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Rumble Strips or Not Along Wide Shoulders Designated for Bicycle Traffic?

PER GÅRDER

Wide, paved shoulders on busy two-lane roads are sometimes designated as bicycle routes. But this shoulder may not be a safe place for bicyclists if inattentive and dozing drivers "use" it too. Preliminary estimates for a road carrying 1,000 vehicles/hr show a fatality rate substantially higher than the average rate for bicycling. To make the shoulder safe, dozing vehicle drivers have to be woken up before they infringe on the bicyclists' part of the shoulder. Continuous shoulder rumble strips have a potential to alert wandering drivers and thus reduce the number of run-off-road automobile crashes, as well as enhance the safety of bicyclists and others using the shoulder. A narrow strip that leaves most of the shoulder to the bicyclists is desired. It is important that this remaining part is kept free from debris so that bicyclists are not forced to ride on the rumble area or out in traffic.

There are several reasons why bicycling should be promoted. It is a nonpolluting form of personalized transportation that can help reduce congestion. Furthermore, bicycling is a form of transportation beneficial to the individual's health as long as injuries are avoided. The National Bicycling and Walking Study (*1*), therefore, set as goals to double current levels of walking and bicycling and to reduce by 10 percent the number of bicyclists and pedestrians killed and injured in crashes. The recent trend in the rising level of bicycling is somewhat encouraging. The bicycle seems to have gained popularity for recreational purposes over the last few years. For transportation purposes, the trend is mixed. Some regions have seen increased usage even for commuting purposes, but the nationwide trend is less encouraging. The 1980 census showed that 0.5 percent of all workers used the bicycle (or other) as their predominant transportation mode to get to work. In the 1990 census, that share dropped to 0.4 percent (*1*). If we want to substitute bicycling for vehicle miles traveled, we have to focus on utilitarian uses. For commuting purposes this doesn't have to mean that the bicycle has to be ridden from door to door. Intermodal trips, where the bicycle is used to get from the home to a transit facility, may also be an effective way to cut pollution, congestion, and vehicle miles traveled.

One of the most frequently cited reasons for not bicycling is fear for safety in traffic (*1*). Therefore, if we want to make bicycling a more popular transportation alternative, it seems logical to try to improve the perceived safety. However, increasing the perceived safety may actually be counterproductive from a safety perspective. The subjectively experienced difficulty should not be reduced but rather increased (*2*) to get fewer crashes per mile ridden. This increased subjective difficulty should be applied to all road users potentially involved in crashes. So, unless motorists and bicyclists are completely separated, neither motorists nor bicyclists should be encouraged to perceive the road as safer than it actually is. This rule is often broken, and that helps explain why partial separation, for example, bike paths that frequently intersect with streets, leads to more crashes per mile ridden than environments where bicycle and vehicular traffic share the same roadway (*3*). It also explains why design criteria should not be based on what bicyclists perceive as safe, unless our goal is solely to increase bicycling irrespective of injury consequences. However, there is nothing wrong with increasing the perceived safety as long as the "objective" (actual) safety is improved by at least the same amount. Then the result will typically be more riders, as well as fewer crashes per mile ridden. How can roads be made safer, both from a subjective and an objective perspective?

To address the question of objective safety, we will early on in this article review bicyclists' involvement in crashes, both fatal crashes and other injury crashes. Seen in a macro perspective, we should try to eliminate a share of these crashes and at the same time avoid introducing new factors that may lead to new crashes. Steps for reaching this goal probably should include engineering measures, as well as educational efforts and encouragement and enforcement activities.

Measures to improve the subjective (perceived) safety include building wide curb lanes, marked bike lanes, and paved shoulders, as well as building separate bike paths. Paths seem to be more effective than lanes or paved shoulders if our goal is to boost ridership. This is supported by interview studies, as well as by studies of actual behavior. In a 1991 Harris Poll, 46 percent of individuals stated they would sometimes commute to work by bicycle if safe bicycle lanes were available, whereas 53 percent would if they had safe, separate designated paths on which to ride (*1*). In the Chicago area, census zones where five linear trails exist averaged 15.6 percent of commuter trips by bicycle, compared with only 1 percent for the region as a whole (*1*).

It is difficult to design safe paths that do not have their own right-of-way, and getting a separate right-of-way may be impossible. Then paved shoulders or bike lanes may be the most feasible option (*3*). It should also be noted that there are bicyclists who prefer to ride on roads shared with automobiles rather than on separate paths. Paved shoulders and bike lanes are typically perceived as safe as long as vehicle speeds and volumes are relatively low. However, wide, paved shoulders are sometimes designated as bike routes even on very busy two-lane roads. ISTEA funding will probably make this practice substantially more common. This raises the question, is the shoulder of a busy highway a safe place for bicycle riders when inattentive or dozing drivers may inadvertently "use" it too?

OBJECTIVE

The issue this article focuses on is the safety level for bicyclists on wide, paved shoulders in rural areas, and whether these shoulders

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should be separated from the traveled lane by continuous rumble strips. Wide curb lanes and striped bicycle lanes can, in this respect, be seen as equal to paved shoulders lacking a separating rumble area.

SHOULDERS AND SAFETY

Paved shoulders give many advantages. An addition of 1.2 m (4 ft) wide, paved shoulders on rural, two-lane roads has been shown to reduce run-off-road, head-on, and sideswipe motor vehicle crashes by 29 percent, whereas 2.4 m (8 ft) wide, paved shoulders yielded a 49 percent reduction (*4*). Paved shoulders also save money in maintenance costs because they reduce degradation of the traveled lane. In addition, they enhance the safety of bicyclists, compared with riding along the same road lacking paved shoulders. But the question is, is this to a level of safety sufficiently high to justify encouraging bicyclists to use paved shoulders on busy rural two-lane roads?

Bicycle Crash Review

In the United States there are about 850 fatalities in motor-vehicle related crashes among bicyclists annually (*5*). This represents about 90 percent of all fatally injured bicyclists (*6*). In other words, we would almost fully solve the problem of fatalities if we managed to totally separate bicycle traffic from motor vehicle traffic. To have this as a goal would, of course, be unrealistic. And for reasons mentioned earlier, it is hard to predict the effect of only partial separation.

We know that nationwide about 73 percent of fatal motor-vehicle-related bicycle crashes happen away from intersections and 36 percent happen outside urban areas (*5*). Thus in theory, at least, the potential number of fatalities that could be avoided if all rural roads had "safe" shoulders seems to be around 240 a year [(73 percent)(36 percent) (850)]. However, some of these crashes happen at junctions with driveways. Shoulders would probably not influence these crashes. Also, there are crashes away from junctions (intersections and driveways) that involve bicyclists crossing the road. Some of the remaining crashes involve a driver who has dozed off. Wide, paved shoulders would definitely not guarantee that these accidents were avoided. An in-depth analysis of all fatal bicycle crashes in Maine from 1986–1991 (*7*) showed that the bicyclist was going straight along the road in the same direction as the vehicle in only 3 of 14 cases.

About 77,000 bicyclists are injured (*1*) in motor-vehicle related crashes in the United States annually. Analysis of all injury crashes in the state of Maine in 1991 showed that 55 percent of them happened at intersections (*7*). These would definitely not be eliminated by the construction of wide shoulders. Half of the crashes between intersections involved a vehicle or bicycle moving in or out of a driveway. Wide shoulders would probably not reduce this number either. The bicyclist was crossing the road away from intersections and not coming from a driveway in 10 percent of all crashes. Again, wide shoulders would probably have no effect. Only 9 percent of all crashes involved a bicyclist and a motorist traveling along the road in the same direction away from intersections and driveways. Wide "safe" shoulders would reduce this number. In 3 percent, the parties were traveling in opposing directions away from intersections and driveways. Wide shoulders would have a potential to reduce this number too, though teaching the bicyclists to ride with traffic may be the most effective measure.

Very few studies have evaluated the effect on bicyclist safety of adding paved shoulders. To be useful, such studies naturally have to be controlled for regression-to-the-mean. Data from Maine (*7*) indicate that the presence of shoulders does not necessarily make roads safe for bicyclists. Almost half (46 percent) of all the roads linked with bicycle crashes had a shoulder on the right-hand side, though often it was narrow, and the type and quality of the surface is typically unknown. On the other hand, only 13 percent of the crashes happened on roads with a right-hand shoulder of 1.8 m (6 ft) or more. Lack of bicycle ridership counts means that these numbers cannot be translated into risk estimates. It is not only the width of the shoulder that indicates how much space is left for bicyclists. The combined width of the traveled way and the shoulders should be considered. The relationship between number of bicycle crashes and total pavement width is illustrated in Figure 1. Very wide pavement width indicates more than two traffic lanes. An analysis showed that only 7 percent of all bicycle crashes (away from intersections) were reported on roads with more than two lanes (2 percent on three-lane roads, 2 percent on four-lane, 1 percent on five-lane, and 1 percent on seven-lane roads). This does not mean that multilane roads are safe, but rather that most bicyclists ride on two-lane roads.

Shoulders used by bicyclists should have a high pavement standard and be kept free from debris and obstacles, including motor vehicles. This is especially important if the shoulder is designated for bicycle traffic. Parked vehicles can be accepted in emergency situations. Moving motor vehicles are more of a threat to the safety of bicyclists. There are many reasons why motorists enter shoulders. A few states permit regular use of shoulders for slow-moving vehicles, and other states permit it under certain conditions. In addition, there is a lot of illegal use. For example, vehicles turning left at T-intersections lacking left turn lanes are sometimes passed on the right by vehicles using the shoulder. This type of situation is dangerous, but the greater threat to the safety of bicyclists is probably the nondeliberate use of shoulders by inattentive or dozing drivers. Inattentiveness can be caused by a driver talking to a passenger, trying to read a map while driving, or looking out a side win-

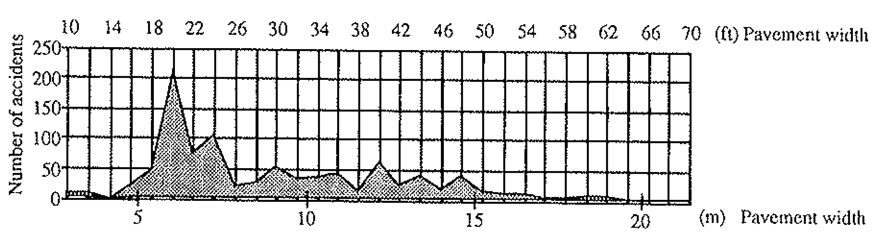

FIGURE 1 Pavement width of link with bicycle accident. (Note that intersection-related crashes are not included.)

dow. The inattentive driver can be made aware that he is drifting onto the shoulder with visual, auditory, or tactile (vibratory) signals. It has been shown that tactile signals give the quickest response. What to do about dozing drivers is addressed below.

FREQUENCY WITH WHICH DRIVERS DOZE OFF WHILE DRIVING

Reports based on police-recorded accidents give clues to how often people have accidents as a result of dozing off, but this information is most likely biased because people are not likely to report the true cause of an accident that is sleep-related. In fact, the accident may not be reported at all, especially if it doesn't involve a second party and takes place on a minor rural road. It may be possible to capture these accidents in other ways, for example, through interview studies or with the use of questionnaires distributed among randomly chosen drivers. According to Dillman (*8*), who commonly is quoted as an expert on interview techniques, people tend to give "socially acceptable answers" in face-to-face interviews, whereas people are more apt to tell the truth if the survey is done in a way that ensures anonymity. This is probably especially true if admitting the truth may reveal embarrassing or even criminal behavior. We therefore chose to use questionnaires for collecting this data. These were distributed in the state of Maine during 1993. A total of 205 drivers participated. Following is a summary of the results. Details are presented in a separate article (*9*).

The average incident rate of dozing off while driving was around once every 45,000 km (28,000 mi) among randomly selected drivers. Younger drivers (<25 yr) are significantly more prone to falling asleep than other groups ($P < 0.1$ percent). Almost every second person (36 out of 79) below age 25 had been asleep behind the wheel during the last 12 months. Their incident rate was around once every 22,000 km (14,000 mi). Men were twice as likely to fall asleep as women (significant difference, $P < 0.1$ percent). Among randomly chosen males, 30 percent had fallen asleep behind the wheel during the last 12 months. The corresponding percentage among females was 14.

Fifteen (13 percent of those who had dozed off) reported a collision as a result of having fallen asleep. Two more reported to have woken up completely off the road, in a ditch and on a lawn, respectively, but because these incidents resulted in no damage to the vehicles, they were not considered to be accidents by the respondents. Only 2 of the 15 drivers reported that they woke up before the collision. One woke up in a hospital. Five of the accidents were collisions with other vehicles, three involving another passenger car and two involving heavy trucks. The remaining 10 were single-vehicle accidents; in 3 cases collisions with guard rails, in 2 cases with trees, in 1 each with a snowbank, a ditch, and a telephone pole (on a sidewalk). Only 5 of the 15 accidents were reported to the police.

Most of the drivers who had not had a collision stated that they were asleep only for a second or two and woke up by themselves. They seemed to think there was not a real threat of an accident.

Type of Road

Drivers fall asleep on all types of roads, but the rate varies. Our hypothesis was that respondents would be able to recall where an incident had taken place, and, accordingly, classify the road section as Interstate highway or freeway, other major highway, local rural road, or urban route. We considered the typical respondent would be unable to classify roads into more specific subgroups such as other principal arterial, minor arterial, major collector, and minor collector. After analyzing the study, we believe that the only classification we can rely on is "Interstate or freeway" and "other rural road." So few incidents took place on urban streets that an analysis of incident rates is not meaningful.

Just over one-half (52 percent) of the most serious incidents took place on Interstate highways. About 18 percent of all vehicle miles traveled in Maine are on Interstate highways (*10*). This means that the incident rate here is about 2.9 times higher than the average, or once every 16,000 km (10,000 miles) on average.

About 45 percent of the incidents took place on "other rural roads." Rural travel excluding Interstates accounts for about 56 percent of all miles traveled in Maine (*10*). This gives us an incident rate that is about 80 percent of the average rate, or once every 56,000 km (35,000 miles).

Time of Day

Drivers go to sleep at all times of day, but especially during times when the person is used to being asleep. Analysis of the 115 incidents in which the drivers could recall the time of day they experienced their most severe incident shows that the highest hourly rate was just around midnight. The incident rate then was double the average. Only 36 percent of the incidents occurred between 7 a.m. and 9 p.m., the time of day most bicycling takes place. This time period encompasses 58 percent of the day, giving an incident rate per unit of time as 62 percent of the average. Vehicle traffic is, of course, also higher during these times. About 82 percent of all traffic occurs between 7 a.m. and 9 p.m. (*11*). This gives a daytime incident rate per vehicle mile driven as 44 percent (36 percent/82 percent) of the average, or once every 102,000 km (64,000 miles). A lot of biking can be expected in the morning rush hour, if biking becomes a common commuting mode. The incident rate between 7 a.m. and 9 a.m. is somewhat higher than the 7 a.m. to 9 p.m. average (Figure 2).

Traffic Volume

The traffic at the time of the incident was usually very light; 53 percent report an incident in which they were more or less alone on the road. However, traffic volume is strongly correlated to time of day. It would be purely speculative to further reduce the incident rate because of higher than average traffic volumes during the times bicyclists typically ride. Maybe what we should do is the opposite; increase the rate some during times when people ride bicycles. In the following section, *Analysis of Sleep-Related Fatal Accidents*, I present an accident analysis of fatal accidents on Maine's Interstate system showing that most sleep-related accidents happen in the summer and in the daytime.

Location When Waking Up

This analysis was to evaluate whether the driver actually infringed on the shoulder or not before waking up. If he or she did, continu-

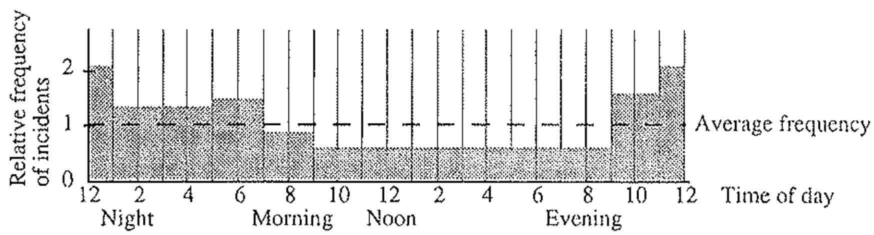

FIGURE 2 Time of day when most severe incident occurred. Relative frequency of incidents is defined as share of incidents reported during a specific time period divided by the portion this time period constitutes. The fact that traffic volumes vary between these time periods is not taken into account.

ous shoulder rumble strips would be fully effective if they produced enough rumble to wake up the dozing driver, and his reaction was to get back onto the traveled way before infringing on the part used by bicyclists.

In 62 percent of the incidents, the driver didn't wake up until after he or she had left the traveled lane. In three out of four of these cases, the driver had drifted off to the right.

Rate of Dozing Off and Drifting Onto Shoulders of Two-Lane Roads in the Daytime

Our best estimate of how often a random Maine driver leaves the traveled way as a result of falling asleep and drifts off onto either of the shoulders before waking up is about once every 206,000 km [(45,000)/(0.80)/(0.44)/(0.62)] (once every 128,000 miles). This rate assumes that the road is lacking devices for waking the driver back up before infringing onto the shoulder. With such devices, these situations could practically be eliminated.

ANALYSIS OF SLEEP-RELATED FATAL ACCIDENTS

Of the fatal accidents on Maine's Interstate system from 1989–1993, 42 percent (33/79) were caused by a driver definitely or very probably having fallen asleep. The investigating officers of these accidents either indicated "driver apparently fell asleep" or noted that the driver or a passenger said that the driver had fallen asleep. Ninety-four people were killed in the 79 fatal accidents; 45 of them died in sleep-related accidents. Table 1 shows the time of day, time of year, and day of the week these sleep-related fatal accidents occurred. There was an obvious concentration of accidents at the time of day and time of year when bicyclists typically ride. This indicated that the frequency with which drivers doze off might have to be adjusted toward higher values per mile than used in this study.

The police report indicated that drivers who fell asleep were operating under the influence of alcohol or drugs in only 2 of the 33 accidents that probably or very probably were sleep related; whereas drivers were operating under the influence in 10 of the remaining 46 accidents (those classified as probably not being sleep related). In total, alcohol or drugs were indicated as a contributing factor in 15 percent (12/79) of the accidents. In other words, our data indicate that sleep is a problem usually not linked to alcohol, and a problem about three times greater than the use of alcohol in fatal accidents on the Interstate system.

RISK OF A SLEEP-RELATED BICYCLE CRASH ON ROADS WITH CONTINUOUS SMOOTH PAVEMENT WITHOUT SEPARATION OF TRAVELED WAY AND SHOULDER

Bicyclists may have several types of crashes when they ride along a road on a paved shoulder. These include single bicycle accidents, as well as collision accidents with other bicyclists, with parked or slow moving cars, or farm equipment. Severe injury and fatal bicycle crashes typically involve a motor vehicle traveling at more than minimum speed. Along a road with paved shoulders, such collisions can occur if the bicyclist leaves the paved shoulder, for example, to swerve around a pothole. More often such a collision is the result of a motorist infringing onto the shoulder. This can be a voluntary movement, for example, when a motorist turns into or leaves a driveway or passes a left-turning vehicle on the right-hand side. In some regions, it is also common practice to use the shoulder for letting faster traffic pass, especially for heavy vehicles on steep grades lacking climbing lanes. The shoulder infringement can also be an involuntary movement resulting from the driver going too fast to control the vehicle, being inattentive, or having dozed off. Below is a risk estimate for this last type of crash. This estimate gives, of course, only a fraction of the total risk to which a bicyclist is subjected.

Let us assume that a bicyclist rides on a paved shoulder with high-quality pavement and no separating continuous shoulder rumble strips along a busy road for 1 hour, that he travels about 16 km (10 mi), and is passed by about 1,000 vehicles. The likelihood of someone dozing off over this section would be about 7.8 percent, using the estimate that drivers fall asleep once every 206,000 km in the daytime on two-lane roads. In-depth interviews with a limited number of drivers who have fallen asleep and gone off the road indicate that often the vehicle travels for quite a long distance before leaving the paved roadway. The angle at which the car goes off the road is argument that proves this. According to the Illinois Division of Highways, the average angle for run-off-road accidents is 3 degrees (*12*). This means that a car travels just over 45 m (150 ft) on the shoulder, if the shoulder is 2.5 m (8 ft) wide, before hitting the pavement edge. A 1.8-m (6-ft) wide car will, on average, occupy 50 percent of the width of the shoulder over these 45 m. With these assumptions and assuming that three out of four drivers veer to the right, we arrive at a risk factor of approximately 1 in 12,000 [(0.078)(150/52,800)(3/4)(0.5)] that the bicyclist will be hit from behind by a dozing driver. And the chance that the injuries would be fatal is high. Our assumptions may not be fully realistic. Our road may not be typical. It may have somewhat more vehicle traffic than the average road with paved shoulders. The risk of falling asleep

TABLE 1 Occurrence of Fatal Sleep-Related Accidents on Maine's Interstate System

Time of day	0-2	2-4	4-6	6-8 (morning)	8-10	10-12	12-2 (afternoon)	2-4	4-6	6-8 (evening)	8-10	10-12
No. of acc.:	4	0	4	1	2	2	5	8	1	3	2	1

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
No. of acc.:	0	3	2	1	5	5	8	3	1	2	1	2

Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
No. of acc.:	5	5	3	3	6	6	5

may decrease in heavy traffic flows, but not as dramatically as one might think. Half the incidents reported in our survey took place on roads with at least "some" traffic. Bicyclists may not use the full width of the shoulder and, therefore, may not have a potential to be hit on more than a fraction of the 45-m section. Finally, some bicyclists may be observant of traffic from behind and evade a collision by leaving the roadway altogether when a car enters the shoulder behind them. An extreme "low estimate" of the actual risk of a collision (10 percent of the calculated number) still produces a risk of collision of 1 in 120,000.

What is the likelihood that such a collision would prove fatal? A German study (*13*) shows that the probability of death for a pedestrian hit by a car is closely related to the collision speed of the passenger car. It gave the following relationships between collision speed and death probability: 20 km/h (12 mph) ≈ 10 percent, 30 km/h (19 mph) ≈ 20 percent, 50 km/h (31 mph) ≈ 60 percent, and 80 km/h (50 mph) ≈ 98 percent. A study of death probabilities among Maine bicyclists supports similar death rates among bicyclists (*7*). Motorists dozing off on rural roads normally continue at high speeds after dozing off. A 50 percent chance that the injuries prove fatal seems rather conservative. This gives a fatality rate around 250×10^{-8} fatalities/bicycle km (400×10^{-8}/bicycle mi) if we use our "best" estimate. The fatality rate would be 25×10^{-8} fatalities/bicycle km (40×10^{-8}/bicycle mi) if we use the extremely low estimate. Even this latter rate is substantially higher than the rate for average bicycling, and this estimate does not include fatalities caused by vehicles drifting onto the shoulder for other reasons than the driver being asleep, or by vehicles traveling in the opposing direction. It would probably be safer for the bicyclists to use a low volume, low speed, parallel road even if it lacks shoulders altogether. However, if we make use of a way to wake up vehicle drivers before they infringe on the bicyclists' part of the shoulder, the situation could be improved considerably.

This example illustrates the risk of riding on the shoulder of a two-lane road. In some states, bicycling is allowed on Interstate shoulders. In that case, the risk of a fatal sleep-related crash is almost four times higher than on a two-lane road carrying the same traffic volume. A separating device becomes a necessity.

Average U.S. Fatality Rate for Bicycling

The average bicycling fatality rate for the United States is about 15×10^{-8}/km (24×10^{-8}/mi). This has been estimated using the statistic of 856 fatalities in 1990 (*5*); whereas total distance traveled by bicycle according to the National Bicycling and Walking Study (*1*) amounted to about 5.5×10^9 km (3.4 billion mi) in 1990. Other studies indicate that the amount ridden by bicycle is higher or about 22×10^9 km (13.5 billion mi) in 1990, which is calculated as the average of low and high estimates of the report *Environmental Benefits of Bicycling and Walking in the United States* (*14*). That would give an average U.S. fatality rate of approximately 4×10^{-8}/km (6×10^{-8}/mi).

HOW TO STOP DOZING DRIVERS FROM DRIFTING ONTO SHOULDERS

Driver monitoring systems and automatic guidance systems resulting from the massive IVHS research currently undertaken may eventually eliminate most accidents caused by people falling asleep while driving. But even if those devices are on the market relatively soon, it will take at least another 10 to 15 years before most vehicles are equipped with them. Cost-effective ways of reducing the problem in the interim would save many lives. These could focus on keeping sleep-prone drivers off the road, keeping them awake while they drive, or waking them up before they cause an accident.

The group of people who are sleep-prone is so large that it would be impossible to keep them off the road completely. Thus, a combination of the other strategies should be used.

Measures preventing drivers from actually falling asleep include medical treatment of people suffering from sleep apnea; driver education and information; and design efforts by engineers, for example, building roads with shorter tangents, "rhythmic" alignment and appealing vistas at irregular but short distances, and, if that is impossible, providing artificial "eye-openers" such as art exhibitions along the road (tried along French Autoroutes), as well as providing rest areas reasonably spaced.

The third category, waking people back up before they cause an accident, is the area in which our research effort is concentrated. Today, small devices are available that can be clipped onto the ear that supposedly awaken a nodding driver, but most drivers will probably never use them, nor do these devices seem very effective. Eventually, "smart cars" will monitor drivers, but until then, other measures should be used. The most effective may be physical measures. We believe that highway engineers too often conclude that an accident caused by a driver dozing off could not have been averted through engineering measures. However, we believe that a simple, relatively inexpensive technique, continuous shoulder rumble strips, is a very effective physical measure that will decrease the likelihood of all accidents caused by dozing or inattentive motorists, not just those involving bicyclists.

USE OF SHOULDER RUMBLE STRIPS ON TWO-LANE ROADS

The departments of transportation of all 50 states were surveyed to find out whether continuous shoulder rumble strips are used along two-lane, two-directional highways.

The use of continuous rumble strips along other roads than limited-access highways is fairly limited. Thirty-five states have no practice on two-lane roads, and only a small fraction of the network has been treated in the remaining 15 states. Alabama's policy is to use continuous rumble strips to separate lanes for car traffic from shoulders designated for bicyclist and pedestrian use. Arizona treats all shoulders of rural divided and undivided roadways on which pavement width, including shoulders, exceeds 10.4 m (34 ft). In California, the policy is that rumble strips are not used where bicyclists use the shoulder unless there is a 1.5-m (5-ft) clear shoulder left on the outer edge. In Colorado, the informal policy is to roll strips into all bituminous overlays, as well as in new construction of all portland cement concrete highways. In Georgia, continuous shoulder rumble strips are used on all paved shoulders that are at least 1.2 m (4 ft) wide. In Idaho, rumble strips are considered on primary highways with a history of run-off-road accidents. In Cook County, Ill., which encompasses the city of Chicago, shoulder rumble strips have been used for 20 years on "all" resurfacing projects, and more than a third of the network has been treated. Now, noise pollution and some opposition from bicyclists have slowed new treatment. In Kansas, two-lane rural roads are treated if shoulders are wider than 1.8 m (6 ft). Kentucky reports that since 1988 shoulder rumble strips have been added to resurfacing, rehabilitation, and new construction on all roads with wide, paved shoulders and narrow shoulders if placed monolithic. In Missouri, all roads with portland cement concrete shoulders or bituminous lift at least 45 mm (1.75 in.) thick and at least 1.2 m (4 ft) wide get continuous shoulder rumble strips as long as the shoulder is not expected to become a travel lane. In Nevada, all rehabilitation and overlay projects require rumble strips if the shoulder is 1.2 m (4 ft) or wider. In New Mexico, all rural highways get rumble strips when they are improved, except for smaller projects, projects in mountainous terrain with many curves, or if shoulders are less than 2.4 m (8 ft) wide and used by many bicyclists. In Pennsylvania, shoulders are treated if there are many run-off-road accidents and the shoulder is at least 2.4 m (8 ft) wide. In Utah, all two-lane two-way roads with safety problems or design speed more than 50 mph and at least 1.2 m (4 ft) shoulders get rumble strips during reconstruction. In West Virginia, all U.S. and state routes with bituminous pavement get rumble strips if shoulders are at least 2.4 m (8 ft) wide [or adjacent to ramps and climbing lanes that have shoulders at least 0.9 m (3 ft) wide].

Adverse Effects of Continuous Shoulder Rumble Strips

One problem associated with rumble strips is noise pollution. This should not be a problem for shoulder rumble strips because they are not supposed to be traversed except for an emergency situation or when a vehicle has left its normal path for some other reason. However, several agencies report noise to be a problem in built-up areas, and even for occupants of individual houses in rural areas, especially in the summer when windows are left open. Noise problems, particularly from trucks, were reported by the Pennsylvania Turnpike Commission and by the State of Wisconsin even on roads where the strip was removed 0.75 m (2 ft 6 in.) from the traveled lane. For this reason, roads in the Milwaukee area are not treated, whereas all other segments of the Interstate system in Wisconsin are treated. A spokesperson for the Wisconsin Department of Transportation thinks the problem may be lessened when the novelty of shoulder rumble strips makes it less common for truck drivers to purposely "play" with them.

Another problem reported with continuous shoulder rumble strips is the risk that a motorcyclist or bicyclist can have an accident as a result of a wheel getting caught at the edge of a rumble strip, which may interfere with the steering of the bike. This problem was recently echoed by an NCHRP Synthesis Report on the use of rumble strips to enhance safety (*15*). However, no accident data seem to support this fear. Motorcyclists have for years been traveling along Interstates with continuous shoulder rumble strips without accident problems. A test by Massachusetts State Police on the Mass. Turnpike (telephone information by J. D. Johnson, Product Manager of Surface Preparation Technologies, Mechanicsburg, Pennsylvania, July 1994) indicated that there were no maneuverability problems for motorcycles traversing the milled-in strip [18 cm (7 in.) longitudinal cut with circle seg-ment profile, spaced at 30 cm (12 in.) with 41 cm (16 in.) transversal width, and a depth of 13 mm (1/2 in.) to 16 mm (5/8 in.), and typically removed about 10 cm (4 in.) from the shoulder line]. In contrast, grooving of the traveled way parallel to the direction traveled (for drainage reasons) has caused numerous motorcycle crashes.

The author, together with 20 students and staff (age varying from 16 to 65), has tested what it is like to ride a bicycle across and along milled-in rumble strips, both ground-in 18 cm (7 in.) long, 13 mm (1/2 in.) deep circular strips and narrower rectangular strips 13 mm (1/2 in.) deep. Several types of bicycles were used, including narrow-wheel road racing bikes. Not a single rider reported any tendency to lose control at any speed or any angle even when not holding on to the handle bars. But every rider reported that riding on the rumble strips was annoying. My conclusion is that there is absolutely no danger if a bicyclist by mistake gets into the rumble strip area, or has to swerve into it to pass broken glass. But if the shoulder is badly maintained, so that the rider cannot ride on it for long distances, the alternative most bicyclists will choose is to go out onto the traveled way rather than use the rumble strip itself. If the rumble strip is put into the only usable 60 cm (2 ft) of shoulder, the rider will move out 60 cm (2 ft) to the left, to a more dangerous location. But if the usable shoulder is 90 cm (3 ft) or more and a 45-cm (18-in.) rumble strip is installed, the remaining 45 cm (18 in.) will be sufficient for riding in as long as it is kept relatively free of debris. An effective narrower rumble strip that does not infringe so much into the bicyclists' area would be preferable to the 45 cm (18 in.) one. Further research should test if such a narrow design is efficient in waking a dozing driver. Rolled-in strips probably do not create any problems for bicyclists because they are much shallower than the milled-in types that were tested. However, neither are they as effective in waking the dozing driver.

CONCLUSIONS

Wide, paved shoulders on busy two-lane roads are sometimes designated as bike routes. ISTEA funding will probably make this practice substantially more common. But this shoulder may not be a safe place for the bicycle rider as long as inattentive and dozing drivers inadvertently use it too. Lack of bicycle statistics makes it impossible to use empirical data for calculating risks. Instead, certain assumptions have had to be made. Based on these assumptions, calculations show that the accident risk on paved shoulders of busy roads is several times higher than that of average bicycling, if the shoulder is not separated from the traveled lane by a device that wakes up the dozing driver. The most efficient device is probably a continuous shoulder rumble strip.

Alabama already has a policy of using continuous rumble strips to separate lanes for car traffic from shoulders designated for bicyclist and pedestrian use; other states have the opposite policy, to avoid using rumble strips where there is substantial bicycle traffic. The reasons for this latter standpoint are that they believe that a bicyclist might have maneuverability problems if he or she gets a wheel into the rumble strip and that the remaining part of the shoulder is difficult to keep free of debris. Tests carried out in this project do not support the fear that continuous shoulder rumble strips will cause maneuverability problems. However, further research should be initiated to find an effective narrower design that infringes less than 18 in. into the bicyclists' area and still remains efficient in alarming a dozing motorist. Maintenance is important even with a narrower design or with no rumble strip at all. A bicycle rider on a road with paved shoulders designated for bicycle traffic should, in my opinion, never be forced to ride closer than 30 cm (12 in.) from the traveled lane.

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Bicycle Use of Highway Shoulders

A. M. KHAN AND A. BACCHUS

Paving highway shoulders offers benefits that include the safe accommodation of bicycles. Although there is much current interest in developing policies and plans for designating bicycle routes based on paved shoulders, there is a lack of methodology for quantifying bicycle-related benefits for inclusion in economic feasibility studies. This article reports research in opportunities and issues in the use of highway shoulders for bicycle routes. Information on existing policies and designs was compiled and summarized from a survey of provincial and state transportation departments in Canada and the United States and from a review of the literature. Design factors for partially and fully paved shoulders are noted from the perspective of bicycle travel. The treatment of safety factors includes issues such as common use of travel lanes and the aerodynamic effects of heavy vehicles and speed on bicyclists. A risk analysis of bicycle-related collisions is presented. Accident reduction benefits attributable to shoulder bikeways are quantified in economic terms. The economic feasibility of partially and fully paved shoulders featuring bikeways and rumble strips is reported. The results show that the inclusion of bikeway benefits enhances the economic feasibility of paving highway shoulders.

There is much interest in North America in developing policies on the use of highway shoulders for bicycling. Also, there appears to be an interest in considering the use of shoulders for bicycling as one of the decision criteria for paving shoulders (*1*).

Paving shoulders is beneficial for a number of reasons. These include:

- Road user safety improvement because of reduced "run-off-road" and "rollover" accidents,
- Enabling the safe accommodation of bicycle travel,
- Pedestrian safety,
- Structural support of the travel lane, resulting in reduced pavement patching and maintenance cost,
- Reduced shoulder maintenance cost,
- Facilitated drainage of the roadway,
- Use of shoulder as a traffic lane during rehabilitation work,
- Enhanced snowplow operation,
- Improved highway aesthetics,
- Enabling the movement of agricultural equipment on shoulders, and
- Providing a sense of safe, open highway.

Shoulder paving criteria in North American practice have varied in many respects, but not until now has bicycle accommodation on shoulders been used as an explicit criterion for decision making.

In this paper, the bicycle use of highway shoulders is discussed and the existing policies and design practices are summarized. Partially and fully paved shoulder designs are discussed from the perspective of bicycle travel. Safety of bicycling in travel lanes and on shoulders is also covered. Because paved shoulders are a prerequisite for bicycling, the economic feasibility of paving shoulders is discussed.

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RESEARCH METHODOLOGY

The research reported is part of a project on highway shoulder issues (*1*). The methodology used for the bicycle part of the overall topic consisted of: (*a*) information acquisition through a survey of provincial and state transportation departments in Canada and the United States; (*b*) study of existing practices, including policies and criteria for decision making and design; (*c*) shoulder design factors from the perspective of accommodating bicycle travel (i.e., pavement width, depth, and buffer space between motor vehicles and bicycles); (*d*) safety analysis leading to the estimation of expected accidents; and (*e*) economic feasibility of paving shoulders "without" and "with bikeways."

EXISTING PRACTICE

Existing Policies and Designs

Bicycle traffic is generally permitted on highway shoulders in Canada, with the exception of certain segments of the Trans-Canada Highway and limited access freeways (Table 1). The provinces of Alberta, British Columbia, and Manitoba appear to have the most comprehensive Canadian policies and designs regarding the use of shoulders for bicycling. Both provinces have developed policies for the accommodation of bicycle traffic under various vehicular and road characteristics. The province of Alberta, which follows the practice of fully paving shoulders, allows bicycling on designated routes that use all types of highways. A minimum of 1.1 m to the right of grooved rumble strips is provided as a bikeway on fully paved shoulders.

In Ontario, bicycles are not permitted on limited-access freeways. The definition of a provincial bikeway network is being developed in which selected highways will accommodate bicycles. Details on the width of shoulder pavements are not available. As for pavement thickness, in the absence of rumble strips, one 40-mm asphalt lift will probably be used.

In the United States, much effort is being devoted to the development of policy on bicycle use of highways and statewide bicycle planning (*2*). Survey responses indicate that there is considerable variation in policies on allowing the use of shoulders on various categories of highways for bicycling (Table 2). Bicycles are permitted on interstates and high-capacity, limited-access highways in some states, but prohibited in many states. The majority of states with policies and design criteria to accommodate bicycles use the *AASHTO Guide for the Development of Bicycle Facilities*, either in whole or in part (*3*).

TABLE 1 Bicycle Accommodation Policies and Design in Canada

Alberta	Bicycles are accommodated on designated routes using all types of highways. A minimum of 1.1m is provided to the right of the shoulder rumble strip for bicycles. Rumble strips are used on shoulders with min. width of 2m. Indented bars are offset 150mm from the edge of the driving lane and are 750mm in length. Additional routes can be designated, if warranted, by the District Engineer.
British Columbia	Bicycles are allowed on shoulders except for Trans Canada Highway and other major highways. Travel lanes adjacent to shoulder bikeway are a minimum of 3.6m wide. Minimum design width is 2.5m for areas where highway design speed exceeds 80 kph and the SADT exceeds 10,000. For freeways and expressways, if bicycles are to be allowed, minimum width is 3.0m .
Manitoba	Design criteria require 50+ cycles per day before consideration of providing a bike path or facility. Separate bikeway facilities are provided for multi-lane highways with posted speed limits greater than 80 km/h and for two-lane highways with SADT exceeding 3000. Dimensions are 1.3m for one-way paths and 2.4m for two-way paths.
New Brunswick	No policy regarding accommodation of bicycles on highway shoulders.
Nova Scotia	Bicycles are not allowed on multi-lane, high volume highways. Consideration is given for upgrading specific routes to accommodate bicycles if Dept. of Tourism can demonstrate need and promote their use.
Ontario	Bicycles are not allowed on limited access freeways. Provincial bikeway network is to be established where selected highways will accommodate bikes. One 40mm asphalt lift will probably be used.
Prince Edward Island	No policies are in place; many bicycles use shoulders during tourist periods. Paved shoulders (2.0m) are provided on primary arterials and highways for other reasons.
Quebec	Shoulders are paved to accommodate cyclists where cycling network overlaps highway. Paved shoulders are a minimum of 1.2m wide and preferably 1.5m.
Saskatchewan	If a large number of bicycles use highways, provision of paved 3.0m shoulder is attempted.
Yukon	No policies are in place; bicycles are allowed to use paved shoulders where they exist.

Notes: 1. Information was not received from Newfoundland and Northwest Territories. 2. SADT Summer Average Annual Daily Traffic.

TABLE 2 Bicycle Accommodation Policies and Design in the United States

Alaska	No general policies; when local conditions warrant, shoulders widened to 2.4m for use as bicycle paths.
Arizona	Bicycles are permitted on all state and U.S. highways and interstates with the exception of those in urban areas. Minimum shoulder width for new construction will accommodate bicycles; policy is not established for that specific purpose.
Arkansas	Bicycles are restricted from using controlled access highways. All highway shoulders are generally paved; not specifically for bicycles.
Connecticut	Policy is under development to accommodate bicycles.
Florida	Bicycles are permitted on all free access facilities upon which at least 1.5m of paved shoulder is provided.
Idaho	Bicycles are classified as vehicles and can be used on all public roadways. Accommodation of bicycles is divided into four types and are based on the AASHTO guide for the development of bicycle facilities. Majority of rural bicycle traffic is accommodated on shoulder bikeways with a desired 1.8m width but a minimum width of 1.2m.
Illinois	Bicycles are allowed to operate on all highways except interstates. Overall policies state consideration and accommodation of bicycles in all highway projects. Specific policies are being developed based on AASHTO guidelines. Policies call for 1.2m to 1.8m paved shoulder depending on speed and ADT.
Indiana	Bicycles are prohibited on interstate highways only. Shoulders are generally paved to an 2.4m width.
Iowa	Bicycles are permitted on all highways with the exception of interstates. Shoulders are paved but not for that specific purpose.
Kansas	Bicycles are permitted on non-interstate and non-freeway highways; however the mixing of high and low speed traffic is not encouraged. The paved shoulders are not designed for bicycles.

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Survey results and literature sources indicate that the demand for the use of shoulders by bicyclists has resulted in decisions on paved shoulder widths ranging from 0.91 m to 1.83 m. Typically, shoulder bicycle lanes are about 1 m wide in each direction, separated from the remainder of the roadway by a buffer space a minimum of 0.5 m wide. The buffer area is indicated by suitable pavement marking, signs, or rumble strips. In some instances, no mention is made of a buffer area.

Shoulder Pavement Width for Bicycle Use

Factors that have influenced decisions on the width ofshoulders that should be paved for bicycle use include adjacent travel lane width, annual average daily traffic (AADT), percentage of heavy vehicle traffic, speed, bicycle traffic volume, and overall width of the shoulder. No formal methodology has been advanced for the quantification of bicyclist benefits.

TABLE 2 (*continued*)

Kentucky	Bicycles must travel away from the travel way by more than the normal shoulder width, except for urban areas with "appropriate" speed limits for motor vehicles.
Louisiana	No law or policy restricts use of paved shoulders by bicycles and no special designs are used.
Maine	Shoulders are not paved as bikeways but are paved so that bicycles can be accommodated. Policies regarding bicycles are being developed.
Maryland	Bicycle traffic is permitted on all roadways except limited access highways. To accommodate bicycles the surface course must have a hot mix asphalt course.
Massachusetts	Bicycles are prohibited on limited access highways. No additional width of shoulder beyond the AASHTO recommended width is added.
Michigan	Bicycles are prohibited from limited access highways. Usually 2.4m or normal shoulder paving is provided and a 0.9m strip is increased to 1.5m to accommodate bicycles.
Minnesota	Detailed design criteria have been established by the state DOT which incorporate ADT, through lane width and shoulder surface type and width. If the road condition is found to be "fair" or "good", then the shoulder width is deemed appropriate. Otherwise, it is improved. The guidelines also include design criteria for grades, curves and superelevation.
Missouri	A 0.9m to 1.5m bikeway is provided on the outer portion of the outside shoulder for bicycles. This area must be outside the rumble strips, if present.
Montana	On roads with a shoulder less than 1.2m the shoulder will be widened to 1.2m if there is significant bicycle traffic: a) 50 bicycles/day in 10 days/month of 3 consecutive months b) 20 bicycles/day for 3 consecutive months. Rumble strips may be deleted if heavy traffic is involved.

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SHOULDER DESIGN FACTORS

In this research, design factors that influence the cost and safety effectiveness of bikeways are of prime interest. These are the width of the paved part of the shoulder, buffer between bikeway and travel lane, and pavement depth. Other design features such as grades, curvature, and superelevation are largely controlled by the design of the highway itself and are therefore not covered in this study. Figure 1 shows shoulder designs based on the 15-m partially paved and 3.0-m fully paved shoulders incorporating bikeways and rumble strips.

A minimum of a 1.5-m partially paved shoulder is assumed for bicycle accommodation on low-speed highways. This width would allow the installation of rumble strips 0.5 m wide and still permit a 1-m paved surface for bicycle use. If bicycles travel close to the edge of the partially paved shoulder, a buffer area of more than

TABLE 2 (*continued*)

Nebraska	When 0.6m rumble strips are in place, bicycles are permitted to use paved shoulder of all roadways except for interstates.
Nevada	Bicycles are allowed on shoulders except for urban freeways.
New Hampshire	With the exception of interstates and turnpikes, cyclists are permitted to use paved shoulders. A few shoulders have been designed for bicycles.
New Mexico	Bicycles are allowed on all roadways except interstates. AASHTO bicycle guidelines are used and a minimum of 1.2m shoulder is provided.
North Carolina	Bicycles are permitted on all highways except for full controlled access highways. Bicycle facilities are constructed in accordance with AASHTO guidelines for bicycles. When used, rumble strips are placed in order to not present hazards to bicyclists.
North Dakota	Shoulders are not designed for bicycle traffic and their use is incidental.
Ohio	For bicycle use, shoulder width should be at least 1.2m. If vehicle speeds exceed 48km/h, if there is a high percentage of heavy vehicles or if obstructions exist on the right side, then additional shoulder width is desirable. Surfaces must be smooth and not surface treated. If rumble strips deter bicycling on the shoulder, the benefit of rumble strips is weighed against the probability that bicyclists will ride into the driving lane.
Oregon	Shoulders are commonly striped as bike lanes and are at "paved" to "full structural capacity". If highway is widened specifically for bicycles, minimal depth asphalt shoulder is used.
Pennsylvania	Policies based on AASHTO bicycle facility guide where minimum paved shoulder bike lane is 1.2m.
South Carolina	Bicycles are prohibited from freeways. Bicyclists must "ride as near to the right of roadway as practicable." Cycling is allowed on paved shoulders. Typically 0.6m partially paved shoulders are provided; 1.2m shoulders considered on a case-by-case basis.

(*continued on next page*)

0.5 m would separate road traffic and bicycles. These design features for the partially paved case are intended for highways that are not in the freeway or expressway category, do not carry much traffic, and have low operating speeds. Also, it is assumed that the width of traffic lanes adjacent to shoulders are established according to design policies and that maximum speed does not exceed 90 km/hr.

To leave 1 m of the paved surface for bicycling, a total of 0.5 m is designated for both short rumble bars and the space between the edge line and rumble bars. This configuration of rumble bars was found to be practical and highly effective by the Pennsylvania Turnpike Commission. Even short, indented bars would alert errant motor vehicle drivers, as well as bicycle users, to travel within the limits of their rights-of-way on the road cross section.

For high-speed, high-volume highways with a substantial proportion of heavy vehicles, the use of fully paved shoulders is preferred.

TABLE 2 (*continued*)

South Dakota	Bicycles are restricted from interstates. With the exception of scenic or special locations, bicycle paths are usually located off the shoulder.
Tennessee	On bicycle routes, paved shoulders are used.
Utah	Use of AASHTO bicycle facility guidelines.
Vermont	Bicycles are prohibited from interstates and certain other limited access highways. State policy is to provide paved shoulders on major highways for a bicycle route system. AASHTO guidelines are used as criteria.
Washington	All highways are available for use by bicycles, except for urban freeways. Paved 1.2m shoulders are desirable.
West Virginia	Bicycles are prohibited from freeways. If allowed, safety grates are placed over inlets and rumble strips are not placed on the outside portion of the shoulder.
Wyoming	Shoulders must be 1.8m or wider in order to accommodate bicycles and rumble strip. The rumble bars have to be short enough to leave space for bicycle traffic. Pavement is at same structural strength as mainline.

Source: State DOTs.

