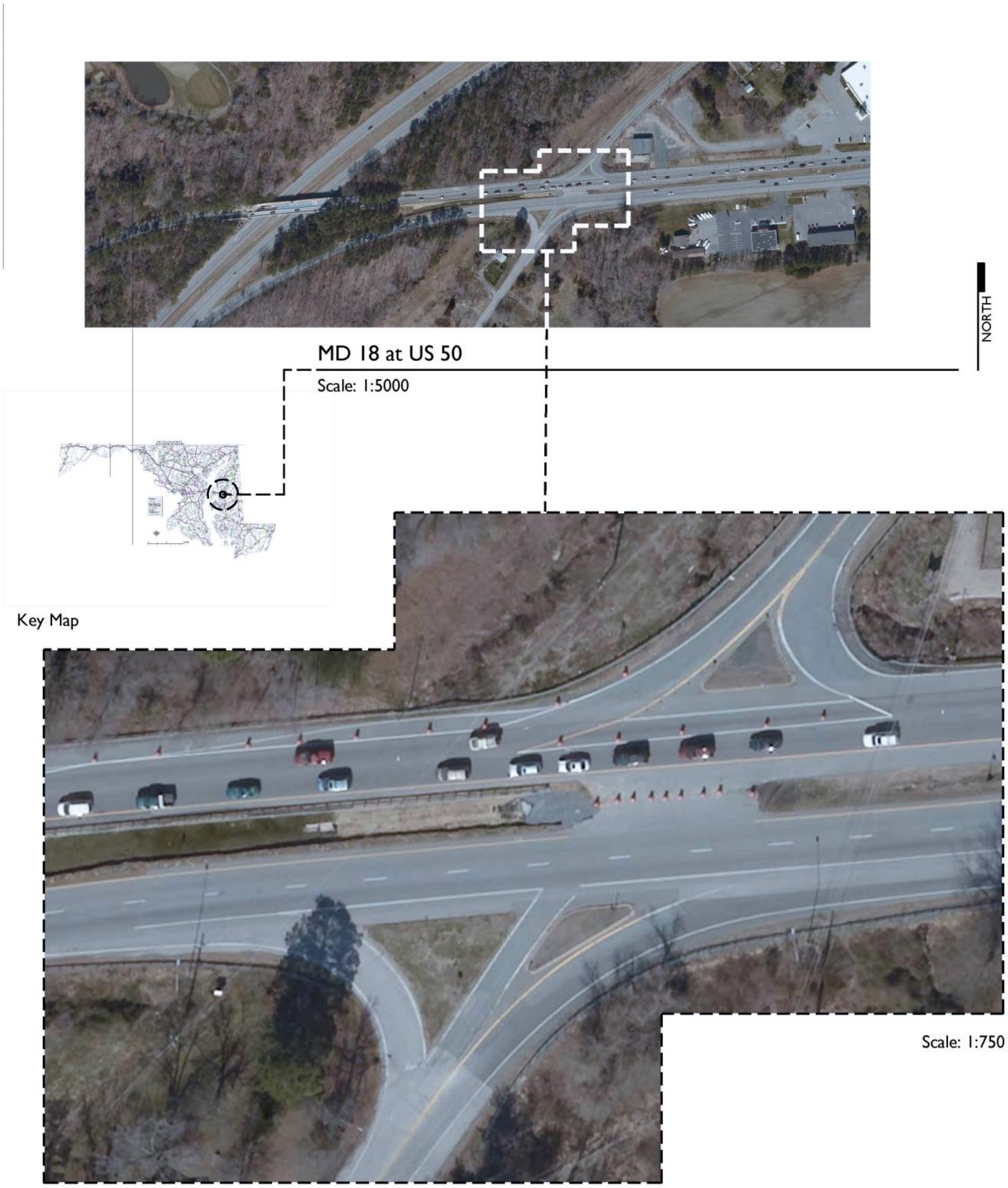


Figure 7a The At-Grade Intersection of US 50 at MD 18 - Existing Conditions

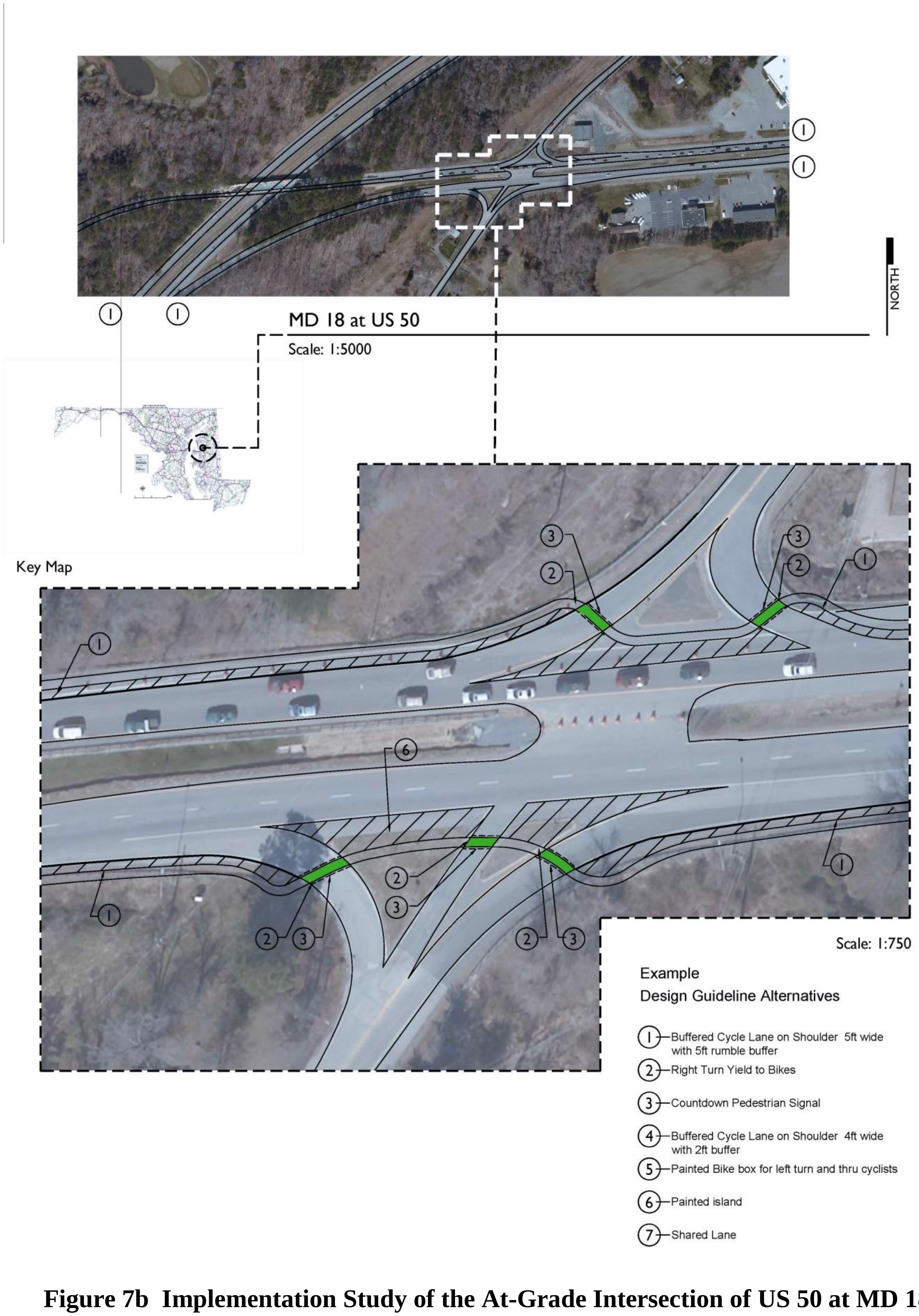


Figure 7b Implementation Study of the At-Grade Intersection of US 50 at MD 18

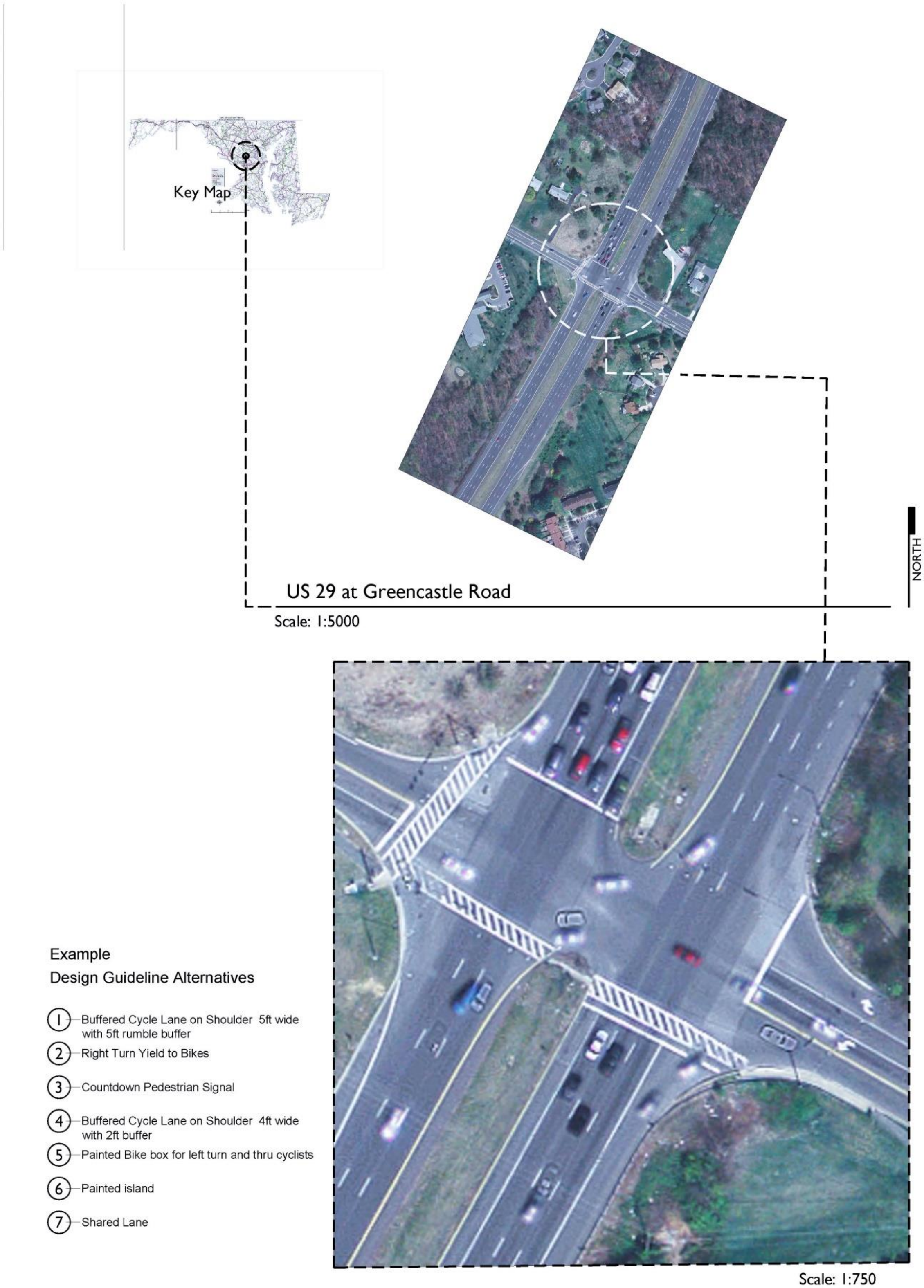


Figure 8a The At-Grade Intersection of US 29 at Greencastle Road - Existing Conditions

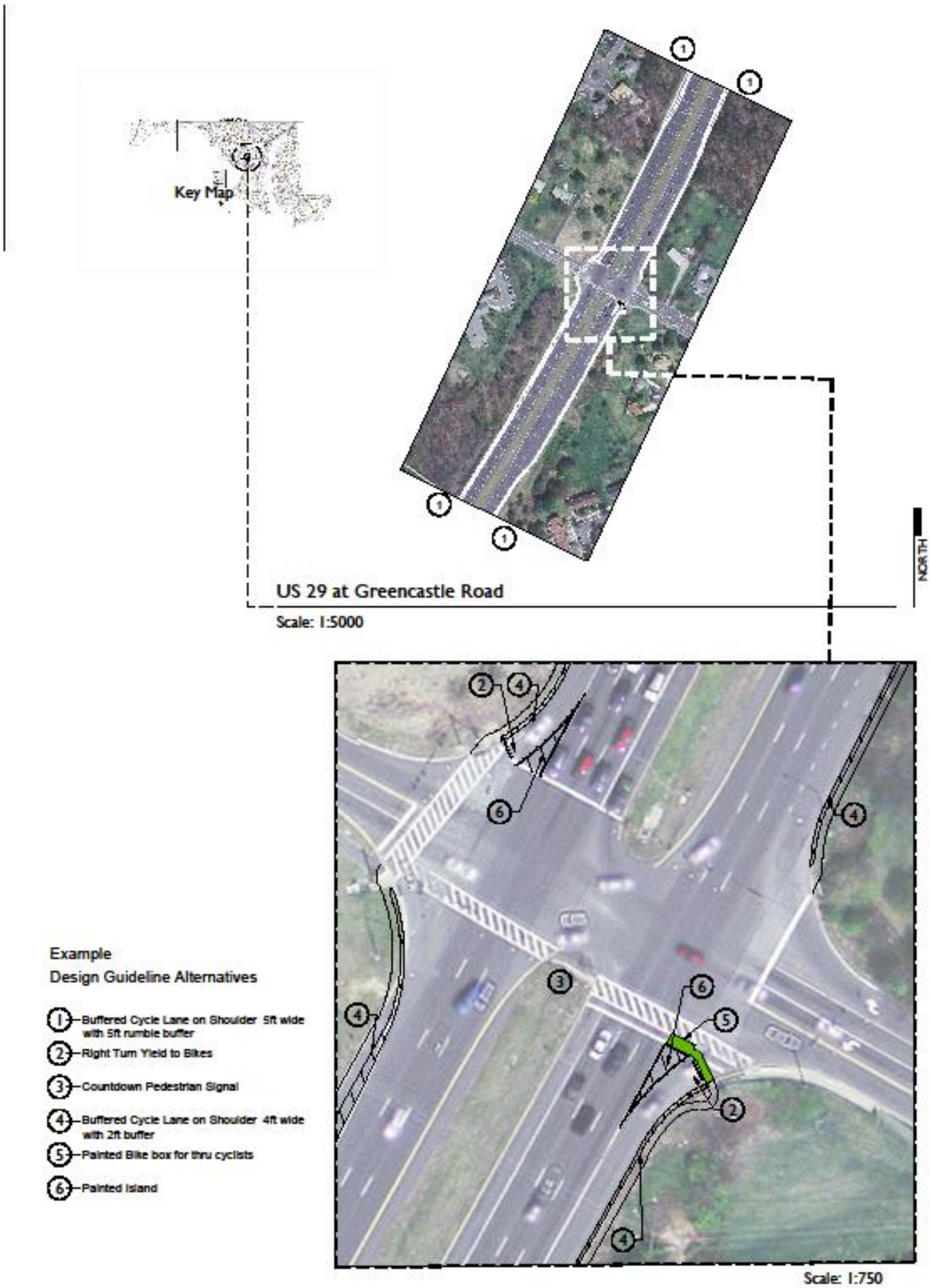


Figure 8b Implementation Study of the At-Grade Intersection of US 29 at Greencastle Road

(Note: Bike boxes currently have interim FHWA approval)

PERFORMANCE MEASURES

Performance measures of bicycle treatment alternatives should provide clear indicators of effectiveness, value, and feasibility. Ideally, they should also be quantifiable using readily-available data. Measures for intersections and interchanges are usually different from measures for continuous road sections. Table 2 presents the recommended performance measures, corresponding units, and possible information sources. Many of the performance measures, including right-of-way, construction and operation costs, accident costs, pollution savings and energy savings, can be translated into monetary units and aggregated into a single measure of overall cost effectiveness, such as a benefit to cost ratio or net present value.

