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16. Abstract

The primary goal of this study was to identify and compile a list of potential hazards to cyclists, to rank order the hazards in terms of their perceived and actual degree of risk, and propose mitigation actions to address these hazards. Of particular concern was the mitigation actions that can be incorporated in an agency's regular maintenance activities; however, in almost all cases, there may be corresponding considerations that are better addressed at the design stage, and these are pointed to as well. This report presents the guidelines developed in this study for the detection and mitigation of the principal roadway hazards for bicyclists.

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BICYCLE Hazard Mitigation Manual

by
Alix Demers
Anne Suddarth
Hani S. Mahmassani
The University of Texas at Austin

and
Siamak A. Ardekani
Shekhar Govind
The University of Texas at Arlington

Detection and Mitigation of Roadway Hazards for Bicyclists
Research Study 0-1394

conducted for
Texas Department of Transportation

in cooperation with
U.S. Department of Transportation
Federal Highway Administration

by the
Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin
and
The University of Texas at Arlington

December 1995

Implementation Statement

The findings of this study can be used by traffic engineers and maintenance personnel in the Texas Department of Transportation and cities in Texas. The final report from this project, 1394, contains more specific implementation guidelines based on this study.

Disclaimers

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data resented herein. The contents do not necessarily reflect the official views of the policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

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Hani S. Mahmassani, P.E. (Texas No. 57545)
Siamak A. Ardekani, P.E. (Texas No. 018753)
Research Supervisors

Foreword

The present manual is intended for the use of transportation agency personnel in charge of maintaining the road network to move traffic efficiently and ensure the safety of the public. The purpose of the manual is to provide simple guidelines to assist agency personnel in identifying situations that pose a hazard to bicyclists, and to suggest some simple solutions to mitigate the hazard. To assist agency personnel in recommending such mitigation strategies, ranges for the cost of these solutions and provided. These costs reflect the recent experience of TX DOT engineers in various districts of the State. However, it should be recognized that these are only approximate values, and that site specific factors may involve either higher or lower values.

This manual was prepared to help disseminate the results of research study 1394. The study was performed jointly by the Center for Transportation Research at the University of Texas at Austin and the Center for Transportation Studies at the University of Texas at Arlington as part of the cooperative research project with the Texas Department of Transportation.

Acknowledgements

This study's investigators would like to express their appreciation to the project director, Mr. Paul Douglas, as well as to the members of the study advisory panel formed by Mr. Douglas. They have provided many valuable comments and suggestions that have substantially contributed to the success of the study. The study investigators would also like to thank Mr. David Jessup, Mr. Paul Cooper, Mr. Seyed Moghaddas, Mr. Mac Elliott, Mr. W.J. "Bud" Melton, III and Mr. Steven Lusky whose guidance and comments proved invaluable to the successful completion of this study.

BICYCLE Hazard Mitigation Manual

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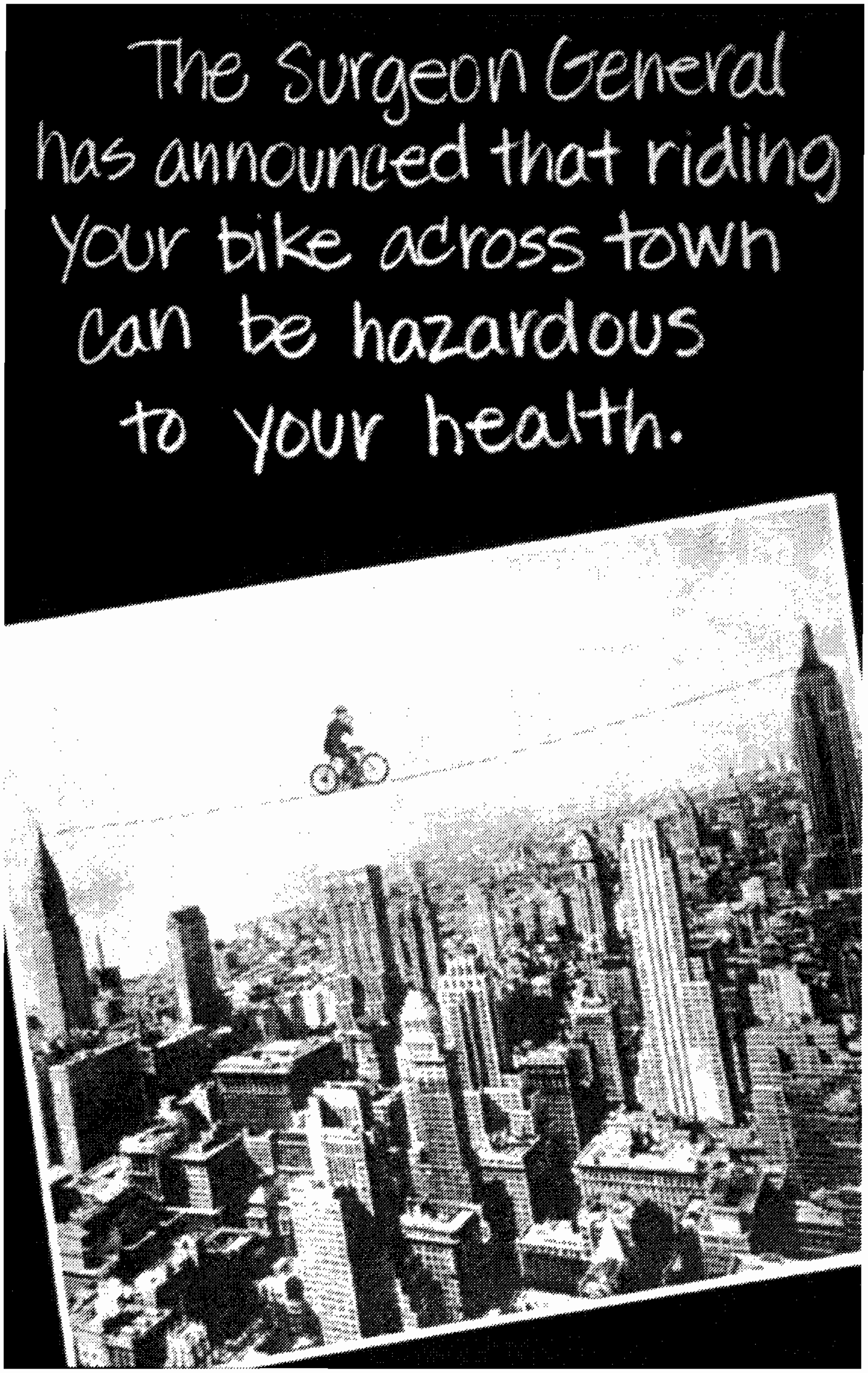
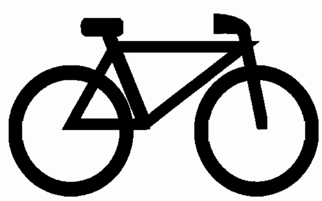
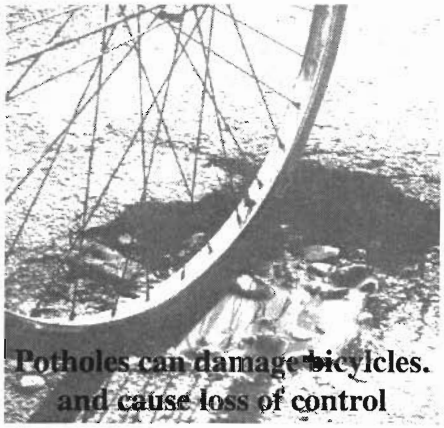


