River Road-Santa Clara, and Willakenzie areas. No surveys were taken to verify this, but riding the system has convinced me of this need. Railroad and industrial property provide a barrier for those in Bethel-Danebo. The bicycle path running along River Road is narrow and automobile traffic there is heavy, thereby increasing the danger and reducing the enjoyment of bicycling for those in River Road-Santa Clara. Those in Willakenzie are faced with the barrier of major freeways (I-105 and Delta Highway) and must navigate through the parking lot at Valley River Center. These barriers must be eliminated if the Greenway Bridge is to meet its full potential.

2. Parking for bicycles should be expanded. Although only 20 percent of bicyclists indicated that convenient parking was a reason for bicycling, it is something that can be provided. A higher percentage of bicyclists indicated that parking was a factor in the winter when the weather was bad. Covered bicycle parking would be a pleasant addition. Casual observation indicates that covered areas for bicycle parking at the University of Oregon store a higher percentage of all bicycles in the winter than in the summer. There are not enough covered spots.

3. Surveys should be made of randomly chosen individuals to ensure that a representative group of bicyclists and nonbicyclists is interviewed. If this were done by mail, longer surveys could be used and more information could be gathered. Surveys on the bicycle paths should also be done. A comparison of both surveys would allow for some comparison and validation of the findings.

4. This evaluation took place shortly after the Greenway Bridge opened. An evaluation should be made in another year to measure the long-term effects.

5. Permanent counters should be installed in future demonstration projects. The rubber hoses on the temporary counters are vandalized, which makes accurate counts difficult. Permanent counters should also be installed at the Greenway Bridge to facilitate the long-term evaluation.

6. Signing is inadequate and should be improved. The approach to the bicycle-path system from River Road does not indicate that a bridge to Valley River exists.

ACKNOWLEDGMENT

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On-Road Improvements for Bicyclists in Maryland

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With the decrease of highway revenues, funds are not available to construct a large system of conventional bicycle routes that are separate from motor-vehicle lanes. The new transportation system management approach to transportation planning places emphasis on efficient use of the existing highway network rather than its expansion. For these reasons, it is now necessary to treat the bicycle as a design vehicle in the design and maintenance of highways without the construction of separate facilities for bicyclists. Three types of low-cost, on-road types of improvements for bicyclists implemented in Baltimore County, Maryland, are discussed: (a) wide curb lanes that provide additional width in the right-most lane by slightly narrowing adjacent lanes, (b) smooth shoulders that facilitate bicycle travel on existing roads, and (c) parking changes that provide more room on the street for bicyclists and increase sight distance for bicyclists and motorists.

Before 1900, bicyclists were a major impetus for improving both urban and rural roads, most of which did not have a hard surface. Bicycle route maps were published that showed roads suitable for bicycling. For example, an 1896 bicycle route map of the Washington, D.C., area (1) not only showed the roads that bicyclists could ride on but also indicated severity of grade and summits of hills by appropriate symbols. As more roads were resurfaced with brick, concrete, and macadam, to the benefit of bicyclists, motor vehicles became dominant and improving roadways for the benefit of bicyclists was forgotten.

Even today, with the increase of interest in the construction of bicycle facilities, adequate consideration is not being given to the bicycle as a design vehicle for the highway network. For the most part, improvements for bicyclists are strictly limited to officially marked or mapped bicycle routes or obvious hazards such as parallel-bar storm-drain grates, which trap bicycle wheels. Unfortunately, these improvements represent only a fraction of the potential improvements that can be made for bicyclists.

This paper reports on three types of improvements for bicyclists and moped riders that have been implemented in Baltimore County, Maryland, and that can be applied economically to many types of roads in the United States. These improvements are

1. Wide curb lanes that provide additional width in the right-most lane where most bicycle travel occurs (this additional width is obtained by narrowing slightly, where possible, the lanes for the same direction and adding this width to the right-most curb lane);
2. Shoulder improvements that facilitate bicycle travel on existing roads; and
3. Prohibiting parking near intersections based on bicycle design speed to provide better sight distance for bicyclists and motorists entering the intersection.

There has been a continuing discussion for the past several years between bicyclists and transportation officials as to what type of facilities should be provided for bicyclists. Some have favored emphasis on on-road improvements without marked bikeways, whereas others have favored conventional class 1 and class 2 bikeways. The basic argument of those who favor conventional marked bikeways is that bikeways tend to be safer because they remove bicycles from the traffic flow. Those who favor on-road improvements without marked bikeways have argued that designated bikeways will cause bicyclists to ride with the motor-vehicle traffic flow and not on bikeways to shorten trip time and in some cases, because of faulty design on conventional bikeways, to increase safety.

Regardless of how the bikeways versus on-road improvements argument is resolved, on-road improvements will remain very important to bicyclists. For example, even if a bikeway system similar to the excellent system in many European countries is developed in the United States, bicyclists will still need to ride on many existing roads to get to and from the bikeways. In most parts of the United States, however, the development of existing roadways occurred without consideration of the bicycle as a mode of transportation, and this often makes bikeway development expensive or impractical. This situation makes low-cost on-road improvements for bicyclists even more important. If bicyclists are legally permitted on a highway, then it is appropriate when designing or maintaining the highway to consider physical improvements for bicycles just as other vehicles in the traffic mix are considered.