SAFETY ANALYSIS

Safety Factors

If bicycle travel is permitted on a highway with gravel shoulders, the bicyclists are likely to use travel lanes. The difficulty that motor vehicle drivers have spotting cyclists, and the speed differential between bicycles and motor vehicles constitute risk factors (*4*). Bicycles have been noted to be the cause of collisions on rural highways. There is also the effect of motor vehicle speed on cyclists in the form of aerodynamic force (*5*) (Figure 2).

On high-speed roads with a substantial amount of heavy vehicle traffic, a cyclist's balance may be adversely affected by the air displacement caused by heavy vehicles traveling at or above posted maximum speed. If vehicle-induced aerodynamic effect is combined with strong winds, there would be an even higher risk of loss of balance.

Although detailed accident statistics of bicycle-related collisions on rural highways are not readily available, some indication can be obtained from the aggregate level accidents. According to 1991 Ontario safety data, out of a total of 396,780 motor vehicles involved in accidents, 4,347 were related to cyclists (*5*). This represents 1.09 percent of accidents. Assuming that this observation applies to highways, about 1 percent of highway accidents could be reduced if bicyclists travel on bikeways and are not hit by run-off-road motor vehicle movements.

The aerodynamic effects can be reduced to an acceptable level if sufficient buffer space is provided. For highways with up to 90 km/hr maximum speed, a 1.5 m wide (minimum) partially paved shoulder should be acceptable, provided that bicycles travel close to the edge of the partially paved shoulder. For high-speed highways with a maximum speed of 100 km/hr or higher, it would be desirable to locate the bikeway on a fully paved shoulder.

Safety Risk Analysis

The approach followed for the quantification of shoulder bikeway safety benefits calls for an estimate of reduction in expected accidents between motor vehicles and bicycles. As an example, the steps are noted in the following list for a two-lane highway case. For safety analysis of highways without bikeways on shoulders, traffic levels have to be specified. It is appropriate to use threshold AADT for economic feasibility of paved shoulder (without safety benefits attributable to cyclist safety and rumble strips) (*1*).

1. From AADT per direction, the AADT per outside lane and the corresponding hourly traffic are estimated. For the two-lane highway case, the AADT per lane is 4,000. Assuming that traffic for the design hour is 17.4 percent of AADT, the hourly traffic = 4,000 × 0.174 = 696 vehicles/hr. From volume = density × speed, using a conservative estimate of maximum speed = 100 km/hr, average density (occupancy) is 696/100 = 6.96 vehicles/km or 3.5 vehicles/0.5 km per outside lane.
2. The arrival and presence of vehicles in a representative segment of the road is estimated by the Poisson probability distribution. For risk analysis, the length of such a segment should be equal to the

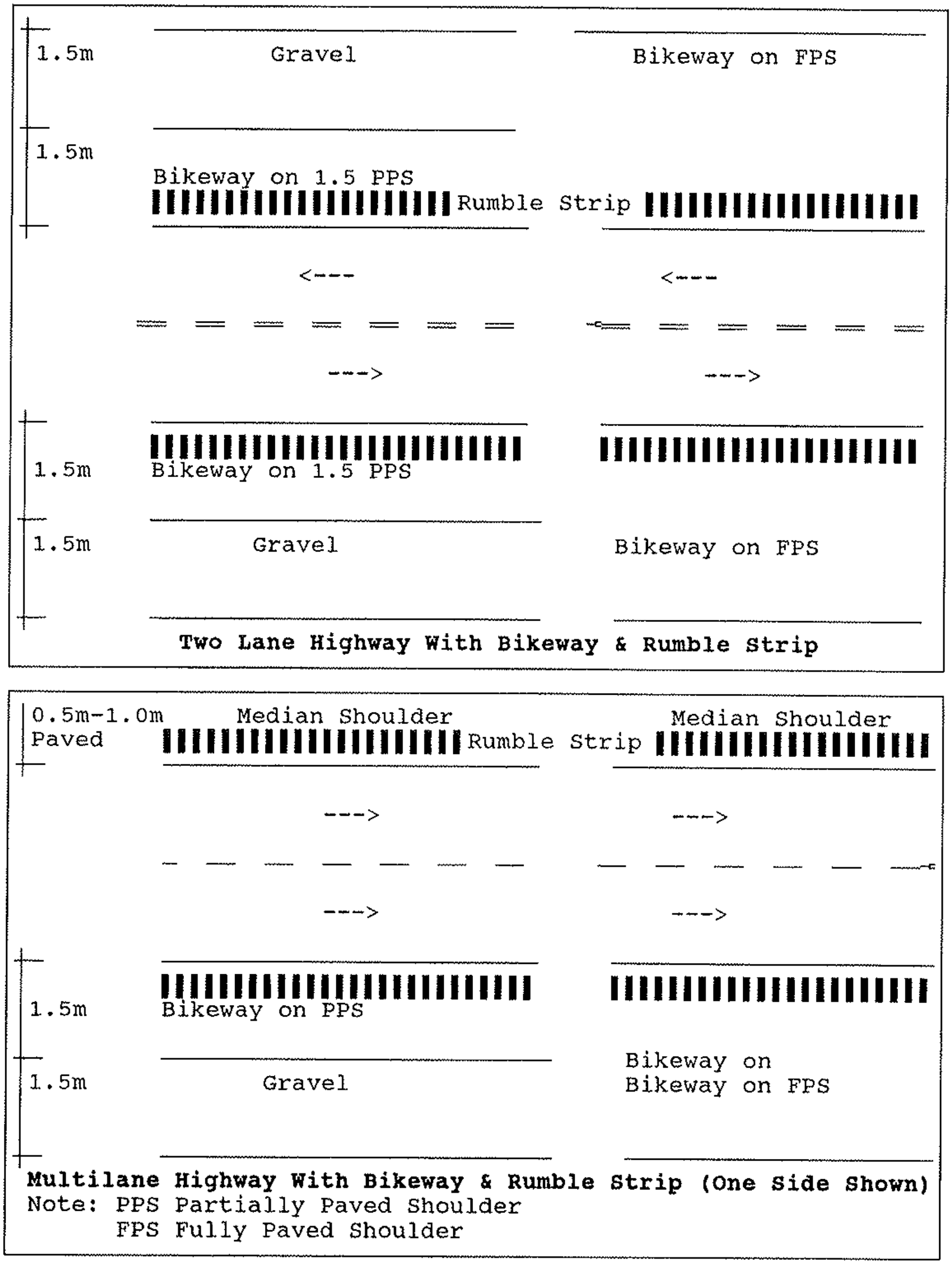
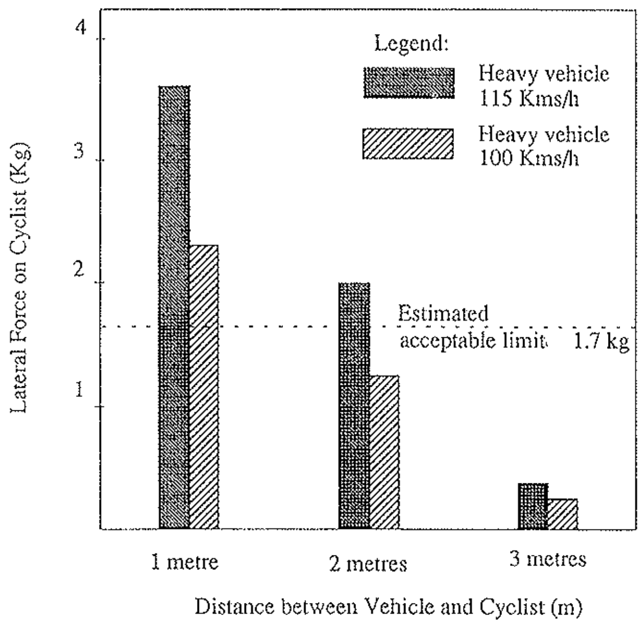


FIGURE 1 Highway shoulder with bikeway.

decision sight distance. For a highway with a 120 km/hr design speed, it is 470 m. For 130 km/hr, 500 m would be required to make complex or instantaneous decisions and to complete evasive maneuvers. In this case, 500 m (i.e., 0.5 km) is used. Probability of (one or more motor vehicles m/0.5 km) = $P(\text{m} > 0) = 1 - P(\text{m} = 0) = 1 - [(\text{avg.m})^0 e^{-\text{avg.m}}]/0! = 1 - [(3.5)^0 e^{-3.5}]/0! = 0.97$.

3. For 50 bicycles/day for both directions, the hourly volume = 50 × 0.174 = approximately 9. Using a speed of 10 km/hr, average density (occupancy) = 9/10 = 0.9/km for both directions or 0.23/0.5 km per direction. Probability of (one or more bicycles b/0.5 km per direction) = $\text{P}(\text{b} > 0) = 1 - \text{P}(\text{b} = 0) = 1 - [(\text{avg.b})^0 e^{-\text{avg.b}}]/0! = 1 - [(0.23)^0 e^{-0.23}]/0! = 0.21$.

4. The probability of a motor vehicle and a bicycle occupying 0.5-km common space on the outside travel lane is found from the joint probability: $P(\text{m} > 0).P(\text{b} > 0) = 0.97 \times 0.21 = 0.20$. The joint probabilities for common-use travel lanes are shown in Table



Source: Reference 4 (Based on an Australian Study)

FIGURE 2 Effect of motor vehicle speed on a cyclist (aerodynamic force) (*4*).

3 for a number of motor vehicular and bicycle traffic levels and facility types.

5. Considering that a run-off-road vehicle may run onto the shoulder bikeway, the joint probability of the arrival of a bicycle and a motor vehicle on the bikeway has to be found. The accident rate for "Other King's Highways" = 1.08/million vehicle kilometers. Considering that run-off-road accidents are 20 percent of total accidents, the run-off-road accident rate is = 0.2[1.08/million vehicle km] = 0.216 accidents/million vehicle km. For a representative 0.5 km of highway and for 3.5 vehicles/0.5 km per outside lane, the number of vehicles that are likely to go over shoulder = 3.5 vehicles [0.216/million vehicles] = 0.756 × 10−6 accidents for one side of highway per 0.5 km of length. From this estimate of average occupancy, the probability of a vehicle going onto shoulder = P(m > 0) = $1 - [(0.000000756)^0 e^{-0.000000756}]/0! = 0.756 \times 10^{-6}$.

6. The probability of a motor vehicle and a bicycle occupying common space on the shoulder bikeway is found from the joint probability $P(\text{m} > 0).P(\text{b} > 0) = (0.756 \times 10^{-6}).(0.21) = 0.159 \times 10^{-6}$. See Table 3 for joint probabilities for a bikeway on the shoulder.

7. Motor vehicle-bicycle accidents per kilometer per year constitute about 1 percent of 1.08 accidents/million vehicle kilometers. For AADT per outside lane = 4,000, these are found as follows: accidents/0.5 km per year per direction = $(1.08/10^6) \times 0.01 \times 4000 \times 365 \times 0.5 = 0.008$. The preceding estimate is subject to the condition that a motor vehicle and a bicycle will jointly occupy a given part of the highway. The use of joint probabilities, presented in Table 4, is essential because a very light volume of bicycle travel is involved. For high volumes of vehicular and bicycle traffic, the joint probability would be equal to 1.0.

8. Expected accidents for AADT of 4,000/outside lane and bicycle volume of 25/day per direction = (0.008 accidents) × [P(m > 0). P(b > 0) of 0.2] = 0.0016/direction per 0.5 km for common use of travel lane. For a bikeway on the shoulder, expected accidents are = (0.008 accidents) × $P(\text{m} > 0).P(\text{b} > 0)$ of $0.159 \times 10^{-6}] = 0.00127 \times 10^{-6}$ accident/0.5 km per direction. Table 4 presents expected accidents per year per direction for a 0.5-km segment of highway.

ECONOMIC CRITERIA

Benefits of Shoulder Bikeway

Although there is much available literature that covers the merits and design of nonmotorized transportation (*6–9*), there is an information gap in the economic criteria for bicycle routes. This research attempts to overcome this deficiency in knowledge.

As compared with common-use travel lanes, bikeways reduce accidents (Table 4). For example, as noted in the previous section of this paper, for AADT of 4,000/direction and 25 bicycles per day per direction, 0.0016 accidents per year per direction/0.5 km are expected to result if bicycles share the roadway with motor vehicles. On the other hand, a negligible number of accidents are expected to occur for a paved bikeway on shoulder. Therefore, 0.0016 accidents per 0.5 km/year per direction can be saved by shoulder bikeways. For both directions, accident reduction amounts to 0.0032/0.5 km or 0.0064/km.

The economic value of preventing an accident is estimated from recently updated cost information reported by the Ministry of Transportation, Ontario (*10*). The total social cost per crash includes direct costs and indirect costs. The direct costs cover property damage (i.e., vehicle and contents, transportation infrastructure damage, buildings and other property damage, and environmental damage) and time and material consumed (i.e., police, fire, ambulance, tow trucks, hospital emergency, hospital ward, other medical, rehabilitation, out-of-pocket expenses, and insurance administration). The indirect costs, estimated through the willingness-to-pay approach, cover value of human life.

From the cost of accident information and Ontario highway safety data on the proportion of various accidents (i.e., fatal, personal injury, or property damage), the value of saving one accident is found to be $76,638.84 (1994 Canadian dollars) (*1*). According to FHWA methodology reported by Cottrell (*11*), the value of preventing an accident is $75,982.90 (1994 Canadian dollars).

The benefits of bikeway = 0.0064 accidents/km per year × $76,638.84 = $490.48/km per year (1994 Canadian dollars) (for both sides of travel). For a 6 percent interest rate (real) and a 12-year life of shoulder pavement, the present worth of benefits = $4,112. These dollar benefits are added to other benefits per kilometer per year, in economic feasibility analyses (i.e., expressed in present worth, $1,503.23 for maintenance cost reduction, $51,709.23 for safety without rumble bars, $8,100.50 for safety of rumble bars). See Table 5 for cost information.

Economic Feasibility

Economic feasibility of partially or fully paved shoulders can be investigated by comparing benefits and costs of shoulder pavement. To begin with, road user safety benefits and reduction of maintenance expenditure are the only benefits that are included in the feasibility analysis. Table 5 presents results in terms of AADT threshold values for economic feasibility of shoulder pavements of two-lane and multilane highways (excluding freeways). In a number

TABLE 3 Probability of a Bicycle and a Motor Vehicle Occupying Common Space

AADT Motor Veh/ Direction	Bicycles/ Day/Dir.	Outside Lane/ Shoulder Traffic	P(m>0)	P(b>0)	P(m>0 x P(b>0)
Two Lane Highway					
Common Use Travel Lanes					
4000	25	4000 veh 25 bikes	0.97	0.21	0.20
4500	25	4500 veh 25 bikes	0.98	0.21	0.21
Bikeway on Shoulder					
4000	25	4000 veh 25 bikes	0.756×10^{-6}	0.21	0.159×10^{-6}
4500	25	4500 veh 25 bikes	0.842×10^{-6}	0.21	0.177×10^{-6}
Four Lane (Undivided)					
Common Use Travel Lanes					
4000	25	2000 veh 25 bikes	0.82	0.21	0.17
4500	25	2250 veh 25 bikes	0.86	0.21	0.18
Bikeway on Shoulder					
4000	25	2000 veh 25 bikes	0.376×10^{-6}	0.21	0.079×10^{-6}
4500	25	2250 veh 25 bikes	0.423×10^{-6}	0.21	0.089×10^{-6}
Multilane (Divided)					
Common Use Travel Lanes					
8000	25	4000 veh 25 bikes	0.97	0.21	0.20
9000	25	4500 veh 25 bikes	0.98	0.21	0.21
Bikeway on Shoulder					
8000	25	4000 veh 25 bikes	0.756×10^{-6}	0.21	0.159×10^{-6}
9000	25	4500 veh 25 bikes	0.842×10^{-6}	0.21	0.177×10^{-6}

Notes: (1) P(m>0) Probability of the presence of one or more vehicles/0.5 km. (2) P(b>0) Probability of the presence of one or more bicycles/0.5 km. (3) The probability of the presence of a motor vehicle as well a bicycle (together). (4) The presence of a motor vehicle on shoulder implies a run-off-road movement. (5) Bikeway on Shoulder is assumed to be paved of at least 1.0m width per direction.

of cases, because the nearest thousand was used as the threshold AADT level, the benefit-cost ratio is greater than one.

The sensitivity of the benefit-cost ratio to AADT levels for various shoulder pavement widths was investigated. Because both the benefits and the cost of paving shoulders increase with increasing pavement width, the threshold AADT levels for various pavement widths do not change appreciably. Although the focus of this paper is not on rumble strips, it is relevant to note that the addition of rumble strip improves the benefit-cost ratios considerably because their benefits are much higher than their costs.

In the case of a bikeway, there is no additional cost involved. On the other hand, the provision of a bikeway contributes safety benefits. Therefore, the addition of bikeway benefits improves the economic feasibility of paved shoulders (Table 5).

CONCLUSIONS

1. Although there is a growing trend toward accommodating bicycles on highway shoulders, there is no consensus on the width of pavement or the need for a buffer area between vehicular traffic and the bikeway.

2. Allowing bicycle use on travel lanes of a highway with gravel shoulders exposes road users and bicyclists to risk of accidents. For

TABLE 4 Expected Accidents Between a Motor Vehicle and a Bicycle Over a 500-m Section

AADT (Motor Vehicle)/ Direction	Bicycles/ Day/ Direction	Joint Prob. P(m>0).P(b>0) (Each Dir.)	Vehicle-Bicycle Acc./0.5Km/Year (Each Dir.)	E(Acc./ 0.5Km/Year) (Each Dir.)
Two Lane Highway				
Common Use Travel Lanes				
4000	25	0.20	0.0080	0.00160
4500	25	0.21	0 0088	0.00185
Bikeway on Shoulder				
4000	25	0.159×10^{-6}	0.0080	0.00127×10^{-6}
4500	25	0.177×10^{-6}	0.0088	0.00156×10^{-6}
Four Lane Undivided				
Common Use Travel Lanes				
4000	25	0.17	0.0040	0.00068
4500	25	0.18	0 0044	0.00079
Bikeway on Shoulder				
4000	25	0.079×10^{-6}	0.0040	0.00032×10^{-6}
4500	25	0.089×10^{-6}	0.0044	0.00039×10^{-6}
Multilane Divided				
Common Use Travel Lanes				
8000	25	0.20	0.0080	0.00160
9000	25	0.21	0 0088	0.00185
Bikeway on Shoulder				
8000	25	0.159×10^{-6}	0.0080	0.00127×10^{-6}
9000	25	0.177×10^{-6}	0.0088	0.00156×10^{-6}

Notes: (1) P(m>0).P(b>0) Joint probability of the presence of a motor vehicle as well a bicycle (together). (2) The presence of a motor vehicle on shoulder implies a run-off-road movement. (3) Vehicle-bicycle accident rate is assumed to be 1% of the total accident rate for the highway. (4) The Motor Vehicle-Bicycle Accidents/0.5 km/Year assume the presence of both a vehicle and a bicycle with a probability of 1.0. (5) E(Acc./0.5 km/Year) Expected accidents = Accidents x Joint Probability. (6) Bikeway on Shoulder is assumed to have 1.0m (min) width per direction.

instance, for a two-lane highway with an AADT of 8,000 or for a multilane divided highway with an AADT of 16,000, if bicycle traffic per day amounts to 50, the expected accident rate is 0.032/0.5 km per year. Even if the use of travel lane is forbidden, the difficulty of bicycling on soft gravel shoulders is likely to result in joint use of travel lanes by motor vehicles and cyclists.

3. Compared with common-use travel lanes, shoulder bikeways reduce accidents. For example, for AADT of 8,000 and 50 bicycles per day, the expected bicycle-related accident rate is negligible (i.e., 0.00254×10^{-6}/0.5 km).

4. The bicycle safety benefits of paved shoulders enhance the overall economic feasibility of paving shoulders. The threshold AADT for feasibility would drop if bicycle safety benefits are included in economic feasibility analyses.

5. The bikeway benefits, as well as rumble strip benefits, are a function of vehicular and bicycle traffic and the economic value of preventing an accident. These do not vary with shoulder pavement width. On the other hand, the combined maintenance and motor vehicle user safety benefits increase linearly with an increase in shoulder pavement width. Because there is a high proportion of motor vehicle user benefits within total benefits (i.e., that would accrue as a result of paving shoulders, installing rumble strips, and allowing a bike route to operate on paved shoulder), total benefits increase with shoulder pavement width. Because capital cost and benefits rise at nearly the same rate, the threshold levels of AADT for various shoulder pavement widths do not differ markedly.

6. Rumble strips are cost-effective for reducing run-off-road accidents and also serve as a buffer between a travel lane and a bicycle route.

7. On low-speed highways (maximum posted speed < 100 km/hr), a 1.5-m (minimum) shoulder pavement width would be sufficient for the provision of a cycle lane, as well as the placement of rumble bars. Pavements for such indented rumble bars, as well as bikeways, should preferably be a minimum of 80 mm asphalt concrete.

8. For high-speed, high-volume highways, the buffer area between motor vehicles and bicycles has to be increased because of the high aerodynamic effect of heavy vehicles on cyclists. In such a case, fully paved shoulders would be desirable.

TABLE 5 Economic Feasibility of Paving Highway Shoulders with a Bicycle Track and Rumble Strips (1991 Canadian Dollars)

	Two Lane	Four Lane Undivided	Multilane With Median
Shoulder Pavement 1.5m on Both Sides			NA
Without Rumble Bars & Without Bicycle Track			
AADT Threshold (2 Sides)	8000	8000	
Cost	$54,144	$54,144	
Benefit/Cost Ratio	Appr.1.0	Appr.1.0	
With Rumble Bars & Without Bicycle Track @AADT = 8000 (2 sides)			
Cost	$56,050	$56,050	
Benefit/Cost Ratio	1.09	1.09	
With Rumble Bars & With Bicycle Track @AADT = 8000 (2 Sides) & 50 Bicycles/Day (2 Sides)			
Cost	$56,050	$56,050	
Benefit/Cost Ratio	1.17	1.13	
1.5m Outside, 0.5m Median	NA	NA	
Without Rumble Bars & Without Bicycle Track			
AADT Threshold (2 Sides)			16000
Cost/Km			$72,192
Benefit/Cost Ratio			Appr.1.0
With Rumble Bars & Without Bicycle Track @AADT = 16000 (2 Sides)			
Cost/Km			$76,004
Benefit/Cost Ratio			1.15
With Rumble Bars & With Bicycle Track @AADT = 16000 (2 Sides) & 50 Bicycles/Day (2 Sides)			
Cost/Km			$76,004
Benefit/Cost Ratio			1.20
Shoulder Pavement 3.0m on Both Sides			
Without Rumble Bars & Without Bicycle Track			
AADT Threshold (2 Sides)	9000	9000	
Cost/Km	$108,288	$108,288	
Benefit/Cost Ratio	1.07	1.06	
With Rumble Bars & Without Bicycle Track @AADT = 9000 (2 Sides)			
Cost/Km	$110,196	$110,196	
Benefit/Cost Ratio	1.13	1.12	

(continued on next page)

TABLE 5 (*continued*)

Shoulder Pavement	Two Lane	Four Lane Undivided	Multilane With Median
3.0m on Both Sides			NA
With Rumble Bars &			
With Bicycle Track			
@AADT = 9000 (2 Sides)			
& 50 Bicycles/Day			
Cost/Km	$110,196	$110,196	
Benefit/Cost Ratio	1.17	1.14	
3.0m Outside,			
1.0m Median	NA	NA	
Without Rumble Bars &			
Without Bicycle Track			
AADT Threshold (2 Sides)			18000
Cost/Km			$144,384
Benefit/Cost Ratio			1.05
With Rumble Bars &			
Without Bicycle Track			
@AADT = 18000 (2 Sides)			
Cost/Km			$148,196
Benefit/Cost Ratio			1.15
With Rumble Bars &			
With Bicycle Track			
@AADT = 18000 (2 Sides)			
& 50 Bicycles/Day (2 Sides)			
Cost/Km			$148,196
Benefit/Cost Ratio			1.18

Notes: (1) Shoulder pavements for two lane, 4 lane undivided and multilane highways (other than freeways) are 80mm depth (two lifts) and life is 12 years. (2) Interest rate is 6% (real). (3) NA Not applicable.

9. Bikeways should be designated only on the outside shoulders of multilane highways. Bicycling should not be allowed on median shoulders.

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DISCUSSION

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The authors have presented an intriguing paper that covers a vital and timely subject. They are to be commended for initiating an effort to consider bicycle usage and safety part of a warrant for the installation of shoulders on highways. I have comments regarding the authors' methodology and conclusions.

The authors have developed a probabilistic basis in an effort to assess the accident exposure of bicyclists. I do not agree with the authors' assumptions or their approach. For example, the authors have defined the conflict frequency as the joint probability of a bicyclist and vehicle occupying the same space. I do not agree that this approach is reasonable because there is such a large speed discrepancy between the vehicles. However, if one accepts their approach, such an approach should be self-consistent.

The joint occupancy of a bicycle and a motor vehicle within a given road segment has been used as a basis for risk analysis. The length of the road segment has been used as the decision sight distance. The authors have chosen to use the decision sight distance for a motor vehicle speed of 130 km/hr (approximately 80 mph), which is excessive. The authors should use the decision sight distance that corresponds to the average speed of the cars on the type of road to which the paper applies. The risk analysis developed by the authors applies to two-lane rural highways with speeds of up to 90 km/hr (approximately 55 mph). The decision sight distance for that speed (250 m) should be used instead of the much greater distance for the higher speed chosen by the authors.

The bicyclist travel speed chosen for the risk analysis is much too slow. The use of extreme values is improper; average speeds should be used for both the bicyclist and the motorist. The average travel speed for the bicyclist should be 25 km/hr for the risk analysis.

The use of shoulders reduces the likelihood of overtaking accidents only. The risk analysis should use the fraction of this type of automobile-bicycle accident rather than all bicycle accidents. This was about 10 percent in a study by Kenneth Cross (*1*).

The foregoing objections to the authors' methodology would reduce the bicyclist accident risk. However, a bicyclist involved in a rural highway overtaking accident is much more likely to suffer extremely serious injuries or death. In the Cross study (*1*), 38 percent of the fatal accidents were of the motorist overtaking type. As a result, the cost of such an accident would be much higher than the cost of an average automobile accident chosen by the authors. The estimated cost for a death is $410,000 (U.S. dollars) (*2*). Because these factors are compensating, I believe that the estimated safety benefit of shoulders derived by the authors of $490/km is acceptable.

I believe that the use of a "real" interest rate to discount future costs to present value is not appropriate. When medical costs are growing faster than all costs (i.e., the inflation rate exceeds the discount rate), then the "real" interest rate of future costs in a present worth calculation would be negative. In other words, the present value of each future annual cost is greater that the present cost. In such cases, I would use a discount rate equal to the inflation rate. For these cases, to determine the present value of future expenditures, the present value is multiplied by the number of years in the period. In the present paper, I believe the present worth of the annualized safety benefit of shoulders for bicyclists should be at least $5,900/km.

The authors have presented the cost-benefit analysis of highway shoulders for bicyclists in Table 5. I disagree with the authors' assumptions in developing the cost-benefit analyses. The authors have chosen to bar bicyclists from the paved shoulder unless it is designated as a bicycle path. Therefore, the safety benefits of the presence of the paved shoulder for bicyclists have not been included. However, the presence of a paved shoulder makes it a bicycle path regardless of designation; therefore, the safety benefits of the shoulder accrue to bicyclists and should properly be included in the cost-benefit analysis.

When rumble strips are present on a paved shoulder without a bicycle track, then bicyclists will be effectively barred from the shoulder and will continue to travel in the vehicle lane. The safety threat to bicyclists must be considered as a cost in this case. The authors have not included this as a cost in their analysis.

When a paved shoulder is present with both rumble strips and a smooth bicycle track of adequate width, then the safety benefit to bicyclists can properly be included as the authors have done. As an experienced commuting and touring bicyclist, I strongly believe that the 1.0-m bicycle track width proposed by the authors is not sufficient. The AASHTO guide for bicycle facilities recommends a minimum width of 1.5 m (5.0 ft) for a bike lane (*3*). I believe that the bicycle path on the shoulder should be at least 1.5 m wide. When 0.5 m wide rumble strips are used as proposed by the authors, the total width of shoulder with bicycle path should be 2.0 m. The cost of the shoulder must be increased accordingly.

I have modified the two-lane portion of the authors' Table 5 to include these cost adjustments; the data are presented as Table 6.

Based on my adjusted economic feasibility analysis, the authors' conclusion that paved shoulders with rumble strips have a favorable benefit-cost ratio for bicyclists is dubious. Using the authors' analysis with my modifications, smooth-paved shoulders are clearly more favorable than shoulders with rumble strips. The additional benefit to motorists of rumble strips is more than negated by costs to bicyclists. Thus, installation of rumble strips does not result in a favorable benefit-cost ratio.

TABLE 6 Economic Feasibility of Paving Highway Shoulders on Two-Lane Highways as a Benefit to Bicyclists

A) 1.5 m Smooth-Paved Shoulders Both Sides:
AADT 8,000
Bikes 50
Cost/km $54,100
Benefit $59,100
B/C ratio 1.09

B) 1.5 m Paved Shoulders With Rumble Strips Both Sides, no Bicycle Track:
AADT 8,000
Bikes 50
Cost/km $62,000
Benefit $61,300
B/C ratio 0.99

C) 2.0 m Paved Shoulders With Rumble Strips and 1.5 m Bicycle Track Both Sides:
AADT 8,000
Bikes 50
Cost/km $74,100
Benefit $67,200
B/C ratio 0.91

D) 3.5 m Traveled Lane With 0.5 m Rumble Strips and 1.5 m Smooth-Paved Shoulders Both Sides:
AADT 8,000
Bikes 50
Cost/km $56,100
Benefit $67,200
B/C ratio 1.20

At the travel threshold assumed by the authors, rumble strips do not show a favorable benefit-cost ratio. Rumble strips can be installed within the right-hand portion of both of the motor vehicle travel lanes so that an adequately wide, smooth-paved bicycle track is provided. This design option yields the benefit of the adequate path on the shoulder for bicyclists and the benefit of the rumble strips for motorists. The favorable benefit-cost ratio for this design option is shown in Option D of Table 6. If rumble strips are to be used, they should be installed at the edge of the automobile travel lane, not in the shoulder.

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AUTHORS' CLOSURE

We appreciate the comments received, although we disagree with most points raised by the discussant. Furthermore, we cannot endorse views expressed by the discussant.

1. The discussant states that he does not agree with our assumptions or our approach. Although he has provided different assumptions in some instances, he does not suggest an alternative approach.

2. The risk analysis methodology we developed can be applied to any highway type. A two-lane highway case is used to illustrate details of the methodology. The methodology is not limited to two-lane highways with speeds of up to 90 km/hr (approximately 55 mph). The rural arterial highways in Canada are designed for a range of 80 to 130 km/hr. See Table A.5a of Reference 1. Two-lane highways with high geometric design standards are used for long distance journeys. On these highways, drivers frequently travel close to design speed. Therefore, a decision sight distance of 500 m is used in risk analysis.

3. A 10 km/hr sustained speed of bicyclists is consistent with the 8 to 12 km/hr range suggested in the literature (*2*). In the case of bicycle tracks that are not on highway shoulders, a design speed of 20 to 30 km/hr is used for establishing radius of curvature, superelevation, and other geometric design features, because such tracks are used for short bicycling trips (*3*). It is doubtful whether bicyclists can maintain sustained speeds higher than 10 km/hr on long distance rural routes. For this type of travel, the bicyclists normally have to transport heavy backpacks, etc., which contributes to slower speeds.

4. The issues raised by the discussant in Item 5 of his discussion are already addressed by our methodology. Details are presented in the Safety Risk Analysis section of the paper.

5. We believe that our estimates of bicycle-related accidents, as well as cost of accidents, are valid.

6. We use a "real" interest rate for discounting future benefits expressed in constant (i.e., real) dollars. The cost of constructing shoulder pavements is presented in present worth terms, therefore no discounting is involved. The purpose of economic analysis in real dollar terms is to work with cash flows adjusted for inflation. If the rate of interest is set equal to inflation (applicable to highway transportation), it amounts to setting the real rate of interest equal to zero. Therefore, the future benefits are not discounted and the benefit-cost ratio tends to favor investments that may not be feasible according to the private sector practices. Therefore, caution should be exercised in setting the real rate of return equal to zero. Further information on this subject can be found in Chapter 13 of Reference 4.

7. The discussant states that "the authors have chosen to bar bicyclists from the paved shoulder unless it is designated as a bicycle path." The fact that bicyclists' benefits are included in the various tables should suggest that the discussant has misunderstood the intent of economic analyses, which show cost-benefit results "without" and "with bicyclists' " benefits. If the bicyclists are permitted by highway authorities to use a given highway and if a paved or a partially paved shoulder is available, it is logical that bicyclists are expected to travel on the shoulder pavement.

8. The discussant states that "when rumble strips are present on a paved shoulder without a bicycle track, then bicyclists will be effectively barred from the shoulder and will continue to travel in the vehicle lane." As noted in Item 7, if bicyclists are allowed to use the highway right-of-way and if a paved or a partially paved shoulder is available, the bicyclists are expected to travel on the shoulder.

9. For one-way travel, a minimum shoulder pavement width of 1 m is adequate and sustainable. It is of course assumed that the bicyclist is not using a trailer. The survey results and literature sources reported in the paper indicate that the demand for the use of shoulders by bicyclists has resulted in decisions that range from 0.91-m to 1.83-m paved shoulders. Given that the "essential space" for a bicyclist is 1 m per direction, it is not surprising that typically bicycle lanes on Highway 4 shoulders are about 1 m per direction and are separated from the remainder of the roadway by a buffer space of 0.5 m (minimum). The treatment of the buffer area differs from agency to agency. These include suitable pavement marking, signs, and rumble strips. It should be noted that lane edge marking and rumble strips of 0.5 m do not interfere with the 1-m "essential space" for cycling. According to survey returns, in some instances no mention is made of a buffer area.

10. The authors do not agree with the discussant's logic or his computations of the benefit-cost ratios.

11. Contrary to the discussant's view, the rumble strips improve the economic feasibility of the shoulder pavements (Table 5). The benefits of installing rumble strips exceed their cost. For example, in the case of a two-lane highway with a 1.5-m partially paved shoulder, the cost of rumble strips per kilometer is $1,906 and benefits per kilometer is $5,045. This gives a benefit-cost ratio of 2.65. Given this information, it is surprising that the discussant states that "at the travel threshold assumed by the authors, rumble strips do not show a favorable benefit-to-cost ratio."

12. We cannot endorse the view of the discussant that rumble strips can be installed within the travel lanes. This action would cause an increase in accidents because the width of travel lanes would be reduced from 3.66 m (12 ft) to 3.16 m (10.4 ft). According to the FHWA (*5*), for a rural two-lane highway on flat terrain with a 1.524-m (5-ft) shoulder pavement and another 1.524-m (5-ft) unpaved shoulder; an average roadside hazard index of three out of seven; a side slope of 7:1; and a recovery distance of 9.15 m (30 ft), reducing the travel lane from 3.66 m (12 ft) to 3.05 m (10 ft) would cause a 29 percent increase in related accidents. If the lane width is reduced from 3.66 m (12 ft) to 3.35 m (11 ft), it would result in a 13 percent increase in related accidents. On the other hand, by providing a minimum 1-m shoulder pavement for use by bicyclists, plus a rumble strip of 0.5 m as a buffer area, the safety of bicyclists as well as motorists would be enhanced. In the case of jurisdictions in which it is considered desirable to provide wider shoulder pavements for use by bicyclists, the threshold levels of AADT are noted in the paper.

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Modeling Bicycle Demand as a Mainstream Transportation Planning Function

ROD KATZ

This article examines the need for quantitative modeling of bicycle demand and reviews the techniques available for incorporating bicycles into existing transportation planning models. It is argued that there is insufficient attention paid to quantitative modeling of bicycle demand and that this results in the case for bicycle provision being poorly based. Transportation modeling, as in many other areas of research, has a traditional method of approach. Improvements in models have tended to be incremental rather than revolutionary. In improving the models of bicycle demand, it is appropriate to review the elements of the traditional approach to determine whether it is possible to tailor those models to the needs of bicycle planning. The location-specific models of traditional transportation models are characterized by considerable spatial detail and very few variables that relate to travel behavior. Although these models are unsatisfactory, particularly insofar as they have treated bicycle transportation, their results continue to be required by practitioners responsible for transportation provision. In the future, however, these models will have a different focus than the predict-and-provide approach taken in years past. This can be expected to result in improved treatment of minority modes such as bicycles. The challenge for incorporating bicycles into future models is to develop a behavioral understanding of bicycle demand that can be incorporated into the spatially defined network models. Some new tools of transportation planning and network management can also be exploited to ensure that bicycle transportation is not forgotten by mainstream transportation researchers.

Quantitative modeling of the demand for bicycles is an essential part of any coherent attempt to establish the bicycle's role in an urban transportation system. Very little progress has been made in this area and current bicycle policy is based on imprecise ideas about the effects of particular measures. Some of the approaches to transportation demand modeling that can be adopted to gain a better understanding of the role of bicycles in our cities are examined. Better understanding, backed by rigorous analysis, will improve policy-making in relation to bicycles. However, modeling bicycle demand is not a simple matter and some of the challenges specific to bicycles are substantial.

The general context adopted in this article is urban Australia. Contrary to many of the images projected abroad of an "outback" Australia, the reality for most of the population is an urban or suburban existence not too dissimilar to North America or parts of Europe. The use of bicycles in urban Australia is similar in proportion to cities in the United States. For instance, journey-to-work-mode share figures for bicycles range from approximately 0.8% in Sydney to 5% in Perth and Canberra.

Information on bicycle riding for trip purposes other than the journey to work is less well known. In this respect, bicycle riding is no different than other modes; however, it is expected that the proportion of commuter bicycle trips to total bicycle trips is lower than for other modes, given the high recreational value placed on bicycle riding by many people and the utility of bicycles for short trips. Noncommuter trips are of increasing importance to transportation planners because of their increasing importance to total travel and the change in planning philosophy away from a sole concern for capacity at the morning peak. Thus, relative interest in bicycle transportation could be expected to exceed its journey-to-work modal share.

This article first considers why formal models of bicycle demand are useful in planning for bicycles and why incorporating bicycles in mainstream transportation strategy formulation is increasingly necessary. The approaches taken to incorporating bicycles in transportation demand models and the benefits and shortcomings of particular methods are then considered.

The concept of demand in transportation is a very broad one and, as a result, many aspects are treated cursorily in this article. It is hoped that this article will serve as a frame of reference for examining bicycle demand studies and identify areas in which research has been completed or where additional work could be usefully conducted.

State-of-the-art transportation research and management methodologies that can be applied to bicycles, such as Intelligent Vehicle Highway Systems (IVHS) and Geographic Information Systems (GIS), are noted as areas to pursue if bicycle research is to become a seriously recognized area for transport research. The promotion of such an image is important in ensuring that opportunities for incorporation of bicycles and other "minority" modes within transportation systems are at least identified, and pursued, with at least the same zeal as the more "futuristic" transport solutions.

WHY MODEL BICYCLE DEMAND?

For many people, the reasons for examining bicycle demand in transportation models may be self-evident. However, it is worth briefly recapping why bicycles are a potentially important part of the transportation mix and why a formal model may be useful.

Importance of Bicycles

One of the major issues facing community and urban planners today is the need to develop sustainable urban systems. An essential aspect of urban life is the need to transport people and goods. Transportation patterns have been identified as having very negative impacts on sustainability because of the direct impacts of certain forms of transportation, particularly the private motor vehicle, and the indirect effects of the transportation system on land use patterns.

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It is widely perceived that a significant change in transportation and land use patterns, away from a reliance on motor cars, is needed to meet the sustainability criteria identified by the Brundtland Commission (*1*). What is not so generally agreed on is the form of the change that should or could be introduced. Some advocates argue strongly that a greater reliance on human-powered modes, particularly bicycles, would reduce the problems of motor vehicles and ensure a greater level of sustainability. Bicycles can be identified as an alternative mode to a substantial number of motor vehicle trips currently made, either alone for short trips, or in combination with public transportation, for longer trips. Others see the private motor vehicle maintaining or even strengthening its position as the primary form of independent transportation because of its advantages in terms of comfort, convenience, and security, not to mention its industrial importance. Bicycles are often considered an obstruction to the smooth flow of motorized vehicles by the latter group.

Although the arguments supporting increased use of bicycles may be attractive, there is considerable debate about whether bicycles are really capable of providing an attractive alternative for a significant number of people and for a significant proportion of their trips. This is a vital issue for bicycle proponents and those people charged with determining transportation policy.

Reasons for Having A Formal Model

Various forms of model, or simplified views of the real world, are used in formulating or justifying particular transportation plans. A broad hierarchy of model types is:

- Mental models. These models are completely opaque to people other than the decision maker. Mental models are generally based on a small number of variables and limited data, often personal experience, relating to those variables.
- Documented qualitative models. These sorts of models identify relationships, either causal or associative. The models may identify policy objectives, a set of relevant variables and assumptions, and expected outcomes from alternative policies.
- Quantitative models. These models typically involve a set of mathematically defined relationships. They may begin with a qualitative model that is translated into a set of mathematical simplifications of the real world. Parameters and statistical confidence levels defining the mathematical relationships may be estimated given available data. As discussed below, there are numerous forms of quantitative models with very different degrees of sophistication in terms of the numbers of variables and the description of the relationships.

Perhaps the major single research project conducted into bicycle transportation in the English-speaking world in recent years has been the National Bicycling and Walking Study mandated by the United States Department of Transportation Appropriations Act 1991 (2). The research was conducted by consultants on behalf of the FHWA. It has produced a series of reports on various aspects of the human-powered modes. Most of the reports involve qualitative models of the demand for and the effects of human-powered transportation. The references to bicycles are primarily an identification of the barriers to cycle trips and the characteristics of other transportation modes that could be influenced to make cycle trips attractive either as a substitute or as a complement to other alternatives, for example, in the case of public transit.

It is recognized in the final report (2) that there is a good deal of research yet to be done in translating the visions of a transportation system more oriented toward nonmotorized modes into planning action. Noted in the report at Action Item 8, point 9 is a reference to "conducting research into patronage estimation and mode split modeling for bicycle and pedestrian services and facilities."

This acknowledgment of the need for quantitative modeling could well be argued to have received insufficient attention to date. The reasons for placing more emphasis on developing quantitative models are discussed below.

Explicit Assumptions

One reason for formalizing the modeling process is the greater likelihood of making explicit key assumptions about factors affecting demand. A well-documented model allows the developer (and users) of the model to reflect on the causal mechanisms underlying the modeled relationships. Relevance of variables included or omitted from the model, and the level of reliability it may have under different conditions and over different time periods may also be considered. This process can lead to model refinement and extension.

An illustration of the importance of explicit assumptions is in the way that land use patterns are incorporated into transportation models. The increased use of bicycles could conceivably contribute to changes in land use. An urban structure characterized by low-density residential, industrial, and other development, commonly deprecated as "urban sprawl," may be of reduced attractiveness for bicycle users compared with motor vehicle users. Adoption of the bicycle as a major transportation mode could see people making long-term decisions about residential and employment location to suit bicycle trip making. The importance of this effect, based on the premise that people choose, or are captive to, a mode of travel and then select residential location and activities suitable to that mode, requires an assumption about the sequence in which people make decisions. Transportation modeling of whatever type requires some such assumptions and their form can have very major impacts on the results of a particular model. Most transportation models take the urban form as being insensitive to mode choice. Better models make these assumptions explicit and qualify the models accordingly.

Justification for Expenditure and Efficient Allocation of Resources

The increased popularity of cycling for recreational and utilitarian use through the 1980s and the recognition of potential benefits of bicycle use have been reflected in increased levels of provision specifically for bicycles. It is fair to say that this provision has been based mainly on mental or qualitative models informing the political process. For a variety of possible reasons, the measured response to many bicycle facilities implemented in Australia has been very limited. The analysis of the "failure" of provision in terms of observed demand response may be interpreted in a number of ways, for example:

1. Providing for cycling is a waste of money.
2. The facilities created may be inappropriate or insufficient to generate any noticeable demand response.

3. Cycling facilities alone will not have a significant influence on demand for cycling without policies directed at changing attitudes, cycling behaviors, and levels of service of other modes. This will influence transportation demand generally in a way which favors sustainable modes such as bicycles.
4. We should not worry about whether demand changes are observed because existing cyclists deserve a better level of service anyway.

Without developing a better understanding of bicycle transportation demand within overall strategic models of transportation, it is not possible to professionally adopt any of these responses. Certainly, before significant resources can be dedicated to cycling policies it is necessary to demonstrate that the first response, a frequently heard comment within road authorities, is incorrect.

The belief structure underlying such a response may be that cycling is unlikely to be attractive to many people because of its perceived negative attributes, such as exposure to weather, effort required (particularly for going up hills), and the level of risk of injury. Formal models would help these beliefs to be reviewed explicitly in evaluating a demand response.

The second and fourth responses are unlikely to carry a rational argument on cycling provision. The second response leaves an open question about how much, by way of resources, needs to be directed to cycling to have an effect on demand. The fourth response is based on an equity argument that is very difficult to win given the competing demands of transit and automobile lobbies and other government spending priorities. The intuitively attractive conclusion gives rise to additional questions about bicycle de-mand relative to demand for other modes. These need to be considered within the context of the urban transportation system as a whole.

All of the suggested responses require additional information to evaluate their relative and absolute values. Different analytical approaches may be biased toward particular responses. The traditional transportation demand modeling approaches are likely to come up with a response along the lines of the first response unless specified to incorporate a range of variables not typically included in such models. The reasons for this and the alternative approaches that have become more widely accepted are discussed below.

QUANTITATIVE MODELING TECHNIQUES

As noted above, quantitative modeling techniques in transportation vary widely in terms of approach and degree of rigor. Some of the techniques developed for planning, particularly at the city-wide level, involve an enormous computational effort. The particular purpose of the model will naturally influence its structure and the resources dedicated to it. By and large the specific bicycling models have been very limited in their scope and have not been readily incorporated within the strategic modeling structures of transportation and land use planning.

One approach to modeling cycling has been to compare the levels of cycling in different cities and to try to correlate these levels with the geographic features of the cities. This approach has been used to define expected levels of cycling for certain trip purposes across cities in the United Kingdom, based mainly on their topography (*3*). A regression model was estimated using the available information on cycling trips and topographical information on cities of equivalent size. Where the topography did not explain a particularly high or low level of cycling, it was suggested that accident risk as a result of poor facilities was the missing explanatory variable.

Mental models and qualitative models are often constructed on the same basis suggesting that given similarities in topography and climate between some European cities in which cycling rates are very high and cities in which rates are low, the difference lies in the level of cycling risk because of poor facilities and driver behavior. Unfortunately, this interpretation may be incorrect for the following reasons. It may be misleading because there are any number of other factors that may influence cycling rates, including attitudes, historical modal shares and, probably most importantly, service levels of other modes. It may provide insufficient guidance about the type of facilities that are required. Facilities in some cities may work well because of the characteristics of the population or city, but work badly in others. For example, a different form of bicycle parking facility may be appropriate in Australia or the United States from that required in Japan where theft is not a common problem. The different urban context of Japan means that bicycles are often used for accessing railways. This makes the provision of parking concentrated at railways particularly effective. Distribution of parking facilities in Australia and the United States would probably need to be more widespread, and thereby expensive, to be as effective from the viewpoint of the cyclist.