Table 2. Performance measures for bicycle treatments on high-speed roads

Measure	Units	Information needs
Required road width	Feet per road direction	Design guidelines, including this report; Geometric information on existing roads, intersections and interchanges
Construction cost	$/road mile $/intersection $/interchange	Construction cost data, including unit costs of pavement, drainage facilities, barriers and grooves May also need estimates of bridge costs and additional right-of-way and utility costs
Operation and maintenance cost	$/mile per year $/intersection per year	Maintenance cost data, including costs for pavement repair and repainting and striping
Maintenance, including snow removal	Qualitative assessments, such as good, marginal, unacceptable	Widths of separate bicycle lanes, accessibility of separate bicycle lanes, vertical clearances, load-bearing capabilities of structures
Expected demand	Bicyclists/year Cyclist miles/year	Results of planning studies, especially regarding modal shares of bicycling; gradients; climate; lighting & other security features
Effects on motor vehicle traffic	Saved vehicle miles/year Changes in speeds, delays and operating costs	Traffic estimates from planning studies and especially modal split estimates. Traffic studies
Reductions in fuel use to aid in mode choice studies	Saved gallons/year Saved BTU’s/year	Traffic estimates from planning studies, combined with fuel use rates

Measure	Units	Information needs
Reductions in emissions resulting from changes in mode choice	Saved pounds of pollutants per year	Traffic estimates from planning studies, combined with forecast emission rates
Net safety effects	Estimated change in accident rates, fatalities/year and injuries/year	Travel estimates from planning studies; Accident rates for various facility types, traffic mix, speeds and environmental conditions Estimated costs for accidents, by severity
Health effects	Expected longevity changes Changes in health cost $/year	Relevant research studies
Continuity	% of bicycle trips on designated bike lanes or other special bike facilities	Maps of planned bicycle facilities; Trip origin-destination tables from planning studies
Accessibility	Average access distance to bicycle facilities Binary accessibility (= fraction of potential bicyclists without physical barriers to bicycle facilities)	Geographic information systems Detailed surveys of household accessibility to bicycle facilities, considering physical barriers
Temporal usability	Fraction of time facilities are practically usable by bicyclists	Lighting conditions Precipitation Snow clearance practices
Cost effectiveness	Benefit/Cost ratio Net present value Agency $/bicycle mile	Estimates of agency costs and bicycle use, included above
Political feasibility	Qualitative assessments, such as good, marginal, unacceptable	Contacts with citizens, bicyclists, and their political representatives Local Master Plan

Appendices

1 APPENDIX A: CLASSIFICATION

1.1 CLASSIFICATION

This appendix provides definitions of terms related to bicycle facility features and implementations.

Bicycle facilities can be categorized into six types (Federal Highway Administration, 2015), as shown in Table 1-1.

Table 1-1 Bike Facility Types

Signed routes (No Pavement Markings) A roadway designated as a preferred route for bicyclists.
Shared Lane Markings A shared roadway with pavement markings providing wayfinding guidance to bicyclists and alerting drivers that bicyclists are likely to be operating in mixed traffic.
On-Street Bike Lanes An on-road bicycle facility designated by striping, signing, and pavement markings.
On-Street Buffered Bike Lanes Bike lanes with a painted buffer increase lateral separation between bicyclists and motor vehicles.
Separated Bike Lanes* A separated bike lane is an exclusive facility for bicyclists that is located within or directly adjacent to the roadway and that is physically separated from motor vehicle traffic with vertical elements.
Off Street Trails / Sidepaths Bicycle facilities physically separated from traffic, but intended for shared use by a variety of groups, including pedestrians, bicyclists, and joggers.

*Also known as cycle tracks, protected bike lanes, and separate bikeways (DuBose et al., 2013; FHWA, 2015; NACTO, 2014).

2 APPENDIX B: REVIEW OF PRACTICE AND LITERATURE ON ACCOMMODATING BICYCLISTS ON HIGH-SPEED ROADWAYS

2.1 KEY FINDINGS FROM THE LITERATURE

This section reviews findings from the literature on the role of infrastructure design and intersection treatment in bicycle safety.

Few safety studies were found that pertain directly to high-speed roadways (i.e. roadways with speeds over 45 mph). However, several factors, although not specifically studied for high-speed roadways, were identified as having signifanct impact on bicycle safety, including the design and maintenance of the built environment, the numbers of bicyclists, and details of treatment type, e.g. lane markings and colors. These factors are discussed next.

Intersections are the locations where bicycles and motor vehicles interact most (Korve & Niemeier, 2002), and the majority of bicycle-motor vehicle accidents occur at at-grade intersections (Wachtel & Lewiston, 1994). The focus in much of the reviewed literature is on reducing the potential conflicts between right-turning motor vehicles and bicyclists (commonly known as the “right-hook” conflict), with less attention given to left-turning traffic (as noted in Weigand, 2008).

With effective safety treatments for intersections, cycle tracks may be a good option to consider for high traffic flow, high-speed roadways (Pucher & Buehler, 2008). Lusk et al. (2011) conducted a comparative study of cyclist injury rates along cycle tracks against reference streets without bicycle facilities. Their study involved six two-way cycle tracks in Montreal. They found that the relative risk of cycle tracks as compared with reference streets was only 0.72. They concluded from their study that cycle tracks reduce crash and injury rates as compared with streets that have no bicycle facilities, and thus argue that AASHTO’s guidance on this topic should be reconsidered. In accordance with this argument, Reynolds et al. (2009) concluded from a review of 23 related papers that safety is greater for bicyclists along well-marked, bike-only routes. Further, cycle tracks that circumvent the intersections by separating bicycle from motorist traffic are much safer than alternative bike lanes and cycling in traffic (the preferred AASHTO alternative). Thomas and DeRobertis (2013) reach similar conclusions from their study of the literature on one-way cycle tracks. They further conclude that one-way cycle tracks are safer at intersections than two-way and appropriate intersection treatment can significantly improve the safety of cycle tracks as an option. While cycle tracks or similar bike paths were found to reduce parallel collisions (due to rear-end crashes, overtaking and interactions with parked vehicles), an increase was noted in crashes with right-turning vehicles and between bicycles and other roadway users, such as pedestrians and mopeds.

From their review of safety studies of cycle tracks, Thomas and DeRobertis (2013) concluded that there are four main effective intersection treatments for this infrastructure type: (1) closer proximity of cycle track to vehicular traffic to increase visibility and awareness; (2) placing a stop line for vehicular traffic well before the intersection to allow greater visibility; (3) raising cycle crossings at the intersections creating a speed hump to slow down oncoming vehicles; and (4) implementing a dedicated signal phase for bicyclists to separate traffic classes during intersection movements. Leden et al. (2000) found that the use of the raised bicycle crossing options increased cyclist safety by 20%.

Despite their advantages, few cycle track facilities have been constructed in the U.S. As of 2013, one related published safety evaluation of these U.S. facilities could be found, and it focused on rural paths (Petritsch et al., 2006).