Except for some recreational bikeways in parklands, most state and federal funding for bikeways is derived from highway user taxes. The largest component of highway user taxes, the motor-vehicle fuel tax, is unlike all other major types of taxes, such as income, property, sales, and excise taxes, because the revenues do not automatically increase with inflation. In the past, the almost continuous increase in the consumption of diesel fuel and gasoline often increased motor-vehicle fuel-tax revenues faster than inflation decreased the value of the revenues. In the next decade, however, the more fuel-efficient automobiles and trucks mandated by Congress and promised by the truck manufacturers will cause consumption of motor-vehicle fuel to level off or decrease with continued inflation. Unless increased funding is provided, which appears unlikely at this time, this will lower the value of revenues to the point where new construction of highways will be significantly curtailed.

One of the principles of transportation system management (TSM), which is an important part of the transportation planning process in most large metropolitan areas, is that emphasis is placed on the efficient management rather than the expansion of transportation facilities. Highways, public transit, private automobiles, pedestrians, and bicycles should be treated as elements of a single transportation system and not as independent systems. Rising construction costs and limited funds have made it more important than ever to use existing transportation facilities efficiently as an alternative to expensive new facilities. This applies as much to bicycles and mopeds as to other types of vehicles. Therefore, ways must be found to improve the riding environment for bicyclists and moped riders on the existing highway network.

In this paper, it should be assumed, unless otherwise stated, that references to bicycles and bicyclists also pertain to mopeds and moped riders.

WIDE CURB LANES

The National Advisory Committee on Uniform Traffic Control Devices, commenting on an official request by the Baltimore County Department of Traffic Engineering to approve the use of wide curb lanes on the Federal-Aid Highway system, indicated that the wording in the Manual on Uniform Traffic Control Devices (MUTCD) permits the narrowing of normal 3.7-m (12-ft) wide traffic lanes to 3.4 m (11 ft) for the purpose of widening the right-most curb lane for bicyclists.

A wide curb lane is basically a 4- to 4.6-m (13- to 15-ft) wide right-most curb lane that is obtained by reducing the adjacent lanes for the same direction of traffic flow to 3.4-3.7 m (11-12 ft). Reducing lane width to 3.4 m is permitted by standards of the American Association of State Highway and Transportation Officials (AASHTO) (2, p. 351). The wide-curb-lane treatment can be used on many curb-and-gutter urban arterials and collectors on which class 1, 2, or 3 bicycle routes may not be appropriate or possible.

Class 1 bicycle routes of the sidewalk type are not usually desirable along urban highways that have many intersecting streets and driveways because motorists exiting from the streets or driveways are looking for approaching motor vehicles in the roadway and not for approaching bicyclists set back from the roadway where the sidewalk or bikeway is located. This is especially true for two-way bikeways, on which bicyclists approach the street or driveway from the opposite direction of motor-vehicle flow. In such situations it is probably more desirable for bicyclists to be riding in a wide curb lane so that drivers exiting from streets and driveways will readily be able to see them when searching for approaching vehicles in the roadway.

According to AASHTO standards (3, p. 22), class 2 bicycle routes usually require at least 4.6 m (15 ft) of paving in the curb lane for a 3.4-m vehicle lane and a 1.2-m (4-ft) bicycle lane. This 4.6-m requirement cannot be met on many highways without reducing the width of the adjacent lanes to less than 3.4 m. In many instances, 4- to 4.3-m (13- to 14-ft) wide curb lanes are the only improvement possible for bicyclists. Even if 4.6 m is available, it may often be undesirable to stripe and sign a bicycle lane because of high traffic volume or speeds. A wide curb lane would, in this instance, be desirable for bicyclists, who would use the facility regardless of whether or not it was marked as a bicycle route.

A curb lane that is widened and yet is still not as wide as a travel lane and a bicycle lane, or 4.6 m, can be considered an incremental improvement for bicyclists. However, a curb lane of 4.6 m can be considered a quantum improvement because it is the same width as a travel lane and a bicycle lane. Class 1 and class 2 bicycle lanes can also be considered quantum improvements, but in many instances an unsigned and unmarked wide curb lane that is 4.6 m wide is preferable to a class 1 or 2 bicycle route. When a quantum improvement is not possible because of physical or cost limitations, it is logical to attempt to implement incremental improvements instead. In many instances, other than the incremental improvement of wide curb lanes (less than 4.6 m), no provisions can be made for bicyclists.

The Highway Administration of the Maryland Department of Transportation is currently planning to widen two curb-and-gutter urban arterial highways in Baltimore County that have commercial strip development. According to policy, consideration must be given to facilities for bicyclists. Because of right-of-way limitations, vehicle speeds of 65 km/h (40 mph), traffic volumes in excess of 40 000 vehicles/day, and many commercial driveways and turning movements, it was decided that wide curb lanes would be the most suitable improvement for bicyclists. Without wide curb lanes, no suitable improvements could be made for bicyclists because the traffic conditions make the marking of a class 1 or 2 bicycle route undesirable. In addition, there is not enough right-of-way available for a class 1 route.

In Baltimore County, wide curb lanes were marked on roads posted for speeds higher than 65 km/h only when the adjacent lanes were 3.7 m (12 ft) wide or wider. It was decided not to reduce the lane width to less than 3.7 m on these higher-speed highways. On highways that did not have a center turning lane or a median to separate opposing traffic flow, it was decided not to reduce lane width to less than 3.7 m unless the posted speed limit was 55 km/h (35 mph) or less.

Wide curb lanes have been marked on many multilane arterial and collector roads in Baltimore County. For example, on York Road (MD-45), a newly constructed 18.9-m (62-ft) wide, five-lane section was marked with two 4.3-m (14-ft) wide curb lanes. The 4.3-m lanes offer enough maneuvering room for motorists to avoid bicyclists without leaving the lane. On another, almost identical, 18.9-m section of York Road, where the curb lanes are only 3.7 m wide, there is considerably less room for motorists to avoid bicyclists. Wide curb lanes have also been successfully applied on other four-, five-, and six-lane roadways and have provided similar benefit for bicyclists.