Given the very different characteristics of trips made, land use distributions, levels of car ownership, etc., across different cities, it is unrealistic to expect a particular type of facility to work well in one city simply because it works well in another.

In view of the limitations of simple correlation type models in understanding bicycle transportation, it is natural to turn to other areas of research directed at understanding the interrelationships of population characteristics, numbers of trips made, modal shares spatial distribution of trips, and land use characteristics. Transportation research has developed a range of techniques to help in our understanding of these relationships and to model the ways in which various factors interact in an urban context. The techniques may be broadly categorized as:

1. "Traditional" land use transportation models,
2. Strategic transportation models, and
3. "Behavioral" models.

Often these models are portrayed as alternatives, with the latter models suggested as improvements on the earlier approaches; however, it needs to be recognized that these models are largely complementary. The major challenge is to integrate the different approaches to allow behavioral findings to be applied in both developing broad strategies and in the detailed provision issues faced by local engineers and planners. Before considering how integration can be achieved, the different types of models are briefly described.

Traditional Models

The classical models have a number of elements familiar to transportation planners. These are trip generation, trip distribution, mode choice, and trip assignment. These four stages address a number of reasonable questions:

1. How many trips will be made,
2. Where they will be from and to,
3. What mode they will use, and
4. Which route they will take at what time.

This sequence of analysis is represented in Figure 1 (*4*).

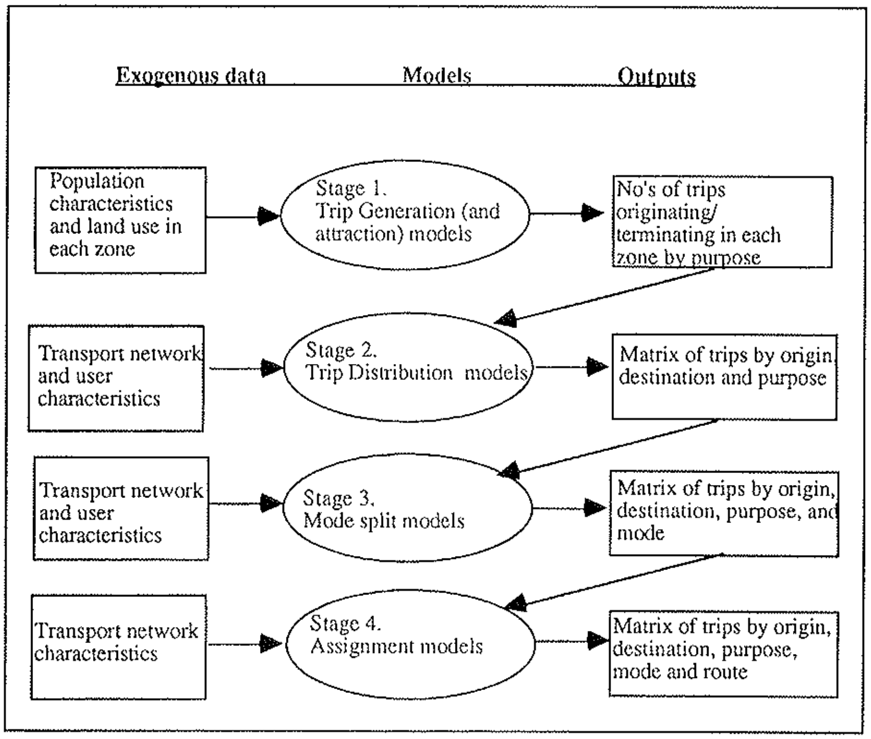

FIGURE 1 Classical four-stage transportation model.

A major advantage of the four-stage model is that it can be applied at a fairly fine zonal or even link-based level. This level of detail is required by many of the people involved in day-to-day transportation supply issues; however, as emphasized by Bates (*5*), this level of detail is achieved at some cost. One of the problems acknowledged by Bates is that the "slow modes" of walking and cycling are often omitted from all stages of the modeling process to reduce the complexity of the modeling structure. There is essentially no theoretical reason to exclude these modes and their omission is often attributed to an institutional and political orientation toward providing capacity for motor vehicles and transit. There have been some exceptions to the omission of bicycles from traditional models, notably as one would expect, in the Netherlands, and in isolated other instances such as Montgomery County, Maryland (*6*).

Many commentators have noted other deficiencies in the use of four-stage models (*5,7,8*). The criticisms of the state of practice in four-stage modeling may be summarized for each stage as follows.

Trip Generation

Trips generated within a particular zone and trips attracted to a zone are generally estimated on the basis of a cross-sectional survey of numbers of trips made by households. Different types of households, based on life cycle stage, income, car ownership, or other readily observed characteristics, are correlated with different trip-generating rates. Different zonal land use characteristics (retail floor-space, office space, etc.) are correlated with trip attraction rates. This cross-sectional analysis does not provide information about changes and is unlikely to stimulate questions about what is causing changes in trip rates over time. The level of trip making itself is generally not a target of policy among transportation planners using a four-stage model, which is something of an anomaly.

The traditional models do not typically attempt to relate trip rates to changes in mode choice, system changes, or availability of different destinations. The trip generation models that emerge are insensitive to policy tools available to transportation planners and are crucially dependent on population changes. Population changes are usually taken from demographic predictions outside the transportation model.

Some trip generation models for bicycles have been calibrated using the techniques typically used in the traditional models. In one English study (*9*), a model of bicycle trip generation incorporating variables such as car ownership and household structure was estimated. Different participation rates in cycling, ranging from 6.6% to 0.4%, were identified across 10 different groups. Extension of this approach is likely to be fruitful in understanding how to maximize benefits through targeting of provision to particular bicyclist groups.

Trip Distribution

Very little progress has been made in modeling people's decisions about trip destinations and how these relate to their origins. In most models, trips generated are allocated origins and destinations based on some measure of separation. The models are then "calibrated" according to an observed matrix of movements. This procedure is unsatisfactory insofar as the reasons why a particular destination is chosen may depend crucially on a number of factors that are simply omitted from the distribution model. This may be attributed to our lack of understanding of complex human activity patterns that determine destination choice.

Although this theoretical basis for trip distribution is unsatisfactory, the lack of accurate data on movements makes calibration inaccurate or nearly impossible in the case of bicycles, which are often omitted from routine traffic movement information collection.

Inaccuracies are compounded when increases in trips generated are predicted. The additional trips are allocated through growth factors applied to origin and destination pairs. These growth factors are often not integrated with projected transportation system and land use changes, making the distribution process even more suspect theoretically and dangerous practically.

Mode Choice

The modeling of mode choice has received a large proportion of attention in research into transportation behavior. A fair amount of this research has been incorporated into the four-stage process but because of the size of areawide four-stage models, often only a limited number of variables and mode combinations are included. Frequent omissions are cycling and other "minority" modes along with variables that may be important in an individual's choice of those modes. The behavioral models often incorporate a significant number of the variables that are omitted from the sequential models for areawide planning.

A frequently neglected aspect of mode choice models in the four-stage process is the interaction of individual and household activity patterns that impose constraints on mode choice and other aspects of personal and household travel characteristics. The work in activity modeling (*10–12*) has indicated some promise in understanding constraints; however, there is still some way to go before these techniques are operational at the detailed level of the four-stage process.

The existence of the sorts of constraints commonly referred to in activity analysis, such as the need to transport children, to link journeys for different purposes in accordance with a time budget, to carry out shopping, etc., are anecdotally important. The application of an activity analysis approach could be of considerable value in understanding the constraints on bicycle use and the opportunities for increased bicycle use if facilities are provided for specific groups. For instance, currently, a parent may decide to travel by car to work at a particular time so they can take a child to school. If a cycle facility were provided allowing the child to cycle to school, the parent may choose a different departure time, possibly outside the morning peak, or have time available to consider taking an alternate form of transportation.

Assignment

Trip assignment components of the classical models tend to be dominated by questions of software and network design rather than the route choice and departure time choice considerations important for individual travelers.

The route choice issues for cyclists are particularly crucial. Inadequate routes for bicycle travel may result in no trip being made or an alternate mode being selected. A choice not to use an inappropriate facility may affect provision of additional facilities, different link characteristics may affect destination choice, and mixing of bicycles with other traffic on particular routes may affect the flow of motorized traffic. None of these interactions are dealt with satisfactorily in traditional models.

A useful discussion of the need for, and difficulties in, inclusion of bicycles in assignment models is provided by Sharples (*13*). She also notes the difficulties in incorporating bicycles within existing software packages designed predominantly for motor vehicles. Bicycles have quite different traffic characteristics from motor vehicles—saturation flows, different speed and trip length distributions, route availability, gap acceptance, propensity to obey particular road rules, etc. These characteristics are poorly understood and may be highly variable according to the context and the particular cyclist.

Strategic Modeling

Despite the criticisms of the classical modeling approach noted previously, the state of practice in applied transportation planning remains largely based around four-stage models. Given this fact, along with the benefits discussed earlier of having a quantitative model rather than making decisions in an information vacuum, the question is how the approach can be used to understand and develop policy responses to the pressing transportation questions.

Increasingly, so-called strategic or sketch planning models have been used for analyzing major policy issues. The advantages of such models are discussed in the following sections.

Reducing Zonal Detail

One major drawback of the very detailed four-stage approach is the level of detail itself. The vast numbers of zones means that computationally there is room for only a very limited number of variables that explain behavior in the models and little or no feedback between stages of the modeling process.

Thus, the most common way of adapting the four-stage approach to strategic issues is to reduce the level of zonal detail. In Sydney, with a population approaching 4 million spread over a very large area, the major transportation model has 720 zones, 7,000 links, and a transit network of 22,000 segments. It has been recognized that to try to work at this level of detail in seeking to understand fairly broad policy implications is computationally intractable. The zonal network has been collapsed from 720 to 86 in the major recent study of strategic options, known as the Future Directions Study, undertaken in 1991 (*14*).

Even this reduced level of detail makes inclusion of a large number of policy variables or feedback mechanisms difficult. For modeling these more complex relationship structures, even smaller numbers of zones may need to be used. Also, specific market segments can be considered alone in modeling many issues, and the network assignment information can be abandoned. This is essentially the approach taken in many of the behavioral models discussed later. Where aggregated zones are used, such as in the Future Directions model, they will ideally be consistent with the detailed zones to make it possible to incorporate findings from the strategic models into the more detailed models.

Sequential Structure

One major criticism of the classical models is the sequential structure imposed on the whole population and the lack of any interaction between elements in that structure. By using a strategic model with a smaller number of zones, it is easier to incorporate the feedback effects that are important in many transportation-related choices.

Incorporating feedback between elements of the sequential process is now a reasonably well-accepted practice in the more sophisticated strategic models but is by no means universal. The order of modeling adopted: trip frequency, destination, mode choice, and route and time selection, may be varied according to different types of people or trip purposes. In the introductory discussion about why it is important to model bicycle demand, it was noted that adoption of bicycles as a primary mode of transportation by some people could affect decisions about where they live. It is difficult to incorporate such an effect in a traditional model because of the computational burden placed on those models from manipulating huge matrices of zones.

Behavioral Models

Other interactions that can also be incorporated into a model that has been freed of the burden of large numbers of zones include many aspects of the decision making process. These models are frequently of the form known as "disaggregate" or "behavioral" models (*15*). They examine the choice process undertaken by individuals in relation to a particular aspect of their travel behavior. These models draw on literature from psychology and economics relating to choice behavioral attitudes, perceptions, information integration, and decision making. This contrasts with the classical models, which are related only tenuously to any behavioral theory.

The disaggregate approaches are very useful for understanding not only what decisions people are making about travel but why they are making them. Young (*16*) presents a general model of the decision making process (Figure 2) that identifies some of the many aspects of decision making that can be investigated in behavioral research into transportation.

The bold lines in Figure 2 represent the main effects and the faint lines represent feedback effects in the decision making process in relation to transportation.

The behavioral approaches have been used most extensively in transportation for modeling mode choice alone but have also been used for other aspects of transportation demand. They could also be used for joint estimation of trip distribution and generation for particular classes of people.

Most of the models have assumed a utility maximization framework for decision making with no express acknowledgment of choice inertia effects or some of the subtleties of perception, attribute evaluation, etc. Some of these subtleties may be important for understanding the longer term potential of cycling as a transportation mode.

A number of useful studies have been conducted in relation to mode choice and route choice by cyclists. Perhaps the most comprehensive application of behavioral modeling techniques to bicycle mode choice in a minority mode share context is the study by Noland (*17*). That study seeks to test some of the hypotheses commonly put forward regarding the role of risk versus other factors, such as comfort, in relation to choice of bicycle transportation.

Other applications of behavioral techniques have been in the area of route choice (*18–20*). These studies have frequently used stated preference techniques to try to elicit information about the value cyclists place on various attributes of routes when making route choices. Stated preference techniques have a considerable potential for future modeling work in other areas related to bicycles in addition to route choice.

INTEGRATING BEHAVIORAL MODELS

The challenge for those seeking to improve our understanding of bicycle use is to integrate insights from behavioral models into areawide transportation planning. The link between behavioral models and system characteristics in networks is often unclear. This

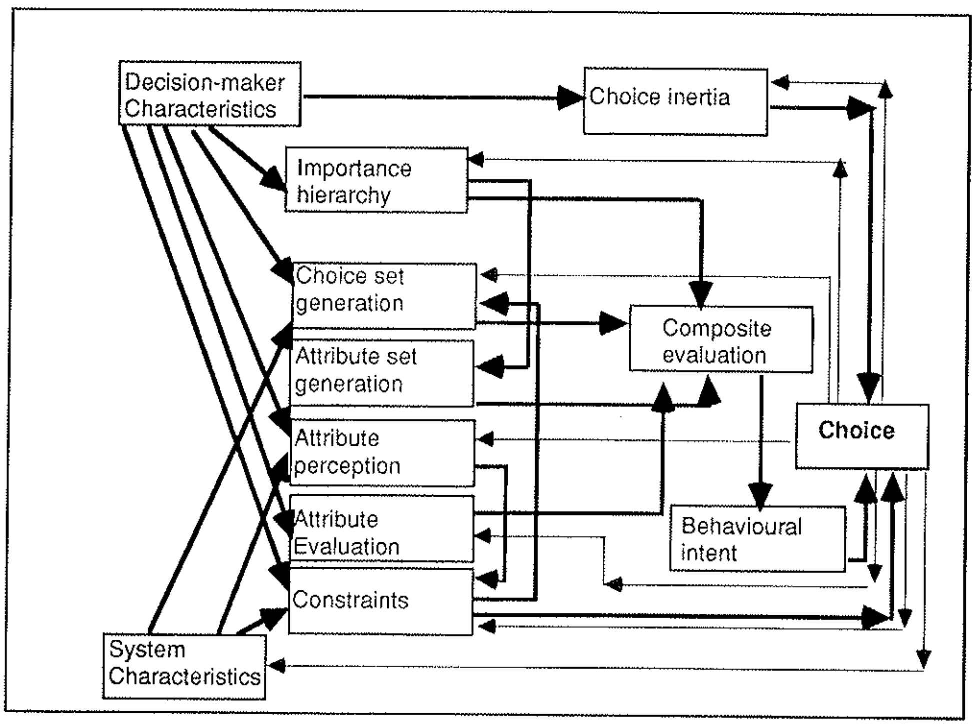

FIGURE 2 A general transportation model (*16*).

is particularly the case for bicycles, as discussed by Sharples (*13*). One method that may be explored as the mechanism for incorporation of variables identified in behavioral models, for instance risk associated with a particular link, is incorporation of specific bicycle factors within the concept of "generalized cost." Information on these factors would need to be available on a network-wide basis.

A key ingredient to such integration is collection of appropriate data relating to the network. This is costly and requires a systematic inventory of our road systems based on factors that are good predictors of bicycle demand. Additional exploratory research would be useful in identifying these predictors.

Inventories of our road networks are constantly being improved. The management of road inventory information has recently become a high priority as its use within GIS systems and for IVHS is being expanded. Already attempts are being made to ensure that bicycles are not ignored in developing such technologies (*21*). However, there is a strong likelihood that they could be omitted from practical applications of these techniques if the possibilities are not considered well in advance and a modeling framework is not established.

CONCLUSION

This article argues that a high priority needs to be given to incorporating bicycles into quantitative transportation models. This contrasts with an alternate view that mathematical modeling of transportation is not an appropriate way to plan urban transportation systems because models are overly restrictive in the variables they are able to include.

The need to incorporate bicycles in quantitative models stems from the need to ensure that planning is fully thought through and therefore resources are efficiently allocated. The successes and failures of implemented bicycle policies may also be better understood and less susceptible to the modal bias of particular institutions or traditional approaches.

Traditional modeling techniques, and even the more recent strategic modeling techniques that have evolved from them, have not been effective in modeling minority modes such as cycling. The challenge in modeling bicycle demand lies in integrating the many subtle factors affecting the demand for cycling into strategic planning models and detailed areawide planning models. This calls for a concentrated research effort to develop behavioral models whose parameters can be incorporated into the models that are spatially linked.

This research requirement does not currently appear to be receiving a great deal of attention. The time is now right to pursue such research through data collection in conjunction with the information requirements of new transportation research areas such as IVHS and GIS. This has the potential to place research into demand for minority modes, such as cycling, into the research mainstream. It may be that this is where they rightly belong given the issues of sustainability currently facing our cities.

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A Cost Model for Bikeways

ROBERT B. CASE

A model for estimating bikeway costs at the planning stage is presented. The development of the cost model proceeded in several phases. In the first phase, a survey of existing bikeway-cost estimating methodologies was completed. Agencies from two regions of the United States were interviewed by phone concerning how each prepares estimates and the standard costs used to do so. Upon finding a large variance in the data of the different agencies, the second phase, creating a data base of the costs of actual individual bikeway projects, was performed. The cost of each project was broken down into categories that were used in the third phase: the estimation of parameters of a cost model to reflect the gathered data. The model is composed of several submodels, one for each type of bikeway project under consideration. The cost model, with limitations specified, provides the user with a concise and sound means of applying the costs of actual bikeway projects to estimate the cost of planned bikeways.

The purpose of this study is to provide a method for estimating the cost of bikeways at the planning stage. The costs of building several types of bikeways, including bike paths along new alignments and bike lanes added to existing roads, are analyzed.

A survey of existing bikeway-cost estimating methodologies was completed. Upon finding a large variance in the data of the different agencies, a data base of the costs of actual individual bikeway projects was compiled. These data were used to calibrate a cost model, which is composed of several submodels. The submodels, one for each type of bikeway project under consideration, are discussed individually.

In spite of the great variety of design standards and environments that affect the cost of planned bikeways, the model presented should prove useful to planners trying to estimate bikeway costs during the planning stage. For the agency with a good cost data base of its own, the model provides a framework for the use of that data for future estimates. Agencies with limited recent bikeway planning experience can apply the model more extensively, since its parameters have been estimated using actual cost data from approximately 20 bikeway projects.

Most of the projects used to estimate the model's parameters are located in the mid-Atlantic region or in Arizona. Therefore, users from other regions may wish to adjust the model's results based on construction costs unique to their area.

DETAILS OF MODEL DEVELOPMENT

Survey of Existing Cost Estimating Methodology

General Methodology

All of the sources interviewed for this study estimate costs for planning purposes in essentially the same manner: they start with a basic cost (per foot or per mile) and adjust it for a specific site. The planners of James City County, Williamsburg, and York County, Va., start with a standard "per mile" figure and add the cost of "big ticket" items (such as utility poles that may need to be moved and major drainage that may be required) based on a drive-by site inspection. Cal Wagner, Trails Coordinator with the Fairfax County Park Authority, also uses this big ticket method. Ritch Viola (Bicycle Coordinator with Arlington County) and Bruce Hancock (Trails Coordinator with the Maryland National Capital Park & Planning Commission), use "per mile" figures that reflect the project's terrain.

Hampton Roads Planning District Commission, 723 Woodlake Drive, Chesapeake, Va. 23320.

Per Mile Costs

To compile a data base of standard "per mile" figures, representatives from the organizations were asked what standard figures they use to estimate the cost of planned bikeways. Tables (1 and 2) are a compilation of their responses. (The results are presented as received-in customary units, not metric.)

The tables show a great variance in the estimates of the standard cost of bikeways, some of which is due to legitimate differences in design and cost of construction. Some of the standard costs, however, are not based on the actual total cost of completed bike projects. They were developed by simply estimating the cost of a few inches of asphalt and a few inches of stone. This process of course does not reflect the complexity of bikeway construction (e.g., drainage, signage, fill, and right-of-way acquisition). Regardless of the reason for the variance, it obviously would not be wise to simply select a figure from this list and multiply it by the length of a proposed project to get an estimate of the cost. A need for more detailed information is indicated.

A New Model

Because of the great disparity among the standard costs used by various organizations around the country to estimate the cost of planned bikeways, a new cost model needed to be developed. To achieve accuracy and validity, the cost model presented is based on the cost of *actual bikeway projects*. Cost data were gathered from more than 20 projects. Because most of the projects were located in the mid-Atlantic region (with some from Arizona), the incorporation of data from more states would be required to label this a true "nationwide" model. Cost submodels were developed by bikeway type (see Figure 1) as follows:

Bike Path Projects

Bike *paths* are bikeways that are physically separated from roadways by open space or barriers. They can be found in their own right-of-way (e.g., along a creek, through a park, or along an aban-

TABLE 1 Standard "Per Mile" Costs—Bike Paths

Source	Cost Per Mile			Comments
Jones, Michael G. Building Bikeways. *Planning*, October 1993, p. 32.	$90,000	to	$200,000	Including right-of-way and bridge costs.
Proposed Additions and Revisions to the Bicycle Element, Washington Council of Governments, 1993.	$63,000	$220,000 to	$65,000	Montgomery County. Prince William County.
Trail Opportunities in the City of Chesapeake Southeastern Virginia Planning District Commission, 1987, pp. 61-100.	$60,000	to	$80,000	Basic construction only (not including bridges, major drainage work, etc.).
Maryland National Park & Planning Commission. (Bruce Hancock, unpublished data)	$95,000	to	$185,000	Construction only, 8' asphalt.
Greenways, Inc. (Chuck Flink, unpublished data)	$125,000	to	$150,000	10' asphalt, not including major items like bridges.
Unit Costs for Bicycle and Pedestrian Facilities. Florida Department of Highways, 1992.		$125,000		
November 1988 Costs for Bikeways. City of Tucson, AZ, 1988.		$46,000		12' wide, 4" thick.
Development Costs of Park Improvements. Fairfax County (VA) Park Authority, 1985.		$98,000 $244,000 $82,000 $212,000	(asphalt, 8') (concrete, 8') (gravel, 8') (stream valley, 8')	The figures at left are for 1992, having been projected by the Authority in1985.
Fairfax County (VA) Park Authority. (Cal Wagner, unpublished data)		$111,000		8' wide, 4" aggregate, 2" asphalt, including excavation & clearing small trees; excluding signs & striping, large tree removal, bridges, and major drainage.
Trails and Greenways Master Plan. Prince William County (VA) Park Authority, 1993, p. 36.	$137,000	to $63,150	$185,000	Independent of road improvement project. With road improvement project.
Paving and Surfacing. National Park Service, National Capital Region, undated.		$135,000		10' asphalt.

doned railroad), or they can lie within the right-of-way of an existing roadway. The cost of bike paths built as part of a road project are not covered by this model.

Ten bikeway projects were used in the development of the bike path cost model (see Tables 3 and 4). The model is based on the project costs as shown on *bid tabulations*, or detailed cost estimates when bid tabulations were not available. Bid tabulations are the portion of the project contract that show the actual quantities (e.g., 934 tons of asphalt), unit costs (e.g. $30/ton), and total (contract) cost of the project. These contract figures are used in the payment of the contractor after the work is finished. Although changes in quantities and the addition of change orders often lead to cost overruns, bid tabulation is a good indicator of the actual cost of a bikeway project.

Project costs were broken down into four main groups:

1. Mobilization,
2. Pavement,
3. Various categories, and
4. Big ticket.

The "various categories" group typically includes all excavation, drainage, traffic control, and erosion control items, regardless of price. (Extraordinary individual excavation, drainage, traffic control, or erosion control items, such as a $40,000 traffic signal, are included as "big ticket" items.) Miscellaneous items are split between the various categories and big ticket groups based on price. Inexpensive (less than $3,000) miscellaneous

TABLE 2 Standard "Per Mile" Costs—Bike Lanes and Shoulders

Source	Cost Per Mile			Comments
Jones, Michael G. Building Bikeways. *Planning*, October 1993, p. 32.	$3,000	to	$30,000	
Review of Paved Shoulders. Virginia Transportation Research Council, April 1990, p. 24.		$72,000		Marginal cost for adding a 4' shoulder when resurfacing an existing road.
Virginia Department of Highways, Williamsburg Residency (Quinton Elliott, unpublished data)	$60,000	to	$70,000	Base cost; add for poles, major drainage structures, etc.
Proposed Additions and Revisions to the Bicycle Element, Washington Council of Governments, 1993.	$55,000	to	$61,000	Leesburg.
Trail Opportunities in the City of Chesapeake Southeastern Virginia Planning District Commission, 1987, pp. 61-100.	$7,000	to	$9,000	Basic construction only; not including bridges, major drainage, etc.
Unit Costs for Bicycle and Pedestrian Facilities. Florida Department of Highways, 1992.		$185,000 $100,000 $100,000		Bike lanes. Wide curb lanes. Paved shoulders.
November 1988 Costs for Bikeways. City of Tucson, AZ, 1988.		$62,000 $32,000		Add 6"x4' pavement, both sides. (with curb replacement) (without curb replacement)
Trails and Greenways Master Plan. Prince William County (VA Park) Authority, 1993, p. 36.		$61,000		5' asphalt.
Pinsof, Susan and John Henry Paige. (Northeastern Illinois Planning Commission) Bicycling as a Transportation Resource. *Operations Review*, vol. 1, no. 2, October 1984, p. 16.		$125,000		5' added to both sides; $80,950 1982 projected at 4%.

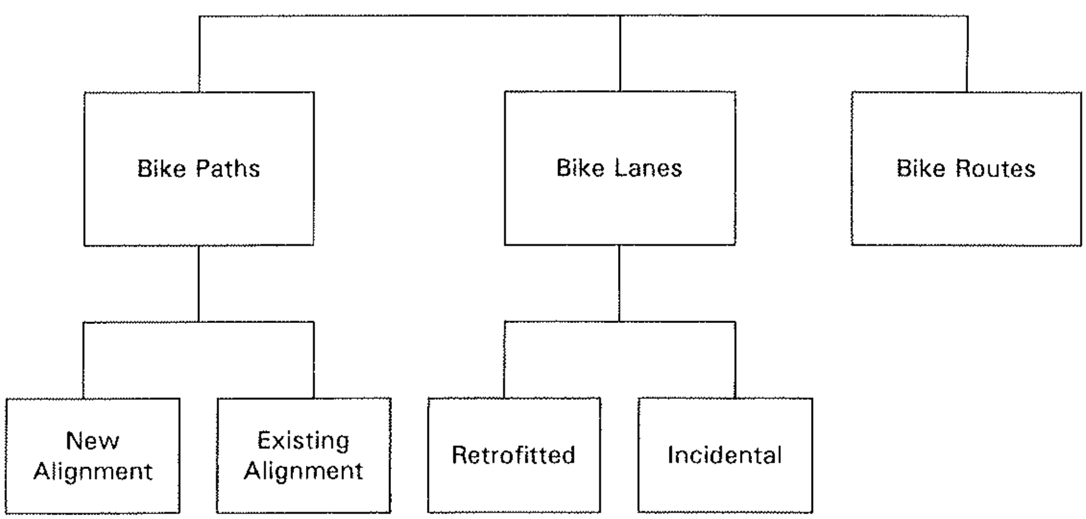

FIGURE 1 Cost model components.

TABLE 3 Bike Path Cost Model Projects

#	Project Name	Source	Length
1	Little Sugar Creek Trail, Option IV, Ph II Path in creek channel; Charlotte, NC; 1991.	Preliminary Cost Estimate	521 m (1709 ft)
2	3rd Creek Greenway Path mostly along creek; Knoxville, TN; 1993.	Bid Tabulation	1434 m (4700 ft)
3	Middle Bolin Creek Greenway/Bikeway Path along creek; Chapel Hill, NC; 1993.	Bid Tabulation	1270 m (4163 ft)
4	Farriss Avenue Greenway Path along creek; High Point, NC; 1991.	Bid Tabulation	1.3 km (0.8 mi)
5	Green Mill Run Pilot Greenway Project Path mostly along stream; Greenville, NC; 1991.	Cost Estimate	1295 m (4245 ft)
6	Fairfax Connector Trail Path through heavily wooded area, 25% of which is swamp; Virginia; 1992.	Bid Tabulation	2193 m (7190 ft)
7	Oyster Point Bikeway Path mostly along existing road right-of-way; Newport News, VA; 1993.	Detail Estimate	2288 m (7500 ft)
8	Research Triangle Park Pedestrian Trail, Ph III Path parallels roadway; North Carolina; 1992.	Bid Tabulation	2440 m (8000 ft)
9	Golf Links Bicycle/Pedestrian Path Path along drainage channel; Tucson, AZ; 1993.	Cost Estimate	1098 m (3600 ft)
10	Capital Crescent Trail Rails-to-trails project; Washington, DC; 1992.	Bid Tabulation	5.6 km (3.5 mi)

items are included in the various categories group. Expensive (more than \$3,000) miscellaneous items are included in the big ticket group. These items, such as bridges, fill sand, and utility pole removal and replacement, must be estimated separately and on an individual basis.

Based on a thorough analysis of the four groups from the data in Table 4, the following process for estimating each category was devised:

1. Mobilization costs for the bike path projects (excluding Little Sugar Creek due to its concrete pavement and high "big ticket" costs) ranged from \$0 to \$12/m (see Table 4). Therefore, mobilization for bike path projects can be estimated using the average value of \$5/m (\$1/ft).

2. Pavement costs for the bike path projects (excluding Little Sugar Creek due to its concrete pavement) range from \$9 to \$20/m^2. The variance in pavement cost is due to differences in the pavement design, cost of materials, and pavement widths. Unfortunately, these factors are difficult to predict when preparing planning cost estimates. Therefore, pavement cost should be estimated using the average value of \$14/m^2 (\$1.33/ft^2).

3. It was found that the costs contributed to projects by items from the "various categories" group varied depending on whether the project was built on a new alignment (e.g., running through a park or along a creek) or on an existing alignment (e.g., paralleling a road) as indicated in Table 4 and Figure 2.

The average cost of the "various categories" group for projects along new alignments was \$38/m (\$12/ft), whereas that of the existing alignment projects was only \$15/m (\$4/ft). Therefore, when estimating the cost of planned projects, the appropriate one of these two figures should be used.

The rails-to-trails project (Project 10) had an even lower various categories estimate cost than did the other alignment projects. Although no separate model was developed for the conversion of railroads to bikeways, the rails-to-trails project, and common sense, indicate that one could expect the miscellaneous costs for such projects to be lower than for bikeways parallel to highways.

TABLE 4 Bike Path Cost Model Data

	Cost per Meter (per Foot) by Project Number[a]										Average, by Type		
	1	2	3	4	5	6	7	8	9	10			
Alignment Type:	New	New	New	New	New	New	Ex.[f]	Ex.	Ex.	Ex.	New[b]	Ex.[c]	All[d]
a. Mobilization	$37 ($11)	$12 ($4)	$0 ($0)	$0 ($0)	$10 ($3)	$5 ($1)	$5 ($2)	$4 ($1)	$5 ($1)	$0 ($0)	$6 ($2)	$4 ($1)	$5 ($1)
b. Pavement	$129[e] ($39)	$53 ($16)	$47 ($14)	$29 ($9)	$37 ($11)	$48 ($15)	$37 ($11)	$26 ($8)	$27 ($8)	$47 ($14)	$43 ($13)	$34 ($10)	$39 ($12)
c. Various Categories	$23 ($7)	$44 ($13)	$45 ($14)	$30 ($9)	$35 ($11)	$50 ($15)	$17 ($5)	$20 ($6)	$17 ($5)	$5 ($1)	$38 ($12)	$15 ($4)	$29 ($9)
d. Big Ticket	$338 ($103)	$43 ($13)	$148 ($45)	$25 ($8)	$148 ($45)	$56 ($17)	$1 ($0)	$5 ($1)	$55 ($17)	$48 ($15)	$126 ($39)	$27 ($8)	$87 ($26)
Total	$527 ($161)	$152 ($46)	$240 ($73)	$85 ($26)	$230 ($70)	$159 ($48)	$60 ($18)	$55 ($17)	$103 ($31)	$100 ($31)	$213 ($65)	$79 ($24)	$159 ($48)

[a] Construction costs only (design and right-of-way acquisition not included).
[b] Average of the projects along new alignments ("New");
Project 1 (Little Sugar Creek) excluded on pavement related items ('Mobilization', 'Pavement').
[c] Average of the projects along existing alignments ("Ex.").
[d] Average of all the projects (project 1 [Little Sugar Creek] excluded from mobilization and pavement totals).
[e] Concrete pavement used.
[f] Existing.

4. Unlike the preceding three groups, the big ticket costs of the projects in the data base did not lend themselves (by definition) to analysis on a *per foot* basis. Because big ticket items tend to be expensive and vary significantly from project to project, they must be *estimated individually* and added to the other three components.

Retrofitted Bike Lane Projects

A bike lane is a portion of a roadway designated for the use of bicycles. The pavement of a bike lane is contiguous with the pavement used by motor vehicles. The cost of bike lanes varies depending on whether the bike lanes are built as an independent project ("retrofitted" bike lanes) or as part of a roadway project ("incidental" bike lanes).

This study assumes that the cost of tearing out long sections of curb and gutter to construct wider pavement areas to accommodate bikes is usually prohibitive. In such an operation, costs are incurred to (a) remove and replace curbs and gutters, and (b) relocate what is behind the curb (e.g., sidewalks, utility poles) to acquire additional right-of-way. Therefore the bike lane cost model presented is

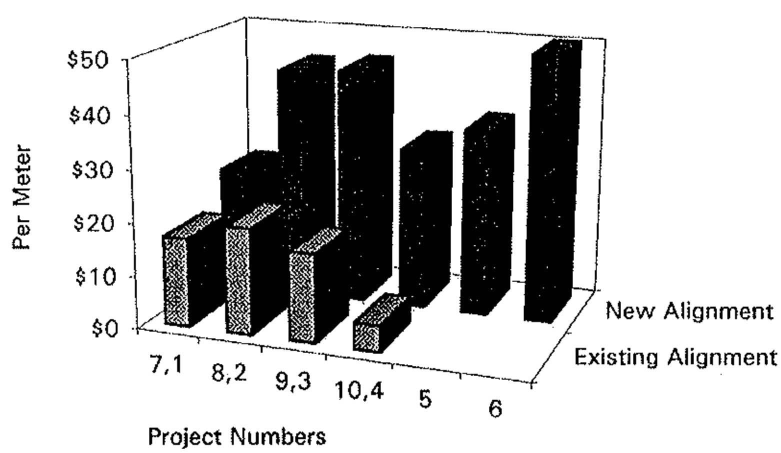

FIGURE 2 Cost of various categories for bike paths by alignment type.

valid only for the widening of roads with predominantly rural cross sections (no curbs and gutters). Of course projects along roads of rural cross sections with short lengths of curb and gutter can be estimated by adding the cost of removing and replacing the curb and gutter as a big ticket item [approximately $50/m ($15/ft)]. Agencies seeking to estimate the cost of projects that involve tearing out long sections of curb and gutter for bike-related widenings could modify the model using the actual completed cost of similar projects.

The data base used for the development of a cost model for bike lanes is composed of the costs of 10 bike lane projects. Because of their similarity, five of the projects from Arizona were averaged and treated as one record ("5 AZs") in the data base. The data base is shown in Table 5.

As with the bike path model, the bike lane models were broken down into mobilization, pavement, various categories, and big ticket groups, as follows:

1. Mobilization: Because of the similarity of mobilization costs of the bike lane projects, their average cost, $5/m ($2/ft), shall be used for the estimation of future projects.

2. Pavement: Because of the similarity of pavement costs of the projects, their average cost, $36/m or $\$15/\text{m}^2$ [$1.38 per square foot; all data base projects are 1.22 m (4 ft) on both sides of road], shall be used for the estimation of future projects.

3. "Various categories": Because of the similarity of "various categories" costs of the bike lane projects, their average cost, $22/m ($7/ft), shall be used for the estimation of future projects.

4. Big ticket items: As with the bike path model, the cost of big ticket items for the bike land model must be estimated *individually* because the variance that they add to projects cannot be explained in any simpler form (such as the "per foot" form used for the other three groups).

TABLE 5 Bike Lane Cost Model Data Base

Abbrev.	Project Descriptions: Description[a]	Data Source	Date
NC86	Bicycle Project on NC-86, NC	Bid Tabulation	1991
5 AZ's	Five Tucson, AZ projects averaged 36th St., La Cholla Blvd. to Mission Lane Bilby Rd., Park Ave. to Tucson Blvd. Columbus Blvd., Broadway Blvd. to 29th St. Roger Rd., Campbell Ave. to First Ave. La Cholla Blvd., 22nd St. to Ajo Way	Cost Estimates	1993
P1	Big Bethel Rd., County line to Hampton Hwy., VA	Cost Estimate[b]	1993
Skyline	Skyline Drive, Orange Grove to Campbell Ave., AZ	Bid Tabulation	1992
Old YH	Old York Hampton Hwy., Hornsbyville Rd. to US17, VA	Bid Tabulation[c]	1992
P2	Allens Mill Rd., Dare Rd. to Wolftrap Rd., VA	Cost Estimate[b]	1993

Cost Grouping	Cost per Meter (per Foot) by Project[d]: NC86	5 AZs	P1	Skyline	Old YH	P2	Average
a. Mobilization	$3	$5	$2	$3	$10	$9	$5 ($2)
b. Pavement	$30	$31	$36	$25	$47	$44	$36 ($11)
c. Various Categories	$20	$22	$21	$12	$25	$30	$22 ($7)
d. Big Ticket	$0	$54	$2	$0	$94	$134	$47 ($14)
Total	$54 ($16)	$112 ($34)	$61 ($19)	$41 ($12)	$176 ($54)	$217 ($66)	$110 ($34)

[a] All projects are 4' widenings on both sides of road.

[b] Cost estimate based on quantities developed by the author for this hypothetical project and unit prices from three local (VA) contractors.

[c] The bid tabulation for this 'roadway improvement' project was modified to simulate a bike lane project.

[d] Construction costs only (design, right-of-way acquisition not included).

Incidental Bike Lane Projects

For a small increase in cost, space can be allocated for bike lanes during roadway construction (for both new roads and reconstruction of existing roads); hence the costs of bike lanes built as part of a roadway project are less than those of retrofitted bike lane projects. This *marginal cost* which bike lanes add to roadway projects is addressed by cost grouping, as follows:

1. Mobilization: Because the contractor is already mobilized to do road work, the marginal mobilization cost for the bike lane can be considered $0/m.

2. Pavement: Due to the economy of the scale of roadway projects (wider pavement widths and more total pavement), the marginal cost of paving a bike lane as part of such a project, $\$10/m^2$ ($\$0.93/ft^2$), is less than that of a retrofitted bike lane ($\$15/m^2$, above), as shown on Table 6.

The costs in Table 6 are based on the assumption that roadway sections with bike lanes will have the same widths of paved and gravel shoulders (in addition to their bike lanes) as roadway sections without bike lanes. Therefore, if an agency decides to reduce or eliminate (due to the inclusion of bike lanes) the regular shoulder width required (i.e., it is decided that little or no additional shoulder width is needed adjacent to the bike lane *because* the bike lane will also serve as a shoulder), the marginal cost of including bike lanes in a roadway section is less than that shown.

3. Various categories: This study assumes that the only significant various categories costs added to a roadway improvement project due to the inclusion of a bike lane are those of bike signs and bike pavement markings. Based on an average of the cost of these items from the NC86, 5 AZs, and P2 projects, the figure of $2/m (or $0.57/ft) is used.

4. Big ticket: If it is known that the additional width required for a bikeway would require the movement of a utility pole, then the cost of such work should be added to the bikeway's portion of the project cost. It is assumed, however, that the marginal big ticket cost for incidental bike lanes is $0/m.

Bike Routes

Bike routes are streets of regular widths that have been designated as a bikeway through the addition of *signs* and sometimes, through the making of minor improvements such as drainage grate modification. The data gathered on the cost of these bikeways can be found in Table 7.

The large variance in the data indicates that estimating the cost of bike routes on a per mile basis is probably not appropriate. Based on the fact that the cost of such routes lies primarily in signage and that bike signs are required primarily at significant intersections (i.e., not minor side streets), bike route costs were developed as shown in Table 8.

Therefore, it is recommended that the figure of $600 per significant intersection be used as the base cost of bike routes (covering signage) to which the cost of additional items, such as grate modifications, should be added. This cost can be reduced by using existing poles for new bikeway signs.

TABLE 6 Pavement Cost for Incidental Bike Lanes

Average Pavement Design[a]	Depth [cm (in)]	Unit Price[b] [per m^2-cm (sy-in)]		Price [per m^2 (sy)]
Asphalt	7.62	$0.65	=	$4.94
	(3)	($1.38)	=	($4.14)
Aggregate Base	17.78	$0.29	=	$5.10
	(7)	($0.61)	=	($4.27)
				$10.04
				($8.41)

[a]Average for projects used in bike lane cost model.

[b]From Old York-Hampton Highway project.

TABLE 7 Standard "Per Mile" Costs—Bike Routes

Source	Cost per Mile
Trail Opportunities in the City of Chesapeake Southeastern Virginia Planning District Commission, 1987, pp. 61-100.	$1,500 to $2,500
November 1988 Costs for Bikeways. City of Tucson, AZ, 1988.	$300
Trails and Greenways Master Plan. Prince William County (VA) Park Authority, 1993, p. 36.	$200

TABLE 8 Bike Route Cost Model Derivation

Project		Sign Cost
NC 86		$180 per sign
Middle Bolin Creek Greenway		$65 per sign
Farriss Avenue Greenway		$148 per sign
Green Mill Run Greenway		$175 per sign
	average	$150 per sign
Bike Route Signs per Major Intersection		4
Estimated Bike Route Cost per Significant Intersection		$600

Cost Overruns

Because problems not anticipated at the design stage generally arise during construction and add (through change orders) to the cost of a project, an accurate estimate of the actual cost of a project includes a factor for cost overruns. A typical figure used in public works projects is 10 percent. Therefore, *10 percent of the construction cost* should be added to cost estimates to account for cost overruns.

Model Validity

After the model was calibrated using a data base of actual projects as described previously, it was tested in two ways.

First, the data for the projects used in calibration were plugged into the model to compare the estimates produced by the model with the actual project costs. This test is recorded for bike path and bike lane projects on Tables 9 and 10, respectively. The test results indicate that the model, though far from perfect, explains enough of the variance in the cost of these bikeway projects to be useful for the estimation of planned projects.

Second, the parameters for a project that had not been used for the calibration, the Centerville Road project in James City County, Va., were compared with those of the model. The model's bike lane (retrofitted project) parameters, as described previously, are similar to those of Centerville Road, as follows:

TABLE 9 Checking Bike Path Model Fit

	Comparison of Model and Actual Costs by Project[a]								
Project #:	2[b]	3	4	5	6	7	8	9	10
I. Mobilization									
Actual cost, /m	$12	$0	$0	$10	$5	$5	$4	$5	$0
Model prediction, /m	$5	$5	$5	$5	$5	$5	$5	$5	$5
II. Pavement									
Width, m	3.05	3.05	3.05	3.05	2.44	2.44	2.44	3.05	2.44
Actual cost, /m^2	$17	$15	$10	$12	$20	$15	$11	$9	$19
Actual cost, /m	$52	$46	$30	$36	$49	$36	$26	$26	$46
Model prediction, /m^2	$14	$14	$14	$14	$14	$14	$14	$14	$14
Model prediction, /m	$44	$44	$44	$44	$35	$35	$35	$44	$35
III. Various Categories									
Actual cost, /m	$44	$45	$30	$35	$50	$17	$20	$17	$5
Alignment Type:	new	new	new	new	new	ex.	ex.	ex.	ex.
Model prediction, /m	$38	$38	$38	$38	$38	$15	$15	$15	$15
Subtotal (I,II,III)									
Actual cost, /m	$109	$90	$60	$81	$104	$58	$50	$47	$51
Model prediction, /m	$86	$86	$86	$86	$78	$51	$51	$60	$51
Error	-21%	-5%	43%	6%	-25%	-12%	2%	27%	0%

[a] Because the model does not predict big-ticket items, they have been excluded from this table.

[b] Project 1 omitted due to concrete pavement.

TABLE 10 Checking Bike Lane Model Fit

	Comparison of Model and Actual Costs by Project[a]					
	NC86	5 AZs	P1	Skyline	Old YH	P2
I. Mobilization						
Actual cost, /m	$3	$5	$2	$3	$10	$9
Model prediction, /m	$5	$5	$5	$5	$5	$5
II. Pavement						
Actual cost, /m	$30	$31	$36	$25	$47	$44
Model prediction, /m	$36	$36	$36	$36	$36	$36
III. Various Categories						
Actual cost, /m	$20	$22	$21	$12	$25	$30
Model prediction, /m	$22	$22	$22	$22	$22	$22
Subtotal (I,II,III)						
Actual cost, /m	$53	$58	$59	$41	$81	$83
Model prediction, /m	$63	$63	$63	$63	$63	$63
Error	18%	9%	6%	54%	-22%	-24%

[a]Because the model does not predict big-ticket items, they have been excluded from this table.

Model Parameters	*Centerville Road Parameters*	
Mobilization, per meter	$5	$7
Pavement, per sq. meter	$15	$17
Various categories, per meter	$23	$23

Although based on only one project, the results of this second test also support the validity of the model.

CONCLUSION

The variance in the standard "per mile" costs used by the agencies surveyed reduces the usefulness of that data set, and indicates a need for a cost model that is based on actual project data and that allows for differing bikeway scenarios and environments. Although the cost model presented is limited by the geographic diversity of the projects from which its parameters were estimated, and although it leaves unexplained a significant amount of variance in the data base, it is an important tool for those preparing planning costs. By providing a simple but effective series of submodels and cost groupings, the model allows the planning estimator, who makes estimates based solely on the length of the project and a "per mile" unit cost, to prepare more accurate estimates. If an agency has a significant number of recent bikeway projects, planners can disregard the projects included in this report and calculate their own model parameters using the framework provided. However, if an agency has little or no recent bikeway project experience, the model allows planners to apply cost data from actual projects to their own proposed project in a simple but flexible way. The cost model is present in Table 11.

TABLE 11 Cost Model Summary

	Unit Prices[a]		
	Mobil-ization [/m (/ft)]	Pavement [/m² (/sf)]	Various Categories [/m (/ft)]
Bike Path, Existing Alignment	$5 ($1)	$14 ($1.33)	$15 ($4)
Bike Path, New Alignment	$5 ($1)	$14 ($1.33)	$38 ($12)
Bike Lane, Retrofitted	$5 ($2)	$15 ($1.38)	$22 ($7)
Bike Lane, Incidental	$0 ($0)	$10 ($0.93)	$2 ($0.57)
Bike Route	$600.00 Per Significant Intersection		

[a]Construction costs only (design, right-of-way acquisition not included).