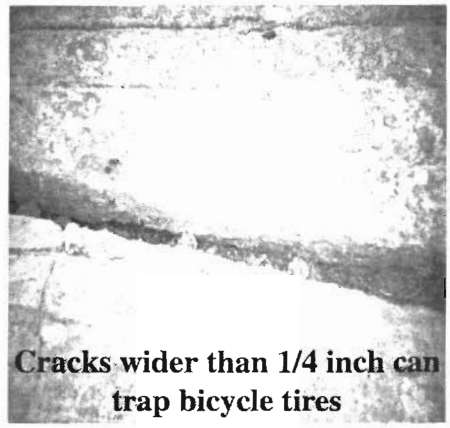
Bicycle Hazard Mitigation Manual



Hazard #1 Surface Irregularities



Potholes can damage bicycles. and cause loss of control



Cracks wider than 1/4 inch can trap bicycle tires

Hazardous rough pavement and non-flush manhole cover

Symptoms

- Potholes 6" long, or longer
- Ruts and cracks wider than 1/4 inches

Solutions

- Patch or repair
- Warn cyclists (striping, signs and/or flashers)
- Schedule regular maintenance/checkups
- Initiate spot improvement progam

Other surface irregularities:

- Steel plates on roadways
- Differential pavement settlement
- Non-flush manhole covers
- Unpaved driveways
- Unpaved/gravel roads
- Unsmooth patches (hardened cement, tar on surface)
- Stone-paved roads (cobblestones)

Surface irregularities such as potholes, ruts and cracks

The most common surface irregularities, which also pose the greatest risk to cycling include potholes, ruts, and wide longitudinal pavement cracks. These problems are not only hazardous to cycling but also greatly compromise the integrity of the pavement structure and are also relatively inexpensive to fix. Therefore they should be immediately addressed. Roadways with regular bike traffic should especially be inspected more frequently.

The solution procedures for these problems are well-established and include filling the potholes, resurfacing the rut area, and sealing the cracks. Currently, most TxDOT Districts seal pavement cracks wider than about 20 mm (3/4"). ***Cracks 7 mm (1/4") or wider should be sealed to accommodate cyclists.*** **Table 1** (next page) provides unit cost estimates for these suggested solutions. These estimates are based on 1993 dollars and are extracted from the Texas Department of Transportation's Routine Maintenance Annual Report.

Table 1. Typical Costs for Various Surface Repairs

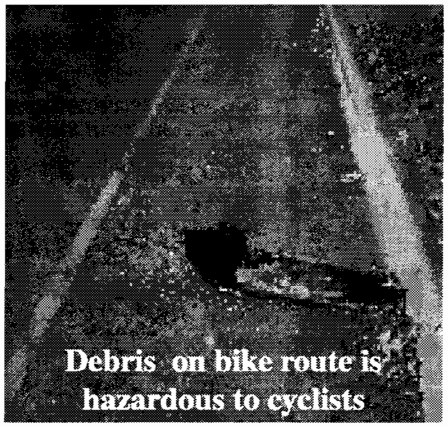
Typical Cost and Time (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Resurfacing (concrete) [3]	$ 5 /sq. yd.	$ 8 /sq. yd.	360
Resurfacing (asphalt)	$ 1.75 /sq. yd.	$ 2.50 /sq. yd.	110, 120 211, 212, 213
Sealing cracks (concrete)	$ 50 /yd.	$ 500 /yd.	320
Sealing cracks (asphalt)	$ 1.25 /ft.	$ 1.75 /ft	221, 222, 231 232, 233, 234
Repair spalling (concrete)	—	—	340
Filling potholes (asphalt)	$ 50 hole	$ 500 /hole	241, 242
Pothole repair (asphalt)	0.5 person hr,	1 person hr,	—

1 Cost and time estimate provided by workshop participants.

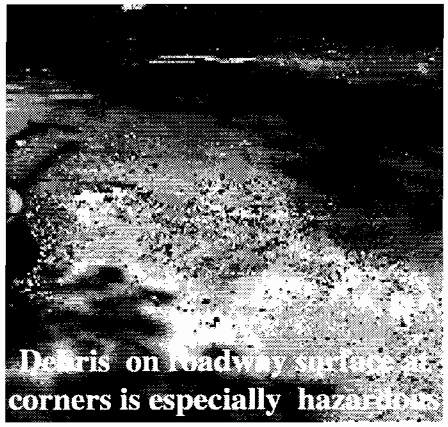
2 Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

3 Small scale resurfacing.

Hazard #2 Debris on Roadway Surface



Debris on bike route is hazardous to cyclists



Debris on roadway surface at corners is especially hazardous

Symptoms

- Debris (e.g., sand, gravel) on roadway surface (especially at turns)

- Debris in bike lanes swept from auto lanes

Solutions

- Identify locations for sweeping and develop a regular sweeping schedule (at least every 10 days and also along designated bike routes)

- Special attention should be given to sweeping roadway work zones and bottle disposal/collec tion sites

- Implement citizen/maintenance roadway surface problem reporting exchange

- Use wide outside lanes where possible (15 to 16')

- Consider controling bottle disposal by deposit laws

Sand, Gravel, and Debris on Roadway Surface
(including debris swept into bike lanes from adjacent motor vehicle lanes)

These problems are also relatively inexpensive to address and are beneficial to motorists as well. Gravel, sand, or debris could substantially reduce surface skid resistance for all traffic. They could also increase frequency of incidents of broken windshields for motorists and flat tires for motorists and bicycles. Sources of roadway debris, sand, and gravel include sanding operations to de-ice bridges and overpasses, unpaved driveways, runoff water, dirt and debris from commercial trucks, and accidents. A primary means of mitigating this problem is to institute a regular roadway sweeping program, particularly for designated bike routes and roadways expected to be frequented by cyclists. To date, many Texas cities have no systematic street sweeping program. Unpaved driveways, particularly along bike routes, should also be paved. When driveway permits are issued for warehouses, loading docks, and other facilities used by commercial trucks, truck wash areas could be required. Washing commercial trucks before they leave these locations would prevent dirt and debris from tracking onto the roadway.

Use of wide outside lanes 4.6 m to 4.9 m wide (15' to 16') where possible would afford cyclists, among other benefits, additional maneuverability to avoid debris. It should however be noted that when wide outside lanes are striped for a separate bicycle lane, motor vehicles would not drive on that part of the pavement and would instead brush roadway debris onto the bicycle lane. Therefore, if a wide outside lane is used, striping it for a designated bicycle lane is not recommended. Finally, a line of communication would need to be established through which cyclists could report roadway surface problems to the maintenance crew. Such a program has been successfully implemented in a number of cities, including Seattle and Dallas. The costs associated with the various treatments discussed above are shown in **Table 2** (next page).