Wide curb lanes can be advantageous to motorists for the following reasons:

1. On many urban roadways, fixed hazards are located near the edge of the curb, and motorists tend to shy away from these fixed objects. Wider curb lanes can add a 0.3-m (1-ft) or greater margin of clearance between motor vehicles and fixed objects.
2. Many high-volume urban arterials have numerous commercial driveways that do not have traffic-signal controls. Motorists exiting from these driveways frequently pull out into the curb lane, attempting to make a turn. This problem can be compounded when sight obstructions such as signs, poles, and vegetation restrict the driver's view to such an extent that the motorist is almost forced to extend the front of the vehicle into the curb lane. The additional clearance that a wider curb lane can provide enables vehicles traveling in the curb lane to more easily avoid vehicles in commercial driveways (see Figure 1).
3. In most cases, the additional width added to the curb lane is obtained by marking the other lanes 3.4 m (11 ft) instead of 3.7 m (12 ft). On roadways that have a posted speed of 65 km/h (40 mph) or less, it is difficult for a motorist to perceive the 0.3-m (1-ft) narrowing of the lanes. However, it can be quite evident to bicyclists that there is additional space between then and motor vehicles in the curb lane (see Figure 2).
4. The additional width in a wide curb lane can allow a vehicle making a right turn into a highway to stay completely within the wider curb lane. This might not be possible otherwise. This is especially true for larger vehicles that are turning where there are depressed curbs or small-radii curb returns at side streets or driveways. The same effect occurs when vehicles are turning into a side street or a driveway from a wide curb lane. In addition, the wide curb lane can effectively increase the radius of turns and thus increase the speed at which turns can be made, thereby reducing interruptions to through traffic in the curb lane.

One application of wide curb lanes is along roadways where many parked vehicles are encountered by bicyclists. If a midsized or larger two-door automobile is legally parked 0.3 m (1 ft) away from the curb and an occupant of the vehicle opens the door on the driver's side all the way, a bicyclist cannot maneuver around the opened door without leaving the 3.7-m (12-ft) lane. A wide curb lane is needed in this situation to allow width for the bicyclist to pass. Figure 3 shows that the normal 3.7-m curb lane is not wide enough to allow a bicyclist to pass the open door of a 1977 midsized Chevrolet without leaving the lane. A 4.0-m (13-ft) lane is the minimum necessary for a bicyclist to maneuver around a fully opened automobile door without leaving the lane; a 4.1- or 4.3-m (13.5- or 14-ft) lane is desirable to permit more maneuvering room. Although most vehicle occupants do not open the door all the way when exiting a parked vehicle, many bicyclists do not ride exactly at the far left side of the parked-vehicle lane either.

The new MUTCD guidelines for grate delineation could conceivably effectively reduce a normal 3.7-m lane to 2.7 m (9 ft) by making a 0.8-m (2.5-ft) grate with a required 0.15-m (0.5-ft) wide edge stripe. A 2.7-m lane is a near minimum for motor-vehicle flow. The effective 2.7-m lane could conceivably be shared by both a bicyclist and a motor vehicle, but the situation would permit little or no clearance between them. If, however, the wide-curb-lane treatment were applied, at least an additional 0.3 m (1 ft) would be available between the bicyclist and the motor vehicle (see Figure 4).

Use and implementation of the many kilometers of wide curb lanes in Baltimore County were observed and studied over a 3-year period. Some of the observations and conclusions made are as follows:

1. Wide curb lanes are best suited for curb-and-gutter highways. On highways that have no curbing, bicyclists would be removed farther from motor-vehicle traffic by providing smooth and adequate shoulders.
2. A 4.9-m (16-ft) lane is wide enough to function as two unmarked 2.4-m (8-ft) lanes by permitting two narrower vehicles to occupy the 4.9-m lane side by side. This is also true, to a lesser extent, of a 4.6-m (15-ft) curb lane, which can be used in this way if severe congestion and capacity problems exist.
3. Older multilane roads in many areas are too narrow to permit the marking of 4- to 4.6-m (13- to 15-ft) wide curb lanes without narrowing other lanes to less than 3.4 m (11 ft). For example, many four-lane divided highways were constructed with two 3.7-m (12-ft) lanes and a 3.0-m (10-ft) parking lane for each half of the roadway, which resulted in two 10.4-m (34-ft) cross sections. As traffic volumes increased, many of these roads were posted with either full-time or part-time parking restrictions and the 3.0-m parking lanes became through lanes, which increased the roadway to six lanes. These 3.0-m lanes often have to be shared by a 2.4-m (8-ft) wide truck or bus and a 0.6-m (2-ft) wide bicycle and rider. This leaves no clearance between wide vehicles and bicyclists in the same lane. It is desirable, therefore, to mark the two left-most lanes 3.4 m (11 ft) wide and mark a 3.7-m right-most curb lane.
4. The standard width for high-volume and high-speed roads is 3.7 m/lane. In many instances, application of a wide curb lane requires a 0.3-m reduction in lane width, which is below the official standard of 3.7 m. A review of previous studies indicates, however, that this reduction in lane width should not adversely affect safety or capacity.