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Method to Determine Level of Service for Bicycle Paths and Pedestrian-Bicycle Paths

Hein Botma

In the Highway Capacity Manual of 1985, no levels of service (LOSs) for cyclists on separate paths are given. In the framework of the Dutch manual on bicycle infrastructure, a measure of quality of operation was developed: the hindrance that users of the path experience due to their interactions or maneuvers. Simplifying this to the frequency of passing and meeting maneuvers, the well-known LOSs from A to F can be defined. A new point is that LOS F is not merely a congested state of traffic, but is defined as a very poor overall quality of traffic operation. This approach was then extended to traffic operation on separate narrow paths used by pedestrians and bicyclists. Using this method the LOS can be determined separately for pedestrians, bicyclists, and the average user of the path. LOSs are a function of the volume of both types of users. Results appeared consistent, but some key parameters used as an input of the procedure have to be estimated empirically in applying this method. That is, they should be based on investigations of rating of maneuvers in terms of hindrance. The results can be used to determine requirements for path width and criteria for separation of bicycles and pedestrians.

In quite a few countries a policy exists to promote use of the bicycle and walking for transportation. The motivations for this policy are the problems that accompany intense use of the car: congestion, required space, air pollution, and noise. Analyzing trips in urban areas, it is found that a large proportion consist of relatively short trips and part of these could be replaced by a trip on foot or on bicycle. Walking and bicycling are also attractive solutions as methods of gaining access to public transportation. What is possible in terms of changing mode choice from car to foot and bicycle will also depend on local conditions such as terrain and climate.

Promoting pedestrian and bicycle traffic has many aspects. One of these is the provision of well-designed and appropriate facilities or infrastructure. Although walking is as old as humanity, and mass use of the bicycle preceded car traffic in many countries, these modes of transportation have not had much attention compared to studies on the automobile system and public transportation. This might have been due to the idea that pedestrians and bicyclists are so flexible that they can manage without special attention. When authorities really want to promote bicycling and walking, it turns out in many cases that sound design principles and methods are lacking.

The Highway Capacity Manual (HCM) of 1985 (*1*) illustrates this point: the chapter about pedestrians does cover some topics, but the bicycle chapter is rather meager. In western Europe the state-of-the-art is not much better, but times are changing. In the new German highway capacity manual (*2*) attention is given to bicycles. In the Netherlands much knowledge has been collected and new studies have been carried out in the framework of the Bicycle Masterplan (*3*). Especially relevant in this context is the *Design Manual for a Cycle-Friendly Infrastructure* (*4*).

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In this study two subjects were treated. First the Dutch guideline for the required width of a separate bicycle path was analyzed and levels of service (LOSs) were determined. Next the same method was used to define LOSs for paths used by pedestrians and bicyclists.

To investigate this method and determine its practical value, field studies and behavioral investigations will certainly be needed. The procedure sketched out herein is intended to guide these studies and make them more specific and therefore more efficient. Consequently the main emphasis of this study is on methods and not on results. The results presented are based on first guesses of some parameters and should be seen as an illustration of how the method can be worked out.

Applications can be found in the design of separate bicycle paths and pedestrian-bicycle paths. For the latter, the method seems appropriate for paths that are not very heavily loaded. It is assumed that in the case of large volumes of either pedestrians or bicyclists a separation is needed. For in-between cases, the procedure proposed could be used to derive criteria for separation.

It can be added that this study does not deal with a mix of motorized vehicles and bicycles on one facility, a very common and sometimes problematical situation. In that case safety is a main concern, whereas in this study comfort and convenience are the points of interest.

CONCEPT OF LOS

The concept of LOS was introduced in the HCM of 1965 (*5*) and maintained in the HCM of 1985, only the view was changed. We quote from the latter: "The concept of LOS is defined as a qualitative measure describing operational conditions within a traffic stream, and their perception by motorists and/or passengers. A LOS definition generally describes these conditions in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience, and safety." Although the definition does not explicitly cover pedestrians, it is assumed they are meant as well as bicyclists. Important in this definition is that the quality of the traffic stream has to be assessed as experienced by the user and not, for instance, from the point of view of the road authority. This choice is debatable, but it will not be discussed in this paper.

The question is how can the operational quality of traffic operation for bicyclists and pedestrians be characterized when they use their own facility. For bicyclists no criterion is given in the HCM. Density is chosen for pedestrians, in the form of number of pedestrians per area. As the situation with a mix of pedestrians and bicyclists on a separate path is rather different from a sidewalk with pedestrians only, density might be less appropriate. However, first a discussion of the criterion suitable for bicyclists on a separate path will be given.

Potential measures of operational quality for bicycle traffic can be found in the HCM of 1985 and checked for suitability.

The first candidate is mean speed or mean travel time. However, in an earlier study it was found that mean speed was not influenced by volume over a large range (*6*). It seems that the behavior of traffic streams on freeways and bicycle paths are similar in this aspect.

The second candidate is density. This criterion is, for example, chosen in the German highway capacity manual (*2*). However, it seems difficult to decide which values are suitable boundaries between quality classes. Some interesting results are presented in a Canadian study (*7*), in which three zones around a cyclist are distinguished: a collision zone, a comfort zone, and a circulation zone. From this are derived LOSs that are much less generous than the ones resulting from the proposal in this paper.

A third candidate is the percentage of bicyclists being forced to follow the vehicle in front due to lack of passing possibilities. This criterion is used for two-lane rural roads in the HCM. However, bicyclists sometimes prefer to follow closely because it reduces air resistance considerably.

Going back to the basic concept of LOS, the terms "freedom to maneuver," "driving comfort," and "convenience" are found. These have been worked out as follows. On a bicycle path the following maneuvers can be distinguished: passing a user going in the same direction, meeting a user going in the opposite direction, and a combination of passing and meeting. Every maneuver brings with it some discomfort, inconvenience, and possible danger for those involved. In the sequel of this paper the term "hindrance" will be used for this concept. It is obvious that the amount of hindrance will depend on the type of maneuver, the parties involved, and the space available for the maneuver (path width).

With either an analytical model or a simulation model, the frequency of the maneuvers can be determined. Using weights called hindrance scores, the total hindrance can be obtained for each type of maneuver. This approach was followed in an earlier Dutch study (*8*), the outline of which is depicted in Figure 1. The upper part illustrates the model and the lower part the accompanying field survey. The goal of that survey was to determine the amount of hindrance perceived by users in real situations, because the users' perceptions should be the ultimate criteria for the quality of traffic operation.

Applying the model to the registered volume and composition of the field survey has yielded two outcomes: the hindrance calculated by the model (*H*) and the perceived hindrance (*P*). Using this relation, the quality of traffic flow can be determined for conditions that have not been investigated.

LEVELS OF SERVICE FOR BICYCLE PATHS

With the relationship established between volume, composition, path width, type of traffic (one-way or two-way), and perceived hindrance of the users, boundary values that define the quality classes or LOSs are still needed. In the Dutch design manual (*4*) only one limit value is given. When less than 10 percent of the path users are experiencing hindrance over 1 km, the quality is considered sufficient. The peak hour is chosen as the period for which this requirement should be fulfilled.

The choice of 10 percent is rather generous for the bicyclists and can be seen as a clear sign of the political tendency to promote the use of the bicycle. According to the author, it represents the approximate limit for LOS A. The other LOSs have been defined on the percent with hindrance scale in such a way that LOS E covers 70 to 100 percent. LOS F presents conditions that are worse than 100 percent of users experiencing hindrance, that is, with more hindrance per user than at LOS E.

The corresponding volumes are determined with a simulation model developed in another study (*8*). For one-way paths, the percentage with hindrance increases linearly with volume; for two-way paths, the increase is sharper than linear.

Consequently a point illustrated in Table 1 is that LOS F is not defined as congested traffic, but as a state in which 100 percent of the users experience hindrance over a distance of 1 km. This implies that on two-lane, one-way paths, LOS F starts at a volume that is only 20 percent of capacity. At this volume mean speed is probably hardly any less than at much lower volumes.

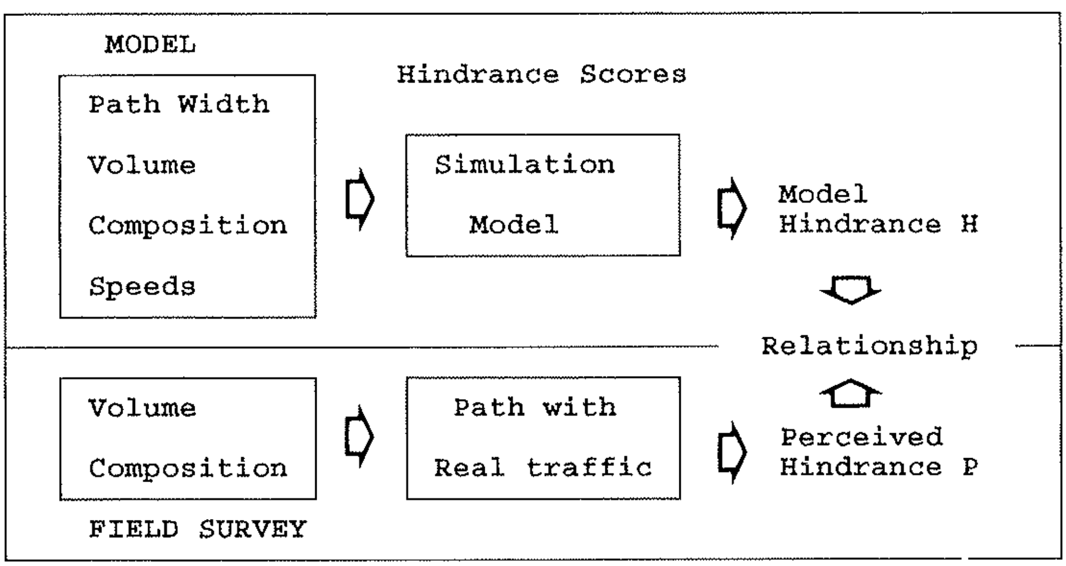

FIGURE 1 Setup of study to determine criteria for required width of bicycle paths.

TABLE 1 Service Volumes According to Hindrance Criterion

LOS	% with Hindrance over 1 km	Service Volume (bic/h) One-Way 2-lane	One-Way 3-lane	Two-Way 2-lane	Two-Way 3-lane
A	0-10	130	780	65	150
B	10-20	260	1560	105	230
C	20-40	520	3120	170	350
D	40-70	910	5460	250	500
E	70-100	1300	7800	325	630
F	100	----	----	---	---
Capacity		6400	9600	3200	4800
Volume Capacity Ratio at LOS E-F		0.20	0.81	0.10	0.13

For a three-lane path, LOS F is reached at 81 percent of capacity. A three-lane path is used much more efficiently than a two-lane path.

For two-way paths no data about capacity are available. The numbers in the table are based on the assumption that, due to the friction of opposing streams, the capacity is half that of a one-way path of the same width. For two-way paths the level of hindrance increases steeply with volume and LOS F is reached at volumes that are only 10 to 13 percent of the assumed capacity.

It is obvious that if density had been used as a criterion for the quality of the flow instead of hindrance, the results would have been quite different. In particular, the different functioning of a two-lane and three-lane path would not have been found.

New Criterion For Quality of Operation

The criterion "percentage of users experiencing hindrance over 1 km" will now be replaced by a simpler one, "the frequency of events with respect to time." It seems more appropriate to use frequency with respect to time than with respect to distance, especially when the concept is applied to users with substantially different speeds, as is the case for bicyclists and pedestrians.

Events are in fact maneuvers in this stage of the development, but they could encompass other phenomena. Events are defined for this study as either passings or meetings. The frequency will be used as a proxy for the hindrance a user experiences. When the frequency increases the quality of operation decreases. Because not all events bring about the same amount of hindrance, some form of weighting will be needed.

It is easier to understand and appreciate the meaning of one event every 15 sec than a frequency of 4 times per minute. Therefore the frequency (F) will be expressed as number of events per second. For example, a frequency of 4 times per minute will be denoted as 1/15 event per second (e/sec).

Further discussion in this paper will be limited to two-lane paths, as a first step in the development. It is more difficult to make a first estimate for the weighting of the hindrance of the maneuvers for paths wider than two lanes without any field survey.

On a bicycle path no lanes are marked by lines, but a basic lane width has been established to be .75 m to 1 m. A narrow two-lane path has a width of 1.5 m, just allowing cyclists to ride two abreast. A more generous path has a width of 2 m, on which bicyclists are easily able to ride two abreast. It is this width that is implied by the phrase two-lane path. It is assumed that this width is really available to the users, that is, that sufficient lateral clearing is present.

Table 2 shows the values of the frequencies for the service volumes in Table 1 for one-way and two-way two-lane paths. For one-way paths the only events considered are passings. An individual bicyclist experiences a frequency that depends on the volume and the speed distribution. Assuming that bicyclists do not impede each other, and assuming a normal probability distribution for the speeds with a mean (U) set at 18 km/hr, standard deviation (σ) set at 3 km/hr, and a certain volume (Q), the frequency is given by the following equation (*9*):

$$F = 2Q\,\sigma/\{U\sqrt{\pi}\} \qquad (1)$$

For the chosen U and σ this works out as: $F = 0.188\,Q$

For LOS F the frequency is one passing per 15 sec or more. An average passing takes approximately 10 sec (*6*); therefore, at this LOS a bicyclist spends about two-thirds of the time carrying out a passing. (Probably the proportion two-thirds has a positive bias, because some passings overlap.) At LOS A there is less than one passing every 2.5 min.

LOS F represents conditions worse than 100 percent hindrance. This percentage cannot increase, by definition, but the hindrance per user does increase with increasing volume. This means that LOS F ranges from LOS E to capacity and over the congestion branch of the speed-flow relation (see Figure 2).

For two-way paths two types of events are of importance: passings and meetings. It is likely that a meeting causes less hindrance than a passing because both parties involved can anticipate the event. On the other hand, the relative speed of a meeting is much higher than that of a passing; consequently, the subjective fear of an accident might be higher.

At a preliminary estimate, a meeting gets half the weight of a passing. This approximation will influence the results, and should be investigated. The weighting can be accounted for by halving the

TABLE 2 Service Volumes and Frequency of Events for Two-Lane Bicycle Paths

LOS	% with Hindrance over 1 km	One-Way Service Volume (bic/h)	One-Way Frequency Passings (e/s)	Two-Way Service Volume[a] (bic/h)	Two-Way Freq. Meetings (e/s)	Two-Way Freq. Passings (e/s)	Two-Way Freq. Total (e/s)
A	0-10	130	< 1/150	65	< 1/55	< 1/589	< 1/95
B	10-20	260	< 1/75	105	< 1/34	< 1/365	< 1/60
C	20-40	520	< 1/35	170	< 1/21	< 1/225	< 1/35
D	40-70	910	< 1/20	250	< 1/14	< 1/153	< 1/25
E	70-100	1300	< 1/15	325	< 1/11	< 1/118	< 1/20
F	100		> 1/15		> 1/11	> 1/118	> 1/20

Mean Speed = 18 km/h, SD of Speeds = 3 km/h
[a]Two-way volume and 50:50 directional split

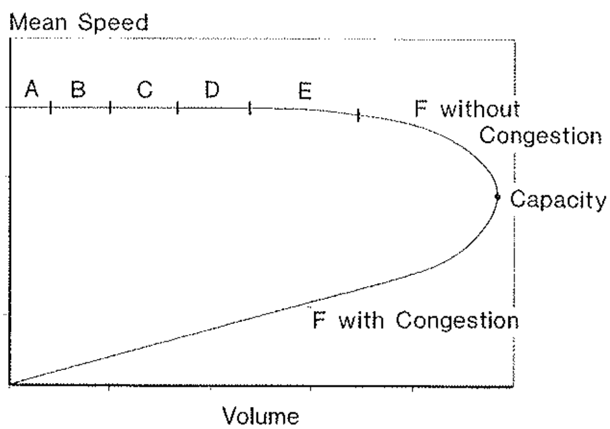

FIGURE 2 Sketch of the LOS in a speed-volume diagram.

frequency of the meetings before adding it to the frequency of passings. The results are presented in Table 2.

It can be seen that the total frequency for the two-way path is not very different from the frequency for the one-way path for the same service volumes. The values in the table are rounded to the nearest multiple of 5 sec and will be used as a first estimate when developing the method for a pedestrian-bicycle path.

LOS FOR PEDESTRIAN-BICYCLE PATH

As with the separate bicycle path the frequency of events or maneuvers will be used as a criterion for the quality of the flow. The treatment will be limited to two-lane facilities. As stated before, these have a width of 1.5 to 2.0 m, and it is assumed there is sufficient lateral clearance. One-way and two-way traffic can be distinguished. Because of space considerations only two-way traffic will be considered in this paper. One-way traffic is a simpler situation and can be derived in a straightforward manner from the two-way situation.

With two types of users on the path, the total hindrance can be divided into four components:

- Pedestrians (peds) experiencing hindrance from other peds. As the volumes of peds in the situations considered will be relatively low, this component will be neglected. Whether this is allowed can be verified by using the LOS for peds using the procedure of the HCM for peds on a sidewalk.
- Peds experiencing hindrance due to the presence of bicyclists (bics).
- Bics experiencing hindrance from peds.
- Bics experiencing hindrance from other bics.

The types of hindrances show that the LOS in a certain situation can be different for peds and bics. This is a consequence of the fact that quality is assessed by the users. The LOS for a group of users should be assessed in the framework of the network of facilities that is meant to provide service for this group. It is likely that the networks for peds and bics are not exactly the same.

Nevertheless it might be desirable to assign one LOS to the traffic situation on a facility with two types of user. This can be done by combining the LOS for both parties into one. The method is to average the frequency of events with weights proportional to the volumes, then derive from this the overall LOS.

Calculations

Consider a two-way path with peds and bics. It is assumed that the situation is symmetrical, with volumes and speeds the same in both directions. However, the procedure to handle unequal volumes in both directions is principally the same and requires no extra assumptions.

Suppose the one-way volume of peds is Q_p ped/hr, and of bics, Q_b bic/hr. Peds have, according to the HCM, a mean speed (U_p) of 4.5 km/hr. For bics on a flat path and without wind, studies in the Netherlands (*6*) indicate a mean speed (U_b) of 19 km/hr. In this study, the value of 18 km/hr is used because that is exactly 4 times the mean speed of pedestrians; using this value makes the numbers in the formulas easier to trace back. It is assumed that the speed distributions of peds and bics are such that they do not overlap, which is nearly always true.

Passings

The events considered are for a ped to be passed by a bic, and for a bic to pass a ped, to pass another bic, and to be passed by another bic.

The average frequency of a bic passing a ped (*9*) is as follows:

$$F\text{-pass}_{p\text{-}b} = Q_b\,(1 - U_p/U_b) \tag{2}$$

For the mean speeds chosen this works out as $F\text{-pass}_{p\text{-}b} = 0.75\ Q_b$

The frequency with which a bic passes a ped is calculated by the equation

$$F\text{-pass}_{p\text{-}b} = Q_p\,(U_b/U_p - 1) \tag{3}$$

And this works out as $F\text{-pass}_{b\text{-}p} = 3\ Q_p$

Consequently the frequency experienced by a bic is 4 times as high as that of a pedestrian, because a bic is 4 times as fast. The slower peds on the path cause relatively much hindrance for the faster bics. This can be compared to a situation with motorized traffic where a few slow-moving vehicles cause a disproportionate amount of hindrance for the faster vehicles.

The frequency of a bic passing or being passed by another bic (Equation 1) is calculated as follows:

$$F\text{-pass}_{b\text{-}b} = 0.188\ Q_b \tag{4}$$

Meetings

A volume of users Q_1 with mean speed U_1 in Direction 1 meets users of an opposing flow having volume Q_2 and mean speed U_2. The number of meetings in a road time domain of size X (length of section) and time T (length of period considered) is calculated as follows (*9*):

$$N_{\text{meet}} = X\,T\,Q_1\,Q_2\,(1/U_1 + 1/U_2) \tag{5}$$

This is the basic formula from which all others can be derived.

A ped with a speed U_p walking in the opposite direction of a flow of bics with a volume Q_b and a mean speed U_b, meets bics with a frequency as follows:

$$F\text{-meet}_{p\text{-}b} = Q_b\,\{1 + U_p/U_b\} = Q_b\,\{1 + 4.5/18\} = 1.25\ Q_b \tag{6}$$

A bic meets peds with the following frequency:

$$F\text{-meet}_{b\text{-}p} = Q_p\,\{1 + U_b/U_p\} = Q_p\,\{1 + 18/4.5\} = 5\ Q_p \tag{7}$$

Comparing Equations 6 and 7, it can be seen that for the same opposing volumes the 4-times-as-fast bic experiences 4 times the frequency of meetings that the pedestrian experiences. For the same distance covered, both parties will experience the same number of meetings but the bic experiences them in a shorter time. Consequently the quality of service is lower for the faster user.

The frequency of a bic meeting other bics is calculated as follows:

$$F\text{-meet}_{b\text{-}b} = 2\ Q_b \tag{8}$$

Total frequency

The frequency of meetings and passings is added to find the overall frequency of events. As noted earlier, the frequency of meetings gets half the weight of the frequency of passings.

The overall frequency of events for a ped in a same-direction flow of bics of volume Q_b and an opposing flow of the same volume Q_b (combine Equations 2 and 6) is calculated as follows:

$$\text{F-total}_p = .75\ Q_b + 1/2\ 1.25\ Q_b = 1.375\ Q_b \tag{9}$$

A combination of Equations 3, 4, 7, and 8 gives the overall frequency for a bic.

$$\begin{aligned} F\text{-total}_b &= 3\ Q_p + 0.188\ Q_b + 1/2\ \{5\ Q_p + 2\ Q_b\} \\ &= 5.5\ Q_p + 1.188\ Q_b \end{aligned} \tag{10}$$

Equation 9 implies that the LOS for peds is a function of the volume of bics only. The service volumes can be calculated and are presented in Table 3. Equation 10 implies that the LOS for bics is a function of the volumes of both peds and bics. This result is presented in Figure 3.

To get the overall LOS for the users of the path, a sum weighed with the volumes of the frequencies of peds, Equation 9, and of bics, Equation 10, is calculated as follows:

$$\text{F-total}_u = \{6.875\ Q_pQ_b + 1.188\ Q_b^2\}/(Q_p + Q_b) \tag{11}$$

From the total frequency for a user, one can now determine the LOS for a given combination of volumes of peds and bics.

Examples

The following examples illustrate the results.

Example 1

$Q_p = 20$ ped/hr and $Q_b = 100$ bic/hr (one-way volumes)

$F_p = 1.375 \cdot 100 = 137.5$ e/hr $= 1/26.2$ e/sec $= >$ LOS $=$ D

$F_b = 5.5 \cdot 20 + 1.188 \cdot 100 = 228.8$ e/hr $= 1/15.7$ e/sec $= >$ LOS $= F$

TABLE 3 Service Volumes for Two-Way Two-Lane Ped-Bic Path

LOS for Pedestrian	Frequency (e/s)	Service Volume One-Way (bic/h)
A	< 1/95	28
B	1/95-1/60	44
C	1/60-1/35	75
D	1/35-1/25	105
E	1/25-1/20	131
F	> 1/20	

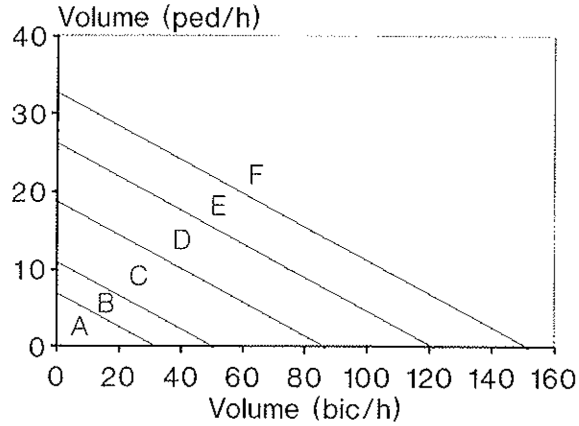

FIGURE 3 LOS for bicyclist using two-way ped-bic path; one-way volumes; directional split = 50:50.

Combination to get the frequency an average user experiences:

$F_u = \{20 \cdot 1/26.2 + 100 \cdot 1/15.7\}/(20 + 100) = 1/16.8$ e/sec
$=> \text{LOS} = F$

Without bics, peds would have a very favorable LOS A, but bics without peds would experience LOS D (see Table 2). Results are summarized in Table 4.

The LOS in this situation is rather bad for either type of user. The peds, whose LOS falls from A to D, are victims of the bics in this case. Bics alone would already have been at LOS D and would go down to LOS F.

Example 2

$Q_p = 100$ ped/hr and $Q_b = 20$ bic/hr (one-way volumes)

The same calculations as in Example 1 lead to results summarized in Table 4.

As in the previous example, both parties suffer from being mixed, with the bics perhaps suffering the most.

A general result is shown in Figure 4, in which the LOS for the users combined is given as a function of the volumes of peds and bics. This can be easily derived from Equation 11. It can be seen that at relatively high ped volumes, the effect of ped volume on the LOS is low and the effect of bic volume is high. At lower ped volumes, the volumes have a more equal influence on the LOS. It should be realized that the result for high ped flows can partly be explained by the fact that hindrance of peds from each other was neglected. However, for the ped volumes considered here that does not seem to be a critical assumption.

DISCUSSION OF RESULTS

It must be emphasized that this method of determining the LOS is a proposal and has a preliminary character. The method is considered more important than the results. A main point is that the assessment of the users is the ultimate criterion for the quality in accordance with the HCM's philosophy. Another important point is that the frequency of the maneuvers was chosen as a proxy for hindrance experienced by the users and this is a criterion for the quality of operation.

The criterion hindrance could be related to safety; this aspect certainly deserves special attention. Information knowledge about the frequency and severity of accidents between a pedestrian and a cyclist is probably scarce, as is information about a relation with geometrical factors such as width of the path.

It is sometimes argued that some cost criterion must be the ultimate yardstick for providing infrastructure. This is one of the reasons that travel time is used so frequently as a criterion for assessing quality. Costs are not an element directly included in this proposal. However, one should look at this aspect from a higher level. Every car trip that is replaced by the user with a foot or bicycle trip brings an economic benefit. For example, compare the required parking space at stations and shopping centers when people arrive as bicyclists or pedestrians rather than by car. Other benefits include improvements in noise, energy use, and air quality.

Some aspects of the development certainly need more studying.

- Is neglecting the hindrance caused by interaction of pedestrians justified at the volumes relevant here?
- Can second-order interactions be neglected? A second-order interaction occurs, for example, when a meeting and passing conflict with each other or when two passings conflict. At LOS A this assumption is certainly justified, but at lower LOSs it must be investigated.

TABLE 4 Two-Way Path with Majority of Either Bics or Peds

	2-way volume user/h	LOS if alone	LOS for user	Combined
Majority of Bics				
Peds	40	superb A	A	240 users with LOS F
Bics	200	D	F	
Majority of Peds				
Peds	200	A	A	240 users with LOS D
Bics	40	A	F	

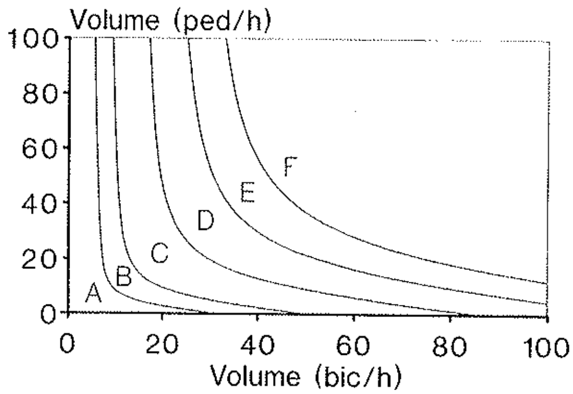

FIGURE 4 LOS of user on two-way ped-bic path; one-way volumes; directional split = 50:50.

- In the proposal some estimates have been made, the most important of which is probably the rating of a meeting at half the hindrance of a passing. Several methods are possible to determine how users rate these two maneuvers with respect to each other. One method would be to stop users of a path and interview them in a structured way. A second method would be to make photographs or, preferably, short videos of maneuvers for traffic experts and a sample of users to rate and discuss. It should be noted that the position of the camera could have an influence on the assessment of the hindrance.
- The speed distributions have an influence on the frequency of events and more field data are required. It is possible that one needs to distinguish between two groups of bicyclists: fast and possibly aggressive ones, and more relaxed ones.
- More information is needed about maneuvers on a pedestrian-bicycle path and on two-way bicycle paths. What is the area and time needed to carry out the maneuvers safely and comfortably?
- Would the passenger car unit (PCU) concept in a modified form be useful? That is, is it advantageous to express pedestrians as bicyclists and vice versa?

A special property of the proposal is the distinct meaning of LOS F, which refers not only to congested conditions, but to an unacceptable quality. This implies that the value of capacity is not that important for determining the LOS and that it need not be known precisely.

Possible applications of these concepts include the following:

- Development of criteria for separating pedestrians and bicyclists;
- Determination of requirements for the width of bicycle paths, pedestrian paths, and pedestrian-bicycle paths; and
- Extension of the concept to other mixed flows, for instance of cars and bicyclists.

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User Counts on Bicycle Lanes and Multiuse Trails in the United States

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The research presented in this paper was conducted as a supplemental activity to the National Bicycling and Walking Study, with the objective of answering the question, if a facility is built, how many people will use it? The first section of this paper examines temporal patterns in the number of bicycle trips along bicycle lanes and trails. Hourly user counts averaged roughly 100 bicyclists per location for lanes in Gainesville, Fla.; Madison, Wis.; and Phoenix, Ariz.; and a trail in Raleigh, N.C. Trails in Washington, D.C. and Seattle, Wash. attracted twice as many daily users on weekends as on weekdays; at one bicycle lane location in Madison, bicycle volumes on Saturday were half those on weekdays. Counts from trails in Eugene, Oreg.; Washington, D.C.; and Madison were generally three to five times higher during the summer months than in the winter. Since 1987, the average volumes per location along bicycle lanes in Gainesville, paths in New York City, and a trail in Madison have ranged from 400 to 1,200 bicycles per day. In Eugene, the installation of bicycle lanes increased bicycle traffic along the routes by up to 40 percent. This study also reports information on the mix of bicyclists and pedestrians found on multiuse trails. On trails in Florida, Rhode Island, and Washington, D.C., and on one bicycle lane in New York City, bicyclists comprised three-fourths or more of all users. For two bridges in New York City and a trail in California, pedestrians dominated.

With the passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), states, metropolitan planning organizations, and localities have more flexibility to plan for and implement facilities and related programs for bicyclists and pedestrians. Planners, engineers, researchers, and bicycling and walking advocates are all interested in answering the question, if a bicycle or pedestrian facility is built, how many people will use it? The research presented in this paper was performed as a supplemental activity for FHWA's National Bicycling and Walking Study, with the objective of gathering information on the number of bicyclists and pedestrians using various facilities.

Most of the bicyclist and pedestrian counts pertained to specific geographical areas. Data on bicycle trips were more readily available, perhaps because bicycle advocacy groups have been more active and are more widespread, or because bicycle counts can be done mechanically and are thus less labor intensive.

This study focuses on bicycle trips that occur on bicycle lanes and multiuse facilities. Bicycle trip counts in mixed street traffic and pedestrian trip counts may be found in a report by Hunter et al. (*1*). The first section of this paper summarizes temporal patterns in bicycle and pedestrian trip counts. Next, information pertaining to the mix of bicyclists and pedestrians on multiuse paths is presented. Possible explanations for the variations in trip counts among facilities are given. Finally, guidelines for data collection are offered.

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TEMPORAL PATTERNS IN TRIP COUNTS

Time of Day

As with automobile trips, the number of bicycling and walking trips varies by time of day. The city of Gainesville, Florida, has records of bicycle counts taken since 1982 (*2*). The number of locations counted has varied from one year to the next. Nine locations were counted from 1989 to 1991, and in 1992 two other locations were added. The locations have a mix of facilities available: designated and undesignated bike lanes, wide curb lanes, and sidewalks.

For 1993, counts were obtained in 15-min intervals between 7 a.m. and 7 p.m. on weekdays, September through December. The total counts for all 11 locations were lowest from 7 to 8 a.m. and from 6 to 7 p.m., and highest from 8 to 9 a.m. and from 5 to 6 p.m. The volumes were actually quite consistent from 8 a.m. to 6 p.m., with about 850 to 950 bicyclists/hr (total of all 11 sites). This pattern probably reflects work and school commuting.

Since the 1970s, Madison, Wisconsin, has been known as a city where bicycling is both popular and an important part of the local transportation system. The 1991 bicycle transportation plan for Madison and Dane County (*3*) reports 159 km (99 mi) of bicycle facilities:

Paths	32 km (20 mi)
Lanes	21 km (13 mi)
Mixed-traffic routes	95 km (59 mi)
Sidewalk routes	11 km (7 mi)

Additional facilities include many rural farm-to-market roads and county trunk highways with paved shoulders, along with two state bicycle trails.

The Madison Department of Transportation has been monitoring bicycle use since the mid-1970s. At the intersection of Mills Street and University Avenue near the heart of the University of Wisconsin campus, continuous bicycle counts are made using loop detectors. Two-way bicycle lanes, both 2.4 m (8 ft) wide, are located on each side of University. University is a one-way street, so one of the bicycle lanes is contraflow. The December 1993 weekday average bicycle volume was 2,309 for a 24-hr period. Peak hourly volume was 131 from 10 to 11 a.m. westbound and 122 from 3 to 4 p.m. eastbound. The lowest average hourly volumes were less than 10 bicycles from 1 to 8 a.m. eastbound and 1 to 7 a.m. westbound (T. Walsh, City of Madison Department of Transportation, unpublished data).

In Raleigh, North Carolina, the Avent Ferry Road Bicycle Path intersects Western Boulevard near the campus of North Carolina State University and Gorman Street a little over 1.6 km (1 mi) south of the campus (*4*). A one-day, 12-hr count revealed that hourly pedestrian usage at Western Boulevard is highest (90–100) between 7 and 9 a.m., falls to around 60–70 during the midday hours, increases slightly between 2 and 4 p.m., then drops to about 50 or lower after 4 p.m. (Figure 1). Bicycle usage followed a similar pattern, with 50–60 cyclists/hr during peak hours and roughly 30 cyclists/hr during midday. These patterns probably reflect students traveling to and from class at the University. The peak hours for joggers may be those times when students are not in class.

In the morning, most bicyclists are traveling northbound, to campus. Over 40 northbound cyclists per hour were counted between 7 a.m. and 9 a.m. During the afternoon, most bicyclists are traveling southbound, away from campus. About 40 southbound cyclists per hour were counted between 3 p.m. and 5 p.m.

For the designated "Bike-to-Work Day" on Wednesday, February 28, 1990, the City of Phoenix, Arizona, established a temporary bike route (*5*). Orange traffic cones were used to mark off separate bike lanes. A total of 560 unduplicated bicycle trips were recorded that day, approximately 200 more than on an average weekday. Of the 560 trips, 232 occurred between 7 and 9 a.m., 74 between 11 a.m. and 1 p.m., and 254 between 4 and 6 p.m. Of 307 survey respondents, 80 percent were making work trips.

Time of Day Summary

Table 1 shows that hourly user counts averaged roughly 100 per location. Peak-hour volumes were about 1¼ times the average hourly volumes. The peak times tended to correspond with commuter and university schedules.

Weekday, Weekend, and Day-of-Week

In some locations, both a weekday and a weekend count were taken. Recreational users were expected to comprise a higher percentage of weekend users than of weekday users. Where commuting dominates, average daily weekend usage may be lower than average weekday usage. At the Mills and University intersection in Madison, Saturday counts were about half the weekday counts and Sunday counts were slightly over one-fourth of the weekday counts (T. Walsh, City of Madison Department of Transportation, unpublished data). On the other hand, a 1987 survey found 1,700 weekend users per day on a trail near the Kennedy Center in Washington, D.C., but only 860 weekday users per day (*6*).

A May 1990 survey of users of the Burke-Gilman/Sammamish River Trail in Seattle, Washington, provides interesting data (Bill Moritz, University of Washington, unpublished data). Six count stations were used along the 40 km (25 mi) of trail from Seattle to Redmond. At the time of the survey all but 2.4 km (1.5 miles) was a Class I facility. Volunteers worked at stations from 7 a.m. to 7 p.m. on a Saturday and a Tuesday, counting total trail users in each direction by mode of travel and distributing survey cards to willing recipients. About 3,200 cards were returned and analyzed. The weather was moderate and without rain on both survey days. On Saturday, 13,204 bicyclists, 1,153 joggers, 1,367 walkers, and 148 other users were counted. The counts for Tuesday consisted of 4,225 bicyclists, 931 joggers, 992 walkers, and 61 other users. Double counting is present to an unknown extent in these totals. A bicyclist traveling completely from one end to the other and back (total of 80 km [50 mi]) would have been counted 12 times.

Figure 2 plots the number of bicyclists by time of day at the station near the University of Washington (westbound is toward the university). On Saturday, westbound flow peaked at about 190 bicyclists/hr from 2 to 3 p.m., while eastbound traffic was 140 bicyclists/hr from 1 to 3 p.m. and from 4 to 5 p.m. The Tuesday plot shows two peaks: 140 bicyclists/hr westbound from 8 to 9 a.m. and 180 bicyclists/hr eastbound from 5 to 6 p.m.

Eugene, Oregon, is home to the University of Oregon and its 18,000 students. The community has had a bicycle coordinator in place for some time and is considered to be proactive for bicycling. The Eugene City Council adopted the Eugene Bikeways Master Plan in 1975 (*7*). The plan proposed 120 routes covering 242 km (150 mi). By 1981, 113 km (70 mi) of bicycle paths, on-street lanes, and signed routes were in place (*8*).

For one-week periods in 1978, daily variations in bicycle volumes at the Autzen Foot Bridge, the Dapple Way Extension (an on-street pedestrian and bicycle connector through a cul-de-sac), and

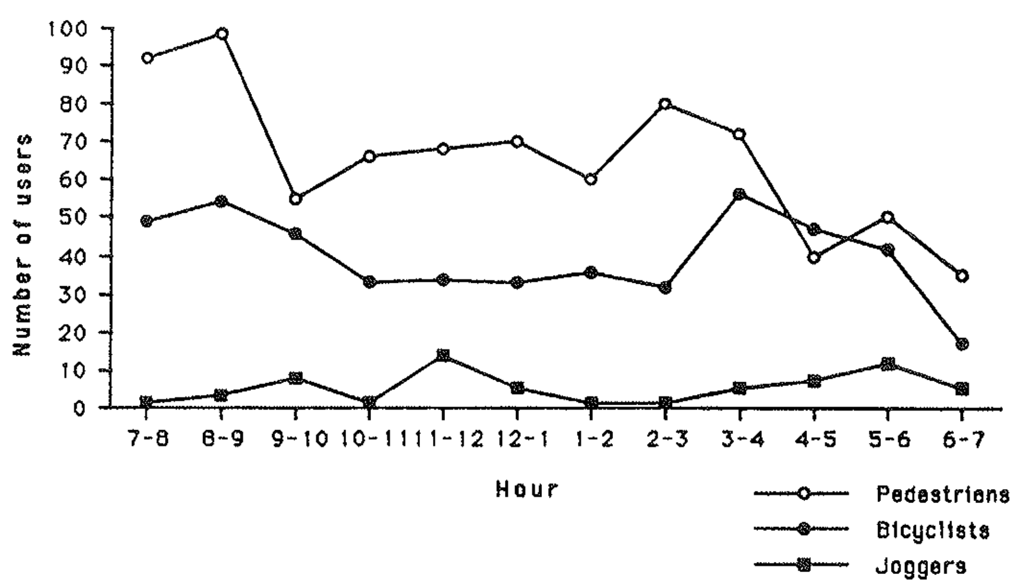


FIGURE 1 Hourly usage, Avent Ferry Road Bicycle Path at Western Boulevard, Raleigh, North Carolina.

TABLE 1 Daily, Peak-Hour, and Average Hourly Bicycle Counts in Four Cities

City	Total Daily Count	Peak Hour Count and Time	Average Hourly Count
Gainesville	10,116 (12 hours, 11 locations)	969 5:00 p.m. - 6:00 p.m. (88 per location)	843 (77 per location)
Madison	2,309 (24 hours, 1 location)	131 westbound 10:00 a.m. - 11:00 a.m. 122 eastbound 3:00 p.m. - 4:00 p.m.	96
Raleigh	787 pedestrians	90 - 100 (pedestrians) 7:00 a.m. - 9:00 a.m.	66 pedestrians
	435 bicyclists	50 - 60 (bicyclists) 8:00 a.m. - 9:00 a.m. and 3:00 p.m. - 4:00 p.m.	36 bicyclists
	115 joggers	10 - 20 (joggers) 11:00 a.m. - 12:00 noon and 5:00 p.m. - 6:00 p.m.	10 joggers
	(12 hours, 1 location)		
Phoenix	560 (6 hours, 1 location)	254 7:00 a.m. - 9:00 a.m.	93

the Ferry Street Bridge in Eugene did not show a consistent pattern (Figure 3) (*7*). For example, each location had a different peak day. Volumes on the Autzen Foot Bridge and the Ferry Street Bridge showed similar fluctuations by the day of the week. The volumes varied by a factor of two to three through the week. The Autzen Foot Bridge was used by 500 bicycles on Tuesday and 1,500 bicycles on Wednesday. Bicycle volumes varied between 375 and 1,200 per day on the Ferry Street Bridge, and between 150 and 450 per day on Dapple Way Extension.

Weekday, Weekend, and Day-of-Week Summary

In Madison, weekday counts were about double the Saturday counts at the Mills and University intersection. Weekend counts were twice as high as weekday counts in Seattle. The peak days for three locations in Eugene were Sunday, Wednesday, and Thursday.

Seasonal

At two locations along the Washington, D.C. Mount Vernon Trail, Belle Haven and Daingerfield Island, automatic counters found that monthly user volumes vary seasonally (Table 2) (*6*). The authors who reported these data do not offer explanations for the unusually high counts at Belle Haven in May 1988 or July 1989, nor for the low count at Daingerfield in July 1988.

Data for November 1991 through March 1994 are provided in Table 3 for the University Avenue location in Madison. In both 1992 and 1993, the highest usage occurred in September and October, when students have returned to the university and the weather is still mild. The counts were the lowest during the winter months. Peak-hour volumes are generally 10 to 15 percent of the total.

Table 4 shows the average 24-hour weekday automatic bicycle counts on the Law and Brittingham Park paths in Madison from 1988 through 1992 (T. Walsh, City of Madison Department of Transportation, unpublished data). These are off-road facilities on park lands in the central business district that are close to the downtown area and the university campus. Both commuters and recreational cyclists use the paths. The total length of the system is 6.0 km (3.7 mi), and segments are nominally 2.4 to 3.1 m (8 to 10 feet) wide. The counts are quite stable from one year to the next, with use tending to be 5 to 6 times higher from April through October than in winter.

Seasonal Summary

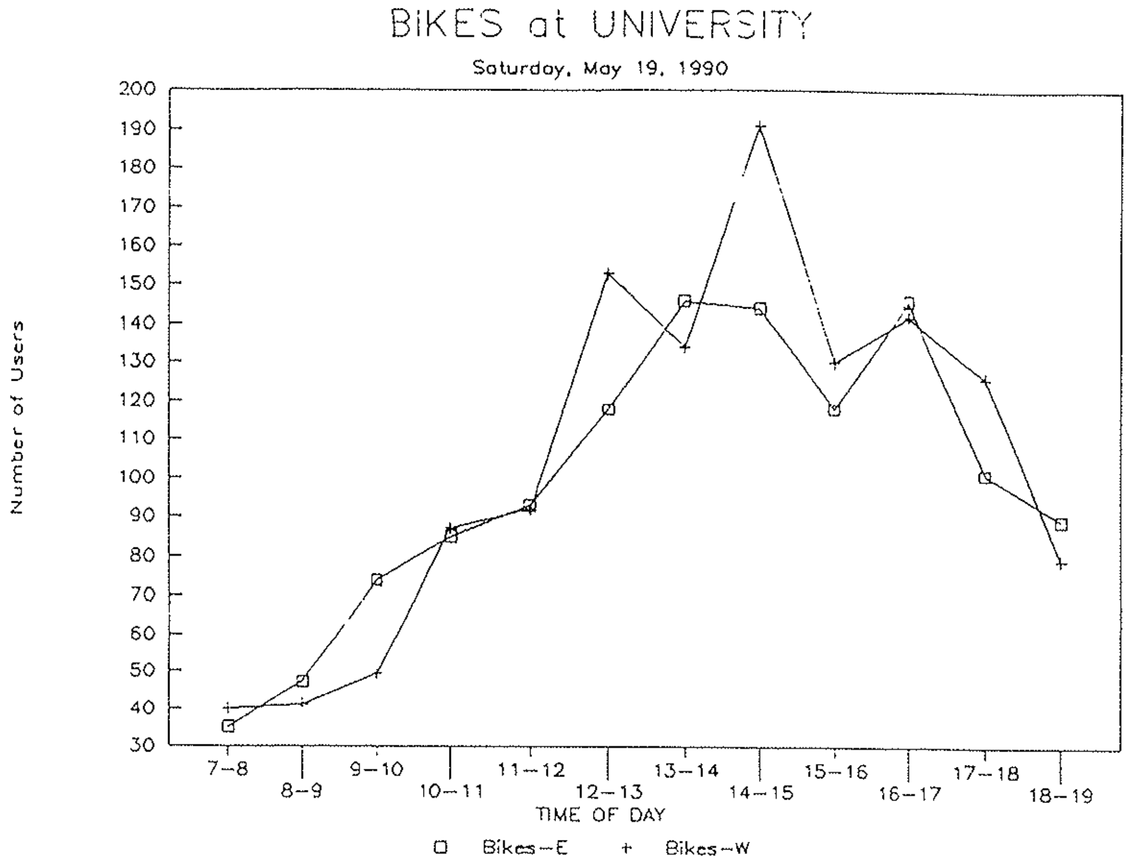
Monthly and seasonal fluctuations in trip counts depend in large part on weather conditions. User volumes were generally highest during the summer and lowest in the winter. For example, daily summer-winter counts averaged 697 versus 138 on paths in Madison between 1988 and 1992. At Daingerfield along the Mount Vernon Trail, the January through March 1988 monthly average was 3,807, increasing to 13,951 for April through September 1988.

Annual Trends

An examination of annual trends in daily counts can reveal changes in long-term travel behavior. Increases in daily counts over time may reflect a higher overall number of trips or modal shifts in favor of bicycling and walking, or both.

A northbound bicycle lane runs along Avenue of the Americas in the Manhattan (New York City) central business district (*9*). The southbound lane runs along Broadway from Columbus Circle south to 24th Street, then continues south along Fifth Avenue to Washington Square Park North. Since 1982, the Avenue of the Americas bicycle lane has had volumes ranging from 772 to 1,594 for a 12-hr period (Figure 4). Volumes along Broadway–Fifth Avenue ranged from 400 to 954 for a 12-hr period.