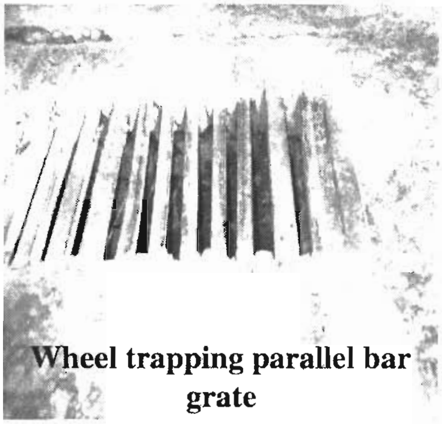
Table 2. Lane Widening and Surface Clean-up Unit Costs

Typical Cost (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Widen lane (1 ft.) – urban	$ 12,000 /mile	$ 21,000 /mile	245
Widen lane (1 ft.) – rural	$ 10,000 /mile	—	245
Edge repair	—	—	270
Street Sweeping	$ 40 / mile	—	521, 522, 524
Surface driveways	$ 3.50 /sq. yd.	$ 4.50 /sq. yd.	593, 594

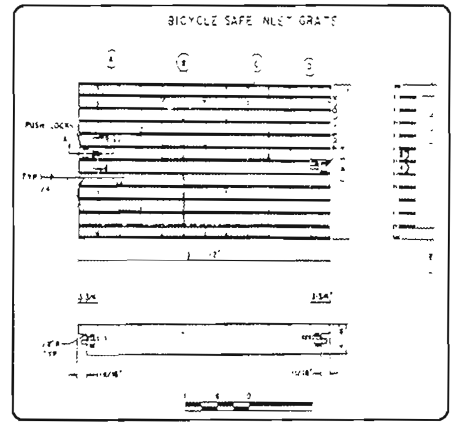
1 Cost estimate provided by workshop participants.

2 Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

Hazard #3 Parallel Bar Grate Catch-Basins


Wheel trapping parallel bar grate


Another example of a wheel trapping parallel bar grate



Symptoms

• Parallel bar grate catch-basins

Solutions

• Identify and either replace parallel bar grates or weld temporary ties across the bars, until replacement

• Warn cyclists with striping, signs and/or flashers

Catch-Basins with Parallel Bar Grates

Drainage catch-basins with bars parallel to the roadway travel path are a serious hazard to cycling and must be remedied on a priority basis. The City of Dallas, for example, let a contract in March 1995 to replace such existing grates with a safer design. The replacement cost in the Dallas project averaged about $280 per grate replacement **(Table 3)**. Additionally, TxDOT calls for a bicycle-safe grate with perpendicular slots on new designs.

Among the potential solutions is the retrofitting of such existing grates with both longitudinal and horizontal bars to minimum design spacing specifications. In such retrofit, hydraulic efficiency should not be overlooked. A more costly alternative **(Table 3)** is to replace the unsafe grates with a criss-cross or angled slot design (U.S. DOT, 1993). In doing so, uniformity of slot orientation should be maintained to reinforce cyclists expectations of the hazards involved. These grates should be secured to the inlet structure/frame by tack welds or bolts to prevent "easy" removal but allow cleaning and maintenance of the drainage structure. One option is to design the grate with an attachment such as 13 mm (0.5") diameter stainless steel five-sided bolts to prevent unauthorized removal. Alternatively, design specifications could discourage the use of grates on pavement surface in favor of curb-opening type inlets.

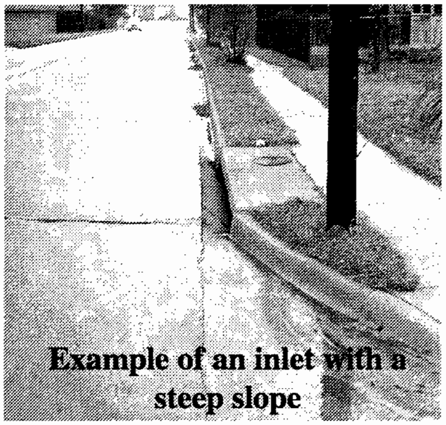
Table 3. Unit Cost and Man Hours Associated with Drainage and Inlet Grates

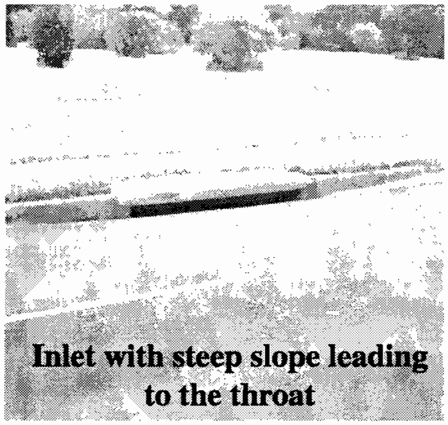
Typical Cost (1993 $)			
	Lower [1]	Upper	Recent Cost [2]
Replace grate ($ / grate)	$ 200	$ 300	$ 280
Replace grate (person-hour)	—	2	—
Realign grate (person-hour)	1	4	—
Grate inlet ($ / grate)	$ 240 ea.	$ 280 ea.	—
Grate inlet (person-hour)	0.5	1	—

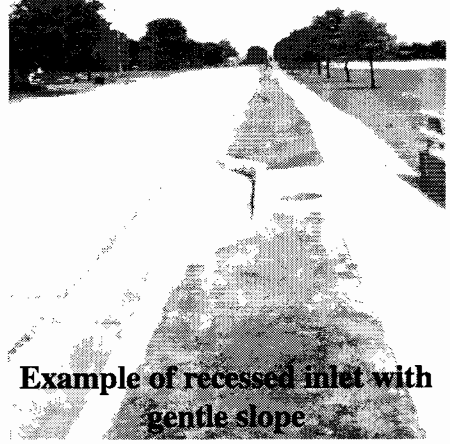
1 Cost estimate provided by workshop participants (includes labor and material).

2 Dallas District March 1995 contract.

Hazard #4 Curb-Opening Catch-Basins


Example of an inlet with a steep slope


Inlet with steep slope leading to the throat


Example of recessed inlet with gentle slope

Symptoms

- Catch-basins with steep curb entry slopes
- Steep sloped gutters

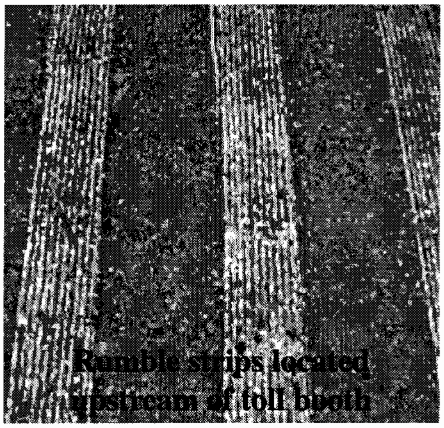
Solutions

- Recess catch-basins into curb
- Keep catch-basins and gutters away from cyclists' path
- Warn cyclists with striping, signs flashers

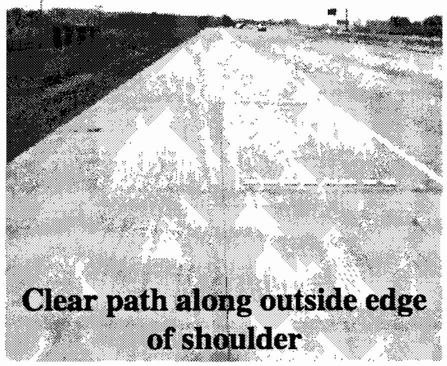
Curb-Opening Catch-Basins with Steep Entry Slopes

Curb-opening catch basins with steep slopes leading to the inlet throat pose a significant hazard to cycling. These inlets should be offset from potential bicycle wheel paths and should be designed with milder and longer slopes to the inlet throat. Recessed inlets are one solution to this problem. However, some recessed inlets may not be hydraulically efficient. Moreover, inlets should be recessed only when sidewalk space is not encroached. In new design, 450 mm to 600 mm (1.5' to 2') of space should be allowed in the right-of-way between the sidewalk and the pavement edge for recessed inlets. Finally, recessing short inlets ($\leq$ 3 m) is generally a safe design. However, longer recessed inlets could pose a problem to motorists who may consider the curb as a delineator of the outside lane. In such cases vehicles could jump the curb at the end of the recessed inlet.