The Highway Capacity Manual (4, Figures 5 and 6) assumes a nearly linear relation between approach width and approach capacity in urban areas, where wide curb lanes are most applicable. Therefore, narrowing one lane and adding width to an adjacent lane for the same direction of flow should not affect the capacity of the approach. Other methods of calculating capacity take lane width into account, however, and would indicate slightly reduced capacity with 3.4-m (11-ft) lanes. But from a practical standpoint, the reduction is more than offset by the fact that the wide curb lanes effectively increase the radii of turns made by right-turning vehicles and thus enable drivers to negotiate turns with less delay and at a greater speed.

Studies conducted on accident rates versus lane widths tend to indicate either that accident rates are not related to lane width or that they decrease as lane width increases to 3.4-3.7 m (11-12 ft). For example, a study conducted by Dart and Mann on rural two-lane Louisiana roads (5, p. 9) concluded from a multiple linear regression of many geometric variables that the accident rate decreased significantly as lane width increased from 2.7 to 3.4 m (9-11 ft) but that the accident rate was slightly higher for 3.7-m (12-ft) than for 3.4-m lanes. Another study conducted by Gupta (6) indicated that, on two-lane urban streets with maximum average daily traffic of 12 000, lane width was unrelated to accident rate. A study by Mulinazzi (6) of 100 urban arterial highway sections in Indiana, which used multiple linear regression on many independent variables, showed that street width was also unrelated to the accident rate.

The results of these studies indicate that the narrowing of roadway lanes from 3.7 to 3.4 m would not adversely affect safety. It is not yet known, however,

Figure 1. Situation before and after wide-curb-lane treatment: approaching vehicle leaves lane and approaching vehicle stays in lane.

Figure 2. Clearance for bicyclists before and after wide-curb-lane treatment.

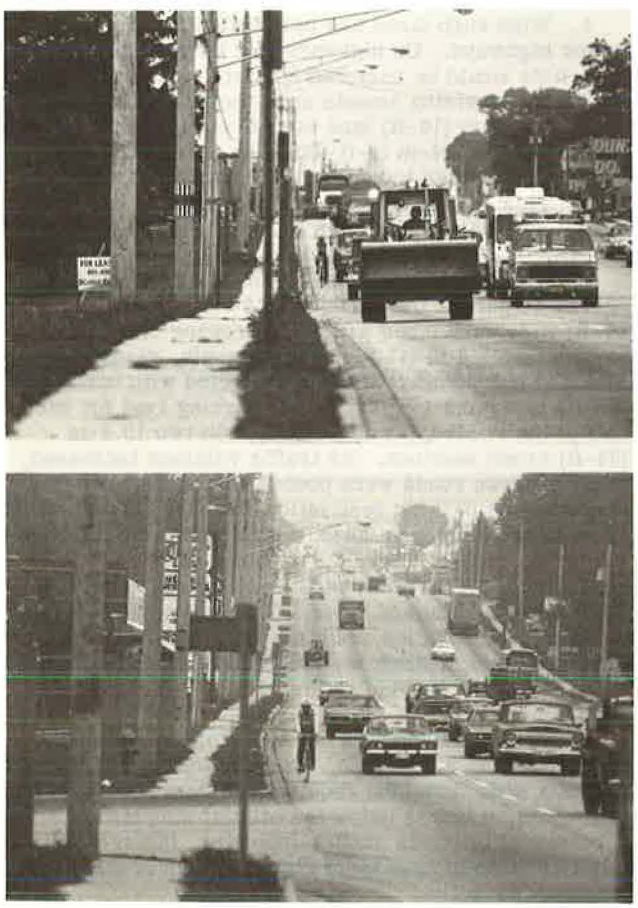
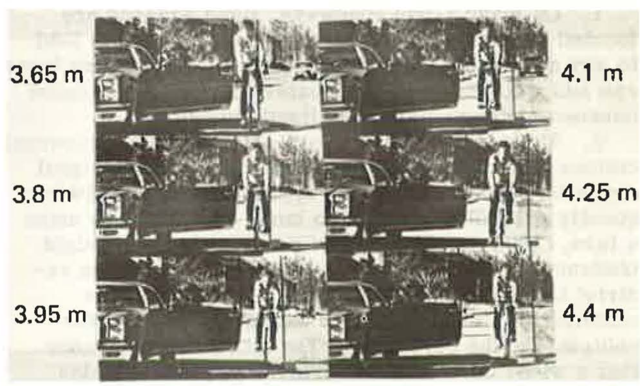


Figure 3. Examples of passing width for bicyclists when parking is permitted.



Note: 1 m = 3.28 ft.

Figure 4. Situation in which a wide curb lane can help bicyclists: avoiding a grate and an overtaking vehicle.

Figure 5. Shoulder before and after smooth-surface treatment.

whether wide curb lanes would increase safety for bicyclists. The wide curb lanes implemented in Baltimore County have not been in use long enough to permit a study of accident rates. Wide curb lanes could be expected to reduce rear-end accidents between motor vehicles and bicycles as well as other types of accidents, but this is currently only conjecture.

5. The best time to mark wide curb lanes on the roadway surface is just after new bituminous concrete is placed and before conventional lane-line configurations are marked. This is especially true when longer-life thermoplastic or tape lane markings will be used. Conventional paint with reflectorized beads has a considerably shorter service life, and it was found in this study that the old lane lines were sufficiently faded after 1-1.5 years that the laterally shifted lane lines resulting from the wide-curb-lane treatment could be applied. It was necessary, however, to repaint the new lines shortly after the first painting to ensure that the new lines would be more prominent than the older, faded lines. This is especially true on highly skid-resistant porous bituminous concrete resurfacing because more of the paint is absorbed into the pavement. The length of the new white skip lines could be increased to the same length as the old 4.6-m (15-ft) white skip lines until the old lines are sufficiently faded.