As Table 4 shows, the annual average of daily bicycle traffic on Madison's Law and Brittingham Park paths ranged from 414 to 552 bicycles/day (T. Walsh, City of Madison Department of Trans-



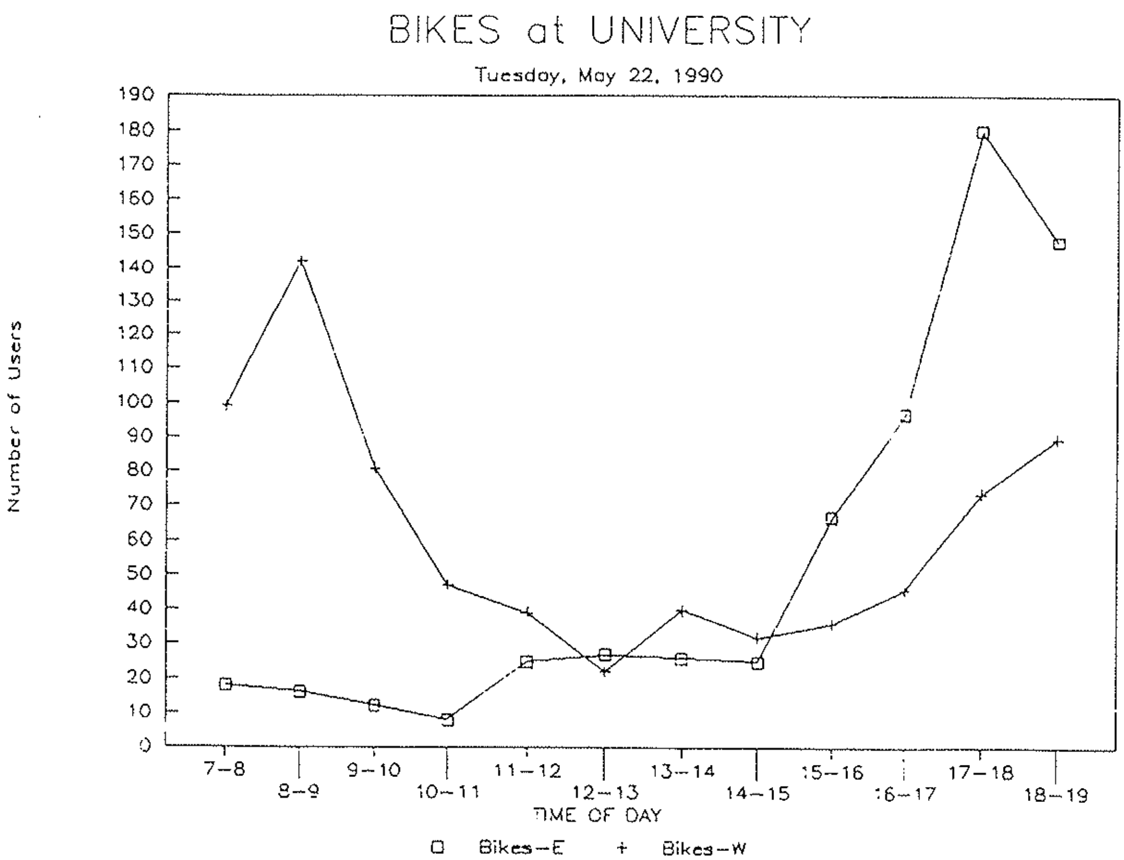


FIGURE 2 Bicyclists by time of day, Burke-Gilman Trail near the University of Washington, Seattle, Washington (Bill Moritz, University of Washington, unpublished data).

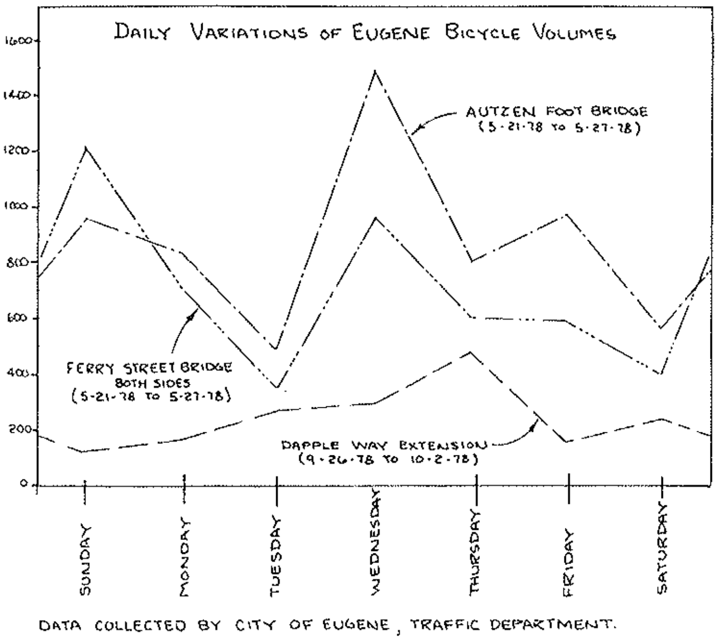


FIGURE 3 Daily variation in bicycle volumes, Eugene, Oregon.

TABLE 2 Monthly User Volumes at Two Locations Along the Mount Vernon Trail, Washington, D.C.

	Location			
	Belle Haven		Daingerfield	
Month	1988	1989	1988	1989
January	779	2,526	927	3,344
February	2,347	4,159	2,791	5,541
March	6,327	10,128	7,703	12,905
April	9,718	6,624	13,435	11,095
May	26,613	13,074	16,386	16,434
June	15,491	14,929	17,723	16,180
July	15,383	43,674	7,262	18,941
August	13,652	13,652	14,859	15,355
September	2,156	10,501	14,043	14,428
October	N/A	9,904	N/A	19,129
November	N/A	N/A	N/A	N/A
December	N/A	N/A	N/A	N/A

N/A = Not available.

portation, unpublished data). The monthly average of daily volumes varied from 41 bicycles/day in January 1991 to 1,243 in June 1992.

Twelve-hour (7 a.m. to 7 p.m.) daily bicycle and pedestrian counts were taken for the bicycle paths along New York City's Brooklyn Bridge, Queensboro Bridge, and Williamsburg Bridge (9). On the Brooklyn Bridge, average daily bicycle counts ranged from a low of 690 in 1989 to a high of 1,633 in 1987. The number of pedestrians was 1,190 per day in 1980 and 2,357 per day in 1987. The peak year for bicycles on the Queensboro Bridge was 1982 (811 bicycles per day counted) and for pedestrians, 1986 (408 pedestrians per day). In 1984, 501 bicycles used the Williamsburg Bridge bicycle path per day. By 1990, that total had declined by one-half, to 248 per day.

Table 5 shows the trend in 12-hr counts in Gainesville, Florida, between 1982 and 1993. Peak volumes occurred between 1984 and 1986. The largest increase over the 11-year period (68.6 percent) occurred at Location 31, which has 1.2-m (4-ft) bicycle lanes. The overall decrease in 1990 may be directly related to five student homicides. Location 28, which has wide curb lanes and sidewalks, and which is near the university, had the steepest decline (23.4 percent).

For all 11 locations (intersections) combined, the total counts increased by 1,128 (12.6 percent) between 1992 and 1993. In general, more bicyclists were observed at four locations near the University of Florida. These four locations accounted for 72 percent of the total, and all have bicycle facilities that feed into the intersec-

TABLE 3 Monthly Bicycle Counts, University Avenue, Madison, Wisconsin

Date	Total	Date	Total
Nov. 1991	3376	Jan. 1993	1148
Dec. 1991	1981	Feb. 1993	2122
Jan. 1992	1328	Mar. 1993	1707
Feb. 1992	2310	Apr. 1993	3634
Mar. 1992	2571	May 1993	3216
Apr. 1992	3466	June 1993	2921
May 1992	3574	July 1993	3418
June 1992	3179	Aug. 1993	2660
July 1992	3420	Sept. 1993	6486
Aug. 1992	2759	Oct. 1993	5895
Sept. 1992	6594	Nov. 1993	4430
Oct. 1992	5927	Dec. 1993	2309
Nov. 1992	3707	Jan. 1994	2343
Dec. 1992	1924	Feb. 1994	1231
		Mar. 1994	2429

[a] Thomas Walsh, City of Madison, Department of Transportation, unpublished data.

tion (Linda Dixon, City of Gainesville Bicycle/Pedestrian Coordinator, unpublished data).

Annual Trend Summary

The average daily bicycle counts per location in each city since 1987 are shown in Table 6. The data do not exhibit a consistent overall trend in any of the cities. Inspection of the most recent 5 years for which data are available shows that average bicycle counts per location dropped by 255 (21.7 percent) in Gainesville, dropped by 22 (4.7 percent) in Madison, and increased by 163 (21.3 percent) for bicycle lanes in New York. Average bicycle traffic on bridges in New York fell by nearly half between 1987 and 1989, then rebounded. Year-to-year fluctuations can result from weather conditions, changes in local employment levels, facility improvements, changes in university enrollment, and any number of other reasons.

Before-and-After Studies

Before-and-after studies are intended to reveal the net change in the number of bicycling and walking trips along a facility before and after the facility was installed.

In the late 1970s in Davis, California, bicycle counts were taken along Anderson Road, Sycamore Lane, and Oak Avenue a few weeks before and one week after a bicycle lane was painted onto Anderson Road (*10*). The 3-hr (7:30 to 8:30 a.m. and 3:30 to 5:30 p.m.) ridership increased by 103 on Anderson Road (7 percent), by 103 on Sycamore Lane (12 percent), and by 95 on Oak Avenue (14 percent). The percent increase in bicycle traffic on Anderson Road with the bicycle lane was less than that on the other two routes, but along Anderson Road, the number of riders 25 years and older increased by 87 percent, from 255 to 477. Interviews with 108 cyclists living near the University of California, Davis, revealed that 45 percent of the cyclists who had previously used other routes switched to Anderson Road.

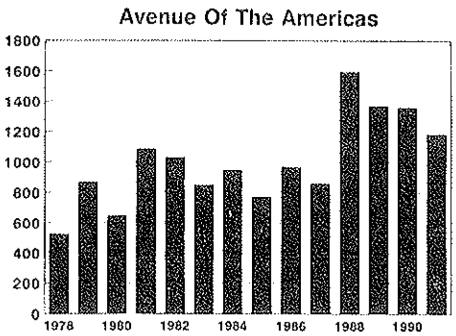
In Eugene, Oregon, bicycle lanes were installed along six streets in August 1993 (City of Eugene Public Works—Transportation Division, unpublished data). "Before" counts were taken in August, shortly before the lanes were installed, for a 7-hr peak count distributed among morning, midday, and afternoon peaks, and totaled 1,309. The volumes ranged from 148 on 18th Avenue to 438 on 13th Avenue. "After" counts taken 1 year later totalled 1,628, for an overall increase of 24 percent. The counts increased

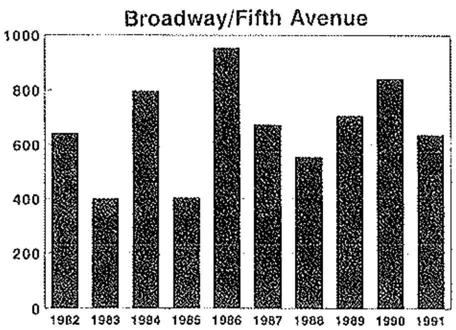
TABLE 4 Average 24-hr Weekday Bicycle Traffic by Month, Law and Brittingham Park Paths, Madison, Wisconsin

(Average of three automatic recording stations)

Months	1988	1989	1990	1991	1992	5-year Average
January	42	89	119	41	107	80
February	118	67	143	127	71	105
March	208	90	238	178	225	188
April	367	474	192	408	355	359
May	840	551	536	1083	601	722
June	1063	1096	785	1160	1243	1069
July	942	672	766	1152	702	847
August	778	747	924	959	678	817
September	581	546	830	763	560	656
October	335	369	524	399	409	407
November	207	176	231	217	253	217
December	91	93	90	142	101	103
Ann Total	5572	4970	5378	6629	5305	5571
Ann Avg	464	414	448	552	442	464
Apr-Oct	701	637	651	846	650	697
Winter	133	103	164	141	151	138

[a] Thomas Walsh, City of Madison, Department of Transportation, unpublished data.





[a]Adapted from (9)

FIGURE 4 Volumes along two bicycle lanes, New York City.

by 32 percent, to 196, on 18th Avenue and by 20 percent, to 527, on 13th Avenue.

The Greenway Bridge in Eugene, spans the Willamette River and connects existing bicycle paths on either side of the river. One-day surveys were conducted, studying 735 bicyclists using the Greenway Bridge and two other bridges in May 1978 and 535 bicyclists in April 1978. According to these surveys, work trips accounted for about 30 to 40 percent of all weekday trips, and another 15 to 20 percent of weekday trips were school trips (*11*). About half of the bicyclists surveyed crossing the Greenway Bridge would not have made their trips if the bridge had not been built. The survey findings suggest that the Greenway Bridge eliminated about 500 automobile trips per week. Summer weekday counts on the Greenway Bridge exceeded 1,100 bicycles per day in 1982, and weekend counts surpassed 2,000 (*8*).

Phoenix, Arizona, has been actively encouraging the use of bicycles for commuting through implementation of facilities, adding bicycle racks to all city buses, and providing showers and lockers at selected city buildings. The bicycle network totals 483 km (300 mi) and includes separate paths, on-street bike routes (signed only), striped bicycle lanes, and wide sidewalks (*12*). There are more than 161 km (100 mi) of on-street bicycle lanes. More than 1127 km (700 mi) of various facilities will eventually be included in the network.

Baseline bicycle usage volumes and riding characteristics data were obtained on nine bike lanes throughout the city in November and December of 1991 (*5*). Trained observers gathered the information for 7 hours (7:00 to 9:00 a.m., 11:00 a.m. to 1:00 p.m., and 3:00 to 6:00 p.m.) at each of the nine locations. The times selected

TABLE 5 Bicycle Volumes, Gainesville, Florida, 1982–1993

No.	Intersection	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
13	NW 34th Street and NW 39th Avenue	93	105	130	162	111	84	129	157	156	176	187	143
15	S. Main Street and SW 2nd Avenue	804	N/A	669	630	529	560	518	566	581	667	668	529
22	SW 34th Street and SW 20th Avenue	795	1,312	1,251	1,053	893	626	731	812	957	732	675	631
23	SW 13th Street and SW 16th Avenue	760	1,478	1,824	2,026	1,231	1,369	1,384	1,564	897	1,621	1,493	785
25	SW 34th Street and SW 2nd Avenue	594	N/A	1,066	1,296	853	867	760	868	767	929	697	819
28	W 13th Street and W. University Avenue	2,085	N/A	2,479	3,188	2,873	2,327	1,944	2,462	1,886	2,112	1,504	2,290
31	SW 23rd Terrace and Archer Road	956	N/A	1,268	1,368	1,191	732	1,034	1,121	1,121	1,144	1,134	1,612
32	NW 34th Street and NW 8th Avenue	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	297	410
37	W 17th Street and W University Avenue	N/A	3,714	3,139	3,365	3,646	2,876	2,484	2,768	2,305	2,281	1,508	2,594
40	E 9th Street and E University Avenue	N/A	N/A	247	225	247	165	224	259	225	314	224	233
54	NW 23rd Avenue and 83rd Street	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	601	70
	TOTAL	6,087[a]	6,609[a]	12,073	13,313	11,574	9,606	9,208	10,577	8,895	9,976	8,988	10,116

[a] Figure includes data for locations where available.

N/A = Counts were not taken at this location for this year.

Note: It should be noted that 1990 counts were taken during and immediately following the five student homicides in the Fall of 1990. During this tense period in Gainesville, students were advised to travel in groups and avoid after dark travel. This may explain the decrease in bicycle volume observed in the Fall of 1990. Incidentally, the decrease in bicycle volume is noticed primarily at locations adjacent to the University of Florida campus and not other locations in Gainesville.

[b] Linda Dixon, City of Gainesville bicycle/pedestrian coordinator, unpublished data.

TABLE 6 Average Daily Bicycle Counts per Location, 1987–1993

Year	Gainesville	Madison	New York	New York -- bicycles on bridges
1987	1067	N/A	767	812
1988	1023	464	1074	533
1989	1175	414	1038	451
1990	988	448	1102	517
1991	1108	552	930	893
1992	817	442	N/A	N/A
1993	920	N/A	N/A	N/A

NOTE: N/A = Not applicable.

targeted commuting bicyclists. Two locations had traffic signals that could be actuated by bicyclists through special push buttons.

Bike to Work Week was held February 24–28, 1992, and two special group rides were arranged for the Tuesday of that week. Data were collected at five of the original nine sites during morning and afternoon commute times (total of 5 hr). Data collection was matched to the same day of the week as the baseline observations obtained earlier, except for the location (23rd Avenue) at which an organized group ride was held.

Comparative results are shown in Table 7. Observations were made on weekdays and in good weather conditions. Overall, 480 bicyclists were observed in November and December, or about eight bicycles/hr. The highest use was 16.7 bicycles/hr. (Lafayette Boulevard) during the late afternoon commute time. In general,

TABLE 7 Summary of Bicycle Observations in Phoenix, Arizona

		November - December 1991				February 1992		
		Bikes per Hour						
Location	Traffic Control	Number Observed	7-9 am	11am-1pm	3-6 pm	Number Observed	7-9 am	3-6 pm
23rd Ave at Camelback Rd	Traffic Signal	86	10.5	11.0	14.3	100	24.5	17.0
Encanto Blvd at 7th Ave	Traffic Signal	34	4.0	1.5	7.7	30	4.5	7.0
7th St at Broadway Rd	Traffic Signal	47	5.0	2.5	10.7	38	5.0	9.3
Washington St at 28th St	Traffic Signal	47	7.0	3.5	8.7	36	5.5	8.3
Campbell Ave and 28th St	Traffic Signal	60	10.0	4.0	10.7	79	15.5	16.0
Encanto Blvd and 39th Ave	Stop Sign	58	6.0	3.0	13.3	N/A	N/A	N/A
Lafayette Blvd at Arcadia	Stop Sign	90	16.0	4.0	16.7	N/A	N/A	N/A
Sweetwater at 28th St	Stop Sign	29	3.5	2.0	6.0	N/A	N/A	N/A
3rd Ave at Encanto Blvd (One Way)	None	29	3.0	3.0	5.3	N/A	N/A	N/A
Total		480	7.2	3.9	10.4	283	11.0	11.5

N/A -- Not available.

volumes were highest in late afternoon (10.4 bicycles/hr), followed by early morning (7.2 bicycles/hr) and then midday (3.9 bicycles/hr), but this would be expected, because bicycle commuters were being targeted.

In February, a total of 283 bicyclists were observed, or about 11 bicycles/hr. The number of cyclists per hour actually declined for Washington Street at 28th Street. An increase of about 50 percent during the morning and afternoon peak hours was seen on Campbell Avenue. The hourly flow during the morning commute on 23rd Avenue (where an organized group ride was held) more than doubled, from 10.5 to 24.5 bicycles/hr.

Before and After Summary

In Eugene, bicycle counts increased 24 percent overall following the installation of bicycle lanes. Morning peak counts were about 50 percent higher during a Bike to Work Week in Phoenix. Counts increased between 7 and 14 percent at three locations in Davis, and bicyclists 25 years and older were particularly attracted to one of the locations.

THE MIX OF BICYCLISTS AND PEDESTRIANS ON MULTIUSE PATHS

Many facilities are built to serve multiple users, such as bicyclists, walkers, and joggers. These multiuse trails and paths are usually completely segregated from motor vehicle traffic. As these trails often traverse parks, greenways, or other wooded settings, many cyclists and pedestrians use the trails for recreational purposes. Other trails are used by individuals commuting to and from work or school. This section presents trip counts for multiuse trails and paths. Information regarding the mix of bicyclists and pedestrians is given when available.

Bicyclists and pedestrians were manually counted at five intersections spread along a 23.5-km (14-mi) bike path built in 1990 between Providence and Bristol, Rhode Island (*13*). Counts were taken on weekdays from 5 to 7 p.m. and weekends from 9 to 11 a.m. The counts were adjusted to estimate the average daily bicycle traffic. The data showed an average modal split of 80 percent bicycles and 20 percent pedestrians.

Several sources of counts on trails in and near Washington, D.C. are quoted in a report compiled by the Denver Service Center (*6*). In August 1983, an 11.5-hr Sunday count found 1,048 users along a section of the Mount Vernon Trail south of Alexandria. Fifty-five percent of the total were cyclists, with runners or joggers and walkers accounting for the remainder. An 11.5-hr Monday count found 788 users and nearly the same distribution of cyclists, runners, and walkers.

A 1985 study counted 820 users per day on the Mount Vernon Trail at the Memorial Bridge but only 400 users per day at the 14th Street Bridge. The mix of users varies by location along the trail. At the Memorial Bridge, 50 percent of the users were cyclists and 60 to 65 percent were commuters. Nearly 80 percent of the users at the 14th Street Bridge were cyclists; 75 to 80 percent were commuters. At both locations, adult males comprised 80 percent of the users.

In August 1993, the Oregon Department of Transportation set up two interview stations to interview users of the I-205 bicycle path in Portland [Michael M. Ronkin, Bicycle/Pedestrian Program Manager, Oregon Department of Transportation regarding I-205 bike path survey, Dec. 7, 1993]. One station was operated for 10 hours on one day only; the other station was operated for 10 hours on each of two days. Bicyclists comprised 598 (64 percent) of the 932 users who passed the interview stations and 217 (77 percent) of the 281 users who completed a questionnaire. Of the bicyclists who completed a questionnaire, 38 percent listed travel as a trip purpose, 67 percent listed recreation, and 86 percent cited exercise. The average bicyclist rode 2.5 times per week for 19 km (12 mi) on the path.

A weekend count conducted on a 6.4-km (4-mi) bicycle-pedestrian path in Brooklyn New York City) in September 1989 from 7 a.m. to 7 p.m. revealed 1,200 cyclists and 1,100 pedestrians (J. Benfatti, New York City Department of Transportation, unpublished data). When the Central Park drives are closed to motor vehicles during the summer, 1,300 bicyclists use the drives between 10 a.m. and 3 p.m. Another 1,100 cyclists use the drives between 7 p.m. and 10 p.m.

Through the years, more pedestrians than bicyclists have used the Brooklyn Bridge bicycle path. In 1991, the daily averages were 1,183 bicyclists and 1,688 pedestrians. On the other hand, every year bicyclists outnumbered pedestrians on the Queensboro Bridge, by 602 to 140 (a factor of 4.3) in 1991. Pedestrian counts for the Williamsburg Bridge were done only in 1987 and 1989. In 1987, there were more bicyclists (368 versus 262 pedestrians), but in 1989, pedestrians dominated (467 versus 248 bicyclists).

A sample of three diverse rail-trails from across the U.S. was studied during 1990 and 1991 (*14*). Eight years old at that time, the 42-km (26-mi), crushed limestone surfaced Heritage Trail traverses rural farmland in eastern Iowa. This trail was estimated to have 135,000 visits annually: 65 percent bicycling, 29 percent walking, and 6 percent other. The 2-year old, 26-km (16-mi) paved St. Marks Trail, which parallels State Road 363, begins on the outskirts of Tallahassee, Florida, and passes through small communities and forests toward the Gulf of Mexico. An estimated 170,000 people used this trail annually: 81 percent bicycling, 9 percent walking, and 10 percent other. The 14 year-old Lafayette/Moraga Trail is a 12.2-km (7.6-mi) paved trail 25 miles east of San Francisco, California, which travels almost exclusively through developed suburban areas. This trail had an estimated 400,000 annual visits: 20 percent bicycling, 63 percent walking, and 17 percent other.

The Pinellas Trail is a popular facility on the west coast of Florida connecting Clearwater with Largo and St. Petersburg. At present about 53 km (33 mi) of trail are open; 77 km (47 mi) are planned to be built in the next few years. The asphalt-paved trail is nominally 4.6 m (15 ft) wide: 3.1 m (10 ft) for bicycles and in-line skaters, and 1.5 m (5 ft) for pedestrians. An 11.5-hr (6:30 a.m. to 6:00 p.m.) survey of users was conducted on Tuesday, November 9, 1993, by the Pinellas County Department of Planning (K. Medwick, Pinellas County Department of Planning, unpublished data). Eight locations near traffic generators such as schools, shopping centers, recreation areas, and medical centers were used as survey sites along the 37 km (23 mi) of trail in use at the time of the survey. Volunteers handed out a brief, self-administered questionnaire to trail users. To protect against double counting, users were asked if they had already filled out a survey. The survey produced 967 responses, and participation was thought to be good. The weather on the survey day was good, although a predicted 60-percent chance of showers may have lowered actual trail use.

While the bicyclist versus pedestrian mix was unavailable, other survey results indicated the following points.

- Use varied little by time of day;
- 63 percent of the users were male;
- 64 percent were adults aged 25 to 65;
- 40 percent lived less than 0.4 km (.25 mi) from the trail, and 35 percent lived more than 1.6 km (1 mi) from the trail;
- 55 percent usually traveled less than 8.1 km (5 mi) each way on the trail, and 45 percent more than 8.1 km (5 mi);
- 88 percent used the trail at least twice a week, and 45 percent at least 5 days per week;
- 67 percent used the trail for recreation, exercise, and so forth, and 33 percent for transportation to work, school, stores, and so forth;
- 60 percent of commuters used the trail 5 days per week, and 87 percent at least 2 days per week;
- 51 percent used a bicycle to get to the trail, while 27 percent walked, 20 percent used a car, and 2 percent some other means; and
- The distance from trail to destination was less than 0.4 km (.25 mi) for 29 percent of users, and more than 1.6 km (1 mi) for 41 percent of users.

Multiuse Path Mix of Users Summary:

Information pertaining to multiuse trails is summarized in Table 8. Average combined bicycle and pedestrian volumes ranged from 25 to 240 users/hr. On most facilities, bicyclists dominated by as much as 81 percent versus 19 percent pedestrians. Pedestrians outnumbered bicyclists on three facilities.

DISCUSSION OF RESULTS

The bicycle and pedestrian counts reported in this paper vary widely from one location to another and even on the same facility (Table 9). Comparisons between cities are difficult, given variations in the time periods counted. For instance, the counts in Davis were taken during one hour in the morning and two hours in the afternoon. Without information as to how counts vary throughout the day, a 12-hour or 24-hour estimate of usage cannot be obtained. In other cities, daily counts were taken over longer periods, such as 6, 12, or 24 hours. Some cities counted on only one or two selected days. The

TABLE 8 User Mix on Multiuse Trails

	Total Users Per Day	Average Per Hour	Percent Bicyclists	Percent Walkers/Joggers
Providence - Bristol, RI				
East Bay Bike Path	200-475[1]	N/A[2]	80	20
Washington, DC				
Mt. Vernon Trail south of	1,048 (11.5 hrs, Sunday)	91	55	45
Alexandria	788 (11.5 hrs, Monday)	69	55	45
Memorial Bridge	820	N/A	50	50
14th Street Bridge	400	N/A	78	22
Portland, OR				
I-205	932 (30 hrs)	31	64	36
New York, NY				
Brooklyn, bicycle/ped path	1,200 cyclists (12 hrs)	100	52	48
	1,100 pedestrians (12 hrs)	92		
Brooklyn Bridge, 1991	1,183 cyclists (12 hrs)	99	41	59
	1,688 pedestrians (12 hrs)	141		
Queensboro Bridge, 1991	602 cyclists (12 hrs)	50	81	19
	140 pedestrians (12 hrs)	12		
Williamsburg Bridge, 1989	248 cyclists (12 hrs)	21	35	65
	467 pedestrians (12 hrs)	39		
Iowa				
Heritage Trail	135,000/year[3]	25[4]	65	35
Florida				
St. Marks Trail	170,000/year[3]	31[4]	81	19
Pinellas Trail	967 (11.5 hrs)	84	N/A	N/A
California				
Lafayette/Moraga Trail	400,000/year[3]	73[4]	20	80

NOTES:

[1] Estimated average daily bicycle traffic based on 2-hour counts.

[2] N/A = Not available.

[3] Estimated based on surveys administered over a 12-month period, two days per week, representing 15 hours per day.

[4] 15 hours/day.

TABLE 9 Summary of Bicycle Counts

Location	Type of Facility	Time Period	Range of Counts
Clearwater-Largo- St. Petersburg, FL	Pinellas Trail	11/9/93 6:30 a.m. - 6:00 p.m.	967 total
		weekday	2,000 - 3,000 users 33% use trail to go to work, school, shopping
Davis, CA	On-street bicycle lane	Weekdays, 1974: 7:30 am - 8:30 am 3:30 pm - 5:30 pm	 255/ 3 hours before 477/ 3 hours after
Eugene, OR	Bicycle path	Summer weekday, 1978 Summer weekend, 1978	1,100/day 2,000/day
	Bicycle lanes	Weekday, 1978	100-3,000/day
	Bicycle path	1974-1977	100-400/day
	Bicycle paths	1977, 1978; Tues, Thu,Sat: 2,6, or 10.5 hours	
	Bicycle routes	5/21/78 - 5/27/78 at 2 locations	< 200 - > 1,400/day
	Bicycle lane & path	9/26/78 - 10/2/78 One week, 12 N to 11 p.m.	450/day lane 567/day path
Gainesville, FL	Urban intersections connected to bike lanes, wide curb lanes, sidewalks	1993: 7 a.m. - 7 p.m.	70-2,594/day
Madison, WI	Bike paths	1988-1992, weekday, 24 hours	41/day (1/91) - 1,243/day (6/92)
	Urban intersection	December 1993, 24 hours	2,309/day (weekday) 1,193/day (Sat), 647/day (Sun)
	Urban street	1991-1994	1,148/day (1/93) - 6,594/day (9/92)
New York, NY	Urban streets	Summer	113 - 1,069/day
	Class I bicycle path	weekday, 1991 7 a.m. - 7 p.m.	602 - 1,183/day
	Class III bicycle lane		673 - 1,186/day

(continued on next page)

values thus obtained may not be representative of an average day during the year. Weekend counts tend to include a higher proportion of recreational users than weekday counts. Weekend totals may be higher, as in Eugene and Seattle, or lower, as in Madison, depending on the relative numbers of recreational users and commuters. Summer counts are higher than winter counts because of favorable weather conditions, as is evident in Madison and Washington, D.C.

It was beyond the scope of this research to investigate other possible explanations such as local land use patterns (which generate and attract trips) for variations in the counts among cities. With the variations in time periods, it is difficult to determine whether cities with high population densities (such as New York) or college towns (Davis, Eugene, Madison, and Gainesville) have higher volumes of bicyclists and pedestrians than other cities. A case study executed as part of the National Bicycling and Walking Study (*15*) found higher rates or modal splits for bicycle commuting in college towns compared to other cities, perhaps because college towns were characterized by shorter commuting distances and higher ratios of bicycle lane mileage to arterial mileage than other cities. Daily university class schedules are reflected by the hourly variations in counts on the Avent Ferry Road Bicycle Path in Raleigh. Counts along University Avenue in Madison were higher even in November than in the warmer months of June through August, because school was in session.

Other factors that are likely to increase bicycle and walking trips are the availability of a connected bicycle lane or path network and the presence of light-to-moderate levels of motor vehicle traffic. Bicycle and pedestrian volumes may vary because of promotional activities (such as Bike to Work Week in Phoenix) or special situations (fear following the homicides of students at the University of Florida). Local terrain and the physical condition of facilities can also affect individuals' choices of whether to walk or bicycle at all and their decisions to use a facility.

TABLE 9 (*continued*)

Location	Type of Facility	Time Period	Range of Counts
Phoenix, AZ	Temporary bike lanes	Wed, 2/28/90: 7-9 am, 11-1 pm, 4-6 pm	560/ 6 hours
	Bike lanes at intersections	Weekdays, Nov and Dec: 7-9 am, 11-1 pm, 3-6 pm	29-90/ 7 hours
	Bike lanes at intersections	2/24 - 2/28: 7-9 am, 3-6 pm	30-100/ 5 hours
Portland, OR	Bicycle path	Two days in August, 1993: 10 hours/day	598
Providence, RI	Bicycle path	1991: Weekdays 5 pm - 7 pm Weekends 9 am - 11 am	Estimated from counts 225-475/day
Raleigh, NC	Bicycle path	September 14, 1988, 7 am - 7 pm	1,331/day
Seattle, WA	Burke-Gilman Trail	Sat 5/19/90 & Tues 5/22/90: 7 am - 7 pm	Bicyclists: 13,204 (Sat) 4,225 (Tues) Pedestrians: 2,520 (Sat) 1,923 (Tues)
Washington, DC	Mt. Vernon Trail	Aug. 1983: Sun - 11 hours	1,048 total
		Mon - 11 hours	788 total
		1985	820 total (Memorial Bridge) 400 total (14th Street Bridge) (60-65% commuters)
		Monthly 1988-1989	Belle Haven 779 (1/88) - 43,674 (7/89) Daingerfield 927 (1/88) - 19,129 (10/89) (75-80% commuters)

CONCLUDING REMARKS

The counts in a number of cities suggest that bicycle lanes and bicycle paths can reach volumes of 1,000 to 2,000 users per day, at least when weather conditions permit (Table 9). While planners in other cities may use these figures as a crude estimate of bicycle travel, they must be aware that counts obtained in one city may not generalize to other cities because of the conditions and limitations under which the counts were made.

No studies were found that related bicyclist and pedestrian trip generation to a comprehensive range of land uses. However, Brownell (*16*) estimated bicycle usage of a proposed 23.3-km (14.5-mile) bicycle facility between Providence and Bristol, which has since been built. He relied on the trip generation equations that estimated the total number of bicycle trips generated by each analysis zone in the facility's area of influence as a function of employment, school enrollment, and population.

If a local modal split is known or can be estimated, it can be applied to trip generation rates given in ITE's *Trip Generation Manual* (*17*) to estimate the number of bicycle and pedestrian trips that a particular land use would generate. Thus, the number of trips generated by a proposed trail can be estimated according to the existing building types and floor space. Sometime after the trail is in place, the estimates should be compared with actual counts to evaluate and refine this modal split approach and other methodologies that rely upon equations.

Ideally, it would be possible to estimate trips directly from some combination of building type, floor space, population, bicycle ownership rates, and information from surveys asking people whether they would switch to a proposed facility or where they would have biked and walked had the facility not been built. To achieve this ideal, a national data base would be needed to provide the data for deriving equations that could be used to estimate trips.

An ideal trip-counting approach might involve counting the number of bicyclists and pedestrians using an existing facility or street that serves as an important route before a new facility is installed, and then counting the number of users on both the existing and new facilities after installation. The inclusion of a control site will provide an indication of whether overall bicycle and pedestrian trip-making is changing. When staff and funding are available, trips should be counted at various locations for at least 10 to 12 hours per day, with days scattered throughout the year. Observers could note the gender and approximate age of users and distribute surveys to ask users about trip purposes and distances traveled. If only the number of users is desired, automatic counters could provide continuous counts.

The National Bicycling and Walking Study (*18*) discusses the benefits associated with increased levels of bicycling and walking. Surveys show that more people would bike and walk if there were more safe, attractive, convenient, and well-maintained facilities, such as sidewalks, trails, bike lockers, and so forth. Information about how many bicyclists and pedestrians are likely to use a proposed facility gives an indication of its benefits, and thus, whether it is worth the investment. Transportation planners would have a sense of the role of bicycling and walking in the overall transportation scene. Traditionally, planners and other officials have given little, if any, consideration to nonmotorized modes of transportation. Given the requirements of ISTEA and the Clean Air Act Amendments, bicycling and walking may become more key components of the American transportation system.

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Demographic and Economic Characteristics of Bicyclists Involved in Bicycle–Motor Vehicle Accidents

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The purpose of this study is to compare the demographic and economic characteristics of bicyclists involved in bicycle–motor vehicle accidents in the large urban area of Dade County, Florida. This comparison is done in an attempt to discern meaningful statistical relationships between those characteristics and the accidents. For this project, police reports of bicycle–motor vehicle accidents occurring in the Miami metropolitan area from January 1, 1990, to December 31, 1991, were collected. The data from these 1,777 accidents were subjected to two reviews. The first was a general comparison of accident patterns between black and nonblack bicycling accident victims. A second review tabulated accidents and accident rates by census tract, which were then compared with 14 economic and demographic characteristics for each census tract using a stepwise linear regression technique. The results of this analysis indicate that economic factors (particularly the percentage of poor households within a neighborhood) play an important role in the prediction of areas with high bicycle accident rates. Limited evidence, in the form of a comparison in accident rates by age between all bicyclists and black bicyclists, suggests that this is probably the result of increased bicycle use. The study concludes that bicycle planners should give greater attention to neighborhoods of lower-than-average affluence, particularly where extreme poverty exists and where transit availability is inferior. It appears likely that rather than being the transportation method of choice, the bicycle is often the mode of last resort.

A central concern of planners and engineers working in the field of bicycle planning is the evaluation of bicycling accidents. Although studies indicate that collisions involving a motor vehicle are a minority of all bicycling accidents, such incidents account for most of the serious injuries to and deaths of bicyclists (*1–3*). Although research into bicycle–motor vehicle accidents has often referenced at least some demographic characteristics of the accident victims, these studies have usually included only age and gender. No known study has systematically evaluated a wider array of economic or demographic variables.

The purpose of this study is to compare the incidence of bicycle accidents between neighborhoods in a large urban area with a selected list of economic and demographic characteristics of those neighborhoods. This comparison is done in an attempt to discern meaningful statistical relationships between those characteristics and the accidents.

There is a need for such information. The characteristics of bicycle accident victims are important for three reasons. First, there is reason to believe that the demographic and economic makeup of these victims may reveal important information about the characteristics of bicycle users. Any factor that tends to increase bicycle use among a population group can be expected to increase the exposure of that group to bicycle accidents. In other words, anything that leads a population group to bicycle more can be expected to increase its incidence of bicycling accidents.

For example, in a theoretical evaluation of the economics of the bicycle as a means of commuter transport, Everett (*4*) concluded that the bicycle as compared with the automobile is a utility-maximizing form of transport only in those cases where the trip length is very short or the income of the commuter is very low. Although the cost of operating a bicycle is small, the bicycle travels more slowly than an automobile under most conditions, resulting in a higher cost when value-of-time considerations are factored in. A study of commuting trips to the downtown area of Davis, California (*5*), indicated that there is a marked tendency for managerial employees to prefer automobiles rather than nonmotorized modes of transportation, regardless of the employees' age or their distance of commute. Sales, clerical, and blue-collar employees, on the other hand, exhibited a propensity to commute by nonmotorized modes, again assuming that age and commuting distance are held constant. A recent study of extremely poor people in Los Angeles (*6*) discovered that 60 percent of the trips taken by the unemployed very poor were by nonmotorized modes, whereas 49.4 percent of the trips taken by the employed very poor were by these modes, with almost 7 percent of total trips taken by bicycle.

This conclusion, however—that the demographics of bicycle accident victims can be used as a marker reflecting the characteristics of bicycle users—is subject to strong mitigating factors. Some population groups may exhibit accidents rates disproportionate to both their representation in the general population and their participation in bicycling. For example, in his study of 919 bicycle–motor vehicle accidents in four American metropolitan areas, Cross (*3*) found that

> [W]hile the accident involvement of 12–15 year old bicyclists is more than twice as great as would be expected from the number of bicycle users in this age group . . . accident involvement of bicyclists between 30 and 59 years of age is less than one-fourth of that expected from the number of bicyclists in this age group.

Although Cross attributed this higher accident rate to specific types of operating characteristics, Kaplan, in his study of club bicyclists (*7*), discovered that both younger bicyclists and women had a higher accident rate, which he attributed to the tendency of both groups to have less bicycling experience. Overall, Kaplan found that the rate of accidents per bicyclist was 50 percent less for those with 10 years or more of bicycling experience than it was for those with less than 1 year of experience.

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The second reason for evaluating the characteristics of bicycle accident victims is to determine if certain population attributes can be used as a marker for other risk-exposing characteristics. These attributes could include urban-form features (population density, street form, and characteristics associated with neighborhood age), which are prevalent in some districts while absent in others.

Obviously, there is some conflict between this objective and the first. A high correlation between some population characteristic and a high incidence of accidents could be explained either as a factor that results in an increased rate of bicycle usage within the group or as a factor that leads to an increase in risk exposure per mile or hour of bicycle use. For this reason, explanations of causality should be treated with caution, and, as is true for any population-group correlation study, the conclusions drawn should be used as a guide for further study and not as a conclusive result.

The third reason for undertaking such an investigation is to know more about the characteristics of bicycling accident victims in order to aid in structuring accident prevention measures. This was the primary purpose of the 1978 Cross study, which had a significant effect on bicycle education programs targeted at different age groups. If demographic or economic characteristics appear to influence patterns of bicycle accidents, then programs marketed specifically at these groups could be considered. Alternatively, knowing more about the composition of high-risk groups could do much toward isolating the specific operating characteristics of such users which lead to increased accidents, and working toward remedial measures aimed at these characteristics. Some examples of high-risk characteristics could include higher rates of nighttime riding (a feature of commuters and those who are bicycling-dependent) or riding in dense, inner-city areas.

ABOUT DADE COUNTY, FLORIDA

Dade County, which contains the Miami-Hialeah Metropolitan Statistical Area (MSA), is the most populous county in Florida, containing 1.94 million residents in 1990. It encompasses a land area of 5035 km^2 (1,944 mi^2) with a population density of 385 persons per square kilometer (996 persons per square mile) (*8*). However, much of the western portion of the county is uninhabitable wetlands, so actual population densities are much higher. The Miami-Hialeah Urbanized Area, measuring 914 km^2 (353 mi^2), is second only to Los Angeles in terms of population density, with 2096 persons per square kilometer (5,429 persons per square mile) (*9*).

The median age of county residents in 1990 was 34.2 years, a figure identical to that in 1970. Unlike most places in the United States, the average age of county residents has not increased, largely because of an influx of Hispanic immigrants over the last 30 years, which has displaced a disproportionately large contingent of older, retired non-Hispanic whites. Therefore, age and ethnicity are to some degree correlated within the county. In 1990, 49.2 percent of all residents were Hispanic. The Hispanic residents of Dade County have broad representation across all economic strata because of the influx of Cuban refugees fleeing Cuba's Marxist-Leninist government, the bulk of whom were from that country's business and professional classes before the revolution of 1958. Over 59 percent of the county's Hispanic residents are of Cuban descent.

The average per capita personal income for the county in 1990 was $17,823, 4 percent less than that for the state ($18,539) and about 5 percent under that for the United States ($18,696) (*8*). Households in the county with incomes under the poverty line accounted for 17.6 percent of all households. Mean household income in 1989 for all households was $37,903; the mean income for Hispanic households was $32,311 and the mean income for black households was $25,870 (*10*).

METHODOLOGY

All law enforcement officers in the state of Florida are required to record on a standardized form vehicle accidents resulting in injury or significant property damage. This form, the Florida Traffic Crash Report, is forwarded to the central safety office of the Florida Department of Transportation (FDOT), which uses it to record crash statistics for the state. Any accident reports involving bicycles or pedestrians are, in turn, forwarded to the FDOT Pedestrian/Bicycle Office, which makes them available to planning and law enforcement agencies in Florida's 68 counties on an annual basis.

For this project, reports involving bicycle–motor vehicle accidents during the two-year period from January 1, 1990, to December 31, 1991, were reviewed. Only those reports containing a residential address for the bicyclist within the county were retained. This resulted in a total of 1,777 incidents. From this review, five pieces of information were recorded:

1. The age of the bicyclist,
2. The age of the motor vehicle driver,
3. The race or ethnicity of the bicyclist,
4. The race or ethnicity of the motor vehicle driver, and
5. The address of the bicyclist's place of residence.

An initial objective of the study was to identify both motorists and bicyclists by race or ethnic origin. However, it quickly became apparent that the recording of persons of Hispanic ethnic background was inconsistently reported on many accident forms. Inquiries to persons knowledgeable about Miami's Hispanic community indicated that there is a tendency for persons of Cuban national origin to report themselves and other Cuban-origin individuals as non-Hispanic whites in situations where the term "Hispanic" is not clearly defined as an ethnic, and not racial, identifier, as is the case on the Florida accident form. Because persons of Cuban national origin compose 59 percent of Dade County's Hispanic population, this raised the possibility of significant statistical bias. A spot survey of 200 accident forms yielded a statistically significant difference in the proportion of persons with traditionally Hispanic surnames who were identified as Hispanics between reporting officers with Hispanic and non-Hispanic surnames. For this reason, the racial composition of motorists and bicyclists was categorized as simply black or nonblack in this study.

The data from these 1,777 accidents were then subjected to two reviews. The first was a general comparison of accident patterns between black and nonblack bicycling accident victims, between black and nonblack motorists, and between black bicyclists and black motorists. This comparison was done for 13 age categories and across-the-board for all victims in an attempt to see whether any significant statistical anomalies were apparent. This analysis is presented in the following section.

A second review was more statistically rigorous. The residential address of each bicycling accident victim was taken from the accident report. This address was plotted by census tract in one of the 256 census tracts in Dade County. The number of accident victims per census tract and the per capita rate of accidents in each census tract were then compared with 14 economic and demographic characteristics for each census tract using a stepwise linear regression technique. A reverse stepwise procedure was used, in which all independent variables were included in the first regression run, after which the independent variable with the worst fit (i.e., a student's-t value closest to zero) was dropped and the regression was rerun. This cycle was continued, with one independent variable dropped after each run, until all remaining independent variables were significant. All dropped variables were then reinserted to determine if they were now statistically significant. The significant independent variables and the residuals of the final regression run were then examined for multicollinearity and heteroscedasticity using graphical analysis techniques.

DEMOGRAPHICS OF ACCIDENT VICTIMS

General Analysis

Of the 1,777 accident reports reviewed in this study, the gender of the bicyclist was included on 1,695 and omitted on 82. Of these 1,695 accident victims, 80.1 percent were male and 19.9 percent were female.

The race of the bicyclist was included on 1,773 accident forms. Of these, 464 were reported as being black, which was 26.2 percent of the total. The race of the automobile drivers was available on 1,480 of the accident forms. Of these, 287 were reported as being black, which was 22.4 percent of the total. Blacks compose a total of 20.1 percent of Dade's population. The difference in data availability was primarily due to the incidence of hit-and-run automobile drivers, which composed 16.7 of all drivers involved in these accidents. Only one bicyclist was reported in this category.

As indicated in Table 1, the elevated accident rate for black bicyclists cannot be plausibly attributed to random chance. Applying the chi-square test, the difference between the expected (20.1) and observed (26.2) percentages of black bicyclist victims is significant at the 99.9 confidence level. On the other hand, the difference between the expected and observed proportion of motor vehicle drivers involved in accidents with bicyclists is not significant.

Figure 1 shows a breakdown of the rate of accidents for all Dade County bicyclists and for the county's black bicyclists by age. For each age bracket, the accident rate is per 1,000 members of the age bracket for the full 24-month period. The accident rate for black bicyclists is sharply higher for the 5–9 and 10–14 age categories, and slightly higher for the 55–59 and 60–60 age categories. Accident rates for the 15–19 and 20–25 age categories are significantly lower than was the case for all bicyclists.

The most likely explanation for the elevated rate of bicycling accidents among blacks in Dade County is a more intensive use of the bicycle by black children between the ages of 5 and 15. These bicyclists have a much higher accident rate than is the case for all bicyclists in this group. Blacks under the age of 15 comprise 47.7 percent of all accidents by black bicyclists.