The safety of any bikeway depends on the details of its design, including even the colored paint that is used. In this context, Brady et al. (2011) studied the effectiveness of lane markings in bike routes and found that certain designs reduced sidewalk and wrong-way riding. Their study concluded that in addition to reducing unsafe bicyclist behavior, motorist behavior also improved as a result of the installation of shared lane markings. In an earlier study (Wachtel & Lewiston, 1994), wrong-way cycling was shown to increase risk of accidents almost four-fold for bicyclists traveling with traffic and nearly seven fold for children. Moreover, there appears to be universal agreement that riding against traffic or on sidewalks should be avoided. Thus, these lane markings can have significant safety benefits.

A more recent treatment suggested for use in urban settings is the bicycle box. Bicycle boxes involve a painted area within signalized intersections. The box allows the bicyclists to position themselves in front of the motorists. The boxes are connected through markings to existing bike lanes. Loskorn et al. (2013) studied the effects of this treatment type on bicyclist and motorist behavior. While only 20-26% of bicyclists stopped in the bike box area, over 90% of all 950 bicyclists observed stopped in front of motorists and were therefore more visible to motorists. No bicycle-motor vehicle collisions were observed during their study.

Fees et al. (2015) produced design recommendations for bike lane widths based on traffic volume, truck volume, on-street parking, lane buffers, and other factors. They concluded, based on the statistical analyses, that:

- Buffered bike lanes provide distinct advantages compared to wider (5 or 6 feet) bike lanes;
- Bicyclists tend to position themselves closer to parked vehicles or curb facilities as traffic and truck volume increase.

They developed the following table (Table 2-1) that provides recommended lane widths and dimensions for various roadway scenarios and conditions (with posted speed limit of 30 mph).

Table 2-1 Recommended lane widths for various scenarios

Widths (ft)—One direction of travel							
Parking lane	**Buffer**	**Bike lane**	**Buffer**	**Travel lane**	**Curb to CL**	**Curb to Curb (ft)**	**Roadway Conditions**
8	3*	4	2	10	27	54	All conditions
7	3*	4	2	10	26	52	All conditions
7	2*	4	2	10	25	50	High volume or high truck percentage
7	3	5	0	10	25	50	Low volume and low truck percentage
7	1.5	4	1.5	10	24	48	High volume or high truck percentage
7	3	4	0	10	24	48	Low volume and low truck percentage
7	2	5	0	10	24	48	Low volume and low truck percentage
7	2	4	0	10	23	46	All conditions
7	0	5	0	10	22	44	All conditions
7	1**	4	0	10	22	44	All conditions

* May consider combining buffers to create a 4-ft buffer between parking and bike lanes.
** Caution that striping of double white lines may cause confusion.
1 The suggested threshold for distinguishing between low and high traffic volume is 20,000 vpd, and the suggested

threshold for distinguishing between low and high truck percentage is 10 percent trucks in the vehicle mix.

Source: Fees et al. (2015)

Another treatment with impact on bicycle safety is the rumble strip. Shoulder rumble strips are normally used on freeways or highways to alert drowsy drivers that they have drifted out of the travel lane. This treatment is believed to have the safety benefit of reducing single-vehicle run-off-road (SVROR) crashes (Torbic, 2009). However, the implementation of rumble strips on high-speed roads can pose great danger to bicyclists using the road. Usually bicyclists will ride on the shoulder outside of the rumble strip, but they occasionally need to cross it to make a left turn or to avoid debris (Outcalt, 2001). Several studies (Bucko and Khorashadi, 2001; Elefteriadou et al, 2000; Outcalt, 2001) have found that the best rumble strips from the sound and vibration viewpoint are typically the worst from the bicyclists' viewpoints. Trade-offs were made in those studies to select a bicycle-friendly and safety-effective design of shoulder rumble strips. The study by Torbic (2001) is the only one found that actually examined the relation between the alerting properties of rumble strips and bicyclists' reaction to them. He found that as vibration increases, bicyclists' comfort decreases. This finding confirms the subjective rating of comfort in the three studies mentioned above. However, Torbic also concluded that there was no clear relation between whole-body vibration and the controllability of a bicycle. Consequently, there is currently no consensus on how the compromise should be made in selecting a rumble strip design that is compatible for all types of road users. Moreover, design suggestions typically focus on the driver's perspective rather than the bicyclist. For example, Torbic (2009) suggests that on roadways where bicyclists can be expected, shoulder rumble strips should be designed to produce sound level differences in the range of 6 to 12 dBA in the passenger compartment. Most relevantly, Moeur (1999) recommended the inclusion of a 12 ft gap every 40 ft or 60 ft of rumble strip on all non-controlled access roadways. These gaps in rumble strips should perform acceptably in allowing bicyclists to cross a ground-in rumble strip pattern.

The importance of maintenance and elimination of hazards to bicyclists, such as debris, overgrown plantings, potholes and nonbike-safe storm drains, should also not be overlooked. An extensive discussion of these issues can be found in (AASHTO, 2012; DeHart, 1978). Such maintenance concerns should play a significant role in adoption of bicycle facility design and related treatment principles.

In addition to the safety studies mentioned above, the effect of weather on bike usage is also an important consideration. Gebhart and Noland (2014) analyzed the effect of weather on the use of the DC bikeshare system and concluded that cold temperatures, rain, and high humidity levels reduce both the likelihood of bike usage and the trip duration. Saneinejad et al. (2012) noted that the use of bicycles is sensitive to temperatures, though only in conditions below 15 ℃ (59 ℉). They also concluded that wind speed and precipitation in the form of showers negatively influence bicyclists. These researchers, however, do not directly comment on the impact of weather on bicyclist safety, but only indirectly through reduced bicycle usage.

2.2 KEY FINDINGS FROM THE STATE-OF-PRACTICE

2.2.1 Design manuals and interviews in U.S.

Table 2-2 lists the state document related to bicycle design that were obtained and reviewed as part of this study.

Table 2-2 State documents on bicycle design

State	Bike Design Guidelines / Bike Master Plan	Reference in General Design Guidelines
ALASKA	Alaska Bicycle And Pedestrian Plan (1995)	
ARIZONA	ADOT Statewide Bicycle and Ped Plan (2013)	
CALIFORNIA		Highway Design Manual, Chapter 1000: Bikeway Planning and Design (2006)
COLORADO		Colorado DOT Roadway Design Guide (2013)
CONNECTICUT	Connecticut Bicycle and Pedestrian Plan (2009)	
DELAWARE	Delaware Bicycle Facility Master Plan (2005)	
FLORIDA		Plans Preparation Manual_Volume 1 (2015)
HAWAII	Bike Plan Hawaii (1994)	
IDAHO	Idaho Bicycle and Pedestrian Transportation Plan (1995)	
ILLINOIS	Illinois Bike Transportation Plan (2014)	
INDIANA		INDOT Design Manual (2013)
KANSAS	Kansas Bicycle and Pedestrian Plan (1995)	
KENTUCKY	KY Bicycle and Pedestrian Master Plan (2007)	Kentucky Highway Design Manual (2006)
LOUISIANA	Louisiana Statewide Bicycle and Pedestrian Master Plan (2009)	
MARYLAND	Bicycle Policy and Design Guidelines (2015)	
MASSACHUSETTS	Massachusetts Bicycle Transportation Plan (2008)	
MINNESOTA	MnDOT Bikeway Facility Design Manual (2007)	
MONTANA	Bike & Ped Transportation Policy Paper (2007)	
NEVADA	Nevada Statewide Bike Plan (2013)	
NEW JERSEY	NJ Statewide Bicycle & Ped	

	Master Plan (2004) NJ Bike Design Guideline (1996)	
NEW YORK		Highway Design Manual, Chp. 17 (2015)
NORTH CAROLINA	NC Bicycle Facilities Planning and Design Guidelines (1994) NCDOT Complete Streets Guidelines (2012)	
NORTH DAKOTA		NDDOT Design Manual, Chp. III-07 (2007)
OHIO		ODOT's Location and Design Manual, Section 300 (2015)
OREGON	Bicycle and Ped Design Guidelines (2011)	
VERMONT	Vermont Ped and Bicycle Facility Planning and Design Manual (2002)	
VIRGINIA		Vtrans Road Design Manual (2005)
WASHINGTON	Washington State Bike and Ped Plan (2008)	
WISCONSIN	Wisconsin Pedestrian Policy Plan 2020 (2001)	
WYOMING	Wyoming Bicycle & Ped Transportation Plan (2002)	

2.2.2 Key findings from international design manuals

Bicycle design manuals were obtained and reviewed for several countries outside of the U.S. These were primarily from Europe. The relevant practice related to high-speed roads is presented in Table 2-3.