In most instances, the older lane lines were separated from the new lines by 0.3-0.6 m (1-2 ft). Because the tires of vehicles in the traffic stream were almost directly over the older lane lines, these lines were often almost completely faded one year after the wide-curb-lane treatment was applied. For this reason, grinding, sandblasting, or placing black paint over the older faded lines is probably not necessary.

6. The concept of wide curb lanes is not so well-suited for concrete pavements because the lane widths are predetermined by the dimensions of the concrete slabs. For wet-pavement conditions at night, the lane lines should coincide with the construction joint in the concrete as much as possible because the construction joint can be more visible to the driver than the lane markings. It is desirable, however, to mark lane lines on concrete surfaces to the left rather than the right of the construction joint, as is now done on concrete surfaces on Maryland highways. The original reason for this change was to increase the effective lane width on the right for larger vehicles, which are more likely to be in the right and slower-moving lanes.

Countermeasures for reducing different classes of accidents between bicycles and motor vehicles were listed in a recent study by Cross and Fisher (7). This study suggested that pavement-marking schemes to encourage drivers to drive farther to the left could decrease accidents in which the bicyclist suddenly swerves into a motor vehicle. Wide curb lanes could serve to reduce accidents of this type by enabling drivers to drive farther to the left and thus increasing the lateral distance between motor vehicles and bicyclists.

Cross and Fisher (7) list bicycle lanes as a possible countermeasure to reduce accidents that involve a motor vehicle overtaking a bicyclist but conclude that it is difficult to justify bicycle lanes from a cost standpoint. Wide curb lanes could serve to reduce overtaking accidents by increasing the lateral separation distance and at less cost. The cost is lower for wide curb lanes because the only thing involved on existing facilities is repainting of motor-vehicle lane lines. On new facilities, a meter or two of additional paving may have to be added, but the cost should still be less than that for bicycle lanes because there are no maintenance costs such as those for special bicycle-lane signing and marking.

It is possible that wide curb lanes could serve to reduce other classes of accidents between bicycles and motor vehicles. Further study is needed, however, to determine how effective wide curb lanes may be in reducing all types of accidents between bicycles and motor vehicles.

SHOULDER IMPROVEMENTS

On roadways without curbs, smooth shoulders are a definite benefit to bicyclists because they enable bicyclists to ride to the right, away from the motor-vehicle lanes (see Figure 5). For this reason, the bicycle should be considered as a design vehicle when plans are made to construct or resurface a shoulder. The design and construction of shoulders for bicyclists should not result in unfavorable benefit/cost ratios because shoulders, by decreasing the accident rate, also provide benefits to motorists (8).

Most bicyclists are reluctant to ride on rough bituminous concrete shoulders because the ride is uncomfortable and it requires more effort to pedal. One common type of rough shoulder surface that is unacceptable to most bicyclists is the double-surface-treated shoulder, which is formed by placing approximately 0.6 cm (0.25 in) of aggregate on top of a bituminous concrete base course with liquid asphalt, which partially cements the loose aggregate to the base. One advantage of this type of shoulder surface treatment is that the rough surface provides a visual and audible warning to motorists who stray onto the shoulder. A disadvantage is that bicyclists will usually choose to ride on the roadway surface, especially when they do not perceive a vehicle approaching from behind.

The Maryland Highway Administration has successfully applied slurry-seal treatment to bikeways on Maryland's Eastern Shore; these surfaces were in excellent condition after the 1976-1977 winter, one of the most severe winters in years. The advantage of slurry-seal treatment is that it is smooth enough for a comfortable bicycle ride yet rough enough to give an audible warning to motorists who stray from the roadway. Unfortunately, the sound and vibration in the motor vehicle are not as pronounced as those caused by the rougher double-surface treatment, but this is an engineering trade-off.

Slurry seal is a liquid asphalt emulsion with approximately 0.15 cm (0.06 in) aggregate that is applied on the shoulder. On the bicycle routes on the Eastern Shore, a 0.5-cm (0.2-in) layer of slurry seal was applied over a double-surface-treated shoulder. The resulting surface was more suitable for bicycle riding than the rougher double-surface-treated shoulder and yet provided both an audible and visual warning to motorists because the slurry is much darker and slightly rougher than most pavements. Some bicyclists, however, do ride on the smoother roadway surface rather than on the rougher slurry-seal surface.

The slurry-seal treatment is applied as a liquid, does not require rolling with heavy equipment, and is much thinner than most overlays, which lowers application costs. The texture of the final surface can be controlled by dragging burlap over the slurry seal before it has hardened. The dragging operation causes longitudinal striations to form on the surface; these striations produce an audible warning for motorists and a slightly rougher ride for bicyclists than the smoother roadway surface. A smoother surface can be produced by rolling the slurry-seal surface with heavy equipment, but this is not a necessary step in the application.

Another common type of shoulder surface treatment is continuing the roadway surface onto the shoulder. This treatment has been well received by bicyclists in Maryland. It has the disadvantage of not providing a visual or audible warning to motorists. But, since this has not precluded its use on freeways, where bicyclists are not permitted, it should have applications on other highways where bicyclists are permitted.

It is possible to pave shoulders with a bituminous concrete that is a different color than the roadway surface to provide a visual warning. However, in order to provide an audible warning, the shoulder usually has to have a rougher texture than the roadway surface. It is important to realize that any substantial increase in roughness will decrease the probability that a bicyclist will ride on the shoulder. This is true even if use of the shoulder is required of bicyclists under motor-vehicle law. For this reason, the shoulder surface should be substantially as smooth as the roadway surface if bicyclists are to be encouraged not to ride in the roadway.