One possible explanation for this elevated rate is that blacks reside in areas with characteristics that contribute to the generation of accidents. Some of these characteristics could include more miles of major arterials or other high-volume streets, a disproportionately high share of streets of older design or in poor repair, lack of sidewalks, or a generally higher level of traffic due to land use or transport network patterns. However, if this were the case, one would expect these factors to result in higher accident rates among black bicyclists of all ages and black motor vehicle drivers involved in bicycle–motor vehicle accidents. This is not the case, as the latter category is consistent with overall population representation and the former category is actually lower for several age classes. In summary, the analysis of this limited data results in findings that, although interesting, are hardly indicative of any overarching causal pattern.

Regression Analysis

As outlined earlier, the residential addresses of the 1,777 cycling accident victims were plotted by census tract into one of Dade's 256 tracts. The total number of accident victims per census tract and the accident rate per 1,000 residents of each census tract was then regressed against a series of independent variables for each tract. These variables included

1. TOTPOP, total population;
2. AREA, land area (excluding water surface) in acres;
3. HOUSEVAL, estimated median home value of owner-occupied housing;
4. RENT, median contract rent of tenant-occupied dwellings;
5. INCOME, mean family income;
6. DENSITY, population density (TOTPOP/AREA);
7. KIDS 18%, proportion of residents 18 years old or less;
8. BLACK%, proportion of black residents;
9. WHITE%, proportion of non-Hispanic white residents;
10. POOR%, proportion of residents meeting federal poverty status in 1989;
11. HISPANIC%, proportion of nonblack Hispanic residents;
12. AVTRVLTME, average reported travel time to work, in minutes;
13. NOCAR%, proportion of households reporting no automobile availability;
14. CARSPERH, average automobile availability per household;
15. DUMMY1, one for census tracts 1.07, 1.08, 38, 39.01,

TABLE 1 Involvement in Bicycle–Motor Vehicle Accidents by Blacks, Dade County, Florida, 1990–1991

	Representation in: County Population (percent)	Representation in: Bicycle/MV Accidents (percent)	Chi-Square Value	Confidence Level
Cyclists		26.2	32.76	99.9
Motorists		22.4	4.72	N.S.
Total	20.1			

N.S. - Not Significant

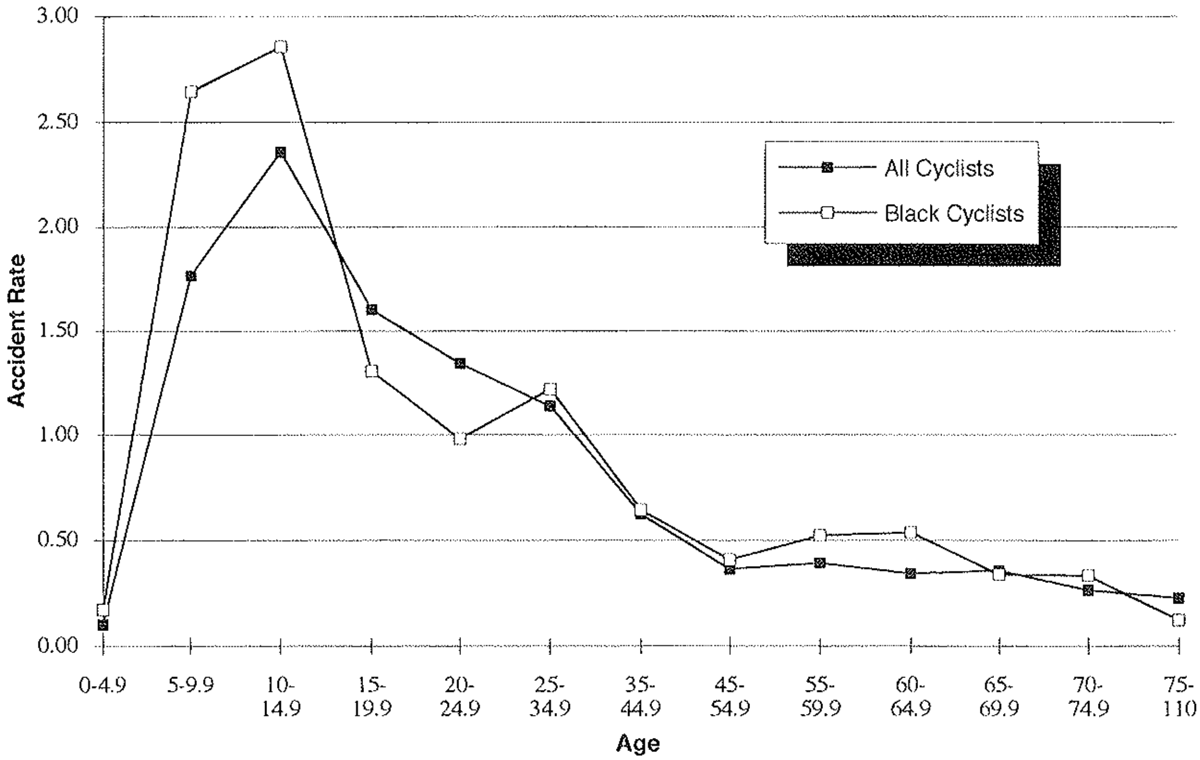

FIGURE 1 Bicycle Accidents per 1,000 Members of Age Cohort in Dade County, Florida, January 1, 1990 to December 31, 1991.

39.02, 39.04, 39.05, 39.06, 40, 41.01, 41.02, 42, 43, 44, 45, and zero otherwise;

16. DUMMY2, one for census tracts 42, 43, 44, 45, and zero otherwise; and

17. DUMMY5, one for census tract 48, and zero otherwise.

DUMMY1 and DUMMY2 were used to adjust for conditions in the city of Miami Beach, which is located on a barrier island in Biscayne Bay. The land use and transportation patterns for this barrier island are profoundly different from those on the mainland, especially for the very dense and highly mixed-use southern one-third of the city, known as South Beach. This area also experiences profound changes in both transportation and land use characteristics between the winter in-season time and the remainder of the year. DUMMY1 tags all Miami Beach census tracts, and DUMMY2 tags all census tracts in the South Beach district. DUMMY5 tags census tract 48, which is the Miami International Airport. This tract contains 105 residents, one of whom experienced a bicycle accident during the study period. This dummy variable was used to adjust for this anomalous situation in regressions examining accident rates per 1,000 residents.

Model 1: Aggregate Number of Accident Victims per Census Tract

The best-fitting model for explaining the aggregate number of accident victims per census tract is presented in Table 2.

The fit of the model was not improved by log-linear conversion of either or both independent or dependent variables. The final form of the model exhibits good—but not outstanding—predictive power, as the five independent variables explain a little over 56 percent of the variation in the number of accident victims. As expected, the most reliable single estimator of the total number of accident victims is the total population of the census tract. Larger census tracts have more victims. Two economic variables (the median rent

TABLE 2 Results of Model 1

Independent Variable	Coefficient	T-Statistic	Significance Level
Intercept	+2.3128107	3.0328	99.5
TOTPOP	+0.0000687	14.0091	99.9
RENT	-0.0023208	3.8291	99.9
POOR%	+7.0053297	4.1964	99.9
HISPANIC%	-2.9542956	3.9160	99.9
DUMMY2	+13.8111180	8.6156	99.9

Dependent Variable: Number of accident victims for the two-year study period.
Adjusted R Squared = .5652 F = 65.7476 Mean Squared Error= 12.3734

of tenant-occupied housing and the proportion of households living under the federal poverty line) are significant, and one demographic variable (the proportion of nonblack Hispanic residents) is also significant. The influence of HISPANIC% is weak, but consistent. The land use patterns prevalent in the southern one-third of the city of Miami Beach also exercise a strong influence, as is evident from the large coefficient and high Student's-T value of DUMMY2.

In summary, the results of Model 1 are not surprising. By far the most important variable explaining the number of bicycle accident victims in a census tract is the size of population of the census tract. In fact, that is why this model was run first: had this not been the result, the entire methodology of comparing accident rate with economic and demographic variables would have been suspect.

However, economics does play a contributory role, as both the median rental price and the proportion of poor households are inversely proportional to the number of victims in a statistically consistent manner. Somewhat surprisingly, demographic factors are not terribly important. The proportion of children, blacks, or whites does not appear to exert a consistent influence, and the presence of increasing numbers of Hispanic residents appears to be correlated with a slight reduction in the number of accident victims. In particular, the nonsignificance of KIDS 18% is unexpected, as previous analyses have indicated a strong influence of age factors on the number of bicycling accident victims. Overall, Model 1, although it sheds some light on the problem, is most valuable in indicating the need to evaluate victim incidence as a per capita rate if greater amounts of usable information are to be gathered.

Model 2: Per Capita Accident Rate

The best-fitting model explaining the per capita rate of bicycle accidents in each census tract is presented in Table 3.

As was the case for Model 1, this model's best fit occurred without a log-linear conversion of either dependent or independent variables. Overall, Model 2 exhibits a better fit than the first model, being capable of explaining about two-thirds of the total variation in accident rates between census tracts. Three of the four statistically significant nondummy independent variables in Model 1 were also significant in Model 2—RENT, POOR%, and HISPANIC%. The sign (positive or negative) and level of impact of these three variables were surprisingly consistent between the two models.

The influence of HISPANIC% was reliable, weak, and negative: census tracts with higher percentages of nonblack Hispanic residents had fewer accident victims and a lower accident rate. However, the impact was so low as to be almost negligible: an increase in the proportion of Hispanics from 20 to 40 percent would only result in an increase in the accident rate of .086—which is a very small increase, considering that accident rates frequently varied between .5 and 2.5.

RENT was reliable, negative, and of moderate impact. Neighborhoods with a higher average rent had fewer victims. An increase in the median rental rate of a census tract of $500 per month results in a decrease in the accident rate of .17.

POOR% was highly reliable in both models, positive, and very strong. A 20 percentage point increase in the proportion of poor households in a census tract results in an increase in the accident rate of over .66—a significant increase in a county in which household poverty rates regularly vary between 10 and 40 percent. Although closely related to poverty, INCOME was only moderately reliable, primarily because its coefficient was so small (a $10,000 difference in household annual income results in a change in the accident rate of .04). Although INCOME is of minor impact, it is illustrative in that it is consistently negative, a finding that supports the significance of RENT. Both findings suggest that reduced socioeconomic status within neighborhoods may point to increased accident rates.

In addition to these three variables, three additional independent variables (and two dummy variables) were significant. Surprisingly, both DENSITY and KIDS 18% were significant, but contrary to popular belief, both were negative. Census tracts with a higher proportion of children have lower accident rates. This is probably the result of a highly inverse correlation between both population density and the proportion of children, and economic status. Those census tracts with a high proportion of children tend to be located in suburban neighborhoods with low population densities and an above-average level of affluence. Both DENSITY and KIDS 18% data were reliable, but weak. However, the fact that both variables are not strongly positive is itself a significant finding. Many municipal and regional bicycle plans prepared in the past have relied exclusively on the proportion of children or population density to predict both bicycle use and bicycle accidents. The evidence uncovered in this study indicates that this may not be a prudent policy.

In addition, neither the data of NOCAR% nor CARSPERH were significant. This was less surprising, in that transit dependency in the county includes many non-automobiles-using households composed of elderly people with a wide range of incomes. These households generally have very low bicycle use rates, as the infirmities that have required elderly people to discontinue automobile use also affect their ability to bicycle. It is possible that one of these variables may prove to be significant in communities where a lack of

TABLE 3 Results of Model 2

Independent Variable	Coefficient	T-Statistic	Significance Level
Intercept	+1.1947987	4.8207	99.9
RENT	-0.0003293	3.3417	99.9
INCOME	-0.0000039	1.7868	90.0
DENSITY	-0.0224237	4.4479	99.9
KIDS18%	-1.9199688	2.8458	99.5
POOR%	+3.3059495	9.3431	99.9
HISPANIC%	-0.4293626	2.9932	99.5
DUMMY2	+1.3857402	5.2120	99.9
DUMMY5	+7.8607701	14.0786	99.9

Dependent Variable: Accident victims per 1000 residents per census tract.
Adjusted R Squared = .6468 F = 57.9983 Mean Squared Error= .29485

automobile access is more closely associated with financial condition and less correlated with age.

CONCLUSION AND RECOMMENDATIONS

Many factors contribute to the generation of bicycle–motor vehicle accidents. This study has examined only a few of these factors. In particular, this study did not examine the role that specific roadway or accident site characteristics play in the generation of such accidents. It is known from both anecdotal evidence and empirical studies that site-specific characteristics play an important role in the generation of accidents. This study did not seek to examine accident locations. Instead, it sought to examine the characteristics of the neighborhoods where bicycling accident victims lived. Several conclusions can be drawn from this examination.

1. Economic status appears to be a significant determinant of at-risk populations for bicycle–motor vehicle accidents. In both Models 1 and 2, economic factors played a significant role in predicting accidents between neighborhoods. In Model 2, economic factors (particularly the percentage of poor households within a neighborhood) played a preeminent role in the prediction of areas with high per capita accident rates. These factors appear to be more important than even the proportion of children or density of the neighborhood. This is not to say that age is not important: the most important at-risk group for bicycle accidents is the 5- to 20-year-old age group. However, it must be recognized that other economic and demographic factors contribute toward the creation of at-risk groups. It is likely that these risk factors may be mutually reinforcing: the very high accident rates for black children between the ages of 5 and 15 should be of particular concern.

2. Although the specific causal mechanism for this effect cannot be determined, variation in bicycle use rates appears to be the most plausible explanation. In the introduction to this paper, it was noted that the economic or demographic characteristics of a neighborhood may affect bicycle accidents in two ways: (1) by increasing bicycle use—primarily through a decreased access to automobile transportation—while keeping accident rates per mile or per hour of use constant, or (2) by increasing the risk of accident per mile or per hour while keeping the exposure level constant. Such an increase could result either from cultural factors (safe or unsafe operating practices) or from factors affecting the riding environment (use in safe or unsafe street environments).

On the basis of the data examined in this study, it is not possible to make a final determination as to which of these two is most significant. Circumstantial evidence, in the form of a comparison of accident rates by age between all bicyclists and black bicyclists suggests that the first explanation is more likely. If black children have such high accident rates as a result of bicycling in neighborhoods with some adverse characteristic (or because they ride more recklessly), why do young adult black bicyclists have an accident rate significantly below that of the population as a whole? A much more plausible explanation is that reduced access to automobile transportation by parents results in higher use rates for black children, and a higher rate of unemployment results in lowered rates of bicycle use by young black adults. The unemployed, of course, make fewer trips than those with regular jobs, whereas the use of young adults in service industries tends to force them to make either the trip to or the trip from work during hours of darkness.

In summary, it appears that in the same way that patterns of economic need heavily influence the use of transit by women, such factors often result in bicycle dependency by males, particularly males under the age of 35. This dependency appears to be increased in lower-density suburban areas, possibly as a result of the lower transit service available in these areas. Poor females use transit regardless of this level of deprivation; males will turn to the bicycle as an alternative. It is important that future studies on the subject address this particular question.

3. Bicycle plans should incorporate economic factors into estimates of bicycle demand. Traditionally, bicycle plans, where they have attempted to estimate ridership demand, have usually relied on the location of schools, universities, and major recreational areas. The data from this study suggest that areas of lower-than-average economic status should be included. This would be especially true in areas of relatively low population density because of lowered transit availability and unwalkable distances between homes, jobs, and retail locations. Suburban poverty may prove to be the single most important factor affecting the demand for bicycle use in large urban areas. This does not suggest that the more traditional demand factors should be ignored but that additional factors should be incorporated if meaningful patterns are to be discerned.

4. Efforts to improve bicycle safety may require reexamination. Bicycle planning as a whole has tended to concentrate on the needs of middle and upper-income neighborhoods. To some degree, this is the case because these neighborhoods are the most recently developed and (being built to newer right-of-way and construction standards) are the easiest to equip with bicycle facilities and other amenities. Because children tend to live in suburban areas, the needs of children and recreational bicyclists can be met simultaneously.

The evidence presented in this study suggests that bicycle planners should give greater attention to neighborhoods of lower-than-average affluence, particularly where extreme poverty exists and where transit availability is inferior. It appears likely that rather than being the transportation method of choice, the bicycle is often the mode of last resort.

Efforts to implement bicycle plans have usually called for a balanced "4-E" approach: engineering, enforcement, education, and encouragement. This strategy may need to be reassessed. If bicycle use is heavily dependent upon economic circumstances, then the importance of encouraging bicycle use becomes obviated. Bicycle use is a function of need, not desire. Likewise, the expenditure of resources on educational and enforcement efforts may need to be reassessed. If utilitarian bicycling is an involuntary activity motivated by the lack of a preferable alternative, then such elaborate outreach programs may have little effect. The audience may simply not be interested in what these programs have to say. This suggests that the role of specialized bicycle facilities may need to be strongly advanced to combat bicycle accident rates among this involuntary and dependent user population.

This study has clearly established that bicycle users are not a homogeneous group. It should be equally obvious that uniform bicycle planning measures are no longer satisfactory. In particular, bicycle planners should realize that many of their constituents may participate in bicycling out of need rather than desire and should structure their traditional 4-E programs accordingly.

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Bicycle–Motor Vehicle Crash Types: The Early 1990s

WILLIAM W. HUNTER, WAYNE E. PEIN, AND JANE C. STUTTS

The purpose of this research was to apply the basic NHTSA bicyclist typologies to a sample of recent crashes and to refine and update the crash type distributions with particular attention to roadway and locational factors. Three thousand bicycle-motor vehicle cases were coded in a population-based sample drawn from the states of California, Florida, Maryland, Minnesota, North Carolina, and Utah. The crash types were distributed as: (*a*) parallel paths—36 percent, (*b*) crossing paths—57 percent, and (*c*) specific circumstances—6 percent. Most frequent parallel path crashes were motorist turn/merge into bicyclist's path (34.4 percent of all parallel path crashes), motorist overtaking (24.2 percent), and bicyclist turn/merge into motorist's path (20.6 percent). Most frequent crossing path crashes occurred when the motorist failed to yield (37.7 percent of crossing path crashes), the bicyclist failed to yield at an intersection (29.1 percent), and when the bicyclist failed to yield midblock (20.5 percent). Future safety considerations should be systemwide and include an examination of intersections and other junctions, well-designed facilities, bicyclist riding practices, and increased awareness of bicyclists by motor vehicle drivers.

Approximately 900 bicyclists are killed each year as a result of collisions with motor vehicles (*1*). According to the 1991 General Estimates System data about 70,000 bicyclists were injured in this type of crash (*2*). Many injuries are not reported to record-keeping authorities. A study by Stutts et al. (1990) showed that less than two-thirds of bicycle-motor vehicle crashes serious enough to require emergency room treatment were reported on state motor vehicle crash files (*3*).

The development of effective countermeasures to help prevent pedestrian and bicyclist crashes is hindered by insufficient detail on computerized state motor vehicle crash files. Analysis of existing crash file data can provide information on where pedestrian and bicyclist crash events occur (city street, two-lane rural highway, intersection location, etc.), when they occur (time of day, day of week, etc.), and to whom they occur (age of victim, gender, level of impairment, etc.), but can provide very little information about the actual sequence of events leading to the crash.

To address this situation, NHTSA developed a system of "typing" both pedestrian and bicyclist crashes. Each identified crash type is defined by a specific sequence of events, and each has precipitating actions; predisposing factors; and characteristic populations, locations, or both that can be targeted for interventions. The original pedestrian accident typology was developed and applied during the early 1970s (*4–7*). Cross and Fisher later developed a similar typology for bicycle crashes (*8,9*). Example bicycle-motor vehicle crash types include:

- Motorist left turn facing the bicyclist;
- Cyclist left turn in front of traffic;
- Motorist drive out from a driveway or alley; and
- Cyclist ride out from a stop sign or flashing red signal.

The purpose of this research was to apply the current NHTSA bicyclist typologies to a sample of recent crashes and to refine and update the crash type distributions with particular attention to roadway and locational factors. An important objective was to develop an updated data base for identifying engineering-based interventions and perhaps other strategies for reducing the frequency of bicyclist crashes and their resulting injuries.

METHOD

Highway Safety Research Center (HSRC) staff became familiar with the bicycle-motor vehicle crash typology scheme currently being used in NHTSA's General Estimates System (GES) data base (*10*). A Coding Variables List comprising the following main groups of variables was then developed and included:

- Crash descriptors—crash type, and motor vehicle and bicycle precrash maneuver.
- Locational characteristics—road feature, detailed bicyclist location, public/private property details, bikelane presence, sidewalk presence, number of lanes, lane width, etc.
- Bicyclist characteristics—helmet use, other safety equipment used, bicycle type, direction of travel at/near impact, etc.
- Intersection action details—bicyclist and motorist intended intersection maneuver, bicyclist entering condition, crossing approach, etc.
- Driver contributing factors—alcohol use, failed to yield, stop sign violation, improper backing, etc.
- Bicyclist contributing factors—alcohol use, failed to yield, stop sign violation, riding against traffic, swerved left while being overtaken, etc.
- Motor vehicle contributing factors—defective brakes, defective steering, etc.
- Bicycle contributing factors—no/defective/ineffective brakes, no relevant lights, etc.
- Roadway/environment contributing factors—glare, vision obstructions, loose material on surface, etc.
- Fault—driver, bicyclist, both, neither, or unknown.

The contributing factors were a growing compendium for driver, bicyclist, and the other listed categories. Based on their analysis of the crash diagram, narrative, and other information, project staff compiled lists of factors pertinent to the crash. Fault was assigned based on the contributing factors and the individual coder's interpretation of prudent motorist and bicyclist behavior. Fault was assigned whether or not the investigating police officer issued a citation.

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The crash sample was selected from the states of California, Florida, Maryland, Minnesota, North Carolina, and Utah. Cases were selected from small, medium, and large communities in each state. Five hundred cases involving the collisions between bicycles and motor vehicles were coded from each state for a total of 3,000 cases. Besides coding the crash type and other variables previously discussed, the cases were also linked to the basic crash file for each state. This increased the number of variables in the analysis, such as age and gender of bicyclist and driver, other roadway descriptors, motor vehicle variables, and others. Upon completion of cleanup and file linkage, 2,990 cases were available for analysis.

OVERVIEW OF BICYCLE-MOTOR VEHICLE CRASHES

This section presents an overview of the 2,990 bicycle-motor vehicle crashes from the six states. The variables reported include those coded by the project team during its review of the crash report form and the variables recorded on the computerized crash files from each state. Selected variables from the previously mentioned coding list are reported in the sections that follow.

Single-variable frequencies are presented in summary tables, while relevant cross tabulations are merely discussed in the text. (More detail is available in the entire project report prepared for the FHWA (*11*)).

Bicyclist Characteristics

Variables describing the crash-involved bicyclist are summarized in Table 1. Nearly half (45.1 percent) of the bicyclists in collisions with motor vehicles were children less than 15 years old, with an additional 15 percent ages 15 to 19 years old. About one-fourth of the bicyclists were ages 25 to 44, compared to about 10 percent in the Cross and Fisher study (*8*) and perhaps reflecting increased ridership for this age groups in the last decade or so.

Almost 80 percent of the bicyclists were male. This pattern tends to be constant across age groups except for bicyclists over age 44, where the male percentage increases to about 88 percent. This tendency seems to have changed little over time and almost surely remains related to exposure.

Less than 2 percent of the crashes resulted in a bicyclist fatality and an additional 17 percent resulted in serious (A-level) injury. This A + K percentage total is considerably less than for pedestrians (typically over 30 percent A + K). Bicyclists older than age 44 were overrepresented for fatal and serious injuries, where "overrepresented" means this group had a considerably greater proportion of fatal and serious injuries than the proportion of fatal and serious injuries for all age groups combined. The terms "more than expected" and "more than their share" are also used to reflect this kind of comparison. The 15 to 19-year-old bicyclists seemed to suffer less serious injuries than the other age groups.

About 5 percent of the bicyclists were judged by the investigating police officer to have been impaired by alcohol or drugs at the time of the crash, and an additional 4 percent impaired otherwise. Alcohol or drug/use was also coded for about 4 percent of the cases as a bicyclist contributing factor. It should be emphasized that most of these outcomes are based on the officer's opinion at the scene of the crash, and not on the results of any chemical tests administered. Alcohol use was highest in the 25 to 44 and over 65 age groups and for males. Bicyclists using alcohol or drugs were more likely to suffer serious and fatal injuries.

Temporal/Environmental Factors

Temporal and environmental factors characterizing bicycle crashes are summarized in Table 2. Bicycle crashes have always been more frequent in summer, and the months of June, July, and August each contained about 13 percent of the crashes. Exposure would certainly be a factor. Crash experience was appreciably less during cold

TABLE 1 Bicyclist Characteristics

Age	N	%	Injury Severity	N	%
0-9	504	18.2	Fatal (K)	46	1.6
10-14	745	26.9	Serious (A)	473	16.6
15-19	406	14.6	Moderate (B)	1315	46.1
20-	292	10.5	Minor (C)	830	29.1
24	641	23.1	None (O)	188	6.6
25-44	134	4.8	Unknown	91	--
45-64	52	1.9			
65+	169	--			
Unknown					
Gender	**N**	**%**	**Alcohol/Drug Use**	**N**	**%**
Male	2246	78.9	Alcohol	131	5.3
Female	602	21.1	Other	93	3.8
Unknown	95	--	None	2252	90.9
			Unknown	467	--

TABLE 2 Temporal/Environmental Factors

	N	%
Month		
January	105	3.6
February	130	4.4
March	180	6.1
April	244	8.3
May	342	11.6
June	385	13.1
July	390	13.3
August	366	12.5
September	296	10.1
October	267	9.1
November	144	4.9
December	91	3.1
Unknown	3	--
Day of Week		
Monday	440	15.0
Tuesday	386	13.1
Wednesday	450	15.3
Thursday	476	16.2
Friday	452	15.4
Saturday	374	12.7
Sunday	362	12.3
Unknown	3	--

	N	%
Weekday/Weekend		
Weekday	2065	70.2
Weekend	878	29.8
Time of Day		
6:00 a.m. - 9:59 a.m.	274	9.4
10:00 a.m. - 1:59 p.m.	547	18.8
	1192	41.0
2:00 p.m. - 5:59 p.m.	739	25.4
6:00 p.m. - 9:59 p.m.	124	4.3
10:00 p.m. - 1:59 a.m.	30	1.0
2:00 a.m. - 5:59 a.m.	37	--
Unknown		
Light Condition	2318	79.2
	169	5.8
	329	11.2
Daylight	111	3.8
Dawn/dusk	16	--
Dark, street lights		
Dark, no lights		
Unknown		

weather months. These trends showed some variability by age group, with children less than 10 years old more heavily represented in crashes in April, May, and September, but not in summer. On the other hand, the 10- to 14-year-olds were somewhat overrepresented in summer. The 20 to 24 and 25 to 44 age groups were overrepresented in cold weather months (October through February). The pattern for those over age 64 had lower frequency and was quite varied. For bicyclist injury severity, fatal injuries were overrepresented in cold weather months (November through March). Male bicyclists were overrepresented in cold weather months and female bicyclists underrepresented.

Unlike pedestrian crashes, bicyclist crashes were not overrepresented on weekends. Patterns within age groups were not distinctive. The 45 to 64-year-old age group was somewhat overrepresented on weekends, while those over age 64 were somewhat overrepresented on weekdays. Gender of the bicyclist seemed to have no effect. Serious and fatal injuries were more prevalent on weekends. As expected, the alcohol-related crashes were heavily overrepresented, with half of these crashes occurring on weekends.

About two-thirds of the bicyclist crashes occurred during late afternoon and early evening hours (41 percent from 2 p.m. to 6 p.m. and 25 percent from 6 p.m. to 10 p.m.). Exposure is likely quite high during these hours, and visibility can be a problem. The pattern again varied by age group. Children less than 10 years old were overrepresented during late afternoon and early evening, while bicyclists 20 to 24 and 25 to 44 years old were overrepresented late at night. The 45 to 64-year-old and the over 65 age groups were overinvolved from 6 a.m. to 10 a.m. and 10 a.m. to 2 p.m. These tendencies are again likely related to exposure.

The serious and fatal bicyclist injuries were more prevalent late night (10 p.m. to 2 a.m.) and early morning (2 a.m. to 6 a.m.). Males were heavily overrepresented during these time periods, as was the presence of alcohol and other drugs.

Almost 80 percent of the bicycle-motor vehicle crashes occurred under daylight conditions. The pattern here by age group was predictable—younger children overrepresented during daylight and those ages 15 to 64 overrepresented during conditions of darkness. Children under 10 had more than their share of crashes during dawn or dusk. Serious and fatal injuries to the bicyclist were heavily overrepresented during conditions of darkness with no streetlights. And as noted earlier, male bicyclists were much more likely than females to be riding under conditions of darkness.

Weather and roadway surface conditions were also examined in this category. The vast majority occurred under either clear or cloudy weather conditions. Four percent occurred under rainy conditions, and less than 1 percent in snow and other situations. Similar results were noted in the road condition variable, where over 92 percent of the crashes occurred on dry roads.

Roadway Factors

A wide range of data pertaining to the roadway is summarized in Table 3. As expected, the largest portion of bicycle crashes (34 per-

TABLE 3 Roadway Factors

Road Class[1]	N	%
Interstate	3	0.2
U.S. route	138	8.0
State route	313	18.1
County route	475	27.5
Local street	582	33.7
Other	217	12.6
Unknown	1215	

[1]Data missing from CA, UT

Speed Limit	N	%
40 km/h or less	666	27.0
48-56 km/h	1234	50.1
65-73 km/h	396	16.1
81+ km/h	168	6.8
Unknown	526	--

(1 km = 0.62 miles)

Road Feature	N	%
No special feature	793	26.5
Bridge	8	0.3
Public driveway	344	11.5
Private driveway	229	7.6
	70	2.3
Alley intersection	1402	46.8
Intersection of roadways	108	3.6
Intersection of roadways related	6	0.2
Non-intersection median crossing	2	0.1
End/beginning of divided highway	8	0.3
Interchange ramp	1	0.0
Interchange service road	3	0.1
Railroad crossing	7	0.2
Bike/multi-use path intersects with road	5	0.2
Parking lot abuts road	3	0.1
Other	8	--
Unknown		

Traffic Control Device	N	%
No control		
Stop sign	1712	57.7
Yield sign	739	24.9
Traffic signal	9	0.3
Flashing signal with stop	473	16.0
sign	3	0.1
Flashing signal without stop sign	5	0.2
Railroad gate and flasher		
Human control	1	0.0
Other	4	0.1
Unknown	20	0.7
	31	--

(*continued on next page*)

cent) occurred on local streets, with county routes (28 percent) close behind. United States and state routes combined accounted for about one-quarter of the total. Young children experienced more crashes on the local and county routes, while bicyclists ages 45 to 64 and 65 and over were overrepresented on higher speed routes. Interestingly, no gender or alcohol presence differences were reflected by the road class variable. There was a slight tendency for the more serious (A + K) crashes to occur on U.S. and state routes.

The typical roadway configuration was a two-lane undivided roadway with a speed limit of 56 km per hour (35 mph) or less. Roads with higher speed limits had more than their share of serious and fatal injuries. Children less than 10 years old had almost 90 percent of their crashes on two-lane roads, while older bicyclists (ages 20 and up) were overrepresented on the 4, 5, and 6 + lane roads. Class A injuries to bicyclists were overrepresented on three-lane roads and fatal injuries were overrepresented on roads with more than four lanes.

Where data were available in regard to lane width, the crashes were spread fairly evenly. Interestingly, about one-fourth of the crashes occurred on roads with lanes over 4.9 m (16 ft) wide. The older bicyclists (45 to 64 and over 65 years of age) were overrepresented in the widest lane category, as well as 3.1 to 3.4-m (10- to 11-ft) and 3.7-m (12-ft) lanes. (Some of these wide lanes may have contained parallel parking spaces that could not be discerned from the police diagram. Parking presence is discussed later in this section.) Class A and fatal injuries were overrepresented on the 2.7-meter (9-ft) or less and 3.1- to 3.4-m (10- to 11-ft) lanes, and, to a lesser extent, on 3.7-m (12-ft) lanes. Serious and fatal injuries were thus underrepresented as lane widths became wider.

In regard to road feature, almost half of the bicycle-motor vehicle crashes took place at roadway intersections, and another 3.6 percent were intersection-related. Almost 20 percent of the crashes occurred at driveways, with another 2 percent at alley intersections. Thus, close to three-fourths of all crashes occurred at junctions of some kind. About one-fourth of the crashes occurred at nonintersection locations with no distinguishing roadway features. At intersections, bicyclists ages 25 to 44 were slightly overrepresented and those less than 10 years old slightly underrepresented. Almost half of the crashes involving children less than age 10 occurred at private driveways. Young children were also overrepresented at alley

TABLE 3 (*continued*)

	N	%
Shoulder Type		
None indicated	2176	74.5
Unpaved	89	3.1
Paved	131	4.5
Curb and gutter	384	13.2
Shoulder indicated, type unknown	142	4.5
Unknown	75	--
Bicyclist Side On-Street Parking		
None	2528	87.9
Parallel parking	341	11.9
Diagonal parking	7	0.2
Unknown	121	--

	N	%
Number of Lanes		
1 lane	46	1.8
2 lanes	1656	64.9
3 lanes	69	2.7
4 lanes	614	24.1
5 lanes	56	2.2
6 or more lanes	109	4.3
Unknown	446	--
Lane Width		
2.7 meters or less	47	9.5
3.1 - 3.4 meters	117	23.7
3.7 meters	116	23.5
4.0 - 4.9 meters	88	17.8
5.2+ meters	126	25.5
Unknown	2338	--
Non-road	164	--
(1 meter = 3.3 feet)		

intersections. Locations with no special feature (e.g., midblock locations) were the sites of serious and fatal injuries more than expected. Bicyclists in private driveway locations had more than their share of Class A injuries.

No traffic control devices were present in about 60 percent of the cases. Stop signs were the controlling device in about one-fourth of the cases and traffic signals 16 percent of the time. This relates to the previous paragraph, where almost half the crashes occurred at roadway intersections. Young children were overrepresented at locations with no control and underrepresented at locations with traffic signals. Cyclists 10 to 14 and 15 to 19 years old were overrepresented at stop sign locations, while bicyclists 20 to 24 and 25 to 44 years old were overrepresented at traffic signal locations. Serious and fatal injuries were slightly overrepresented at locations with no traffic control device.

No shoulders were indicated about three-fourths of the time. Curbs and gutters were noted in 13 percent and paved shoulders were indicated in less than 5 percent of the crashes. Actual shoulder width on the bicyclist's side of the road was rarely available. Where available, just over 40 percent was coded as 1.5 to 2.7 m (5 to 9 ft) wide. Unpaved shoulders and shoulders where the type was unknown were overrepresented for serious and fatal injuries. Although sample sizes were small, shoulders at least 3.1 m (10 ft) wide reflected serious and fatal injuries more than expected.

Just under 90 percent of the crashes occurred at sites with no on-street parking on the bicyclist's side of the road. Where noted, the vast majority of parking was the parallel type. Young children were overrepresented at sites with parallel or diagonal parking.

Contributing Factors

Numerous factors contributing to the occurrence of the bicycle-motor vehicle crash were identified from the information provided on the crash report form. These contributing factors were coded into the categories of bicyclist, bicycle, motor vehicle driver, motor vehicle, and roadway/environment. An initial listing of factors was identified for each category, and other codes were added as identified during the course of the coding. Up to three factors were listed in each category for each crash coded. The results reported in Table 4 reflect the total number of times any given factor was coded and the percentage of cases involving each factor. (Note: Table 4 reflects a combined list of contributing factors that appeared with some frequency.) For example, 114 bicyclists had alcohol or drug use noted as one of their three possible contributing factors, so that the percentage of bicyclists coded with alcohol/drug use was 114/2,990 or 3.8 percent. Since more than one factor could be coded for each bicyclist, the percentages in Table 4 total more than 100 percent.

The most frequently coded bicyclist factors were:

- Failed to yield 20.7 percent
- Riding against traffic 14.9 percent
- Stop sign violation 7.8 percent
- Safe movement violation 6.1 percent

These all involve riding practices. Bicyclists riding against traffic are particularly vulnerable at intersections, especially for right-turning vehicles from a perpendicular street.

Lack of conspicuity was coded in 5.1 percent of the cases, but probably could have been coded a much higher percentage of the time had more detail been available on the crash report form. (Overall, about 20 percent of the crashes occurred during nondaylight conditions.) Bicyclists riding into an intersection from the sidewalk were cited in slightly more than 5 percent of the cases (and another 4 percent for coming off of a sidewalk at a driveway/alley location). Bicyclists riding in this location are not easily seen by drivers because the natural driver scanning pattern is in the roadway. Improper turn/no hand signal (4.8 percent) and traffic signal violations (4.7 percent) were also cited with some regularity.

TABLE 4 Contributing Factors to Bicycle-Motor Vehicle Crashes

Bicyclist Factors	N	%
None	701	23.4
Alcohol/drug use	114	3.8
Failed to yield	621	20.7
Stop sign violation	235	7.8
Traffic signal violation	140	4.7
Exceeding speed limit/safe speed	36	1.2
Improper lane change/use of imp. lane	53	1.8
Improper turn/no hand signal	145	4.8
Lack of conspicuity	153	5.1
Safe movement violation	182	6.1
Riding against traffic	446	14.9
Inattention	80	2.7
Reckless riding/no hands/stunt ride/race	41	1.4
Pass veh on rt/ride between stopped veh	42	1.4
Improper road or lane position	30	1.0
Swerved left	75	2.5
Came off sidewalk at intersection	153	5.1
Came off sidewalk at driveway	123	4.1
Improper passengers	52	1.7
Misjudged intent of other party	40	1.3
Didn't see vehicle (bicyclist claim)	137	4.6
Couldn't avoid crash (bicyclist claim)	73	2.4
Lost control	82	2.7
All other	327	10.9

Bicycle Factors	N	%
No defects/none	2734	91.1
No/defective/ineffective brakes	92	3.1
No relevant lights	131	4.4
No/defective reflectors	28	0.9
All other	50	1.7

Driver Factors	N	%
None	1294	43.1
Alcohol/drug use	46	1.5
Yield violation	719	24.0
Stop sign/traffic signal violation	56	1.9
Exceeding speed limit/safe speed	65	2.2
Improper passing	65	2.2
Improper turn	91	3.0
Safe movement violation	62	2.1
Improper backing	48	1.6
Right on red	60	2.0
Hit and run	428	14.3
Inattention	60	2.0
Reckless driving	41	1.4
No license	43	1.4
Assault/possible assault with veh	40	1.3
Failed to look both ways	106	3.5
Didn't see cyclist	366	12.2
Couldn't avoid crash (driv. claim)	86	2.9
All other	322	10.7

Roadway/Environment Factors	N	%
None	2471	82.4
Sun/other glare	41	1.4
Parked veh. vision obstruction	79	2.6
Moving or stopped veh. vision obstruction	91	3.0
Other vision obstruction	122	4.1
All other	280	9.4

Alcohol or drug use by bicyclists was noted in 3.8 percent of the cases, and the vast majority of these citations pertained to alcohol use. Almost 5 percent of the bicyclists claimed that they did not see the motor vehicle. About one-fourth of the bicyclists had no contributing factors.

Patterns of bicyclist contributing factor overrepresentation by age group included the following:

- 0 to 9 years old—yield violation, stop sign violation, improper turn, safe movement violation, inattention, didn't see vehicle, couldn't avoid crash, lost control;
- 10 to 14 years old—yield violation, stop sign violation, traffic signal violation, exceeding safe speed, improper lane change/use, improper turn, safe movement violation, inattention, reckless or stunt riding, swerved left, came off sidewalk at intersection, improper passengers, or didn't see vehicle;
- 15 to 19 years old—traffic signal violation, improper lane change/use, not conspicuous, riding against traffic, reckless or stunt riding, pass vehicle on the right/ride between stopped vehicles, improper road or lane position, came off sidewalk at intersection and at driveway, improper passengers, or misjudged intent;
- 20 to 24 years old—alcohol/drug use, traffic signal violation, exceeding safe speed, not conspicuous, reckless or stunt riding, pass vehicle on the right/ride between stopped vehicles, came off sidewalk at driveway, couldn't avoid crash;
- 25 to 44 years old—alcohol/drug use, not conspicuous, pass vehicle on the right/ride between stopped vehicles, improper road or lane position;
- 45 to 64 years old—alcohol/drug use, improper lane change/use, not conspicuous, improper road or lane position, misjudged intent of other party; and
- 65+ years old—alcohol/drug use, improper lane change/use, improper turn, swerved left, came off sidewalk at intersection, misjudged intent of other party.

Bicyclist contributing factors that produced more than their share of A + K injuries included alcohol/drug use, stop sign violation, improper lane change/use, improper turn, not conspicuous, safe movement violation, improper road or lane position, and swerved left.

It was rare that any bicycle contributing factors were coded (less than one-tenth of the cases). When coded, the most frequent factors were:

- No relevant lights (4.4 percent)
- No/defective/ineffective brakes (3.1 percent)

No or defective reflectors were cited in just less than 1 percent of the cases.

Cyclists ages 15 years and older were overrepresented in failing to have relevant lights, while children ages 10 to 14 were overrepresented in failing to have adequate brakes. Cyclists without relevant lights had more than their share of A + K injuries.

The most frequently coded driver contributing factors were:

- Failed to yield (24.0 percent)
- Hit and run (14.3 percent)
- Did not see bicyclist (driver claim or police conclusion) (12.2 percent)
- Failed to look both ways (3.5 percent)
- Improper turn (3.0 percent)

Hit and run would typically not be a contributing factor in the sense of crash causation but nonetheless was identified in 14 percent of the cases. Not all cases were blatant hit-and-run events. At times the driver would stop immediately and ask about the condition of the bicyclist. If told the bicyclist was "ok," the driver might leave the scene. Sometimes a parent would then report the crash a few hours later. In cases like this the investigating police officer would usually mark the case as hit and run, and coders would do likewise.

"Failed to yield" was coded as a driver contributing factor in about one-fourth of the cases but was not always a clear-cut label when, for example, the bicyclist emerged from a sidewalk or was inconspicuous. Failure to see the bicyclist could have resulted from a visual obstruction, bicyclist lack of conspicuity, etc. This was not coded unless claimed by a driver or concluded by the investigating officer.

Alcohol or drug use by drivers was coded in less than 2 percent of the cases. Nearly 43 percent of the cases had no driver contributing factors.

An examination of driver contributing factors by age of bicyclist tended to portray patterns of exposure. For example, when a driver was backing improperly, a young child was most likely the crash-involved bicyclist. Drivers who claimed they could not avoid the crash tended to strike children 0 to 9 and 10 to 14 years of age. Drivers improperly passing were more likely to strike middle-aged and older bicyclists. Driver contributing factors that produced more than their share of A + K bicyclist injuries included alcohol/drug use, exceeding the speed limit, improper passing, safe movement violations, reckless driving, and being unable to avoid the crash.

In regard to motor vehicle contributing factors, 91 percent of the cases had none and another 8 percent were coded as "unknown." Thus, there were only scattered instances of defective tires, wheels, brakes, etc.

Roadway/environment factors were also seldom identified, coded as "none" in 82 percent of the cases. Vision obstructions were the most frequently coded items. It was very difficult to determine if weather-related variables were actually contributing factors to the crash. Thus, these kinds of variables were treated more like inventory items and are reported earlier in the temporal/environmental factors section. The road condition was wet in about 7 percent of the cases.

Two points about these contributing factors should be emphasized. The percentages are likely conservative, because of a lack of detail on the crash report form, although California reports were a noteworthy exception. In addition, these should be viewed as possible contributing factors, based only on the information provided on the report form. A much more thorough crash reconstruction process would be necessary for a definitive identification of contributing factors.

SPECIFIC CRASH-TYPE INFORMATION

A total of 45 distinct bicycle-motor vehicle crash types are identified in the NHTSA Manual Accident Typing (MAT) for Bicyclist Accidents Coder's Handbook. Each type is characterized by a specific sequence of causal events or bicyclist/driver actions preceding the crash occurrence. For example, in a motorist drive-out from a driveway or alley, the motorist usually enters the street from a right angle and fails to perceive the bicyclist in the traffic stream.

Instead of dealing with all 45 crash types, this study concentrates on the three major categories from which the 45 crash types derive, namely, specific circumstances, parallel paths, and crossing paths. Specific circumstances include "weird" or unusual events (e.g., bicyclist struck by falling cargo), bicyclist riding a play vehicle (e.g., a tricycle), a motor vehicle that was backing, and nonroadway situations such as parking lots. For parallel path crashes, the bicycle and motor vehicle are approaching on parallel paths, either heading in the same or opposing direction. For crossing path crashes, the bicycle and motor vehicle are on intersecting paths. The bicycle-motor vehicle crashes are distributed into the three main categories as follows:

Category	*n*	*%*
Specific circumstances	209	7.0
Parallel paths	1,061	35.5
Crossing paths	1,720	57.5
Total	2,990	100.0

Within the NHTSA coding scheme, the three major categories further subdivide into 15 groups. Table 5 shows the distribution of the 15 groups by state. For the parallel path cases, the most frequent crash types were:

Crash-Type Groups	*n*	*% of Parallel Path Crashes*	*% of All Crashes*
Motorist turned or merged into the cyclists path	365	34.4	12.2
Motorist overtaking the cyclist	257	24.2	8.6
Cyclist turned or merged into the motorist's path	219	20.6	7.3

For the crossing path cases, the most frequent crash types were:

Crash-Type Groups	*n*	*% of Crossing Path Crashes*	*% of All Crashes*
Motorist failed to yield to cyclist	648	37.7	21.7
Cyclist failed to yield to motorist at an intersection	501	29.1	16.8
Cyclist failed to yield to motorist, midblock	353	20.5	11.8

There was considerable variability in crash type by state.

TABLE 5 Major Crash Type Groups by State

Group	CA	FL	MD	MN	NC	UT	Total
Specific Circumstances	8 (1.6)	50 (10.0)	47 (9.4)	19 (3.8)	42 (8.5)	43 (8.6)	209 (7.0)
Parallel Paths							
Motorist turn/merge into path of cyclist	81 (16.2)	58 (11.6)	36 (7.2)	73 (14.6)	50 (10.1)	67 (13.4)	365 (12.2)
Cyclist turn/merge into path of motorist	35 (7.0)	36 (7.2)	31 (6.2)	37 (7.4)	48 (9.7)	32 (6.4)	219 (7.3)
Operator on wrong side of street	7 (1.4)	15 (3.0)	23 (4.6)	7 (1.4)	23 (4.6)	9 (1.8)	84 (2.8)
Motorist overtaking the cyclist	33 (6.6)	53 (10.6)	53 (10.6)	27 (5.4)	64 (12.9)	27 (5.4)	257 (8.6)
Cyclist overtaking motor vehicle	32 (6.4)	12 (2.4)	14 (2.8)	8 (1.6)	12 (2.4)	4 (0.8)	82 (2.7)
Operator lost control	13 (2.6)	7 (1.4)	8 (1.6)	3 (0.6)	15 (3.0)	8 (1.6)	54 (1.8)
Crossing Paths							
Cyclist did not clear intersection	9 (1.8)	3 (0.6)	2 (0.4)	8 (1.6)	2 (0.4)	18 (3.6)	42 (1.4)
Motorist failed to yield	137 (27.5)	125 (25.1)	73 (14.7)	119 (23.9)	62 (12.5)	132 (26.5)	648 (21.7)
Cyclist failed to yield, midblock	40 (8.0)	50 (10.0)	86 (17.3)	72 (14.4)	64 (12.9)	41 (8.2)	353 (11.8)
Cyclist failed to yield, intersection	65 (13.0)	67 (13.4)	101 (20.3)	96 (19.2)	92 (18.5)	80 (16.1)	501 (16.8)
Motorist turning error	4 (0.80)	5 (1.0)	3 (0.6)	2 (0.4)	1 (0.2)	4 (0.8)	19 (0.6)
Cyclist turning error	6 (1.2)	1 (0.2)	2 (0.4)	3 (0.6)	3 (0.6)	6 (1.2)	21 (0.7)
Crash occurred at an intersection	25 (5.0)	9 (1.8)	12 (2.4)	17 (3.4)	8 (1.6)	15 (3.0)	86 (2.9)
Unknown/insufficient information	4 (0.8)	8 (1.6)	7 (1.4)	8 (1.6)	11 (2.2)	12 (2.4)	50 (1.7)

Figures 1–6 describe the parallel and crossing path crash types listed previously and provide detailed information about the pattern of the crash. The patterns of overrepresentation indicate more involvement than expected for any particular variable when compared to all crashes. For example, Figure 1 shows that bicyclists ages 20 to 24 were overrepresented in crashes where the motorist turned or merged into the path of the bicyclist. Bicyclists ages 20 to 24 were involved in 21.3 percent of these motorist turn/merge crashes as opposed to making up 10.5 percent of the overall sample of crash-involved bicyclists.