Hazard #5 Rumble Strips



Rumble strips located upstream of toll booth



Clear path along outside edge of shoulder

Symptoms

- Improperly designed rumble strips (e.g., continuous jiggle bars, raised buttons, short flush strips)

Solutions

- Allow for bike travel on right side of rumble strips (4 to 6 ft)
- Limit use of continuous rumble strips (alternate strips with smooth pavement)
- Ideal continuous strips should have about 460 mm wide plain flush pavement followed by about 150 mm wide depressed strip with depression approximately 5 mm deep
- Limit use of raised pavement markers (use paint markings instead)
- Remove rumble strips used at gores and intersections
- Warn cyclists with striping, signs and/or flashers

Improperly Designed Rumble Strips

Rumble strips are pavement grooves or raised buttons laid out laterally across driving lanes or shoulders. Once driven over, they generate a jiggling noise, which warns drivers that they are leaving the road or they are approaching a low speed limit area such as a tollbooth. Rumble strips constructed with raised buttons are often referred to as "jiggle bars". The previous page shows typical jiggle bars along the outside shoulder of a freeway.

When jiggle bars are used in shoulder areas, an effective bicycle accommodation is to provide 4'-6' wide channels along the outside edge of the shoulder. This includes providing a clear open path through jiggle bars used at exit and entrance gores as well as for intersection channelization. **Table 4** (next page) lists the typical costs of removing raised buttons as well as pavement sanding and restriping, which may be necessary when jiggle bars are removed.

A more traditional rumble strip is one constructed through pavement grooves laterally across the pavement. A variety of designs in terms of the groove width, depth, and spacing exist. While some of these designs represent a rough and uncomfortable ride for cyclists, other designs are tolerable.

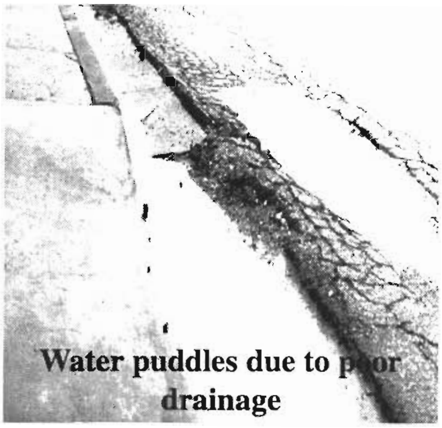
Table 4. Unit Costs for Removal or Installation of Rumble Strips and Jiggle Bars

Typical Cost (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Remove button	18 ¢ / button	40 ¢ / button	713, 715
Remove 4" stripe	50 ¢ / ft.	—	715
Sandblast	10 ¢ / ft.	—	711
Paint	15 ¢ / ft.	—	710, 713
Thermoplastic	30 ¢ / ft.	—	712
Restripe pavement	$ 1 / ft.	$ 2 / ft.	710, 711, 712, 715
Install buttons / jiggle bars	$ 1 / button	$ 5 / button	750

1 Cost estimate provided by workshop participants.

2 Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

Hazard #6 Poor Surface Drainage



Water puddles due to poor drainage

Symptoms

- Standing water

Solutions

- Patch or resurface area
- Install under-drains and curb and gutter

Poor Surface Drainage

Poor surface drainage results in reduced skid resistance and accelerated pavement deterioration, particularly in cold climates. These problems affect both motorized and bicycle traffic. In addition, cyclists riding through puddles of standing water would have little idea on how deep the standing water may be. There is also the splashing water effect from passing traffic. Although most remedies for poor surface drainage are fairly expensive, for the above reasons remediation of such problems should be a top priority item.

All such problem areas should be identified and patched or resurfaced. Patching, while a less expensive remedy, could often lead to more problems if not done properly. These include uneven riding surfaces and seepage of water into the subsurface pavement layers. Where possible resurfacing should be considered. Resurfacing cost estimates are provided in **Table 5**.

Installations of under-drains and curb and gutter may also be necessary to prevent the recurrence of drainage problems. Gutters should be designed as an integral part of the outside driving lane, without longitudinal joints. Also as a design issue, designers should consider roadway cross-slope and longitudinal grade in combination to provide proper drainage.

Table 5. Typical Resurfacing Costs and Time Requirements

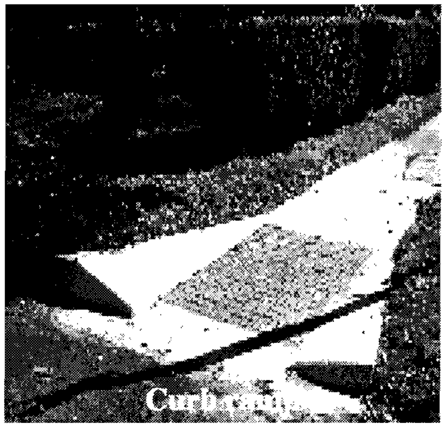
Typical Resurfacing Time & Costs (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Cost (per lane mile)	$ 20,000	$ 40,000	110, 120
Cost (per sq. yard)	$ 200	$ 250	821, 822, 823
Time (person-days / lane-mile)	4	8	—
Install under-drains	—	—	130
Install curb and gutter	—	—	485

1 Cost estimate provided by workshop participants.

2 Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

Hazard #7 Paths Discontinued by Curb


Bike path discontinued by curb


Curb ramp

Symptoms

- Bike paths that are discontined by a curb

Solutions

- Identify and replace with a curb ramp
- Install warning sign until replacement

Bike Paths Discontinued By A Curb

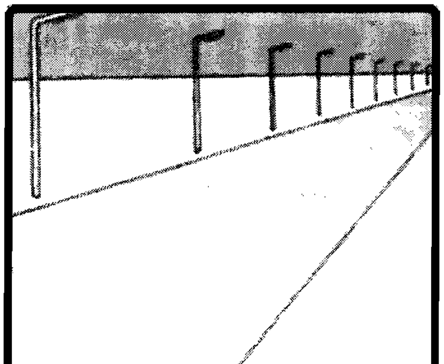
Bicyclists should generally be discouraged from using sidewalks. Riding on sidewalks could result in serious conflict with pedestrians. Children, however, have a tendency to ride on sidewalks, particularly near school areas. At times, sidewalks in these and other locations have a curb ramp at one end while the other end is discontinued by a curb. In general such situations should be avoided as they are in direct conflict with Americans with Disabilities Act requirements. **Table 6** summarizes costs associated with constructing curb ramps.