Table 2-3 International practice on accommodating bicyclists on high-speed roads

Country	**Practice**	**Reference**
UK	Where the 85th percentile speed exceeds 40 mph (64.4 km/h), segregated bicycle facilities (tracks/paths) should generally be provided. For high-speed roads with low traffic volumes (less than 3,000 vehicles per day/less than 300 vehicles in the typical AM peak hour), on-road bicycle lanes may also be considered.	TfL (2005)
Germany and Denmark	Should provide fully integrated off-road paths and bicycle lanes along roads as well as at intersections in cities and surrounding areas.	Pucher & Buehler (2008)
The Netherlands	Bicyclists should always be separated from high-speed traffic by providing a separate path or alternative (cycling) route. Consideration should also be given to lowering traffic speeds at conflict points.	CROW (2007)
New Zealand	On urban roads with a speed limit of 80 km/h (50 mph) or more, cycle paths should be provided. Where speed limits are 70 km/h (45mph) and volumes are less than 2,000 vehicles per day, paved (colloquially termed sealed) shoulders may be acceptable.	LTSA (2004)
Italy	Bicyclists are not allowed on high-speed facilities, but rather only on secondary roads (called strade di servizio in Italian) of such facilities	Italian Ministry of Infrastructure and Transport (2013)

Table 2-3 shows international consensus on the need for separation between bicyclists and motor vehicles for roadways with speed limits that exceed 50mph. This is generally accomplished by providing separation between motorized vehicles and bicycles. Bike lanes or paved shoulders are deemed acceptable in some locations when traffic volumes are low. In some countries, e.g. Italy, bicyclists are prohibited from entering high-speed roadways altogether.

Many jurisdictions, including New Zealand (LTSA 2004), the United Kingdom (TfL 2005; DfT 2008; DTO 2002), and the Netherlands (CROW 2007) provide guidance on the most suitable type of bicycle facility on urban roads based on the combination of the 85th percentile traffic speed and volume. At traffic speeds of 80 km/h (50 mph) and above, a bicycle path separated from the road is the recommended treatment (for example, see Figure 2-1). On 70 km/h (45 mph) urban roads with low traffic volumes, and on all high-speed rural roads, some guidelines (LTSA, 2004; TfL, 2005) suggest that paved shoulders (or bicycle lanes) are also acceptable.

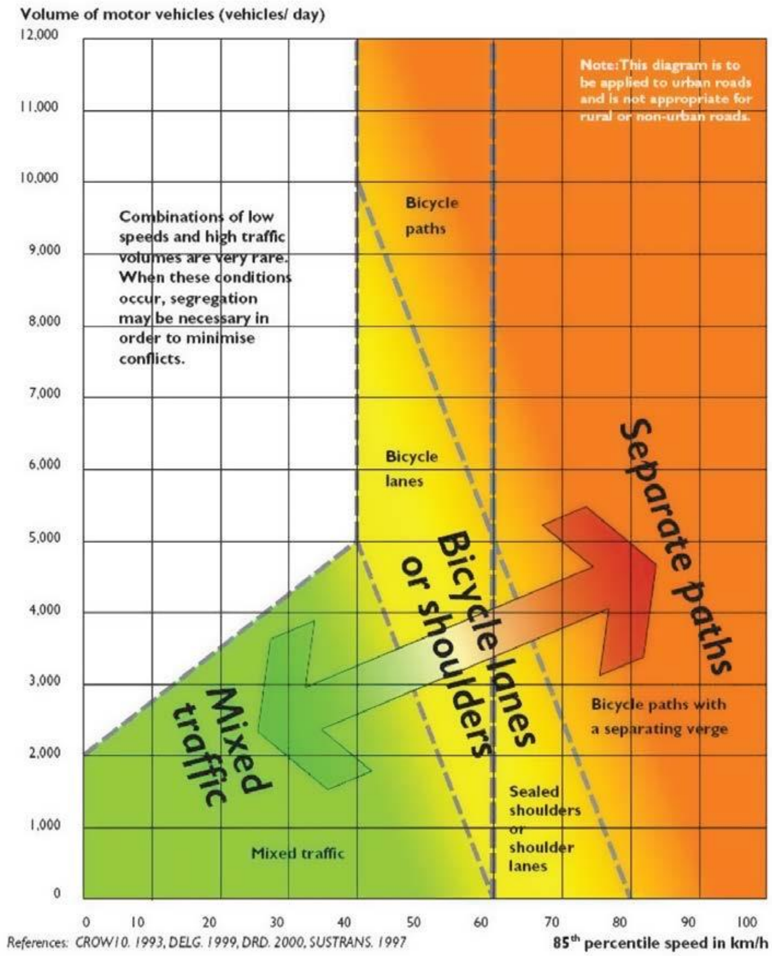


Figure 2-1 Preferred separation of bicycles and motor vehicles according to speed and volume (Source: Austroads AGTM04 2009f)

Also of note, the *Design Manual for Bicycle Traffic* (CROW, 2007) provides suggestions on cycle track widths (both one-way and two-way cycle tracks) on the basis of peak-hour bike volume. These recommendations are shown in Table 2-4.

Table 2-4 Recommended cycle track width (adapted from the Crow Design Manual)

One-way cycle track		Two-way cycle track	
Peak hour bike volume (bikes per hour)	Width (ft)	Peak hour bike volume (both directions, bikes per hour)	Width (ft)
0-150	6.56	0-50	8.20
150-750	9.84 (8.20)	50-150	8.20 to 9.84
>750	13.12 (11.48)	>150	11.48 to 13.12

Regardless of speed limit, the *Design Manual for Bicycle Traffic* (CROW, 2007) also recommends the implementation of cycle tracks or parallel roads for “district access roads” (perhaps principal arterials) that exist within a built-up area. The only exception this manual makes is for cases in which the roadway is a 2-lane highway and the speed limit is 50 km/h (31 mph) or less, i.e. not for high-speed roadways. On district access roads outside the built-up area and for which the speed limit is over 80 km/h (50 mph), cycle tracks or parallel roads are recommended regardless of motor vehicle traffic volumes. In these cases, the separation width between the roadway and cycle track depends on the speed limit for the roadway adjacent to the cycle track. The recommended, minimal separation widths by speed limit are listed in Table 2-5. Considerations include the creation of a buffer between the two traffic streams, known as a partition verge (referred to in the Dutch manual), as well as the creation of a clear line of sight of the cycle track for motorists. The space between the cycle track and roadway (partition verge) can serve as a ‘receptor’ for vehicles that run off the roadway when this space is paved and at grade and as a ‘buffer’ for preventing accidents between bicyclists and motorized traffic. In its Dutch application (CROW, 2007), the forms of separation include paved verge, unpaved verge, raised curb, fence, and barriers. Appendix 5.1 provides additional discussion of forms of separation between motorized traffic and a coexisting cycle track.

Table 2-5 Recommended cycle track separation widths outside a built-up area

(adapted from the Crow Design Manual)

Speed limit	Cycle track separation width (**recommended (minimum)**)
37 mph	8.2 (4.9) ft
50 mph	19.7 (14.8) ft
62 mph	32.8 ft

3 APPENDIX C: NOTES CONTAINING INPUTS FROM BICYCLE ADVOCACY GROUPS AND OTHER EXPERTS

3.1 LIST OF PEOPLE INTERVIEWED: BICYCLE ADVOCACY GROUPS AND OTHER EXPERTS

Table 3-1 lists the people interviewed most of which are representatives from bicycle advocacy groups. Drs. Furth and Buehler have extensive expertise in bicycles as a transport mode. A supplementary document is available that contains notes from these discussions.