One possible compromise suitable only for shoulders approximately 2.4 m (8 ft) wide or wider is to provide a smooth surface on the left for the first 1.2-1.5 m (4-5 ft) of the shoulder for bicycle riding. Then, on the rest of the shoulder to the right, an audible warning can be provided by using a rough surface for motorists who stray off the roadway.

On a wide shoulder, most bicyclists will choose to ride on the left portion of the shoulder near the roadway anyway. This occurs for many reasons, the most important being that the air currents generated by passing motor vehicles tend to sweep the left side of the shoulder free of debris such as stones, sand, soil, leaves, sticks, and trash. Much of the debris is swept from the left side to the right side of the shoulder, and this makes bicycle riding even more difficult or hazardous on the right.

Other conditions can cause the right side of the shoulder to be unsuitable for bicycle riding. These include a greater tendency for the right portion of the shoulder to deteriorate and break up, which can cause drainage problems with standing water or ice. Snow piles from plowing operations block the right side of the shoulder more frequently than the left. The right portion of the shoulder is often blocked by parked vehicles or by vegetation growing up through or hanging down onto the pavement.

The bicyclist who rides near the left edge of the shoulder is more visible to motorists who are exiting from side streets or driveways and also to drivers on the main highway who are turning left or right across the bicyclist's path.

The existence of at least a narrow strip of shoulder is an important factor for bicyclists because of their tendency to use the portion of the shoulder near the roadway edge. The AASHTO recommended minimum class 2 shoulder width is 1.1 m (3.5 ft) (6). Although this is certainly desirable, it is often not practical or economically feasible. It should be realized that any smooth surface shoulder is a definite benefit to bicyclists, even if the AASHTO minimum cannot be met, as a study of the lateral placement of bicyclists and motor vehicles (described later in this paper) has shown. Additional smooth-shoulder width on a narrow roadway enables bicyclists to ride away from the flow of motor-vehicle traffic, which reduces the risk of a rear-end accident and unacceptable wind forces from passing vehicles.

There are many conditions that preclude placement of continuous 1.1-m (3.5-ft) or wider shoulders. Some of these restrictions are limited right-of-way or slope easements, existing drainage ditches or structures, vegetation, poles, fire hydrants, slopes, or retaining walls. When roadways or shoulders are resurfaced or repaired, these adverse field conditions should not cause shoulder widening for the benefit of bicyclists to be dropped from consideration solely because the AASHTO minimum cannot be met. If the minimum cannot be met, the widened shoulders should not be signed as a class 2 route. Highways improved for bicyclists do not have to be signed as bicycle routes because the bicycle should be treated as a design vehicle in highway design and maintenance.

The study by Cross and Fisher (7) lists overtaking accidents on two-lane rural highways as a major cause of fatal accidents involving bicycles and motor vehicles. Smooth shoulders could be expected to reduce overtaking accidents by enabling bicyclists to ride out of the roadway. The fact that shoulders also reduce accidents for motor vehicles should help to justify shoulders from a cost standpoint. This, however, needs further study.

PARKING CHANGES

Parking on urban streets takes up space on the roadway that can be used by bicyclists. On-street parking is often necessary, but it can be controlled for the benefit of bicyclists by restricting the areas in which parking is allowed. A 32-city study made in 1965 (9) indicated that the parking-related accident rate decreases as street width increases and as parking is prohibited.

For the benefit of bicyclists, parking was prohibited on many roadway sections in Baltimore County that were not marked as bikeways. It was realized, however, that this is not possible in many locations, especially in front of single-family homes. Where parking could not be prohibited entirely, it was felt that prohibiting parking at intersections would improve the sight distance for both bicyclists and motor vehicles. Most residents who were prohibited from parking in front of their homes were able to accept these prohibitions because they lived on corner lots and could park around the corner. There was little need to prohibit parking along the entire frontage of both sides of a corner lot because only one side of a corner is on an approach to an intersection and there is more value in increasing the sight distance for the near side of an intersection than for the far side. In addition, most of the corner lots involved a collector street that intersected a minor street, and it was felt that there was less need to remove parking from the minor street.

Equations were developed to help in determining how far back from an intersection parking should be prohibited for both near-side and far-side situations (see Figure 6):

$$PD_{FS} = SD_{FS}\,[(2.4\text{ m} + DE)/(DE + CL)] - FD \quad (1)$$

Figure 6. Determining how far back from intersections parking should be prohibited to increase sight distance (Equations 1 and 2).