Table 6. Unit Costs for Construction of Wheelchair Ramps at Curbs

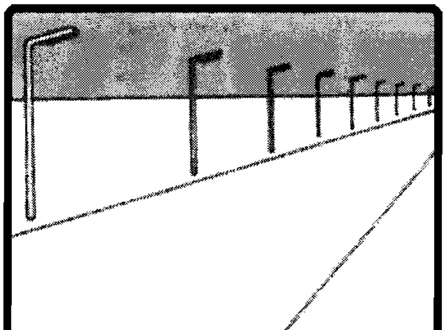
Typical Ramp Costs (1993 $)		
	Lower [1]	Upper
Ramp from curb to pavement (per feet of curb)	$ 3	$ 4
Ramp from curb to pavement (per sq. yd.)	$ 35	—

1 Cost estimate provided by workshop participants.

Hazard #8 Lighting



Strobing should be avoided



Optimized spacing of fixtures provides uniform light

Symptoms

- Insufficient lighting along designated bike paths

Solutions

- Insufficient lighting in areas cyclists ride
- Provide/add lighting where appropriate (including underpasses)

Insufficient lighting

Roadways that are expected to accommodate cyclists at night should be well-lit. The height and spacing of light fixtures is critical, however. Light poles that are spaced too far apart create strobes that are also hazardous to nighttime cycling.

An acceptable lighting treatment is sodium lights spaced on 12-meter (40-foot) poles at 75m-90m (250'-300') with 250 watts. This arrangement will provide sufficient lighting for two lanes. Therefore, on a two lane street, light fixtures will be needed only on one side of the roadway. See **Table 7** (next page).

Table 7. Typical Street Lighting Costs and Labor

Typical Lighting Cost and Time (1993 $)			
	Lower [1]	**Upper**	**Function Codes** [2]
Street lighting – cost / mile	$ 33,000	—	742
Street lighting – cost / pole	$ 1,500	$ 2,000	—
Street lighting – person-days / pole	4	6	—

1 Cost estimate provided by workshop participants (includes labor and material).

2 Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

Hazard #9 Roadside Obstructions

Symptoms

- Obstructions restricting vertical clearance
- Unpruned trees more than 3' from pavement edge
- Signs close to roadway lower than 7'

Solutions

- Identify and eliminate obstructions and/or place adequate warning signs
- Schedule regular and spot maintenance

Roadside Obstructions with Inadequate Vertical Clearance

The most common roadside objects that could restrict vertical clearance to cyclists include traffic signs that are too short and overgrown tree branches. Mitigation measures should include quick identification of such cases, relocation of signs that are too short, and regular trimming of trees and other overgrown vegetation, particularly along bike paths.

To implement such measures, an inspection program should be initiated to identify all signs lower than 2.1 m (7') and to replace or relocate them so that they no longer pose a problem. Another project to be considered is an "Adopt-A-Bikepath" program. In this program bicycle groups and other interested entities help in maintenance of a bike path by regularly inspecting the paths and reporting such hazards as badly placed signs, overgrown vegetation, etc. Regular trimming of trees and other vegetation along streets and bike paths should also be implemented. **Table 8** (next page) summarizes the person-hours of effort required for trimming.

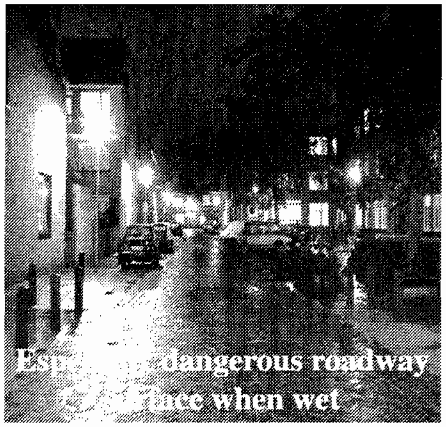
Table 8. Labor Needs for Right-of-Way Maintenance Activities

	Typical Time		
	Lower [1]	Upper	Function Codes [2]
Trim tree (person-hours/tree)	2	3	552
Remove signs	—	—	580, 581, 734
Install signs	—	—	732, 733
Adopt-A-Highway	—	—	525

1 Time estimate provided by workshop participants.

2 Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

Hazard #10 Pavement Friction



Esp[illegible] dangerous roadway [illegible]face when wet

Slick when wet pavement

Symptoms

- Slippery-when-wet-pavements (especially near intersections, horizontal curved downhill grades and immediately upstream of intersection stop lines)

Solutions

- Add small lateral grooves to pavement to improve drainage and traction (broom finish, seal coat)

- Install "Slippery-When-Wet" signs

- Consider stricter construction guidelines

Slippery-When-Wet Pavements

Slippery-when-wet pavements could be due to a variety of sources. Main causes include motor oil spillage-especially near intersections, improper asphalt mix design resulting in asphalt bleeding, polished pavement surface texture, and friction reducing paint used in pavement marking.

Locations where reduced pavement friction is particularly problematic are at horizontal curves, downhill grades, and immediately upstream of intersection stop lines. Every effort should be made to identify the locations and the causes of pavement slipperiness at these critical areas. Mitigation measures vary depending on the cause of friction loss. They include use of thermoplastic material for pavement marking, slurry seal (sand-asphalt) or seal coat to provide texture, and grooving rigid pavements at the time of laying the pavement to enhance skid resistance. **Table 9** provides cost estimates for some of the above solutions.

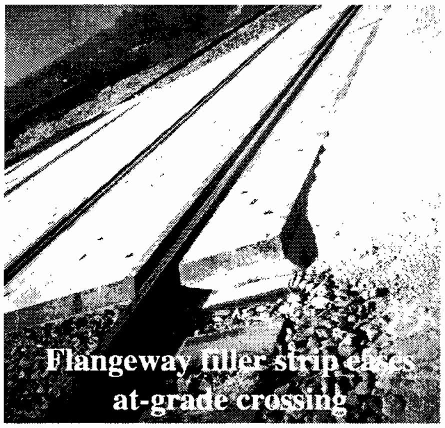
Table 9. Unit Costs for Various Pavement Maintenance Activities

Typical Costs (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Milling	—	—	252
Groove rigid (per sq. yd.)	> $ 1	—	—
Asphat bleeding	—	—	260
Remove layer – flexible (sq. yd.)	$ 1	—	232
Slurry seal (per ton)	$ 140	—	231

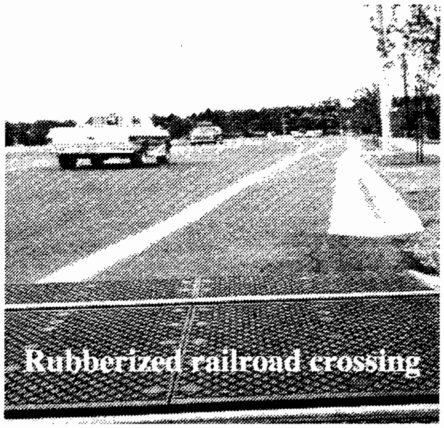
1 Cost estimate provided by workshop participants.