Table 3-1 List of people interviewed

Name	State	Organization
Dave Synder	California	California Bicycle Association
Todd Scott	Michigan	Detroit Greenways
Gina Poertner	Kansas	KanBikeWalk
Liz Cornish	Maryland	Bikemore
Nate Evans	Maryland	Bike Maryland
Richard Fries	Massachusetts	Massachusetts Bicycle Coalition
Amy Johnson Ely	South Carolina	Palmetto Cycling Coalition
David Goodman	Virginia	BikeArlington
Garrett Hennigan	District of Columbia	Washington Area Bicyclist Association
Ted Heyd	Colorado	Bicycle Colorado
Bob Beane	Arizona	Coalition of Arizona Bicyclists
Ed Barsotti	Illinois	Ride Illinois
Steven Goodridge	North Carolina	BikeWalkNC
Bonnie Winslow	Oklahoma	Oklahoma Bicycling Coalition
Brent Hugh	Missouri	Missouri Bicycle and Pedestrian Federation
Rob Sadowsky	Oregon	Bicycle Transportation Alliance
Peter Furth	Delaware	Northeastern University
Ralph Buehler	Virginia	Virginia Polytechnic Institute and State University

4 APPENDIX D: ALTERNATIVE DESIGNS AND TREATMENTS

Interesting, although, perhaps not directly relevant, are some of the alternative designs that were identified from across the globe during our study. This section provides an overview of these designs.

4.1 ROADWAY SEGMENT

4.1.1 Center median bike lane covered with solar panels: A Korean example

A bike lane design in Korea was identified that has several novel features (Shin et al., 2013). This bicycle treatment involves center median bike lanes protected by iron fences on both sides. It is installed on a 8-lane highway in South Korea. The highway is used by commuters between the cities of Daejeon and Sejong. The bike lanes runs for 20 miles along the highway median and is covered by solar panels. The solar panels provide shade for the bicyclists and simultaneously generate electricity. There are underway exit and entry roads built at five locations along the bikeway such that bicyclists are separated from motor vehicle traffic not only when riding on the bikeway but also when entering and exiting to and from it. The design is illustrated in Figures 4-1 and 4-2. More details can be found at: http://www.treehugger.com/bikes/bike-lane-down-center-korean-highway-covered-solar-panels.html.

This solution allows for undisrupted bicycle flows near high-speed merging or diverging vehicular roadway lanes.

Figure 4-1 Center median bike lane in South Korea

Figure 4-2 Birds' eye view of center median bike lane in South Korea

4.2 INTERCHANGE: CANADIAN EXAMPLES

The following section presents the interchange design treatments found in Canada (see Figures 4-3 and 4-4).

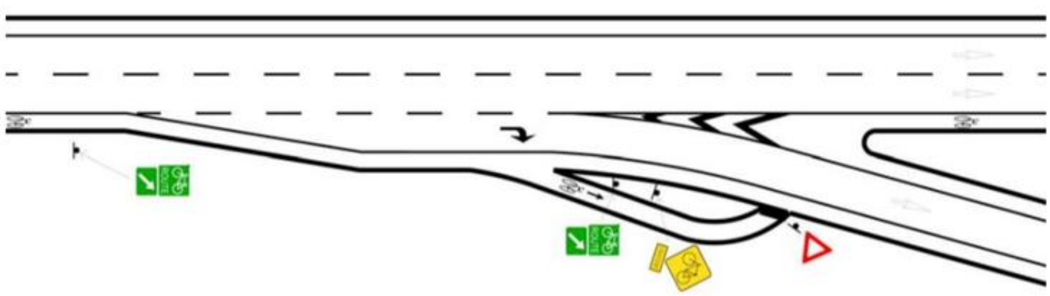
According to the Canadian Design Guidelines (BC Recreation and Parks Association, 2010; Transportation Association of Canada, 1999), a bikeway that is at least 1.5m (5 ft) wide should be provided at any interchange with two exceptions:

i. The minimum width increases to 2.0 m (6.5 ft) with a posted speed limit between 70 and 80 km/h (45 and 50 mph) and between 5000 and 10000 motor vehicles per day;
ii. The minimum width increases to 2.5m (8.2 ft) with posted speeds over 80 km/h (50 mph) and daily traffic volume greater than 10,000 motor vehicles.

Note that freeway entrance type ramps are potentially more dangerous than the freeway exit type ramps because: 1) bicyclists must look over their shoulder to establish the presence of oncoming motor vehicle traffic in order to weave across a ramp lane; 2) bicyclists should yield to motor vehicle traffic, according to the Canadian Design Guide (Transportation Association of Canada, 1999).

Taking the above concerns into consideration, two design alternatives are proposed for diverging ramps on roads with posted speed limits over 70 km/h (45 mph).

The first one is a jug handle design (see Figure 4-3) similar to that which is recommended in the AASHTO guide (AASHTO, 2012). Note that wayfinding signage is suggested in conjunction with the geometric design of the bikeway. The wayfinding signage at the ramp entrance can encourage bicyclists to use the curved bikeway. The warning sign for motorists together with the yield sign for bicyclists clarifies the right-of-way for both parties at the ramp.



Source: TAC Bikeway Traffic Control Guidelines for Canada

Figure 4-3 Canadian design 1 for diverging ramps

The second one (see Figure 4-4) is to guide bicyclists to a location downstream the ramp with shoulder widened by 3.5m (11.48 feet), in addition to the width of the shoulder, to provide bicyclists with a waiting area. This design has several weaknesses, including that: 1) the potential cyclist crossing area is triangular and gives drivers more difficulty in predicting bicyclists' crossing path; 2) the additional shoulder width is hard to maintain because of possible plowability problems.

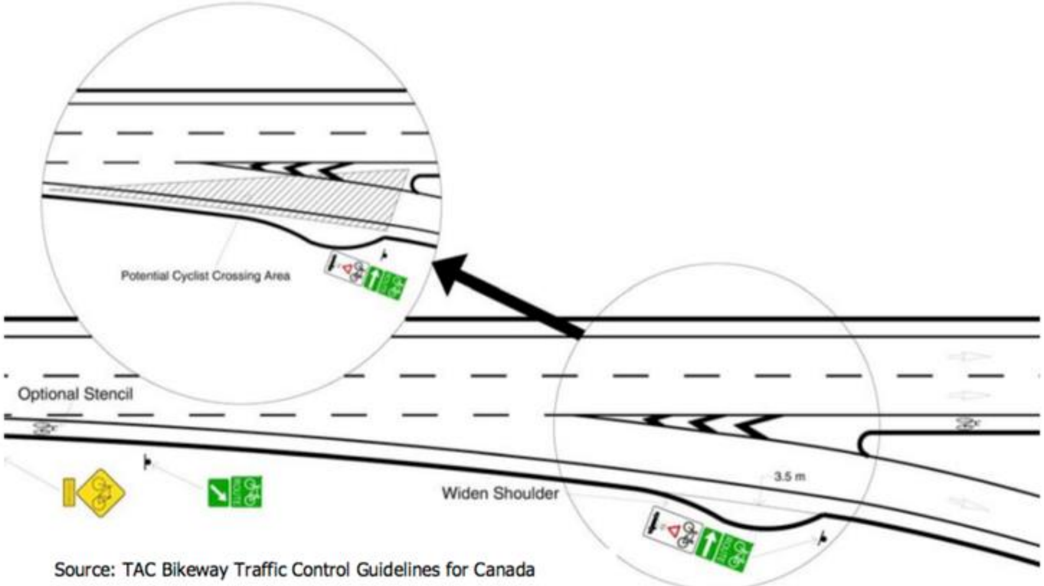


Figure 4-4 Canadian design 2 for diverging ramps

4.3 ACCOMMODATING LEFT-TURNING BICYCLISTS: AUSTRALIAN EXAMPLES

4.3.1 Protected left-turn bay for bicyclists only in the median

The following design (see Figure 4-5) shows a protected left-turn bay for bicyclists. (It should be noted that the figure presents a right-turn bay as this is an Australian example where motorists drive on the left side of the roadway.) This treatment provides bicyclists a safe left-turn location that is physically separated by a curb along with a plastic barrier. Application of this design in a high-speed environment would require additional treatments to enable the cyclist to reach the turning bay.