DISCUSSION OF RESULTS

This paper includes findings from a study of bicycle-motor vehicle crash types occurring in 1991 and 1992. The following points are offered as a summary:

1. The basic crash patterns are similar to those seen in the late 1970s. Intersections, driveways, and other junctions continue to be locations where many crashes occur. Emerging facilities should be designed with this fact in mind.

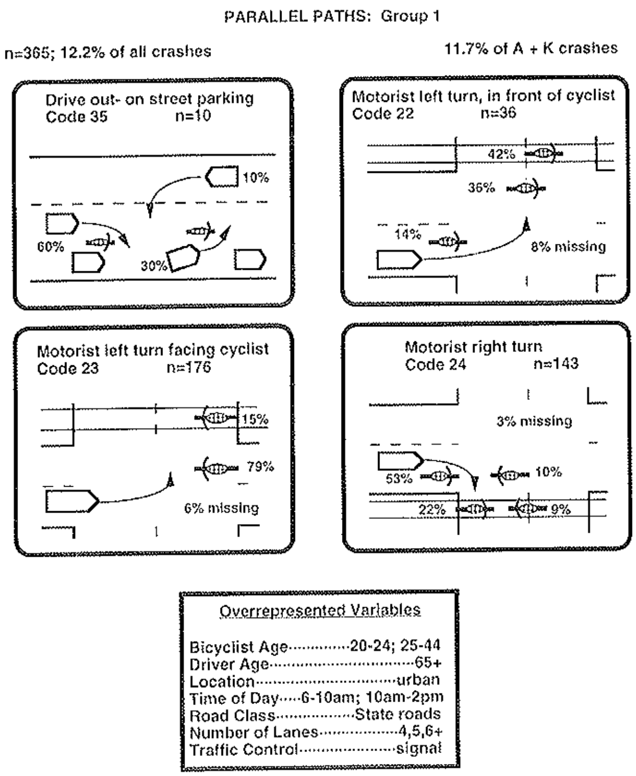

FIGURE 1 The motorist turned or merged into the path of the bicyclist.

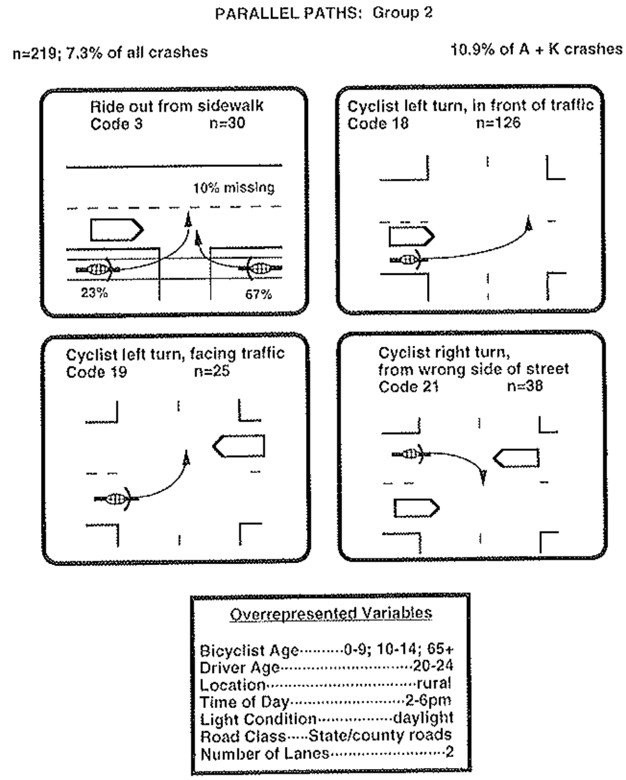

FIGURE 3 The bicyclist turned or merged into the path of the motorist.

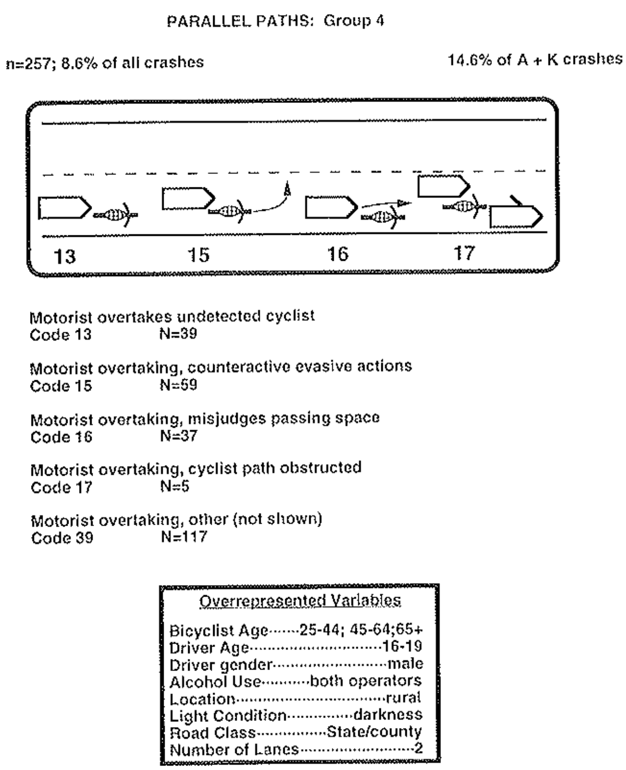

FIGURE 2 The motorist was overtaking the bicyclist.

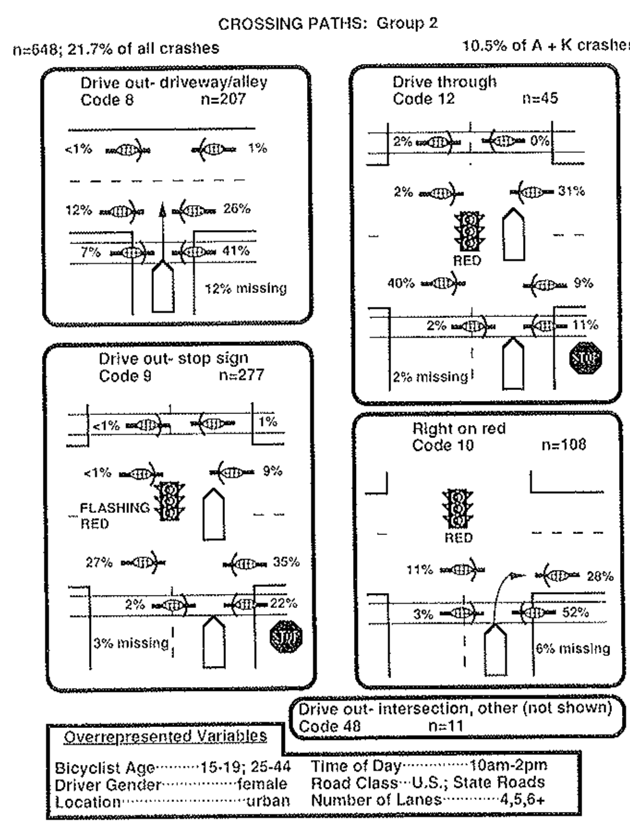

FIGURE 4 The motorist failed to yield to the bicyclist.

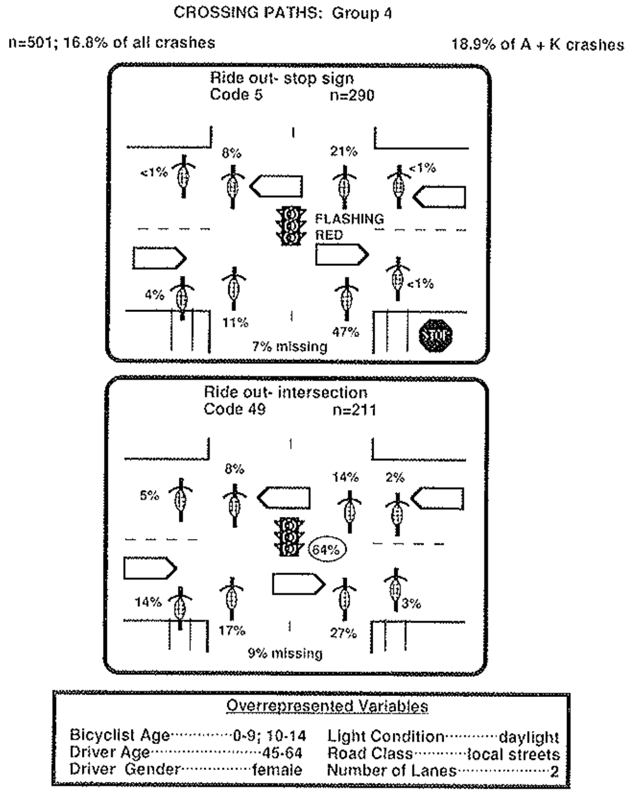

FIGURE 5 The bicyclist failed to yield to the motorist at an intersection.

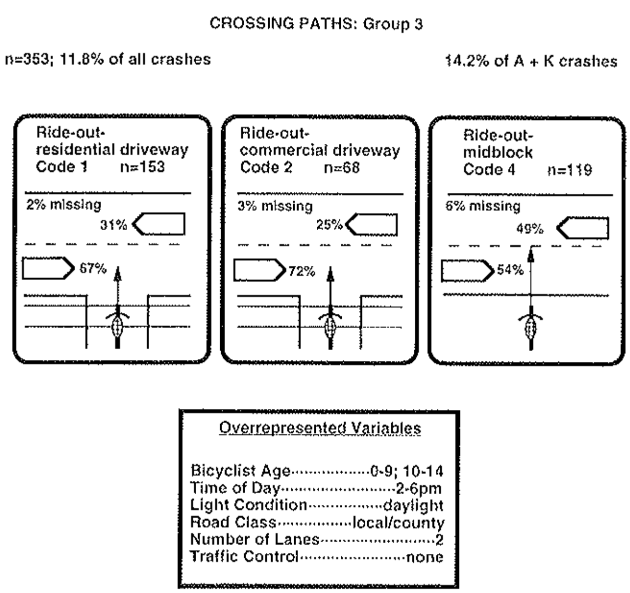

FIGURE 6 The bicyclist failed to yield to the motorist, midblock.

2. Roads with narrower lanes and roads with higher speed limits were associated with more than their share of serious and fatal injuries to bicyclists.

3. Alcohol use was noted in about 5 percent of all crashes, but was 15 percent for the 25 to 44-year-old age group. This would appear to be an emerging problem.

4. Much of what is reported in this study seems strongly connected to basic riding and driving patterns—in other words, related to exposure. Future studies of bicyclists or bicycle facilities should be planned with this need in mind.

5. Bicyclist riding practices, such as riding against traffic and failing to obey traffic signals, are factors in these crashes. Cyclists need training about how to ride in traffic.

6. As a measure of accountability, it is recommended that local and state pedestrian-bicycle coordinators continually track crashes in their jurisdictions. A simplified crash typing procedure that coordinators can easily use should be prepared and disseminated.

7. With the current increased interest in both bicycling and walking, crash investigators at the state and local levels should be urged to report completely on any bicyclist and pedestrian crashes.

8. A systemwide approach will be necessary to make safety gains as well as reach the goals of the National Bicycling and Walking Study (*11*), namely: (*a*) to double the number of trips made by bicycling and walking, and (*b*) to reduce by 10 percent the number of bicyclists and pedestrians injured and killed in traffic collisions. Engineering, education, and enforcement approaches are vital to improved safety. There is a continuing need to establish the mindset that bicyclists (and pedestrians) are worthy and viable users of our transportation system.

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Nonmotor Travel in the 1990 Nationwide Personal Transportation Survey

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Efforts to develop nonmotor travel in the United States have increased over the past several years, though few studies have examined the travel behavior of nonmotorists. This study examines data from the 1990 Nationwide Personal Transportation Survey (NPTS) to explore nonmotor travel behavior in the United States. Individuals in the 1990 NPTS were classified as nonmotorists, motorists, or mixed-mode travelers (who used both motorized and nonmotor transportation) based on their travel in the 24-hour period of the NPTS survey. Nonmotorists were more likely to be under 21 or over 65 years old. They were less likely to be employed, less likely to be licensed drivers, and less likely to live in households with at least one motor vehicle, as compared with mixed-mode travelers and motorists, but were more likely to live in central cities. A comparison of nonmotor and motorized (automobile) trips found nonmotor trips were shorter in distance and less likely to be taken for work. Pedestrians and bicyclists, and the characteristics of walking and bicycling trips, were also compared. Results of the analyses suggest it would be beneficial to concentrate efforts to improve travel conditions for the existing population of nonmotorists in central cities where more nonmotor trips take place. Planners should consider the needs of young travelers, the elderly, and people with limited incomes when designing transportation improvements to aid nonmotor travel. Motorists should be encouraged to walk or bicycle for some of their non-work-related trips, to increase the proportion of nonmotor trips relative to motorized trips.

Interest in nonmotor travel in the United State has increased since the 1970s, when concerns about environmental quality grew (*1–5*). Yet few studies of travel behavior have included walking and bicycling (*6–9*), and theory regarding nonmotor travel behavior is not well developed. Transportation and community planners would benefit from a clearer understanding of the nature of nonmotor travel when designing programs and environments to increase walking and bicycling. Data from the 1990 Nationwide Personal Transportation Survey (NPTS), a national survey on travel, provide the opportunity to examine nonmotor travel behavior in the United States (*10*). Many studies of travel behavior have used travel diary data collected in Europe; however, land in the United States is less densely developed than land in Europe, and people in the United States are relatively more automobile-dependent. These differences are reflected, in part, in vehicle miles traveled, automobile ownership, and driver licensing. Renner (*2*) provides data indicating differences in vehicle miles traveled circa 1985 in the United States (9,801 miles per car), the United Kingdom (8,073 miles per car), and Sweden (7,452 miles per car). Bannister (*11*) reports that in Britain in 1985, 86 percent of men between the ages of 30 and 50 were licensed, whereas the NPTS data indicate in the United States in 1990, 95 percent of men between the ages of 30 and 50 were licensed. A comparison of auto ownership reveals a similar trend, with 565 cars per 1000 people in the United States, 400 cars per 1000 in Oslo, and 461 cars per 1000 in Germany (*11*). These differences suggest the results of studies of nonmotor travel conducted in Europe may not be entirely generalizable to the United States, thus studies of nonmotor travel behavior that are specific to the United States are needed.

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STUDY PURPOSE

The purpose of this report is to contrast nonmotor and motorized travel in the United States, to identify factors that may influence the use of nonmotor transportation. Although many different approaches to the study of travel have been used, there is a growing consensus in studies of travel activity that the individual is the appropriate unit of analysis in efforts to explain travel decisions (*12,13*). This study focuses on individuals to determine factors that are relevant to nonmotorists' travel decisions. Personal characteristics, trip purpose, and travel resources are examined to determine their influences on mode choice.

The specific objectives of the study are: 1) to determine the characteristics of individuals who are more likely to use nonmotor transportation, and 2) to contrast the characteristics of nonmotor (walking and bicycling) and motorized (automobile) trips. Pedestrians and bicyclists are also compared, as are the characteristics of walking and bicycling trips. At the level of individuals, the following factors are examined: age, gender, education, household income, employment status, driver licensing, number of vehicles owned by household, household size, stage in family life cycle, and level of urbanization in the area of the household. At the trip level the factors examined include trip purpose, trip distance, time of day of travel, weekday versus weekend travel, traveling alone or with others, and level of urbanization in the area of the household. Other factors which may also influence travel behavior and help to explain nonmotor travel behavior, such as details about the design of the travel environment (*14,15*), and psychological or behavioral factors that may influence travel choices, are not available in the 1990 NPTS data.

STUDY METHOD

Data used for the analyses presented in this paper are from the 1990 NPTS, a survey of travelers in the United States sponsored by the Federal Highway Administration, U.S. Department of Transportation. The 1990 NPTS data were collected from a nationally representative sample of 26,172 households. The survey collected information on household characteristics, household-member characteristics, and all trips taken by household members during a specified 24-hour time period (*16*).

Individuals in the NPTS dataset who were 12 years of age or older ($N = 33,195$) were included in the analyses for this report. These individuals were classified into one of several "traveler groups" on the basis of the transport modes they used during the 24-hour period of the NPTS survey (Table 1). The traveler categories were determined by examining individuals' trips to determine which travel modes (walk, bike, auto, public transit) were used. In the NPTS, trips are defined as travel between two addresses. *Nonmotorists* were defined as individuals who used only nonmotorized transportation (walk and/or bike) for trips reported in the survey. *Motorists* used only motorized transportation (automobile only, or both automobile and public transit) either as drivers or as passengers. *Mixed-mode travelers* used both nonmotorized (walk/bike) and motorized (automobile and/or public transit) transportation. Among mixed-mode travelers, 39.1 percent reported using motorized transport more frequently than nonmotor transport, 26.7 percent used motorized and nonmotor transport equally, and 22.4 percent used nonmotor transport more frequently than motorized transport. This classification method may not be entirely reliable as the NPTS survey covered only a 24-hour period of time and may not have captured the full range in individuals' travel behaviors (*8,17*). Generalizations about the characteristics of travel in the three groups of individuals are made with recognition of the possibility of misclassification.

Trips taken by the individuals in the three traveler categories were classified as *motorized* (automobile) or *nonmotorized* (walk or bike). Public transit trips were excluded from the analysis of trips to focus on differences between automobile and nonmotor trips.

Cross-tabulations were used to contrast the personal characteristics of the three groups of travelers and to contrast the characteristics of travelers' automobile and nonmotor trips. Results of two-way cross-tabulations are presented in Tables 2-4 and are discussed, along with results of selected three-way cross-tabulations, in the following section. In Tables 2 and 3, the column variable is traveler group, whereas the row variables are traveler characteristics. In Table 4, the column variable is mode type, whereas the row variables are trip characteristics. The column percentages provided enable the reader to compare the distributions of cases across traveler groups and across mode type groups. The Pearson chi-square statistic (χ^2) tests the hypothesis that row and column variables are independent. The large sample sizes used in the analyses increase the power of the chi-square test to detect statistically significant differences even when the differences are apparently minor, thus the results of the chi-square tests should be viewed with caution.

RESULTS

Characteristics of Nonmotorists, Motorists, and Mixed-Mode Travelers

Table 2 presents results of the two-way cross-tabulations for traveler characteristics. Overall, the analysis depicts nonmotorists as individuals with less education, lower household incomes and fewer travel resources, as compared with motorists and mixed-mode travelers. Nonmotorists were less likely to be licensed drivers and more likely to be unemployed.

Age

A higher percentage of nonmotorists relative to motorists were under 21 or over 65 years of age. Although the youngest and oldest travelers cannot be excluded from the following analyses without

TABLE 1 Traveler Categories

	Modes Used				Number of Travellers (%) (n=32,092)	
	Walk	Bike	Auto	Transit		
Non-Motor	•				1,216	(3.7)
(n=1,358)		•			111	(0.3)
	•	•			31	(0.1)
Mixed-Mode	•		•		1,490	(4.5)
(n=2,283)	•			•	418	(1.3)
	•		•	•	184	(0.6)
		•	•		115	(0.3)
	•	•	•		40	(0.1)
		•		•	18	(0.1)
		•	•	•	12	(0.1)
	•	•	•	•	5	(0.0)
	•	•		•	1	(0.0)
Motor[a]			•		27,783	(83.7)
(n=28,451)			•	•	668	(2.0)

[a] Individuals who used only public transit (n=1,103) were excluded from the sub-sample used in the analyses for this paper.

TABLE 2 Percentage Distributions of Travelers: Personal Characteristics and Level of Urbanization

	Non-motorist (n=1,358)	Mixed (n=2,283)	Motorist (n=28,451)	χ^2	d.f.	Sig.
Age (years)	(n=1,358)	(n=2,283)	(n=28,451)	1159.90	10	.000
12-20	37.4	28.9	12.3			
21-35	23.8	32.2	33.4			
36-45	11.5	16.6	21.0			
46-55	7.0	8.4	13.6			
56-65	8.0	7.1	10.3			
65+	12.3	6.7	9.3			
Gender	(n=1,358)	(n=2,283)	(n=28,450)	4.32	2	.116
Male	49.8	46.3	48.1			
Female	50.2	53.7	51.9			
Education	(n=1,330)	(n=2,272)	(n=28,136)	877.85	8	.000
< H.S. Dipl.	46.8	30.7	18.2			
H.S. Dipl.	24.4	23.0	34.4			
Tech. School	2.0	2.4	3.0			
College	22.3	32.4	35.4			
Graduate School	4.5	11.4	9.0			
Household Income (in dollars)	(n=1,013)	(n=1,797)	(n=21,565)	581.76	14	.000
<5,000-14,999	34.7	17.8	11.7			
15,000-24,999	19.4	17.0	15.2			
25,000-34,999	15.2	18.0	18.3			
35,000-44,999	10.1	12.9	15.9			
45,000-54,999	7.5	9.9	12.9			
55,000-64,999	4.9	6.4	9.0			
65,000-74,999	3.4	6.2	5.8			
75,000+	4.7	11.9	11.2			
Employment Status	(n=1,358)	(n=2,283)	(n=28,451)	782.44	2	.000
Employed	35.3	57.5	69.3			
Not Employed	64.7	42.5	30.7			
Licensed Driver	(n=1,051)	(n=1,935)	(n=1,935)	2751.52	2	.000
Licensed	57.9	79.0	95.3			
Not Licensed	42.1	21.0	4.7			

(continued on next page)

compromising the depiction of the nonmotorist, age nonetheless confounds the analyses of education, employment status, and driver licensing. This issue is addressed at the end of this section.

Gender

The distribution of male and female travelers was similar in all three traveler categories. Gender was the only factor examined which did not have a statistically significant value for chi-square.

Education

Almost half (46.8 percent) of the nonmotorists had less than a high school education as compared with 18.2 percent of motorists and 30.7 percent of mixed-mode travelers. Relatively more of the motorists and mixed-mode travelers had a college degree or some college education (35.4 and 32.4 percent, respectively), as compared with nonmotorists (22.3 percent). The lower level of education among nonmotorists may reflect the fact that these individuals are younger on average. Low levels of education may also be associated with low incomes which may constrain travel choices.

Household Income

Nonmotorists were more likely to have low household incomes of less than 15,000 dollars (34.7 percent) as compared with mixed-mode travelers (17.8 percent) and motorists (11.7 percent). Relatively fewer of the nonmotorists were in the highest income category (4.7 percent at or above 75,000 dollars) as compared with mixed-mode travelers (11.9 percent) and motorists (11.2 percent).

TABLE 2 *(continued)*

	Non-motorist (n=1,358)	Mixed (n=2,283)	Motorist (n=29,554)	χ^2	d.f.	Sig.
Vehicles Owned by Household	(n=1,358)	(n=2,283)	(n=29,554)	3914.56	6	.000
None	28.1	14.6	2.4			
One	32.5	27.0	21.5			
Two	24.8	37.2	45.1			
Three or more	14.6	21.2	31.1			
Household Size	(n=1,358)	(n=2,283)	(n=29,554)	351.66	18	.000
1 person	15.4	12.0	8.7			
2	21.1	24.8	30.0			
3	19.0	22.5	21.9			
4	19.2	20.9	22.0			
5 or more	25.3	19.9	17.2			
Stage in Family Life Cycle	(n=1,356)	(n=2,282)	(n=29,541)	47.51	6	.000
No Children	32.0	34.0	34.8			
Children 0-15	47.4	46.8	43.0			
Children 16-21	6.8	9.0	9.5			
Retired	13.8	10.2	12.7			
Level of Urbanization	(n=1,358)	(n=2,283)	(n=29,554)	315.97	4	.000
Urban MSA Central City	51.8	44.6	33.8			
Urban not MSA Central City	23.0	27.0	29.1			
Not Urbanized	25.3	28.4	37.1			

TABLE 3 **Percentage Distributions of Travelers Aged 21–65 Years: Personal Characteristics**

	Non-motorist (n=683)	Mixed (n=1470)	Motorist (n=22,300)	χ^2	d.f.	Sig.
Education	(n=663)	(n=1,460)	(n=22,080)	185.48	8	.000
< H.S. Dipl.	21.0	8.2	9.7			
H.S. Dipl.	34.8	27.4	36.2			
Tech. School	2.4	3.4	3.3			
College	33.9	44.3	40.2			
Graduate School	7.8	16.8	10.5			
Employment Status	(n=683)	(n=1,470)	(n=22,300)	239.50	2	.000
Employed	56.5	77.5	80.5			
Not Employed	43.5	22.5	19.5			
Licensed Driver	(n=682)	(n=1,467)	(n=22,284)	1944.12	2	.000
Licensed	65.0	85.8	97.1			
Not Licensed	35.0	14.2	2.9			

TABLE 4 Percentage Distributions of Nonmotorized and Motorized Trips by Trip Characteristics and Level of Urbanization

	Non-motor Trips (n=9,029)	Motorized Trips (n=119,273)	χ^2	d.f.	Sig.
Trip Purpose	(n=9,029)	(n=119,240)	5440.87	8	.000
Work Related	13.3	24.2			
Shop/Family Business	35.3	44.4			
School/Church	13.7	6.7			
Social/Recreation	36.1	23.8			
Vacation	1.5	0.9			
Trip Distance (km)[a]	(n=8,927)	(n=117,381)	28037.68	12	.000
<1	68.8	8.5			
>1-8	29.7	50.6			
9-16	0.9	18.2			
17-32	0.5	13.4			
33-65	0.1	6.1			
66-161	0.0	2.5			
>161	0.0	0.6			
Daytime/Nighttime Travel	(n=8,492)	(n=114,702)	160.10	2	.000
Daytime	29.8	31.0			
Nighttime	70.2	69.0			
Weekday/Weekend Travel	(n=9,029)	(n=119,273)	446.49	2	.000
Weekday	77.0	72.1			
Weekend	23.0	27.9			
Accompanied by Others	(n=9,002)	(n=119,160)	929.23	2	.000
Accompanied	32.9	47.4			
Not Accompanied	67.1	52.6			
Level of Urbanization	(n=9,029)	(n=119,273)	1317.52	4	.000
Urban MSA Central City	49.6	33.6			
Urban not MSA Central City	23.6	29.4			
Not Urbanized	26.8	37.0			

[a] 1 km = 0.6 mi.

Employment Status

The majority of nonmotorists were unemployed (64.7 percent), whereas most mixed-mode travelers and motorists were employed (57.5 and 69.3 percent, respectively). This finding may imply that constraints on travel imposed by the commute to and from work (e.g., time of day, distance, route choice) make commute trips less suitable for nonmotor transport.

Driver's License

Only 57.9 percent of nonmotorists were licensed drivers, as compared with 95.3 percent of motorists and 79.0 percent of mixed-mode travelers. Most motorists in the 12–20 age category (83.7 percent) were licensed drivers, whereas only 42.6 percent of nonmotorists aged 12–20 were licensed. (This result, from a three-way cross-tabulation, is not shown in Table 2.)

Stage in Family Life Cycle

The relative distribution of individuals across the stage-in-life-cycle categories was similar across traveler groups, with most individuals in families with no children or children aged 0–5 years.

Household Vehicles

Only 1.5 percent of the motorists lived in households without motor vehicles, as compared with 14.6 percent of mixed-mode travelers and 28.1 percent of nonmotorists. A further analysis (not presented in Table 2) indicated that, in households with no owned vehicles, relatively few individuals were licensed (37.9 percent overall). In households with at least one motor vehicle, most motorists (97.4 percent) and mixed-mode travelers were licensed (92.3 percent), whereas relatively fewer nonmotorists were licensed (75.4 percent). These findings suggest that even in households with vehicles, the lack of a driver's license may constrain some individuals to use nonmotor transport; age may also be a factor in this finding as over half of the nonmotorists in households with three or more vehicles were in the 12–20 year age category. Yet it is also possible that licensed individuals choose to walk or bicycle, even in households with more than one vehicle. Women in all three traveler categories were more likely than men to live in households without motor vehicles, though women on average were not more likely to use nonmotor transportation.

Household Size

The pattern of household size across traveler groups was similar, with the majority of individuals living in households with two to four members. Nonmotorists were somewhat more likely to live in one-person households (15.4 percent), as compared with mixed-mode travelers (12.0 percent) and motorists (8.7 percent).

Urbanization

Nonmotorists were more likely to live in urban areas (51.8 percent) as compared with mixed-mode travelers (44.6 percent) and motorists (33.1 percent).

Age, Education, Employment Status, and Driver Licensing

A separate analysis was conducted to examine the characteristics of travelers aged 21 to 65 years, to determine whether, in the absence of the youngest and oldest travelers, nonmotorists would still appear to be less educated, more likely to be unemployed, and less likely to be licensed drivers as compared with mixed-mode travelers and motorists (Table 3). Nonmotorists aged 21 to 65 were more likely to have less than a high school education and less likely to have a college education, as compared with mixed-mode travelers and motorists in the same age group. Relatively more of the nonmotorists aged 21–65 were unemployed relative to mixed-mode travelers and motorists. And relatively more of the nonmotorists were not licensed drivers. As compared with the statistics presented in Table 2 for travelers aged 12 and up, the associations between lower levels of education, unemployment, lack of a driver's license, and the likelihood of using nonmotor travel remain strong though they are less pronounced in the 21–65 age group.

Restrictions on travel options appear to be the primary determinants of the choice of nonmotor travel, perhaps coupled with the fact that nonmotorists were more likely to live in central cities where land is more densely developed and walking or bicycling may be more feasible. These findings suggest efforts to improve conditions for the existing population of nonmotorists should be focused in urban areas, targeting young travelers (aged 12 to 20 years), the elderly, and individuals with limited travel resources.

Characteristics of Nonmotorized and Motorized Trips

Table 4 presents the characteristics of nonmotorized and motorized trips taken by individuals in the three traveler categories. Nonmotorized trips include walking and bicycling trips, whereas motorized trips include travel by automobile but exclude public transit and air travel. About 93 percent of the trips were automobile trips (N = 119,273) whereas about 7 percent were nonmotor trips (N = 9,029). Overall, nonmotorized trips were shorter in distance, more often taken alone and taken relatively less frequently for trips to work.

Trip Purpose

The most frequent purposes for nonmotor trips were social or recreational (36.1 percent), and shopping and family business (35.3 percent), with fewer (13.3 percent) being for work. The most frequent purposes of motorized trips were shopping and family business (44.4 percent), work (24.2 percent), and social or recreation (23.8 percent). The relatively smaller percentage of nonmotor trips taken for work may reflect the relatively smaller percentage of nonmotorists in the analysis who were employed.

Trip Distance

By far the majority of nonmotor trips were under eight kilometers in distance (68.8 percent, less than 1 km; 29.7 percent, 1–8 km), with none of the nonmotor trips above 64 km. About 50 percent of the automobile trips were between 1 and 8 km, with 8.5 percent under 1 km—a reasonable distance for nonmotor travel.

Time of Day/Weekday versus Weekend Travel

Nonmotor and motorized trips were distributed approximately equally with respect to time of day and weekday versus weekend travel.

Accompanied by Others on Trip

Nonmotor trips were relatively more likely to be taken alone (67.1 percent) as compared with motorized trips (52.6 percent). This finding may reflect the fact that nonmotorists were more likely to live in one-person households and suggests that nonmotor travel may be more feasible when traveling alone.

Urbanization

Almost half of the nonmotor trips were taken in urbanized central cities (49.6 percent), whereas the majority of motorized trips (37.0 percent) were taken in non-urban areas. This finding may reflect the feasibility of nonmotor travel in urban environments, where land is more densely developed and land uses are well integrated.

These findings suggest efforts to increase opportunities for nonmotor travel should focus on trips of short distances taken for shopping, socializing or recreation.

Comparison of Pedestrians and Bicyclists

The earlier analysis of traveler characteristics does not distinguish pedestrians from bicyclists within the nonmotorist traveler group. Many issues regarding planning for pedestrians and cyclists are similar, though the details related to environmental designs for the two groups often differ. An analysis of nonmotorists was conducted to determine whether pedestrians and bicyclists differed in their personal characteristics. The two groups compared included people who traveled exclusively by walking ($N = 1,216$) and people who traveled exclusively by bicycling ($N = 111$). Results are presented in the following paragraph. Overall, the greatest differences between pedestrians and bicyclists were with respect to gender, age, licensing, number of household vehicles, and stage in family life cycle. Bicyclists were found to be younger than pedestrians, with fewer years of education, and were less likely to be licensed drivers. Pedestrians had relatively lower household incomes, were more likely to live in households with no owned vehicles, and were more likely to be female.

A higher percentage of bicyclists (51.4 percent) than pedestrians (35.4 percent) were in the 12–20 age bracket. Most bicyclists were male (75.7 percent) whereas most pedestrians were female (53.3 percent). Pedestrians (54.4 percent) were more likely than bicyclists (45.9 percent) to have more than a high school education. Relatively more pedestrians were in the lowest income category (36.2 percent) as compared with bicyclists (21.2 percent). The majority of pedestrians (64.7 percent) and bicyclists (61.3 percent) were unemployed. Pedestrians were more likely to be licensed drivers (43.7 percent) as compared with bicyclists (22.1 percent). And pedestrians were more likely to live in households with no motor vehicles (29.9 percent) as compared with bicyclists (11.7 percent). A higher percentage of pedestrians (16.4 percent) than bicyclists (5.4 percent) were from one-person households. Pedestrians were less likely to live in households with children aged 0–15 years (45.6 percent) as compared with bicyclists (60.4 percent). Pedestrians were also somewhat more likely to live in urbanized central cities (52.4 percent) as compared with bicyclists (45.9 percent).

Comparison of Walking and Bicycling Trips

A further analysis was conducted to compare the walking and bicycling trips taken by nonmotorists and mixed-mode travelers, to complement the analysis of pedestrians and bicyclists presented in the preceding section, and to illuminate differences between the two modes. A total of 8,243 walking trips and 786 bicycling trips were analyzed. Results are presented in the following paragraph.

Bicycling trips were relatively more likely to be taken for social or recreational purposes (50.6 percent as compared with 34.7 percent of walking trips), whereas walking trips were more likely to be taken for shopping and family business (36.4 percent as compared with 23.7 percent of bicycling trips). The walking and bicycling trips differed most with respect to distance, with 72.1 percent of walking trips under 1 km, and 56.5 percent of bicycling trips between 1 and 8 km. Bicycling and walking trips were distributed about equally with respect to time of day of travel and weekday versus weekend travel. Relatively more of the bicycling trips were taken alone (77.9 percent) as compared with walking trips (66.1 percent). And bicycling trips were somewhat more likely to be taken in non-urban areas (30.5 percent as compared with 26.4 percent of walking trips).

DISCUSSION OF RESULTS

Factors distinguishing non-motorists from mixed-mode travelers and motorists include age, education, household income, employment status, driver licensing, and number of household vehicles, whereas factors that distinguish nonmotor trips from motorized trips include trip purpose, trip distance, accompaniment on the trip, and level of urbanization. Many of these factors, such as lack of access to a family-owned vehicle, restrict nonmotorists to choose walking or bicycling. Thus many nonmotorists in the United States, at present, appear to walk and bicycle less often by choice than from necessity because they are too young or too old to drive, or lack the resources needed to drive a motor vehicle. Past efforts to develop an automobile-based transportation system in the United States have succeeded so well that alternatives to motorized transportation are rarely attractive, except for recreation or as a minor addition to the usual pattern of motorized travel.

Ideally, the proportion of mixed-mode travelers relative to motorists should increase in the future in direct response to efforts to improve the environment for nonmotorists. The importance of constraints on mode choice in the findings of the analyses, however, suggests that incentives to increase walking and bicycling, such as environmental improvements, may not succeed without complementary constraints on automobile use. In Europe, constraints on motor traffic, such as low traffic speeds and limited thruways in residential areas, have succeeded in stemming the increase in motorized travel, while creating a more favorable and safer environment for bicyclists and pedestrians. Further studies are needed to compare the effects of incentives to walk and bicycle, and disincentives to drive, on nonmotor travel.

Results of the analyses in this report suggest it would be beneficial to concentrate efforts to improve conditions for the existing population of nonmotorists in central cities where most of the nonmotor trips take place, and to include planning for travel by children and young adults, the elderly, and people with limited incomes. Efforts to increase nonmotor travel among motorists should focus on trips of short duration taken for shopping, family business, socializing, and recreation. Approximately 8 percent of the motorized trips analyzed in this study were less than 1 km in distance, suggesting motorists may be especially encouraged to walk or bicycle for some of these trips. (Further analyses would be needed to determine whether these short trips were combined with longer trips, as this would reduce the percentage of short motorized trips suited to nonmotor travel.) Special efforts to support walking trips in central cities and bicycling trips taken by younger travelers in non-urban areas may also be effective. Innovative land use designs in new developments and redesigned areas can link residential areas, shopping, and schools, making nonmotor travel easier for young travelers and the elderly.

As discussed previously, the classification of individuals as motorists, nonmotorists, or mixed-mode travelers presented in this report may be inaccurate due to the short time period covered in the NPTS. The reliability of this classification method can be tested by using travel data covering at least several days. A further limitation of the study is the predominant use of bivariate analyses. Multivariate analyses are planned for future work to determine the strength of relationships between mode use and other variables, and to determine whether the effects of certain factors on mode use remain when other influential factors are controlled for in the analysis.

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DISCUSSION

AAD RÜHL

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A researcher dealing with travel survey issues related to nonmotor travel is not likely to discover the reasons why people do not use nonmotorized modes and or to develop appropriate policies for promoting nonmotor traffic.

Indeed, a researcher receives the impression that nonmotorized travel is only used when people have no access to motorized vehicles. This finding complicates the creation of a policy to promote nonmotor travel, as now envisaged in the U.S.

In order to be a viable alternative, walking and cycling should be considered an appropriate and safe mode of transportation, and not as a sign of the physical or financial inability to travel in another way.

Walking will be most important in central cities; cycling, however, will play an important role in suburban areas and will help keep emissions from traffic within prescribed limits.

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Evaluation of Different Types of Pedestrian-Vehicle Separations

SHEILA SARKAR

One of the key elements of traffic planning is elimination of conflicts, particularly between the nonmotorists and vehicles. The importance of this planning issue was realized by the ancient and medieval planners who separated the pedestrians and vehicles at the street level. Until the late nineteenth and early twentieth centuries, most of the separations were at grade and simple. But with the proliferation of automobiles, separations became complex and diverse. This paper attempts to subdivide different types of separations on the basis of their unique physical and regulatory attributes, and then compares their performance in delivering safety, equity, comfort, and convenience to the different road users (especially to the pedestrians and bicyclists).

> Where paths cross roads, the cars have power to frighten and subdue the people walking, even when the people have the legal right of way.
>
> Christopher Alexander, *A Pattern Language*

In his book *Relations in Public*, Erving Goffman described the differences between a vehicular unit and a pedestrian unit. His definition captured the differences in essence. Goffman noted:

> A vehicular unit is a shell of some kind controlled (usually from within) by a human pilot or navigator. . . , a road and its traffic will support shells of somewhat different kinds—cars, bicycles, horse-drawn carts, and of course pedestrians. Viewed in this perspective, . . . the individual as pedestrian—can be considered as encased in a soft exposing shell, namely his clothes and skin. (*1*, p. 6)

Goffman further commented:

> . . . the role of unintentional physical contact differs in the two systems, collision apparently being a matter of more concern on the road than on the sidewalk. Pedestrians can twist, duck, bend, and turn sharply, and therefore, unlike motorists, can safely count on being able to extricate themselves in the last few milliseconds before impending impact. Should pedestrians actually collide, damage is not likely to be significant, whereas between motorists collision is unlikely to be insignificant. (*1*, p. 7)

Given the above differences between pedestrians and vehicles, it is important to employ different design standards for each of them so that their paths only cross at defined locations. And when their paths do cross, the pedestrians' safety is not compromised.

DESIGNING FOR PEDESTRIANS' SAFETY: ELIMINATION OF CONFLICTS

Importance of pedestrians' safety was recognized from the earliest of times. Ancient planners of the city of Pompeii separated the path of pedestrians and the vehicles. They also provided stepping stones at regular intervals for pedestrians to cross over. The stepping stones served two functions: (*a*) they acted as elevated crosswalks for pedestrians to cross over easily and (*b*) they also reduced the speed of the horse drawn carts, as the riders had to carefully negotiate the wheels between the gaps in the stepping stones.

During the Renaissance, Leonardo da Vinci had envisioned a double system of streets: street level arteries for vehicular traffic and an elevated walkway system for the pedestrians. He had worked out their structures down to the last detail, including rainwater gutters and light shafts for the lower passages. Unfortunately, the ideas were way ahead of his time (*2*).

Designing for pedestrians' safety had taken back seat in this century until the 1960s. It was the European countries that reestablished the standards and requirements for safety of pedestrians in the cities during the post-war reconstruction. By the 1970s, many of the downtown streets with high pedestrian volumes were converted into pedestrian streets or transit streets (*3*). Between the 1960s and the present, over 500 German cities and a couple of hundred Dutch towns converted some areas of their downtowns into pedestrian precincts (*4*).

In the United States, the first attempt to redesign urban downtowns for pedestrians was proposed by Victor Gruen, who had stated:

> I am perfectly willing to risk the attacks of the traffic planners when I insist that the solution to co-existence of the human and automotive population does not lie in the taming of and training of people, but in the taming of the motor car (*5*, p. 212).

He redesigned the layout for the downtown of Fort Worth, Texas. The new design would protect the central area from vehicular traffic and would be served by transit and slow-moving vehicles (for those who need special assistance). He also envisaged a vertical separation between service traffic and the pedestrians.

Gruen's ideas were never fully realized, but portions of it were used to improve pedestrian safety, such as the design of the downtown pedestrian and transit malls and the design of the suburban shopping malls.

SEPARATION OF MODES

Literature on the safety of pedestrians has stressed the importance of separation of modes. Following are a few who have written on this subject: Buchanan (*6*), Gruen (*5*), Rudofsky (*2*), Pushkarev and Zupan (*7*), Fruin (*8*), Prokopy (*9*), Breines and Dean (*10*), Brambilla and Longo (*11*), Braun and Roddin (*12*), Untermann (*4*), Smith et al. (*13*), Whyte (*14*), Zegeer and Zegeer (*15*), Tolley (*16*), Bach and Pressman (*17*), and Zegeer (*18*).

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Others, such as Appleyard (*19*), Homburger et al. (*20*), Eubank-Ahrens (*21*), Hass-Klau et al. (*22*), Vahl and Giske (*23*; interview with Vahl on October 16, 1993, in city of Culemborg, The Netherlands), and Bach and Pressman (*17*), have discussed, at length, soft separation and traffic calming.

On the basis of the review of the literature, four types of separations are possible for eliminating pedestrian-vehicular (including bicycles) conflicts: (*a*) horizontal separation, (*b*) time separation, (*c*) vertical separation, and (*d*) soft separation. Each type of separation can be subdivided further on the basis of its physical configuration and differences in regulatory attributes (Figure 1).

Each of these types of separation requires different design and planning requirements using physical, psychological, visual, and legal tools to eliminate conflicts. The different types of separations, along with the different design needs, have been explained in the following pages. In addition, this paper also discusses the performance of each type of separation in eliminating or promoting the following:

1. Elimination of conflicts;
2. Safety of vulnerable groups such as the elderly, children, and the physically/mentally impaired;
3. Elimination of barriers for nonmotorists;
4. Optimal use of public space for outdoor pedestrian activities;
5. Equitable use of the public space;
6. Comfort and convenience; and
7. Ensuring conformance.

Horizontal Separation

Horizontal separation has been used from ancient times to eliminate pedestrian-vehicular conflicts, and it still continues to be used widely all over the world to fulfill the same function.

There are three different types of horizontal separations: (a) parallel elements that accommodate all modes; (b) parallel systems that eliminate some of the vehicular traffic; and (c) displaced elements that have no vehicular traffic.

Parallel Elements Shared by All Modes. These systems accommodate pedestrian movement adjacent and at grade to vehicular movements. The elements work well when there are sufficient spaces available to distribute equitably among modes on the basis of their efficiency and productivity (Figure 2). The quality of the public space depends on the skillful use of the design elements explained in Table 1.

TABLE 1 Horizontal Separation: Parallel Elements that Accommodate All Modes

Design Characteristics of the System	Examples	Specific Elements Ensuring Protection to Pedestrians from conflicts with cars and bicycles
Parallel Elements where all modes are accommodated.	•Sidewalks (Figure 3) •Arcades/ Canopied sidewalks. •Semi malls (sidewalks are widened and there is no parking but vehicular traffic is allowed).	*Physical Means* • Separate channelization of the modes. • Barriers such as -- bollards, landscaping (Figure 5), high curbs are used to prevent improper movements of different modes. *Psychological Means* • Equal attention is given to all the modes, no one mode dominates over the others. • Low level lighting (4-5 m or 12-15 ft) along the walkways. *Visual Means* • The layout is consistent with the uses of the street. • The layout induces the expected behavior from the different road users. • Pedestrian use is uninhibited due to the absence of barriers. *Legal Means* • Time separations are provided, using traffic control devices -- signals, and stop signs. • Signs posted to remind different users to conform to the expected behavior.

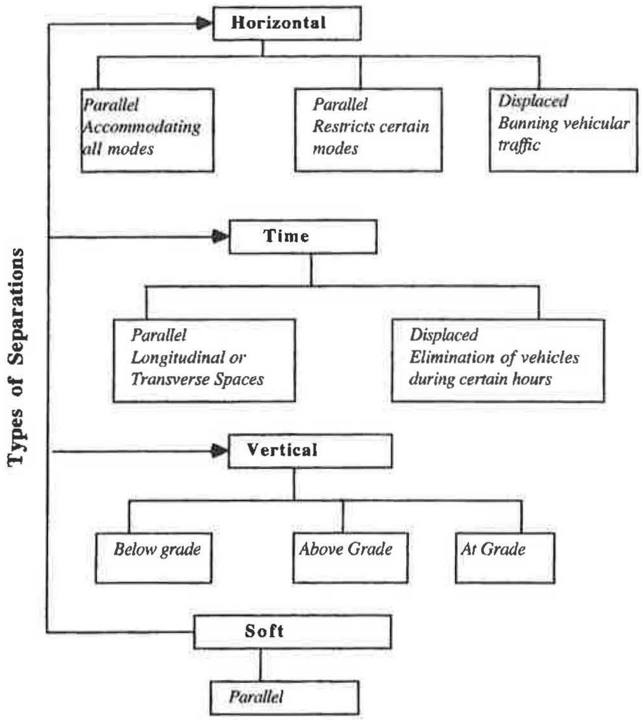

FIGURE 1 Classification of different types of separation.