2 Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT

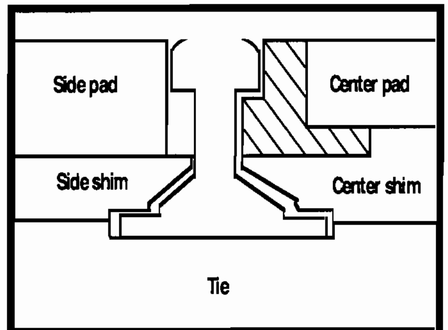
Hazard #11 Railroad Crossings



Flangeway filler strip eases at-grade crossing



Rubberized railroad crossing



Rubberized flangeway filler strip

Symptoms

- Poorly designed crossings (e.g., not at right angle, at-grade)

Solutions

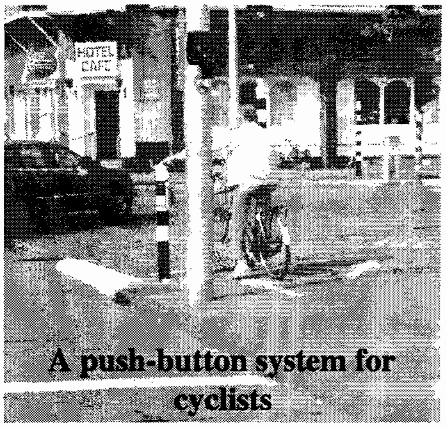
- Provide crossings at right angles to rails
- Improve signing and pavement markings
- Build road surface up to track level
- Build under/over crossing
- Install rubberized crossing mats and flanges (not for high speed train movements)

Poorly-Designed At-Grade Railroad Crossings

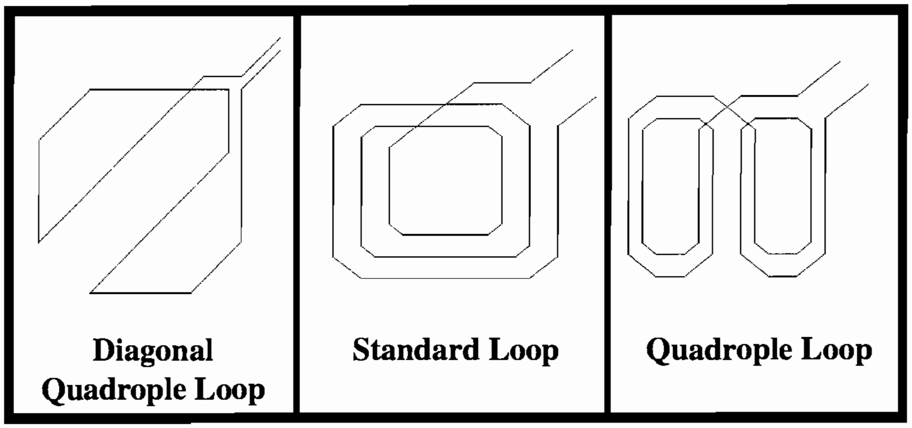
The combination of high tire pressure, high suspension stiffness, short wheelbase, and high center of gravity make bicycles difficult to control when the rider hits even a small surface bump or depression. One such condition is an at-grade railroad crossing, which could easily cause loss of control of cycles. The problem is further aggravated if the railroad crossing is not at a right-angle to the roadway it crosses, as a bicycle tire could easily be trapped by the flangeway.

Typical remedies include use of rubberized railroad crossing with flangeway fillers. This allows the railroad crossing to be level with the pavement surface without significant gaps between the railbed and the rail. Use of this treatment should be coordinated with railroad companies and should be limited to low-speed, lightly traveled tracks. On high-speed trunk railway lines, trains risk derailment at locations where fillers are used as fillers do not compress fast enough (U.S. DOT, 1993). Finally, at crossings which are not at right angle, a designated bicycle crossing lane which intersects the track at a right-angle should be provided.

Hazard #12 Signal Detectors



A push-button system for cyclists



Symptoms

- Insensitive bicycle signal detectors

Solutions

- Place detectors (broken laser beam or motion) in areas that cyclists ride
- Mark pavement to delineate detector or most sensitive locations on detector
- Replace/install bicycle sensitive detectors
  Type D, quadropole in bike lanes
  Type Q, diagonal quadropole for shared road
  Type A, standard loop detects over wires
- Add push-button for bike crossing close to roadway and at proper height

Bicycle Insensitive Signal Detectors

Pavement-embedded loop detectors for actuated signals are often not sensitive enough to detect bicycles. This is the case for both magnetic, magnetometer, and inductive loop technologies. The diagram on the previous page presents a number of loop configurations with bicycle detection capability (U.S. DOT, 1993). An alternative to loop detection is the use of cyclist activated push-buttons, which are common in Europe. However, the presence of such rigid obstacles near the pavement driving edge should be a concern regarding the motor-vehicle traffic safety. **Table 10** (next page) presents typical costs of loop detector and push-button detector installations. Other potentially useful detection technologies include motion detectors or infrared beams which could activate a signal once crossed. The rate of false activations due to non-vehicular movements in the detection field (e.g. pedestrians, birds, etc.) should be a concern in the use of such detectors.

Table 10. Cost and Labor for Detector Installation

Typical Intallation Cost and Time (1993 $)		
	Lower	**Upper**
Loop Detector (cost) [1]	$ 4 /ft.	$ 6 /ft.
Loop Detector (time)	2 person-days	3 person-days
Push-button (installed)	$ 300	—

1 Cost estimate includes equipment and installation.

Hazard #13 Bicycle Underpasses

Sharp curve leads up to dark underpass (Hudson 1992)

Symptoms

- Narrow underpasses (less than 10')
- Underpasses with long and/or curved entry approaches
- Insufficiently lighted underpasses (less than 150 kw)

Solutions

- Widen underpass
- Install warning signs such as "Ride to Right" or "Caution, Tunnel Ahead"
- Provide/add additional lighting where appropriate (including daytime illumination)
- Paint underpass ceilings and walls white

Poorly Designed Bicycle Underpasses

Common problems related to underpasses for cyclists include narrow widths, insufficient lighting, and sharp entrance/exit horizontal curves. Several State Guidelines (e.g. AZ, NC) specify 3.1 meters (10 ft) minimum widths for bike path underpasses. However, experience with these underpasses shows that 3.1 meters (10 ft) can be dangerously narrow (Elliott, 1995). Entering from bright sunlight into a tunnel, cyclists tend to shy away from the dark interior walls and move towards the center of the path. Moreover, many underpasses have long and/or curved entry approaches and cyclists gain speed going down into the underpass. Oncoming cyclists also gain speed as the approach in the other direction for the climb out. This is the recipe for a common accident scenario where cyclists using an underpass approach each other at high speed, one blinded by the darkness, the other blinded by the light, and both riding near the center line.

Mitigation measures should therefore include sufficient underpass lighting (at least 150 kw). The width of the underpass should be a minimum bike path width plus 0.6 m (2 ft) of lateral clearance on each side, or bikepath width plus 1.2 m (4 ft). Where such widths are not attainable, a minimum width of 3.6 m (12 ft) should be provided.

While sharp, steep entrance ramps to underpasses should be avoided in new designs, such existing ramps could be somewhat rectified through caution signs and flashing beacons. Signs such as "Caution, Tunnel Ahead". "Slow", or "Ride to Right" should be installed upstream of the underpass entrance. Furthermore, tunnel ceiling and walls should be painted white and daytime illumination in tunnels should be increased, especially at tunnel entrances (may need to lower illumination levels at night to decrease contrast with the dark) (Elliott, 1995). **Table 11** (next page) shows typical costs for lighting fixtures and installation.