Figure 4-5 Right-turn bay for bicyclists in Australia

4.3.2 Jug handle treatment for bicyclists at T-intersections

This section including Figure 4-6 presents a design treatment aimed at accommodating bicyclists at T-intersections. The treatment directs bicyclists onto a path off to the left of the road and provides storage area where bicyclists can wait until they are given a green signal to cross the main road.

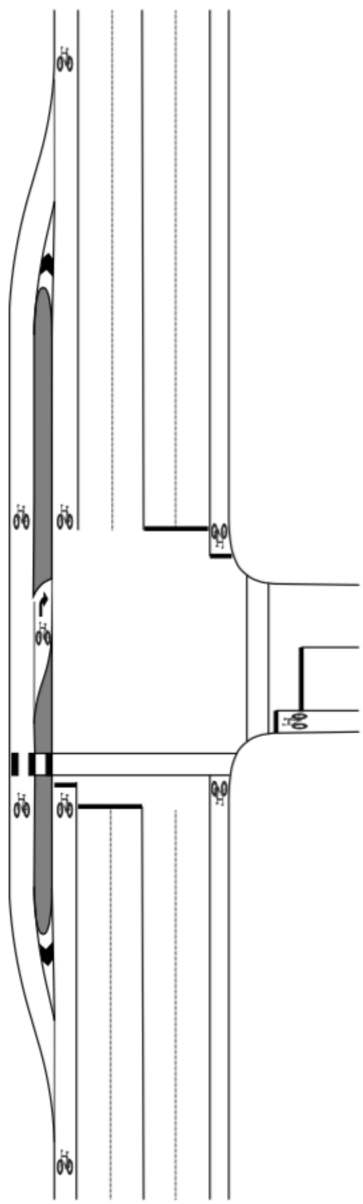


Figure 4-6 Jug handle treatment for right-turn bicyclists in Australia

(Source: Eady & Daff, 2012)

*The figure shows right turns because Australians drive on the left

4.4 ACCOMMODATING RIGHT-TURNING BICYCLISTS: AN AUSTRALIAN EXAMPLE

4.4.1 RT slip lane for bicyclists

To better accommodate right-turning bicyclists, Australians proposed the design of a right-turn slip lane for bicyclists (see Figure 4-7). A 2.3 m (7.5 ft) wide bike lane should be provided, marked with green paint, white bicycle symbols and, signage indicating the lane is bicycle only. A median island separates the lane from right-turning traffic and the right-turn slip lane joins with green delineated bike lanes. This can be a cost-effective treatment when incorporated in intersection upgrades.

Figure 4-7 Left-turn slip lane for bicyclists in Australia

*The figure shows a left-turn slip lane because Australians drive on the left

4.5 SIGNAGE, COLORED MARKINGS AND TEXTURES

4.5.1 Colored pavement on bike lanes

Colored pavements are another treatment used in bicycle facility implementations. Hunter et al. (2000) studied the effect of blue pavement markings with an accompanying “Yield to Bicyclists” sign on reducing bicycle-motor vehicle conflict in the city of Portland, Oregon. The crossings were at locations where bicyclists travel straight and motorists cross the bike lane to exit (such as an off-ramp situation), enter a right-turn lane, or merge onto a street from an on-ramp. It was found that significantly higher numbers of motorists yielded to bicyclists and more bicyclists followed the colored bike lane. Hunter, Srinivasan, & Martell (2008) found a significant increase in yielding behavior by motor vehicles when evaluating a colored bike lane in St. Petersburg, Florida.

A study carried out by Sadek, Dickason, & Kaplan (2007) evaluated the effectiveness of a colored (green) bicycle lane and crossing treatment located on a cloverleaf interchange in South Burlington, Vermont. They concluded that the colored bike lane encouraged the use by bicyclists of the bike lane over the sidewalk or other travel lanes. The study did not find evidence of motorists yielding to bicyclists at conflict points as a result of this treatment. The use of colored pavement to highlight conflict points, including alongside bike lane lines, is also recommended by ITE (Mitman & Rideway, 2014).

5 APPENDIX E: CYCLE TRACKS

5.1 FORMS OF CYCLE TRACK SEPARATION

Table 5-1 provides an overview of separation strategies for cycle track implementations. The selection of separation type(s) should account for the presence of on-street parking, overall street and buffer widths, cost, durability, aesthetics, traffic speeds and speed limits, emergency vehicle and service access, and maintenance (Federal Highway Administration, 2015). Advantages and disadvantages in relation to these characteristics are included in the table.

Table 5-1 Types of cycle track separations (Adapted from Separated Bike Lane Planning and Design Guide, FHWA)

Type of separation	**Advantages**	**Disadvantages**	**Feasible to install on high speed roads**	**Vehicle access in case of emergency**
Flexible posts	• Low cost • Good visibility • Easy installation	• Low durability • Low aesthetic quality	Yes	No
Bollards	• Provide a strong vertical element to the buffer space	• Increased cost • May not be as appropriate on higher speed roadways	No	No
Concrete barrier	• Provide the highest level of crash protection to bicyclists • Less expensive • Little maintenance required	• Less attractive to road users • May require additional drainage and service vehicle solutions	Yes	No
Raised median	• Attractive to bicyclists • Little long-term maintenance required	• Expensive	Yes	Yes
Raised lane	• Make the bicyclists more visible	• May require additional drainage considerations • May be difficult to maintain during winter snow removal	No	Yes
Planters	• Aesthetic • Quick to install	• Expensive • Require landscaping • Crashworthiness questionable	No	No
Parking stops as form of separation	• Inexpensive • High durability • Good solution when minimum buffer width available	• Low level of comfort and protection for bicyclists	Yes	Yes
Parked cars	• Provide additional protection and comfort for	• A minimum width of 3 ft buffer is needed to allow for door opening	No	No

	bicyclists	• Should be combined with additional means of separation		

These forms of separation are not all appropriate for use in high-speed roads. Considering installation cost, durability, maintenance, and emergency vehicle access, flexible posts, bollards, concrete barriers, raised median and parking stops are potential candidates for separating cycle tracks from vehicle lanes. While bollards and concrete barriers may provide more protection for bicyclists, as they provide rigid separation, they preclude vehicle access in emergencies. It may also be the case that where cycle tracks are implemented, space originally reserved for shoulders is utilized. In these situations, emergency vehicle access to both vehicular and bicycle facilities will be intrusive. Flexible posts, raised median, and parking stops may offer benefits in terms of emergency vehicle access. Note that separation types can be combined to provide solutions that are safe for bicyclists and also reserve emergency vehicle access.

No specific studies of safety concerns for the various separation types could be identified. However, statistics from cities where cycle tracks or buffered bike lanes have been installed suggest that the provision of separation between bicycles and motorized vehicles can increase bicycle usage while the crash rates and cyclist injury risk remain unchanged or even show a reduction. Studies specific to the safety of buffered bike lanes and cycle tracks in the District of Columbia and New York City have been published. Goodno et al. (2013) found that bicycle volumes quadrupled in corridors in which these facilities were installed. It was also noted that crash rates remained unchanged after the bicycle facility installations. New York City conducted a study of routes with cycle tracks using three years of post-installation data (New York City Department of Transportation, 2014). This study found that cyclist injury risk decreased on the cycle tracks in New York City as bicycle volumes increased.