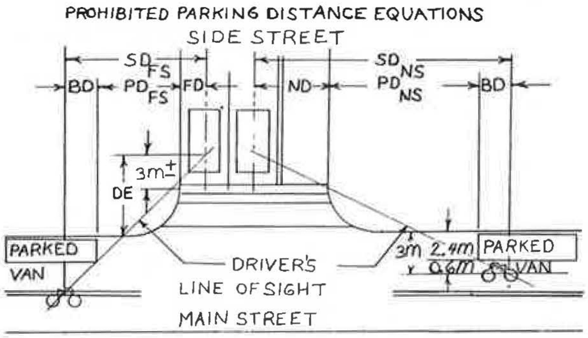
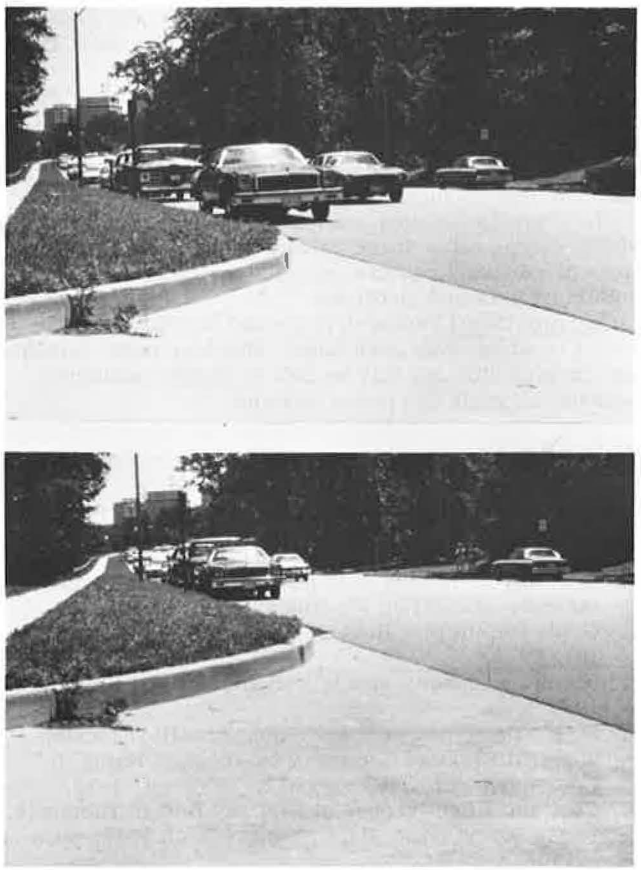


Figure 7. Situation before and after parking was prohibited farther back from intersection: limited sight distance and increased sight distance.



$$PD_{NS} = SD_{NS}\ [(2.4\ \text{m} + DE)/(3.0\ \text{m} + DE)] - ND \qquad (2)$$

where

- PD_{FS} = far-side prohibited parking distance,
- PD_{NS} = near-side prohibited parking distance,
- SD_{FS} = far-side bicycle-design-speed stopping distance,
- SD_{NS} = near-side bicycle-design-speed stopping distance
- DE = driver's eye distance from curb,
- CL = centerline distance to curb,
- FD = far-side distance,
- ND = near-side distance, and
- BD = behind-vehicle distance.

To determine how much of the view would be obstructed by a parked vehicle, a worst case was assumed: a van—which obstructs vision more than an automobile or a small truck—parked so that the left edge of the van is 2.4 m (8 ft) from the curb. It was also assumed for the worst probable case that a bicyclist would be separated from the van by 0.3 m (1 ft) of clearance. The design bicycle and rider are 0.6 m (2 ft) wide so that the center, or eyes, of the bicyclist would be 0.6 m from the van and 3 m (10 ft) from the curb. The prohibited parking distance from the intersection is then a function of stopping sight distance, which is based on AASHTO criteria for bicycle-design-speed sight distance.

Corrections would have to be made if there were a curve in the main-street section of roadway, if the cross street did not enter the main street at a right angle, or if an obstruction existed in the line of sight between the bicyclist's eye and the driver's eye. If wrong-way bicycle riding is a problem, it might be advisable to prohibit parking on the far side of the intersection as much as on the near side.

The study by Cross and Fisher (7) lists parallel parking as a contributing cause of accidents when a bicyclist rides out of a driveway into the path of a motor vehicle. Total removal of parking is usually not possible, but selective removal of parking at high-bicycle-volume driveways and public streets could serve to reduce accidents when motorists and bicyclists pull out in front of each other. The degree to which accidents could be reduced by selective removal of parking requires more study.

Angle parking, which is more hazardous than parallel parking, was removed from two streets in Baltimore County (9, Ch. 10, p. 10). The added width available for bicyclists was used as a warrant to remove angle parking (see Figure 7). The vision of a driver exiting from an angle parking space is obscured, and the view of a bicyclist can be obscured completely. Cross and Fisher (7) list the removal of parallel parking in favor of angle parking as a way of reducing accidents that involve a bicyclist riding out of a driveway into the path of a motor vehicle. It is possible that any reduction in this class of accidents would be more than offset by an increase in accidents that involve motorists backing out of angle spaces into bicyclists. This, however, should be studied further.

LATERAL PLACEMENT OF MOTOR VEHICLES IN RELATION TO BICYCLISTS

To determine the lateral placement of motor vehicles when they pass bicyclists, photographs were taken of a single bicyclist riding with traffic as motor vehicles passed him (because of the time that would have been required to photograph a statistically valid number of unwitting bicyclists, and since I am myself an experienced bicyclist, I was the bicyclist photographed). This experiment was conducted in a curb lane nominally 3.7 m (12.25 ft) wide, in a curb lane nominally 4.3 m (14.25 ft) wide, and on a shoulder nominally 0.8-1.1 m (2.5-3.5 ft) wide. The lateral placement of motor vehicles without the presence of a bicyclist was also photographed for the control part of the experiment.

The location of the bicycle on the road surface was approximately the same in all instances because chalk marks were placed on the pavement at closely spaced intervals. The chalk marks were placed approximately 0.7 m (2.25 ft) from the curb because the storm-drain grates on the roadway were nominally 0.6 m (2 ft) wide.