Table 11. Cost and Labor for Installation of Light Fixtures for Underpasses

Typical Cost and Time (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Install light fixture (sodium vapor)	$ 200 each	$ 300 each	—
Install light fixture	$ 450 each	$ 500 each	—
Install light fixture – (person days)	2	4	—
Flashing becons	—	—	739

1 Cost estimate provided by workshop participants (includes labor and material).

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Hazard #14 Riding Against Traffic

Symptoms

- Observed/reported instances of repeated riding against traffic

Solutions

- Install "Wrong Way" and "Right Way" signs, especially near schools and at the end of two-way bike lanes
- Education and enforcement

Riding Against Traffic

This problem is particularly prevalent near schools, where children often tend to ride against traffic. This dangerous behavior partly results from the common misconception about the risk of being rear-ended by motor vehicles. Bicycle accident data show that cyclists being rear-ended is an uncommon occurrence, whereas riding against traffic is the cause of a relatively much higher percent of automobile-bicycle accidents (Mattingly, 1994).

Educating the public about dangers of riding against traffic as well as rules of the road related to bicycling in general will be beneficial. Classrooms, print media, radio and television public service announcements, and defensive driving and driver's license handbooks are examples of the educational tools available.

A traffic engineering tool which could prove beneficial is the installation of "wrong way" signs, such as shown, near school zones and at other locations where such movements are anticipated. An even more effective treatment will be "Right Way" signs to be installed in tandem with the Wrong Way signs, i.e. each Wrong Way sign could be a two-sided sign where the other side shows the Right Way message. Costs associated with installation of signs are provided in **Table 12** (next page).

Table 12. Unit Costs for Installation of Traffic Signs

Typical Costs (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Install sign (1 pole)	$ 200	$ 500	732, 733, 734
Aluminum sign	$ 17 /sq. ft.	—	—

1 Cost estimate provided by workshop participants.

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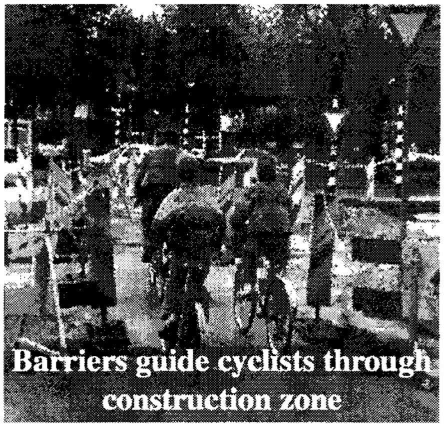
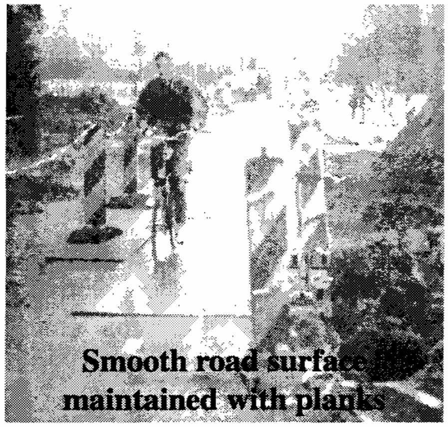
Hazard #15 Roadway Workzones



Barriers guide cyclists through construction zone



Smooth road surface is maintained with planks

Symptoms

- Insufficient lighting
- Debris on roadway
- Surface irregularities
- Confusing traffic patterns
- Improper drainage
- Obstructions (vertical and otherwise)

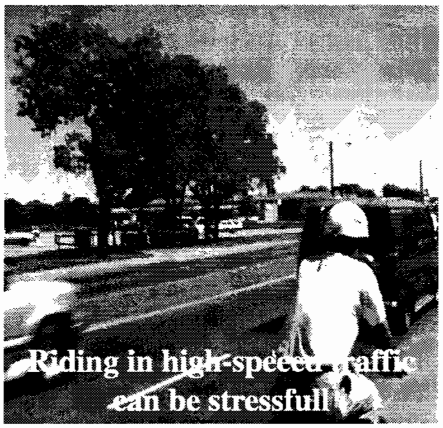
Solutions

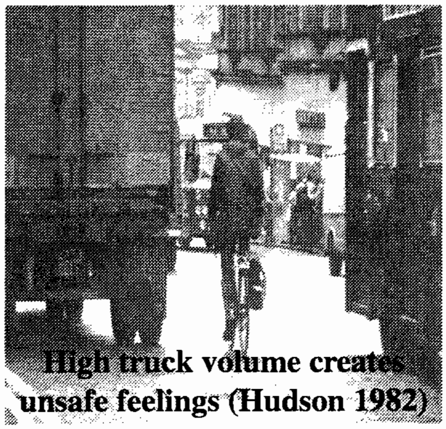
- Provide cyclists with a detour/safe path around or through work zone
- Place warning signs
- Schedule spot maintenance for duration of roadway work
- Slow drivers with geometrics or police

Cycling Through Roadway Workzones

Workzones are particularly inhospitable to cyclists. Not only are geometric widths generally more restricted but also a workzone is a major source of debris. Preferably, cyclists should be detoured away from workzones when feasible. If doing so would mean very long detours, a separate bike lane through the workzone should be erected. Such lanes should be properly signed and protected by means of barriers. Removable planks could also be used to maintain smooth debris-free surfaces through workzones. When neither detours nor dedicated lanes are feasible, consideration should be given to prohibiting bicycle traffic through workzones.

Hazard #16 High-Speed/Volume Roadways





Symptoms

- Cyclists on high-speed or high-volume roadways

Solutions

- Provide a suitable alternate route
- Provide a separated parallel route (protected lane)
- Restrict trucks along bike routes
- Install "Drive Friendly" signs

Cycling Along High-Speed or High-Volume Roadways

Cycling through roadways carrying a high volume and/or high speed traffic is highly stressful to cyclists (Sorton, 1994). Roadways with a curb lane peak hourly volume greater than 325 vphpl and average speeds of 64 km/h (40 mph) or greater can be classified as high speed/high volume roadways, producing high stress levels of 4 to 5 on a 1-5 scale (NCTCOG, 1995). While presenting a stressful condition, these roadways generally constitute the most direct paths to cyclists' destinations.

Remedial solutions include widening the outside lanes to 4.6 m or 4.9 m (15' or 16') in urban areas and providing exclusive separated bike paths in rural conditions. Exclusive bike paths in rural areas are considerably less expensive per square foot than contiguous roadways designed for 40-ton vehicles (**Table 13**).