The most relevant studies have compared perceived safety and comfort levels for the various separation designs. Monsere et al. (2014) concluded that separation approaches that employ a physical barrier have greater perceived safety than a buffer created through the application of paint. Additionally, actual separation between bicycle and motor vehicle traffic streams has significantly greater impact on perceived safety than bicycle facility width alone. Figure 5-1 shows the comfort rating of different separation types in descending order in comparison to a conventional bike lane (shown at the top of the figure).

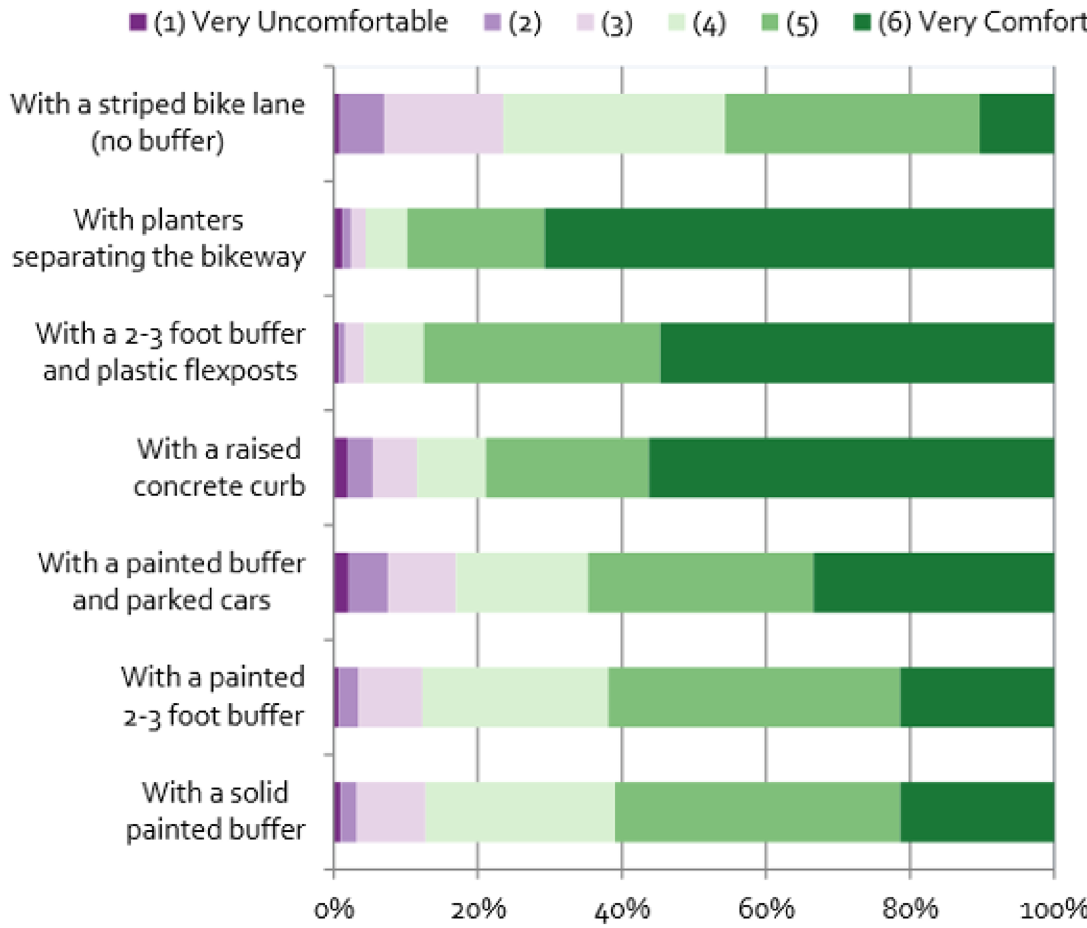


Figure 5-1 Perceived safety of bike facilities (Source: Lessons from the Green Lanes)

McNeil et al. found that 71% of all residents and 88% of the "Interested but Concerned" would be more likely to ride a bicycle if motor vehicles and bicycles were physically separated by a barrier. McNeil et al. (2015) suggest striped or painted buffers offer some level of increased comfort, while buffers with some level of physical protection, even as minimal as plastic flexposts, can increase perceived safety. Increased bicycle ridership can be expected with increased perceived safety.

6 APPENDIX F: SHALLOW GROUND-IN/IN-LINE CYCLE RUMBLE STRIP

6.1 MINNESOTA TREATMENT

An example is illustrated below of a ground-in/in-line rumble strip deployed for a bike lane in Minneapolis, Minnesota:

Figure 6-1 Ground-in/In-line cycle rumble strip. Minneapolis Minnesota

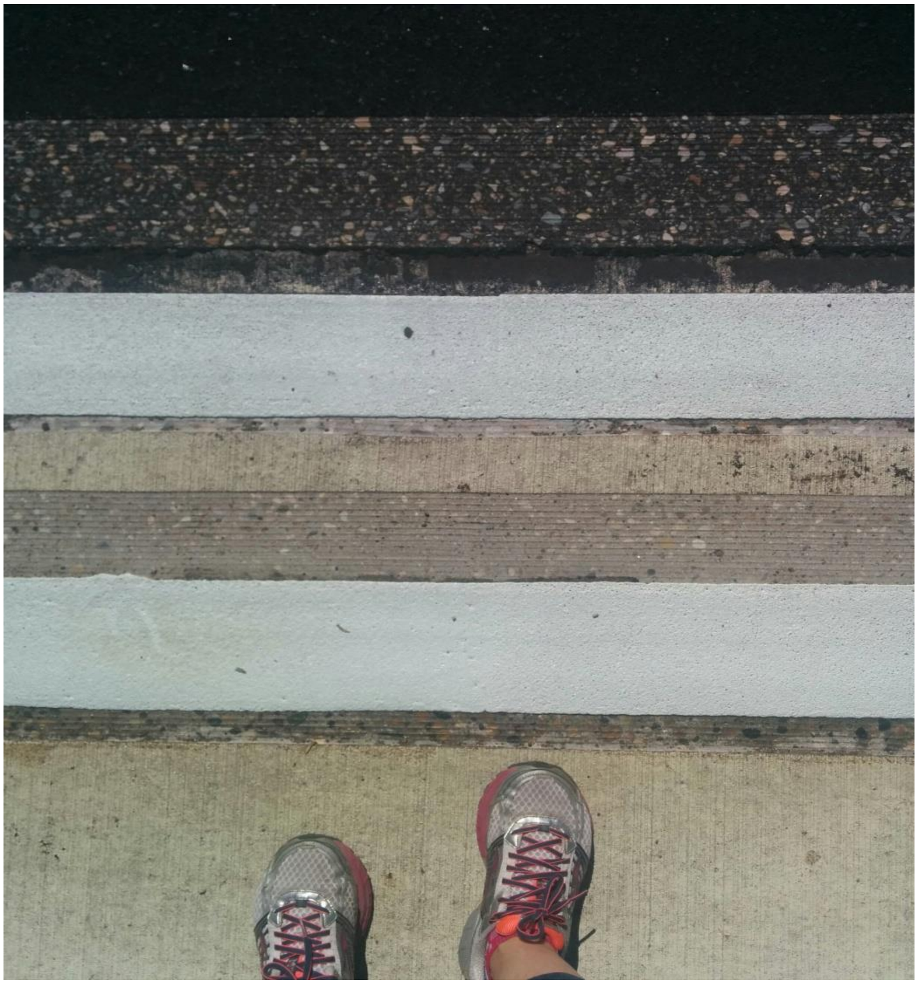


Figure 6-2 Detail A: Ground-in/In-line cycle rumble stip

Figure 6-3 Detail B: Ground-in/In-line cycle rumble strip

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