The two curb-and-gutter study sections used (the same ones described previously in the discussion of the advantages of wide curb lanes) were on York Road (MD-45), a five-lane urban arterial in Timonium, Maryland. Both sections are almost identical geometrically except that one section opposite the Maryland State Fair Grounds is marked with 4.3-m (14.25-ft) curb lanes and the other section, approximately 1.6 km (1 mile) to the south, is marked with 3.7-m (12.25-ft) curb lanes. These locations provided a unique opportunity to study the operating characteristics of the two different lane widths without the influence of other factors. To reduce the influence of turning movements caused by almost continuous commercial strip development, the study sections were selected to have the fewest commercial driveways, and the morning peak hours of 7:15-9:15 a.m. were used.

As the shadow cast by the bicyclist became even with the shadow cast by the passing vehicle, an inconspicuous photographer took a picture using a 300-mm telephoto lens and camera on a tripod. The photographs used for the data reduction were black-and-white negatives or color slides, which were projected onto a screen. Measurements were taken from the photographs of license plates, lane width, and bicycle height and were compared with field measurements.

From accuracy calculations and sample variance, it was determined that sample sizes of about 30 were needed to obtain a 95 percent confidence limit. A sample size of at least 40 was obtained for all six experimental conditions, however.

The findings were as follows:

1. The average lateral clearance between the bicyclist and motor vehicles was 1.5 m (5.0 ft) in the 3.7-m (12.25-ft) lane and 1.61 m (5.3 ft) in the 4.3-m (14.25-ft) lane, which is not a statistically significant difference. The variance of the data for the 3.7-m lane was 0.54 m (1.79 ft) compared with a variance of 0.44 m (1.47 ft) for the 4.3-m lane. The higher variance is explained by the tendency of motorists in the narrower lane to either travel closer to the bicyclist in the lane or to avoid the bicyclist completely by crossing far over into the adjacent lane. Both of these tendencies are undesirable for bicyclists because the closer-moving vehicles increase the risk of a collision and vehicles that are partially in the adjacent lane cause conflicts and interruptions in the traffic flow.

2. When no bicycle was present, the mean motor-vehicle placement was 1.25 m (4.1 ft) from the face of the curb in the narrower lane and 1.61 m (5.3 ft) in the wider lane. The difference in the means was 0.36 m (1.2 ft), which is approximately equal to 0.3 m (1 ft), the difference between the centerline locations of the two lanes. The increased displacement from the curb in the 4.3-m lane could benefit bicyclists because, presumably, the greatest danger posed to bicyclists by overtaking vehicles is the motorist who is unable to see or avoid them. The increased vehicle distance from the curb should therefore be a benefit to bicyclists.

A study of lateral placement was also conducted on Wilkens Avenue (MD-372), a two-way, two-lane road that is nominally 6.4 m (21 ft) wide and has shoulders that vary in width from 0.8 to 1.1 m (2.5-3.5 ft). The data indicated that the mean lateral clearance of vehicles from the edge line was 0.53 m (1.7 ft) when no bicyclist was present and 1.34 m (4.4 ft) when a bicyclist was present. The bicyclist maintained approximately the same position off the edge line—0.6 m (2 ft)—even though the shoulder width varied.

The results indicated that, even though the shoulder width was substandard for a class 2 bikeway, acceptable lateral clearances could be maintained between the bicyclist and the motor vehicle. When the bicyclist was not present, none of the vehicles observed encroached on space over the shoulder that the bicyclist would have occupied.

CONCLUSIONS

1. On-road improvements should be implemented for bicyclists where no alternate bikeways exist, and roads improved for bicyclists do not need to be marked as bicycle routes.
2. The bicycle should be considered as a design vehicle in highway design and maintenance.
3. By providing additional space between bicyclists and motor vehicles, wide curb lanes can be a benefit to bicyclists on many urban arterials and collectors when other bikeway facilities are not available.
4. Wide curb lanes can be marked on many lower-speed curb-and-gutter arterials without adversely affecting motor-vehicle safety or capacity.
5. Smooth-shoulder improvements can be a benefit to bicyclists even if minimum standards for a class 2 bikeway are not met.
6. Smooth shoulders should be considered on roads that are used by bicyclists.
7. Parking changes can benefit bicyclists by providing more usable space on streets. Parking restrictions at intersections can increase sight distance for both bicyclists and motorists.
8. Additional research is needed to determine the extent to which wide curb lanes, shoulder improvements, and parking changes may be able to reduce accidents between bicycles and motor vehicles.

REFERENCES

1. S. P. Johnson. Bicycle Route Map, 1896. Maryland-National Capital Park and Planning Commission, Laurel, MD, May 1975.
2. A Policy on Design of Urban Highways and Arterial Streets. AASHTO, Washington, DC, 1973.
3. Guide for Bicycle Routes. AASHTO, Washington, DC, 1974.
4. Highway Capacity Manual. HRB, Special Rept. 87, 1965.
5. O. K. Dart, Jr., and L. Mann, Jr. Relationship of Rural Highway Geometry to Accident Rates in Louisiana. HRB, Record 312, 1970, pp. 1-16.
6. Cost and Effectiveness of Highway Design Elements: Phase 1. NCHRP, Rept. 3-25, March 1976, pp. 69-70.
7. K. D. Cross and G. Fisher. A Study of Bicycle/Motor Vehicle Accidents. National Highway Traffic Safety Administration, U.S. Department of Transportation, Rept. DOT-HS-4-00982, Sept. 1977.
8. R. C. Gupta and R. Jain. Effect of Certain Geometric Design Characteristics on Accident Rates for Two-Lane, Two-Way Roads in Connecticut. Civil Engineering Department, Univ. of Connecticut, Storrs, Aug. 1973.
9. One-Way Streets and Parking. Highway Users Federation for Safety and Mobility, Washington, DC, 1971.

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