Table 13. Roadway Widening Costs and Labor

Typical Cost and Time (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Widen street – urban (1 ft. / mile)	$ 12,000	$ 21,000	245
Widen street – rural FM (1 ft. / mile)	$ 10,000	—	245
Time (person-days / mile)	4	8	—

1 Cost estimate provided by workshop participants.

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Hazard #17 Parked Cars

Parked cars along bike route

Symptoms

- Curbside parking along bike routes

Solutions

- Prohibit auto parking along bike routes or lanes
- Place bold stripes on both sides of bike lanes

Curb-Side Parking Along Bike Routes

Curb-side parking along bike routes is a serious problem to cyclists. Not only motorists would have to cross the path of cyclists to park but also cyclist's path could be encroached on by opening doors. This is a fairly difficult problem to address, particularly when considering the potential adverse impact on motorized traffic. Possible solutions include:

1. Provide dedicated bike lanes to the left of the parking lane
2. Widen the driving lane adjacent to the parking lane to 4.6 m to 4.9 m (15'-16')
3. Remove the parking lane on one side and widen the outside lane on the other side
4. Prohibit curb-side parking

Major concerns in implementing any of these solutions are the right-of-way acquisition cost and the adverse impact on motorized traffic. Right-of-way cost becomes a significant factor when existing roadway width is not sufficient for restriping and maintaining minimum lane widths. **Table 13** provides costs associated with restriping as well as pavement widening.

Table 14. Costs Associated with Pavement Restriping and Widening

Typical Costs (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Remove 4" stripe	50 ¢ / ft.	—	715
Sandblast	10 ¢ / ft.	—	711
Paint	15 ¢ / ft.	—	710, 713
Thermoplastic	30 ¢ / ft.	—	712
Widen street (1 ft. width / mile)	$ 12,000	$ 21,000	245
Land value (urban) / sq. ft.	$ 5	$ 10	—

1 Cost estimate provided by workshop participants.

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things to look for

(Bicyle hazards fall into several major categories. Some of which the City has influence over, and some it does not)

List of Bicycle Hazards

Geometric Design
Other Design Elements
Traffic Control Elements
Pavement Conditions
Roadway Maintenance
Bike Characteristics
Cyclist Behavior
Motorist Behavior
Policy & Enforcement

Geometric Design

- At-grade railroad crossings
- Bike path/route on same roadway as a bus route (e.g. leapfrog between the buses and bicycles, buses enter the bike lane for bus stops, etc.)
- Bike paths that are discontinued by a curb
- Bike paths with poorly designed ramps (e.g. sharp turns at the top or bottom of ramps, poor sight distance, etc.)
- Crossing major barriers (e.g. main roads, railways, canals, rivers)
- Cycle paths too narrow
- Frequent driveways
- Lack of lateral space for load-carrying cyclists
- Large roundabouts
- Narrow right lanes/no bike lanes
- Narrow, unmarked shoulders
- Non-uniform designs for bike lanes/paths
- Oblique right-turns (motorist often does not slow down, signal, or look over his/her shoulder)
- Right-turn channelization (signalized intersection with pork chop islands for right-turn channelization)
- Roadway bottlenecks/squeeze points (e.g. narrow bridges, sudden narrowing of roads)
- Sidewalks without curb cuts
- Striped right-turn lane (cyclist forced to ride between the right-turn lane and the through lane)
- Turning radius on horizontal curves (especially at the bottom of steep grades)
- Wide curb radii (larger radii encourage higher speed turns)

Other Design Elements

- Blind corners (poor sight distance)
- Bridge expansion joints
- Improper bridge railing height (if too short cyclists could flip over, if too high could restrict sight distance)
- Insufficient lighting
- Metal grate bridge decks
- Stairways
- Wheel-trapping catch-basin grates, gutters, and drainage grates

Traffic Control Elements

- Bike insensitive signal detectors
- Cars parked too close to intersections
- Curbside auto parking (especially in bike lanes)
- Friction reducing paints for roadway markings (e.g. used in striping crosswalks)
- High-speed or high-volume auto traffic
- High truck volumes
- High-volume bicycle traffic
- Inability to see optically programmed signals
- Improper signal time for cyclists (e.g. short green/amber times)
- Lack of signage devoted to bike traffic
- Lack of speed separation for cyclists in bike lanes
- Nonstandard delineation for bike lanes (solid stripes, dashed stripes, grade separation)
- Non-uniform design standards (difference in designing cycle paths and lanes)
- Raised lane markers
- Rumble strips
- Signs too close to roadway
- Speed bumps

Pavement Conditions

- Asphalt ripples due to braking action, etc.
- Cold weather and poor drainage leads to ice patches
- Debris in bike lanes swept from auto lanes (especially at turns)
- Differential pavement settlement (especially at bridge connections)
- Dropoffs at overlays (in the direction of travel)
- Hot weather and asphalt leads to soft asphalt patches
- Newly chip-coated roads
- Non-flush manhole covers
- Oil leaks, particularly near intersections and where cars park (slippery)
- Open drainage ditches across the street
- Poor drainage (puddles of water covering other hazards, especially on cyclepaths/lanes)
- Potholes, ruts, wide pavement cracks
- Slick/smooth pavement (especially when wet)
- Stone and tile paved roads (subject to shifting and cracking, slippery when wet)
- Unpaved driveways (source of sand and gravel on pavement)
- Unpaved/gravel road
- Unsmooth patches (e.g. hardened cement, tar on surface)
- Wide, longitudinal pavement joints

Roadway Maintenance

- Debris in bike lanes swept from auto lanes (especially at turns)
- Overgrown vegetation / unpruned trees (blocking bike path/bike lane)
- Poorly managed and signed work zones
- Unswept debris on pavement
- Vandalized signs and lights on bike paths

Bicycle Characteristics

- Difficult to control speeds on downgrades
- Difficult to ride on uphill grades (e.g. zigzagging)
- Exclusive left turn phase too short
- Lack of acceleration when turning left (especially on permissive only signals)
- Inadequate sight distance at crossings
- Large gap requirements (especially when crossing wide streets)
- Unstable at low speeds

Cyclist Behavior

- Carrying unstrapped bulky packages (in hands or on the handlebars)
- Exceeding design speeds on downhill grades (especially in residential areas)
- Failure to signal movements
- Failure to yield right of way
- Following a vehicle too closely
- Installing unbalanced panniers (saddlebags)
- Lack of safety equipment (especially at night)
- Lapse of rider's attention
- Not maintaining a straight or predictable path
- Reluctance to decelerate or stop at crossings
- Riding against traffic (wrong-way riding)
- Riding at night
- Riding too fast
- Riding under the influence
- Sidewalk riding
- Turning left from the right lane/bike lane
- Turning right from left of exclusive bus lanes
- Weaving in and out between parked cars

Motorist Behavior

- Driving under the influence
- Encroachment of autos in space for bikes (opening car doors or parking cars in bike lanes)
- Failure to yield right of way
- Lapse of driver's attention
- Left turning vehicle crossing bike path
- Motorist error
- Motorist following cyclist too closely
- Motorist harassing/bothering cyclist (honking horn, yelling, etc.)
- Not knowing/observing cyclist's right to use road
- Right turning vehicle crossing bike path

Policy & Enforcement

- Air quality (e.g. congested urban arterials)
- Bike paths through high-crime neighborhoods
- Insufficient cyclist education and training
- Insufficient motorist education and training
- Lack of enforcement of road rules for cyclists and drivers
- Lack of safe/proper bike parking
- Pedestrians jaywalking
- Pedestrians/joggers/skaters on bike paths/lanes
- Persons throwing objects at cyclists (e.g. bottles)
- Police harassment/insufficient education of police officers
- Stray animals, dogs not on leashes
- Traffic engineers unfamiliar with cyclists' concerns
- Unable to transport bike on bus/ferry/taxi/train/tram

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