FIGURE 2 Equal distribution of space among all modes; Houten, The Netherlands.

TABLE 2 Horizontal Separation: Parallel Elements with Elimination of Certain Modes

Design Characteristics of the System	Examples	Specific Elements Ensuring Protection to Pedestrians from conflicts with cars and bicycles
Parallel Elements with elimination of certain modes.	Transit Malls (Figure 3)	*Physical Means* • Wide sidewalks. • Landscaping and bollards to prevent improper movements. • Bicycles share the roads with the transit vehicles. *Psychological Means* • Streets are designed with pedestrians and cyclists in mind. Vehicular traffic (except for light rail and emergency vehicles) is banned. • Low level lighting emphasizing pedestrianization of the street. *Visual Means* • The layout is distinct and consistent with the uses of the street. *Legal Means* • Signs warning vehicles on the restrictions imposed on them. • Signs warning pedestrians of the presence of transit vehicles. • Transit vehicles are warned of the pedestrianization of the street.

Parallel Elements with Restriction on Certain Vehicles. These vehicles, which accommodate pedestrian movements adjacent and at grade, allowing certain types of vehicles in most instances, are transit vehicles (Figure 3). To maintain a conflict-free environment, cars are restricted from driving through, and service and delivery vehicles are allowed during fixed hours. Although these have limited applications, they are very useful solutions in urban areas with dense retail activities and high pedestrian volumes (Table 2).

Displaced Elements. These have eliminated vehicular traffic within the area through design and regulatory signs to facilitate pedestrian and bicycle usage. These types of systems rely on efficient underground transit systems for success (Table 3). Although they have limited application, they offer a productive, environment-friendly use of the public space. Pedestrian zones, or auto free zones, as they are popularly known, are most useful in urban areas with dense retail activities and high pedestrian volumes, or in historic areas (Figure 4).

The level of performance of different types of horizontal separations is shown in Table 4.

Time Separation

Time separation enables different road users to safely use the public space at different time intervals. There are two popularly used time separations, parallel or displaced. ("Scramble" or "all walk" has not been classified separately.)

Parallel Elements

These are transverse or longitudinal systems placed at regular intervals that are widely used to enable pedestrians and vehicles to use them at different time intervals without conflicts (see Figures 5 and 6). The design requirements are explained in Table 5.

Displaced Elements

These are systems that ban vehicular traffic and allow pedestrian movements along the entire rights of way during certain times of the

TABLE 3 Horizontal Separation: Displaced Elements

Design Characteristics of the System	Examples	Specific Elements Ensuring Protection to Pedestrians from conflicts with cars and bicycles
Displaced Element with elimination of the motorized modes.	• Pedestrian Malls • Permanent Street Closures (Figure 4). (Transit services are along parallel streets or underground.)	*Physical Means* • Bicycles are allowed where (a)the sidewalks are wide enough for pedestrian activities; and (b) the roadways can accommodate bi-directional bike movements with minimal conflict. • Bollards, and landscaping placed at ends of the street, to prevent vehicles from driving through. *Psychological Means* • Street is redesigned with pedestrians and cyclists in mind. • Low level ornamental lighting to emphasize pedestrianization of the street. *Visual Means* • The layout is distinct and consistent with the uses of the street. *Legal Means* • Vehicular traffic is banned (except emergency vehicles). • Signs warning vehicles that it is a pedestrian zone (Figure 8) . • Signs warning bicyclists that pedestrians have the right of way.

FIGURE 3 Transit street; Munich, Germany.

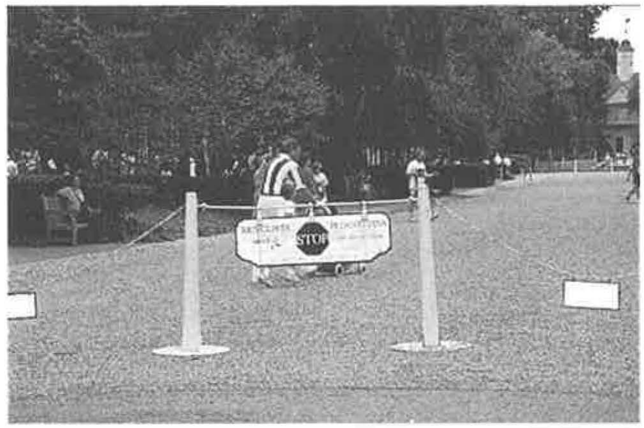

FIGURE 4 Auto-free zone; Colonial Williamsburg, Va.

TABLE 4 Performance of Horizontal Separations

	Parallel Elements (all modes are accommodated)	Parallel Elements (some of the modes are eliminated)	Displaced Element with elimination of motorized traffic
Elimination of Conflicts	• Depends on (a) the physical design; (b) treatment of psychological, visual, and legal attributes of the design; (c) the vehicle speed.	• High - Very high	• Very high
Safety of Vulnerable Groups	• Depends on the (a) physical design; (b) effective treatment of psychological, visual, and legal elements of the design; (c) the vehicle speed.	• High - Very high	• Very high
Elimination of Barriers for non-motorists	• Depends on the (a) design standards for removal of physical and perceptual barriers; and (b) the vehicle speed.	• High - Very high	• Very high
Optimal use of public space for outdoor pedestrian activities	• Depends on the (a) user-friendliness of the environment; and (b) the surrounding land use.	• High - Very high	• Very high
Equitable use of the public space	• Depends on the division of the right of way.	• In favor of non-motorists.	• In favor of non-motorists.
Comfort and Convenience	• Depends on the design for noise control, pollution dispersion etc.	• High - Very high	• Very high
Enforcement required	• Varies with the (a) design; (b) vehicle speed; and (c) attitude towards traffic rules.	• Low due to regulatory signs and designs.	• Low due to regulatory signs and designs.

FIGURE 5 Bollards and trees separate pedestrians from vehicles; Rome, Italy.

FIGURE 6 Time separation transverse with respect to Orange Avenue, Orlando, Fla.

TABLE 5 Time Separation: Parallel Elements

Design Characteristics of the System	Examples	Specific Elements Ensuring Protection to Pedestrians from conflicts with cars and bicycles
Parallel Elements Transverse or Longitudinal Separation	• Marked or Unmarked Crosswalks	*Physical Means* • Raised crosswalks to discourage drivers from speeding or blocking intersections. • Curbs are extended to improve the visibility of the pedestrians and drivers. • Tactile cues are provided to guide visually impaired. • Presence of pedestrian refuges where needed (Figure 12). *Psychological Means* • Intersection is redesigned with pedestrians and cyclists in mind. • Low level lighting to emphasize pedestrian crossing zones. *Legal Means* • Well designed traffic signals restricting vehicular movements: -- exclusive pedestrian signals; -- "all walk" signals; -- allowing pedestrian movement parallel to the traffic flow without any turning movements. (Time separation is void if turning movements are allowed.) • Stop signs at intersections along with signs warning drivers that they must yield to pedestrians. • Signs warning drivers not to block crosswalks.

day or night. They are a useful planning tool for historic areas or older urban areas, where the rights of way cannot be increased to accommodate high pedestrian volumes and vehicular traffic (Figure 7). They are a low-cost method of eliminating pedestrian-vehicular conflicts. The design requirements are explained in Table 6 and Figure 8.

The performance of time separation in ensuring safety, equity, comfort, and convenience is shown in Table 7.

Vertical Separation

These are systems in which the vehicles are displaced vertically from the nonmotorized traffic. The earliest designs for vertical separation were proposed by Leonardo da Vinci; unfortunately, they were never implemented. Three types of vertical separations are possible: below grade, above grade, and at grade. The design requirements for each type of separation are explained in Table 8.

Below-Grade Systems. The vehicular movements are above, and pedestrian movements are below the ground (Figure 9); for example, Place Bonaventure, Montreal; Transit Concourse; and Munich.

Above-Grade Systems. The pedestrian movements are above, and vehicular movements are at grade (Figure 10), for example, skyway systems of Minneapolis, and Arlington, Virginia.

Both of these systems have been used increasingly in urban areas with freezing or excessively high temperatures. Although expensive and difficult to retrofit, they can offer excellent systems of climate-controlled conflict-free walkway systems.

TABLE 6 Time Separation: Displaced Elements

Design	Examples	Specific Elements Ensuring Protection to Pedestrians from conflicts with cars and bicycles
Displaced Elements *Vehicular traffic is banned during the peak pedestrian hours (except emergency vehicles).*	Daily street closures during certain hours	*Physical Means* • Bicycles are allowed where the sidewalks are wide and the roadways can accommodate bi-directional bike movements with minimal conflicts. • Sidewalks are wide enough to accommodate pedestrian activities after the streets are reopened to vehicles. • Vertical deflections on the road surface, such as road bumps, chicanes, raised crossings, to control speed after streets are reopened to vehicular traffic (Figure 8). *Psychological Means* • Streets are redesigned with pedestrians and cyclists in mind. • Low lighting to emphasize the pedestrianization of the street. *Visual Means* • The layout is distinct and consistent with the uses of the street. *Legal Means* • Signs warning vehicles that it is a pedestrian zone during the posted hours. • Signs warning bicyclists that pedestrians have the right of way. • Reduced speed designs to warn the motorists to modify their behavior after pedestrian-only hours.

FIGURE 7 Chestnut Street Transit Mall, Philadelphia, closed to vehicular traffic during peak hours.

FIGURE 8 Street with 30-km speed limit and vertical deflections; Delft, The Netherlands.

TABLE 7 Performance of Time Separation

	Parallel Elements -- Longitudinal and Transverse	Displaced Elements
Elimination of Conflicts	• Depends on (a) the physical design; (b) treatment of psychological, visual, and legal elements; (c) the vehicle speed; and (d) the type of traffic control devices.	• Very high during street closure periods. • Variable (depending on design to eliminate conflicts) during other times of the day.
Safety of Vulnerable Groups	• Depends on --(a) design, (b) traffic control devices; and (c) vehicle speed.	• Very high during *street closure* periods. • Variable during other times of the day, depending on the design to eliminate conflicts.
Elimination of Barriers for non-motorists	• Depends on -- (a) the width of the parallel elements and presence of pedestrian refuges; (b) presence of well designed traffic control devices; (c) vehicle speed.	• Very high during street closure periods. • Variable at other times, depending on the extent to which the physical and perceived barriers have been eliminated.
Optimal use of public space for outdoor pedestrian activities	--	• High
Equitable use of the public space	Depends on -- (a) design; and (b) traffic control devices.	• In favor of non-motorists during certain times of the day or night.
Comfort and Convenience	• Depends on the design of the (a) curb ramps or raised crosswalks; (b) presence of tactile cues for the visually impaired; and (c) the type of traffic control devices.	• Depends on the design -such as- landscaping, noise control, pollution dispersion, walking surface etc.
Enforcement required	• Depends on regulatory designs (extended curbs, corner blips) and regulatory signs.	• Low due to regulatory signs and designs.

TABLE 8 Vertical Separation at Different Grade Levels

Design Characteristics of the System	Examples	Specific Elements Ensuring Protection to Pedestrians from conflicts with cars and bicycles
Below Grade	• Subways • Transit Concourses • Subwalks • Underground retail and commercial concourses or malls	*Physical Means* • Vertical separation of pedestrians from bicycles, and vehicles. • No at-grade crossings. *Psychological Means* • Well lit wide walkways. *Visual Means* • The layout and design of the walkways are coherent and consistent with the use. • The walkways are lined with retail activities making them attractive to the pedestrians.
Above Grade	• Skywalks (+5 or the +15 systems) • Skyways • Pedestrian Bridges	*Physical Means* • Vertical separation of pedestrians from bicycles, and vehicles. • No at-grade crossings. *Psychological Means* • Well lit wide walkways. *Visual Means* • The layout and design of the walkways are coherent and consistent with the use. • The walkways are connected to retail, business, and commercial activities for the convenience of the users.

FIGURE 9 Transit concourse; Munich, Germany.

FIGURE 10 Skywalk; Arlington, Va.

TABLE 9 Performance of Vertical Separation

	Below Grade	Above Grade
Elimination of Conflicts	• Very high	• Very high
Safety of Vulnerable Groups	• Very high	• Very high
Elimination of Barriers for non-motorists	• Very high	• Very high
Optimal use of public space for outdoor /indoor pedestrian activities	• Outdoor public space has limited use for activities because of inclement weather or unattractive conditions. But indoor pedestrian activities are very high.	• Outdoor public space has limited use for activities because of inclement weather, or unattractive conditions. But pedestrian activities are very high on the skyways.
Equitable use of the public space	• High - Very high	• High - Very high
Comfort and Convenience	• High - Very high	• High - Very high
Enforcement required	• Low, when appropriate design for security has been implemented.	• Low

At-Grade Systems. The vehicular traffic is directed either above or below, and pedestrian movement is maintained at grade. This type of separation has limited application, and is used more often to separate through traffic from the local vehicular traffic.

The performance of above/below-grade systems in ensuring safety, equity, comfort, and convenience is shown in Table 9.

Soft Separation (Traffic Calming)

Soft separation has been used increasingly in European countries for reclaiming public space for diverse uses. The distinctive feature of this system is that it stresses integration instead of separation of traffic in dense urban areas. Pedestrians and cyclists are treated equally in this system, and the cars are domesticated by design to adapt to the environment (*16,22*).

The parallel elements system enables different modes to share the same right of way because: (a) the existing right of way is unable to accommodate clear separation of the modes, or the designers have deliberately designed the street with narrower right of way; (b) there are high levels of pedestrian activities; (c) it would discourage excessive use of vehicles and encourage use of greener modes; and (d) it would ensure a safer environment with better quality of life.

Wide application of this type of separation is possible. It can be retrofitted in the existing residential areas and other land uses, or used in the design of new residential neighborhoods, college campuses, retail districts, etc. Soft separations with traffic-calming designs are usually applied to larger areas, thus requiring more detailed planning analysis and areawide traffic management.

The design and other requirements of such systems are detailed in Table 10 (see Figures 11 and 12).

The benefits of soft separation are more widespread, and they improve the quality of life for a large number of people when larger areas are redesigned. This alleviates transferring the problem (traffic) to surrounding streets.

The performance of soft separation in ensuring safety, equity, comfort, and convenience is given in Table 11.

USEFULNESS OF CLASSIFICATION

Most transportation planners are aware of the different types of separation, and several authors have enumerated all of them or some of them in their works (*7,2,8,9,24–26*). However, very little attempt has been made to compare and analyze the various design and planning tools required to ensure the success of each type of separation.

This paper attempts to break down the five planning and design tools, physical, psychological, visual, social, and legal, that would ensure the success of these separations in eliminating conflicts. Although no environment can be foolproof from conflicts, close encounters can be eliminated to a considerable extent if the planners attempt to address all of these five elements in the right proportions. Excessive reliance on one or two of these elements will not often yield the desired results, and this work explains the unique functions performed by each of these planning and design tools in ensuring the smooth working of different types of separations.

Additionally, in order to ensure highest possible use of the public space by the efficient and environment-friendly modes, each

TABLE 10 Soft Separation with Traffic Calming

Design Characteristics of the System	Examples	Specific Elements Ensuring Protection to Pedestrians from conflicts with cars and bicycles
Pedestrians and vehicles may share the same right of way after certain changes have been initiated.	• Dutch "*Woonerf*" or residential precincts. • Dutch *erf* and German (tempo 30) 30 km zones. • Swedish "*Handerf*" areas.	*Physical Means* • Vertical deflections in the road surface, such as road bumps, raised crossings, platform junctions raised at pavement level. • Roadway width constrictions, chicanes, corner blips, bends along the roads. • Traffic throttles, bollards, trees, street planters, barrels, lamp posts etc. *Psychological Means* • Street designed/redesigned with the pedestrians and cyclists in mind. Drivers feel like guests in these areas. • Low pedestrian lighting to stress the urban atmosphere. • Meandering vehicle paths emphasize the need to restrict speed. • Entrance to built up areas or neighborhoods is emphasized through gateway effects created by vertical features such as pergolas, barriers, or planters. *Visual Means* • The layout is clear and consistent with the appropriate uses of the street. • The layout induces the expected behavior from the drivers.
Parallel Elements		*Social Means* • Adequate information dissemination and consultation with the residents and the users of the street, on the priority changes in the area. *Legal Means* • To achieve the desired driving behavior, signs with the speed limits and the uniqueness of the precinct, are posted to remind the motorists that they must modify their behavior.

FIGURE 11 Examples of soft separations from Delft, The Netherlands.

FIGURE 12 Examples of soft separations from Delft, The Netherlands.

TABLE 11 Performance of Soft Separation

	Parallel Elements
Elimination of Conflicts	Very high due to low speed and traffic calming designs.
Safety of Vulnerable Groups	Very high due to low speed and traffic calming designs.
Elimination of Barriers for non-motorists	Very high
Optimal use of public space for outdoor pedestrian activities	Very high
Equitable use of the public space	Protects the rights of non-motorized modes.
Comfort and Convenience	Depends on the quality of the designs -- walking surface, presence of ramps, protection from weather etc. More favorable to pedestrians than vehicles and bicyclists.
Enforcement required	Low, if appropriate design and regulatory signs are used.

right of way should be graded on how well it performs with regard to safety, equity, comfort, and convenience. Each type of separation has certain inherent weaknesses or drawbacks, and these have been highlighted in this work for the convenience of traffic planners, so that they can address them effectively while improving the existing separations or designing new ones.

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Private Provision of Public Pedestrian and Bicycle Access Ways: Public Policy Rationale and the Nature of Public and Private Benefits

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The preparation and implementation of a system of access ways throughout the community will result in economic improvements that will benefit the entire community. Private property owners will benefit, especially for commercial property that allows access to nearby customer bases in residential areas and employment centers. At the same time, the provision of access ways will reduce the magnitude of the public's subsidies to and adverse externalities that result from automobile dependency. Separating pedestrian and bicycle traffic from streets and providing pedestrian and bicycle access ways will make travel easier for all who access such ways. Public benefits include reduced congestion, reduced air and noise pollution, reduced public costs associated with highway construction and maintenance, reduced energy consumption, improved pedestrian and bicyclist safety, and overall improvements in environmental and social quality of life factors. Private benefits include reduced driving costs, increased investment in downtowns, and increased private property values.

The vitality of urban areas depends on the provision of multiple access ways. In modern American cities, those ways include roads, sidewalks, and bicycle pathways—the latter two often designed to accommodate all nonmotorized transport modes. Planners and analysts are learning that if any one of these three access ways is lacking, the quality of the urban environment is compromised, with adverse effects not only on the community at-large, but on the value of individual private property.

This study presents a framework for viewing multiple access ways as not only necessary for the public health, safety, and general welfare but necessary for the economic vitality of communities and privately owned property therein. It begins by reviewing the conflict created in communities with insufficiently diverse access ways. The public and private benefits of multiple access ways are then reviewed. It concludes with a discussion on the role of comprehensive planning and implementation of planning through exaction in providing multiple access ways that benefit public and private property owners.

THE CONFLICT

The interaction between pedestrians and vehicles places pedestrians at a distinct disadvantage (*1*). One obvious result is the annual pedestrian accident toll of more than 85,000 in 1992 (*2*). The nature of the pedestrian-vehicle conflict includes spatial, environmental, and sociological dimensions (*1*).

The spatial conflict is the competition for the same urban space. Vehicles require large amounts of space for movement and storage, and demand priority in traffic. Such space requirements for vehicles thereby determines urban form, typically making it more sprawled and less interconnected (*1*).

As for environmental effects, vehicles produce noise, dust, fumes, and visual pollution (*1*). Together, highways and vehicles obscure scenic views and disrupt the aesthetic features of the cityscape (*1*). Traffic control devices, parking meters, and other types of street furniture connected with vehicles create visual clutter (*3*).

On the sociological dimension, heavy volumes of vehicular traffic affect community identity, individual desires to maintain property, and the nature of social interaction (*4*).

The following passage illustrates how problems associated with the pedestrian-vehicle conflict are intensified in downtowns of all sizes because of their more intense development.

> The typical downtown is a regional center for business, shopping, cultural, social, and governmental activities served by a tributary transportation network. There is a basic functional differentiation between the transportation feeder systems required to support a downtown area, and the distributor systems within the downtown area. Traffic in and out of downtowns is comprised of concentrated through movements radiating from the central core. Traffic within downtown is dispersed and comprised of many short, irregular, multi-purpose trip linkages. Trip patterns of this type are most efficiently accommodated by walking, and in terms of total trips, walking is the predominant means of movement within all downtown areas (*1*).

Oddly, many downtown areas are experiencing business declines because of competition from suburban shopping malls (*1*). Shopping malls are exclusively pedestrian-oriented and free of vehicular traffic (*1*). Because the conflict between pedestrians and vehicles has been removed, significant improvements are made in the physical and visual environment (*1*). The result is that shopping malls are more sensitive to the human requirements of security, convenience, comfort, and social-interaction than downtowns (*1*).

If public officials wish to make downtown areas more attractive as commercial centers they must recognize the importance of the pedestrian function (*1*). The pedestrian function also extends to bicycling pathways. Bicycle riding in many American towns and cities, like walking, is neither enjoyable nor safe because of the

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dominance of the automobile (*5*). Simply put, the automobile and the bicycle are not compatible (*6*). Yet bicycles are an important transportation mode, especially when used to connect residential and commercial areas (*6*).

THE BENEFITS

Private property owners in downtowns benefit from pedestrian and bicycling improvements. Historically the center of activity, downtowns were originally structured to serve pedestrians. The concentrated, mixed-use physical layout of downtowns fostered walking. Sidewalks connected stores to one another and to residential areas where many customers live (*5*).

Communities set up for walking and bicycling reduce the cost of commuting, delivery of goods and services, and police and fire protection. Pedestrian improvements have revitalized many small community shopping areas, creating new jobs in what formerly appeared to be financial and community disasters. Most pedestrian-oriented districts have reported increases in private-sector building. For instance, Nicolete Mall in Minneapolis helped attract new buildings worth more than $1 billion. [(*6*) Note: Figures updated and adjusted to 1992 dollars from original.] Other savings, such as from reduced pollution and noise, increase property value for residential property and, as a result, for all downtown property (*7*).

These benefits are usually reflected in the private real estate market. Consider Peachtree City, Ga. Its comprehensive plan, which dates from the 1960s, includes a system of pedestrian-bicycle ways (called "cart paths") that was designed to connect all major land uses to one another, and especially connect commercial areas to residential areas to reduce congestion associated with short-haul convenience shopping trips. Its system is considered a model for suburban city planning (*8*).

Within Peachtree City (a planned new town), developers are required to reserve right-of-way (ROW) and construct cart paths in accordance with the *Peachtree City Comprehensive Plan* whether subdividing or applying for a building permit. Local commercial real estate brokers acknowledge cart paths' contribution to property value. J. Tate Godfrey, a commercial broker with Peachtree Brokerage Group, states that cart paths along all types of property have a positive effect on the value of such property, although the amount varies by kind of property (personal communication). Industrial property probably would not value access to cart paths as highly as residential and commercial properties. The greatest increase in value is seen in neighborhood commercial properties connected to residential areas. Likewise, Ralph McCurdy, a commercial broker with ReMax, states that the major factors in commercial property prices are visibility, access to highways, and access to cart paths (personal communication).

On the other hand, automobile-dependent property, including downtowns and commercial areas devoid of pedestrian and bicyclist facilities, enjoy considerable automobile subsidies proffered by society-at-large. These subsidies are not paid by benefiting property. As such, society is entitled to have these subsidies compensated through a variety of public-serving planning decisions, including dedications and improvements resulting in improved walking and bicycling activity.

From society's perspective, pedestrian and bicycle facilities are needed to offset subsidies to automobile-dependent property. The value of these subsidies can be measured by comparing the total costs of congestion, pollution, parking, driving costs, road maintenance, energy consumption, pedestrian safety, transportation capital investments, and general environmental and social effects to the costs attributable to walking and bicycling. The difference is the subsidy. These differences are quantified later. Some of this discussion is based on Todd Litman's previously cited work (*9*).

A review of trends is shown in Table 1. This table graphically shows national travel trends before 1970. The nation is becoming more automobile-dependent and less integrated economically and socially as people and their activities physically become much farther removed from one another (*10,11*). If this trend were efficient, that is, not induced by inefficient behavior such as explicit price subsidies and unpriced externalities, it may not be troublesome. However, this trend is fueled by explicit price subsidies and unpriced externalities which, if unchecked, could damage the economic foundation of the nation as other nations take action to correct such subsidies and unpriced externalities through public policy.

Congestion Reduction

Pedestrians and bicyclists occupying spaces reserved for walking, bicycling, or both contribute nothing to street congestion and actually remove potential vehicles from streets, resulting in an overall improvement in total transportation system flow. On the other hand, forcing pedestrians and bicyclists onto highways reduces highway capacity, as shown in Table 2. Where there is no facility for pedestrians and bicyclists (such as shoulders) highways are reduced to up to 70 percent of their capacity to accommodate vehicles. However, providing pedestrian and bicycle access ways will help reduce highway congestion. (The counter-argument is that such separation can lead to higher highway speeds that may threaten pedestrian and bicyclist safety. This is possible, but one major objective of separating motor vehicles from pedestrians and bicyclists is to improve overall safety.) Designating spaces for pedestrians and bicyclists should improve vehicular flow and improve air quality; however, these are qualitative outcomes that are not easily measured and would likely be short-lived as highway capacity is absorbed over time.

The effect of bicycles within travel lanes of otherwise free-flowing highways is shown in Table 3. For example, suppose an intersection has capacity for 500 vehicles per hour (vph). The effect of bicycles on the automobile capacity of travel lanes less than 4.27 m (14 ft) wide can be estimated using the following formula (*12*):

$$vph_{\text{Auto}} = \text{Capacity}_{\text{Auto}} - (\text{Bicycles} \times \text{Adjustment Factor})$$

For example, suppose an intersection averages 100 bicycles per hour, one-half of which are opposed, and the travel lanes are 3.66 m (12 ft) wide. The resulting vph for automobiles is calculated as follows:

$$vph_{\text{Auto}} = 500 - ((100 \times 0.5 \times 0.5) + (100 \times 0.5 \times 0.2)) = 465$$

While pedestrians and bicyclists can reduce highway capacity if not separated from vehicular traffic, separated pedestrian and bicycling facilities can induce drivers to walk or cycle, thereby improving overall highway capacity (*13–16*). When one considers that at least 50 percent of all automobile trips, including a large share of work trips, are less than 5 mi, it should become obvious that there is great potential for pedestrian and bicycle access ways to reduce congestion of highway facilities (*6*).

Suppose a lengthy, but not unreasonable, walk or a moderate bicycle trip is 4 km (2.5 mi), which is equivalent to roughly one-

TABLE 1 Travel Trends in the United States—1969–1990

Measure	1969	1977	1990	Percent Change 1969-90
Population[10]	202,677,000	220,239,000	249,924,000	23%
Average Annual Vehicle Kilometers (Miles) Traveled Per Household[11]	1,496 (929)	2,151 (1,336)	2,523 (1,567)	88%
Average Annual Vehicle Trips Per Household[2]	213	268	345	62%
Average Vehicle Trip Length in Meters (Miles)[2]	7.1 (4.4)	8.1 (5.0)	8.2 (5.1)	16%

Sources
1 *[10]*
2 *[11]*

TABLE 2 Effect of Pedestrian/Bicycle Clearance on 3,66-m (12-ft) Lane Capacity for Automobiles [*12*]

Usable Shoulder Width for Pedestrians and Bicyclists	Capacity Effect Where 1.0 = Maximum Lane Capacity	
	Level of Service A to D	Level of Service E
1.83+ Meters (6+ Feet)	1.00	1.00
1.22 Meters (4 Feet)	0.92	0.97
0.61 Meters (2 Feet)	0.81	0.93
0 Meters (0 Feet)	0.70	0.88

TABLE 3 Effects of Bicycles on Lane Capacity for Automobiles [*12*]

Bicycle Direction (Movement)	Lane Width in Meters (Feet)		
	Less than 3.36 Meters (11 Feet)	3.36 to 4.27 Meters (11 to 14 Feet)	More than 4.27 Meters (14 Feet)
Opposed (Interferes with traffic)	1.2	0.5	0.0
Unopposed (Does not interfere with traffic)	1.0	0.2	0.0

quarter of all automobile trips (*11*). For each 1.61 km (1 mi) during commuting periods, the congestion cost savings can be up to $0.32 per 4 km (2.5 mi) urban commute trip and $0.03 per 4 km (2.5 mi) urban noncommute trip (*9*).

Air and Noise Pollution Reduction

Walking and bicycling produce virtually no air or noise pollution. Because walking and bicycling replace short-haul trips, which cause the most pollution when done by automobile, pollution savings can be substantial. Cost savings attributable to walking and bicycling are estimated to be about $0.40 per 4-km (2.5-mi) urban commute trip and $0.24 for all other 4-km (2.5-mi) urban trips (*9,16,17*). Noise pollution savings range from $0.02 per 4-km (2.5-mi) urban commute trip and $0.01 per 4-km (2.5-mi) urban noncommute trip (*9,14,15,17,18*).

Parking Reduction

Commuters and shoppers alike receive free parking, a cost that is subsidized by all workers and shoppers who do not use automobiles (*7*). Free parking also results in environmental costs associated with greater impervious areas than would occur without parking spaces. Typical urban and suburban parking facilities range from $50 to $100 per month (*16,19,20*), or about $2.50 to $5.00 per urban commute trip and $0.25 to $0.50 per urban shopping trip. But at up to 20 bicycles per equivalent parking stall, the monthly cost is one-tenth that of commute and shopping trips done by automobile. Savings attributable to bicycling trips replacing automobile trips are $2.25 per 4-km (2.5-mi) urban commute trip and $0.225 per 4-km (2.5-mi) urban noncommute trip.

Driving Costs Savings

Driving or "user" costs of automobiles include insurance, gasoline, maintenance and repairs, and depreciation. Savings of $0.60 per 4-km (2.5-mi) urban commute trip and $0.40 per 4-km (2.5-mi) noncommute trip are estimated when walking or bicycling substitutes for automobiles (*9,21*).

Road Maintenance Cost Savings

Roads need to be maintained, but in most states and local areas road maintenance costs are borne by taxpayers through income, sales, and property taxes and not through road use taxes or fees. Some estimate this cost at about $0.02 per 4-km (2.5-mi) urban commute trip and $0.01 per 4-km (2.5-mi) urban noncommute trip (*9,14,16,17*).

Energy Consumption Reduction

By one estimate, 14 to 23 percent of the energy consumed in the United States is used by the automobile (*6*). Greater energy is consumed by automobiles in short-haul trips, typically done for shopping purposes (*22*). By some estimates, energy costs range from about $0.12 per 4-km (2.5-mi) urban commute trip to $0.10 per 4-km (2.5-mi) urban noncommute trip (*9,16,23,24*).

Pedestrian Safety Improvement

In the absence of separated pedestrian and automobile facilities, pedestrian casualties rise. In commercial areas, pedestrians and bicyclists using pedestrian ways face the highest risk of accidents, as shown in Table 4 (*25*). As seen in Table 5, in the absence of sidewalks and pathways, the risk of pedestrian accidents increases by 72 percent.

Cost-Effective in Transportation Investment Gains

The capital costs of new transportation facilities are rarely paid by users in relation to the amount of use, location, cost characteristics, or nature of use. Instead, transportation facilities are often paid through general taxation, such as income taxes, property taxes, and sales taxes. Those who use roads heavily, for example, are subsidized by those who do not use roads as much. The comparative capital costs of four types of roads are compared with such costs for bicycle ways and pedestrian ways in Table 6.

TABLE 4 Distribution of Pedestrian Exposure to Accidents by Land Use Type [25]

Land Use	Distribution of Pedestrian Exposure to Accidents
100% Residential	6.5%
Commercial	71.8%
Mixed Land Use	21.6%

TABLE 5 Relative Accident Rates Between Sidewalk/Pathway Provision and No Such Provision [25]

Environmental Characteristic	Relative Accident Weight
Pedestrian Accommodation	
No Sidewalks/Pathways	2.17
Sidewalk/Pathway	0.87

General Environmental and Social Cost Reductions

Automobile dependency leads to other environmental and social costs characterized as urban sprawl (*26*), degradation of neighborhoods (*27*), reduced residential and certain commercial property values (*7*), and decreased mobility for nondrivers including the poor (*28,29*), among other potential costs. At least one estimate conservatively places this cost at $0.23 per 4-km (2.5-mi) urban trip of any kind, which would be saved with walking or bicycling (*9*).

Summary of Savings Attributable to Walking and Bicycling

Table 7 summarizes many, but not all, of the costs that could be saved for each automobile trip that is replaced with walking or bicycling.

THE PLANNING POLICY FRAMEWORK

In effect, Table 7 shows the nature of subsidies accruing to private property relative to walking and bicycling. By not having motorists face these expenses, the costs are borne by the public and the avoidance of such costs are internalized as benefits by private property. If these costs were accounted for, land use patterns would change to reflect the true cost of automobile use relative to alternative modes. Public agencies need to devise ways to offset this inefficient outcome. A logical method is to exact the provision of pedestrian and bicycle access ways from new development. Such an exaction

TABLE 6 Comparative Costs Per Trip Mile Capacity of Transportation Facilities

Facility	Cost/1.61 Kilometers (Mile)[1]	Maximum Capacity Per 1.61 Kilometers (Mile) Per Hour[2]	Cost Per 1.61 Kilometer (Mile) to nearest $
Freeway Four Lanes	$11,143,000	7,600	$1,466
Secondary Highway Two Lanes	$1,393,000	2,800	$498
Bikeway Two 4-foot Lanes	$67,000	2,000	$34
Sidewalk Four-foot Path	$33,000	6,000	$6

[1] Cost per mile excluding right-of-way, California Department of Transportation 1972 figures adjusted to 1992 dollars [*1*].

[2] Based on level of service E for all facilities. [*14*]

TABLE 7 Estimated Savings Per 4-km (2.5-mi) Automobile Trip Reduced by Walking or Bicycling [9]

Cost Factor	Urban Commuting Trip	Urban Noncommuting Trip
Congestion Costs	$0.32	$0.03
Air Pollution Costs	$0.40	$0.24
Noise Pollution Costs	$0.02	$0.02
Parking	$2.25	$0.23
Driving Costs	$0.60	$0.40
Road Maintenance Costs	$0.02	$0.02
Energy Costs	$0.12	$0.10
Environmental/Social Costs	$0.23	$0.23
TOTAL	$3.42	$1.27

Source - Adapted from Reference [9]. Does not include facility capital costs or pedestrian and bicyclist casualty costs.

would have at least three important positive outcomes. First, congestion, pollution, and other adverse effects of automobile-dependency are reduced. Second, private development is made somewhat more responsible for otherwise contributing to the adverse effects of automobile-dependency. Third, improving access to property increases its value. In this regard, commercial and residential property would likely have the largest gains in value attributable to the provision of pedestrian and bicycle ways, although all property value is likely to gain in some respect (personal communication, Godfrey and McCurdy).

Providing multiple access ways requires comprehensive planning. Unfortunately, in most modern city planning since the Industrial Revolution, coordinated pedestrian and bicycle planning has been lacking. For the past generation, however this has been changing (*30*). Now, national planning organizations recommend pedestrian and bicycle access way planning as part of a community's comprehensive planning efforts (*5*). Many states require its consideration if not its outright provision (*31–35*). It has become commonplace to plan and develop pedestrian and bicycle routes that connect homes with schools, parks, shopping, bus stops, places of work, and community services (*5*). Whether or not it is explicitly stated, the city planning rationale for providing multiple access ways include:

- Improving interconnectness among land uses;
- Reducing negative environmental, social, and fiscal effects associated with automobile dependency; and
- Correcting inefficiencies associated with subsidies to automobile transportation facilities and modes.

Although there is no formal accounting of the trend, anecdotal evidence suggests that hundreds if not thousands of communities have plans that integrate automobile, public transit, pedestrian ways, and bicycle ways into an overall transportation scheme designed to maximize means of access to all parts of the community. Because of the Intermodal Surface Transportation Efficiency Act and the Clear Air Act amendments of the early 1990s, many more communities will prepare such plans.

The major obstacle to achieving good city form is not planning, but implementation (*36*). Implementation is achieved in two ways: (*a*) dedication of resources by the public through governmental agencies and (*b*) exactions from private property. If governments possessed all resources, no exactions would be needed from private property. The U.S. government does not have all the resources, nor does it need all the resources, to implement its plans. Actions taken by the government often improve the value of private property. Often, this value is not recaptured by government except in small increments (such as taxes) that do not recover any meaningful share of the value government creates. For example, the construction of a new highway serving landlocked property will usually increase the value of such property immensely, and the property owners may not have invested anything close to the cost of the highway. Other taxpayers have paid for the highway. It is not unreasonable, then, to secure an easement or dedication of ROW from benefiting property because the value of the remaining land attributed to the highway investment likely exceeds the prehighway value of the land dedicated.

Thus, local governments often require developers to dedicate part of their land to widen existing streets or create new ones. Moreover, developers are often required to pay for necessary on-street and off-street improvements (*37*). Sometimes dedication means maintenance of a facility. For example, it is common practice among many major cities to not only require private property owners to construct sidewalks, but to maintain them as well (*27,38*).

The constitutionality of such dedications has been challenged typically on due process grounds (*37*). In general, the courts have upheld the legality of dedications authorized by state statutes. The rationale is that such laws fall within the state's police power and are reasonably related to the public welfare (*37*).

Local government fails to meet important constitutional tests when private property is "taken" for public purpose and is thereby deprived of reasonable economic use, or when it receives no reasonable benefit from the exaction. Generally speaking, if property can be used to produce goods or services that are economically viable after the exaction, there probably is no constitutional taking.

Of more interest to city planners is the relationship between the exaction and the benefit. The easiest way to meet this test is to employ a rational nexus test, derived from development impact fee case law and statutes. The rational nexus test is met when (*39*):

- New development creates a need for new or expanded facilities, services, or other public good;
- The net cost of accommodating new development is determined; and
- New development is not assessed more than its proportionate share of the cost of the new or expanded facilities it is reasonably expected to use.

Development impact fees are applicable only to a small share of total development requirements imposed on new development. For example, a city wishes to create a bicycle pathway system that connects residential neighborhoods and commercial centers. A portion of the proposed path passes along a creek—a typical bicycle path location—on property proposed for commercial development. The city's comprehensive plan provides for the dedication of pathway ROW upon development of property in its path. Finally, because the city intends to construct the path after the ROW is acquired, it has not devised a development impact fee program and, instead, intends to acquire ROW through exactions. What should city planners do?

First, planners need only demonstrate that a share of the potential bicycle pathway traffic will become customers of the commercial development. Indeed, this may be presumed because commercial development depends on traffic of all kinds. Even when an argument can be made that a particular commercial tenant has no use for bicycle traffic this relationship is reasonable because tenants come and go but commercial activity per se depends on all forms of traffic.

Second, when the pathway is to be located in areas not allowed for development because of underlying environmental or setback restrictions, construction of the pathway could be viewed as a pure net gain by such development in two respects: (*a*) it could not use the area being developed as a pathway because of underlying environmental or setback restrictions, and (*b*) it will improve its traffic and thereby its commercial trade.

Third, given that commercial development already receives considerable subsidies or externalities, any value lost by the dedication of a bicycle pathway not otherwise recovered by increased traffic is likely not to be offset by the value of such subsidies or externalities. Table 8 illustrates the magnitude of total costs incurred by the public to subsidize or incur the externalities of commercial development. This table estimates the total cost of subsidies and externalities society bears from a general retail operation during its economic useful life. Conservative assumptions are used, such as: (*a*) the lower noncommute trip costs from Table 7 instead of the commute trip costs; (*b*) 300 days of use instead of 365 over the course of a year; and (*c*) 10 percent capitalization rate instead of a lower rate that has been effective in years.

The magnitudes may appear startling. Over its economic useful life, 1860 m^2 (20,000 ft^2) of retail space will impose more than $3 million in subsidy and externality costs on society including its taxpayers. (The choice of this example was stimulated by the recent Supreme Court decision [*Florence Dolan v. City of Tigard, Oregon, —US—1994*.] The case involved, in part, plumbing store owner Florence Dolan's objection to the City of Tigard's (Oregon) conditioning a variance to allow expansion of an existing store into a flood plain on the dedication of a 15-ft ROW for a bicycle-pedestrian path that the city would build at its expense. Dolan wanted to expand a retail store in downtown Tigard and add more parking spaces. The pedestrian-bicycle way would connect a high-density residential area directly to the development, effectively making the site among the most accessible in the downtown area. Chief Justice Rehnquist, writing for the majority, found that since the city did not demonstrate a rough proportionality between the traffic impacts of store expansion and the mitigation of such impacts associated with the pathway, the condition amounted to an unconstitutional taking. Oddly, the Supreme Court admitted that the city could have denied Dolan's permit outright and there would have been no case.) It is in local government's interest on behalf of society to mitigate the magnitude of these costs through expansion of less costly means of transportation. A calculation that compares the exaction value to the magnitude of societal subsidies and externalities benefiting the center would likely show that the exaction is less than such subsidies and externalities.

SUMMARY

This study reviewed the need for and the historical basis of separating pedestrian and bicycle traffic from streets and showed that providing these access ways is beneficial to the public and to private property. To review, these benefits include:

- Reduced congestion;
- Reduced air and noise pollution;
- Reduced public subsidies of parking;
- Reduced private driving costs;
- Reduced public road construction and maintenance costs;
- Reduced public and private energy consumption;
- Improved pedestrian and bicyclist safety;
- Improved environmental and social quality of life;
- Increased private investment in downtowns; and
- Increased private property value.

Implementation of plans that systematically integrate a variety of access ways will lead to economic improvements benefiting all

TABLE 8 Total Subsidies and External Costs of Commercial Development Calculated Over Useful Life of New Development

Square Meters (Feet)	Noncommuting Trips @ 40.67 Per 93 Square Meters (1,000 Square Feet)[1]	Noncommuting Costs @ $1.27/Trip[2] 300 Days/Yr @ 10% Capitalization Rate
1,860 (20,000)	813	$3,097,530
4,650 (50,000)	2,034	$7,749,540
9,300 (100,000)	4,067	$15,495,270

Sources

1 "Specialty Retail Center" (including quality apparel, hard goods, real estate offices) [*40*].

2 From Table 7 and assumes the average trip is 4 km (2.5 mi) attributable to the center.

property, especially commercial property gaining access to nearby customer bases found in residential areas and employment centers. At the same time, the provision of such ways will reduce the magnitude of the public's subsidies to, and adverse externalities that result from, automobile dependency.

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Evaluation of Safety for Pedestrians at Macro- and Microlevels in Urban Areas

SHEILA SARKAR

In the modal hierarchy, pedestrians "encased in soft exposing shell" are the most vulnerable when exposed to conflicts and barriers. In dense urban areas, where walking is an important mode to complete short trips, there is a continual need for evaluation of the existing roads and walkways, so that appropriate actions can be taken to eliminate or redress conditions that compromise pedestrians' safety. This paper proposes a method that would enable professionals to examine different facets of safety. The proposed method evaluates the existing design and conditions at two levels: first, at macrolevel (Service Levels A-F), and second, at microlevel [Quality of Service (QOS) Levels A-F]. Also discussed in this work are the methodologic processes for using the service and QOS levels, and the strengths and weaknesses of the method.

In his book *Relations in Public,* Erving Goffman explained the differences between a vehicular and a pedestrian unit. His definitions captured the dissimilarity in essence. Goffman noted (*1*):

> A vehicular unit is a shell of some kind controlled (usually from within) by a human pilot or navigator.
> . . . a road and its traffic will support shells of somewhat different kinds—cars, bicycles, horse-drawn carts, and of course pedestrians. Viewed in this perspective, the individual himself, moving across roads and down streets—the individual as pedestrian—can be considered as encased in a soft exposing shell, namely his clothes and skin.

Goffman further commented:

> . . . the role of unintentional physical contact differs in the two systems, collision apparently being a matter of more concern on the road than on the sidewalk. Pedestrians can twist, duck, bend, and turn sharply, and therefore, unlike motorists, can safely count on being able to extricate themselves in the last few milliseconds before impending impact. Should pedestrians actually collide, damage is not likely to be significant, whereas between motorists collision is unlikely to be insignificant.

Given the above differences in pedestrians and vehicles, it is important to employ different design standards for each of them so that their paths only cross at defined locations. And, when their paths do cross, the safety of the pedestrians should not be compromised.

EVALUATION METHOD

A proposed method has been developed using design and planning principles that make the urban sidewalks and intersections safe for the vulnerable groups: the elderly, children, and physically impaired.

The method has two discrete evaluations: first, the Service Levels A-F (SL A-F) that evaluate the macrolevel design and conditions on the walkways and intersections; second, the Quality of Service Levels A-F (QOS Levels A-F) that evaluate the microlevel design and conditions on the walkways and intersections (Figure 1).

The proposed method was developed after extensive research and study of the existing literature on safety in engineering, planning, urban design, and environmental psychology. In addition to literature review, existing evaluation methods on safety developed by Braun and Roddin (*2*), Smith et al. (*3*), and Khisty (*4*) have been studied.

ESTIMATION OF SERVICE LEVELS A-F WITH RESPECT TO SEPARATION OF MODES

A review of the literature indicated that the emphasis in all pertinent research on safety in urban streets has been on the level and effectiveness of the separation between modes. Several authors have contributed to this subject, to cite a few (chronologically): Buchanan (*5*), Gruen (*6*), Rudofsky (*7*), Pushkarev and Zupan (*8*), Fruin (*9*), Prokopy (*10*), Breines and Dean (*11*), Brambilla and Longo (*12*), Braun and Roddin (*2*), Untermann (*13*), Smith et al. (*3*), Whyte (*14*), Zegeer and Zegeer (*15*), Tolley (*16*), Bach and Pressman (*17*), and Zegeer (*18*).

Others, such as the following, have discussed at length soft separation and traffic calming: Appleyard (*19*), Homburger et al. (*20*), Eubank-Ahrens (*21*), Hass-Klau et al. (*22*), Vahl and Giskes (*23*; interview with Vahl on October 16, 1993, in city of Culemborg, The Netherlands), and Bach and Pressman (*17*).

The proposed service levels were shaped by the author's understanding of the aforementioned research. These levels, based on the type of separation between different modes, will enable designers and planners to perform a qualitative evaluation of pedestrians' exposure to hazards.

The fundamental principle in forming this classification system is to offer directness and clarity in defining the proposed service levels, so that they can be used easily by a wide variety of groups, from professionals to community and neighborhood organizations.

The service levels proposed in this work have five levels of separation, from A-F, as defined in Table 1. "F" was used instead of "E" to emphasize the failing conditions of the road in affording safety.

Table 1 summarizes the essential conditions that are proposed to be included in each of the six service levels. The summary for each of the proposed service levels explains in essence the type of separation and the safety conditions that pedestrians would encounter.

Network of Employers for Traffic Safety (NETS), Regional Coordinator for San Diego, Customized Training, Building 1600, Southwestern College, 900 Otay Lakes Road, Chula Vista, Calif. 91910.

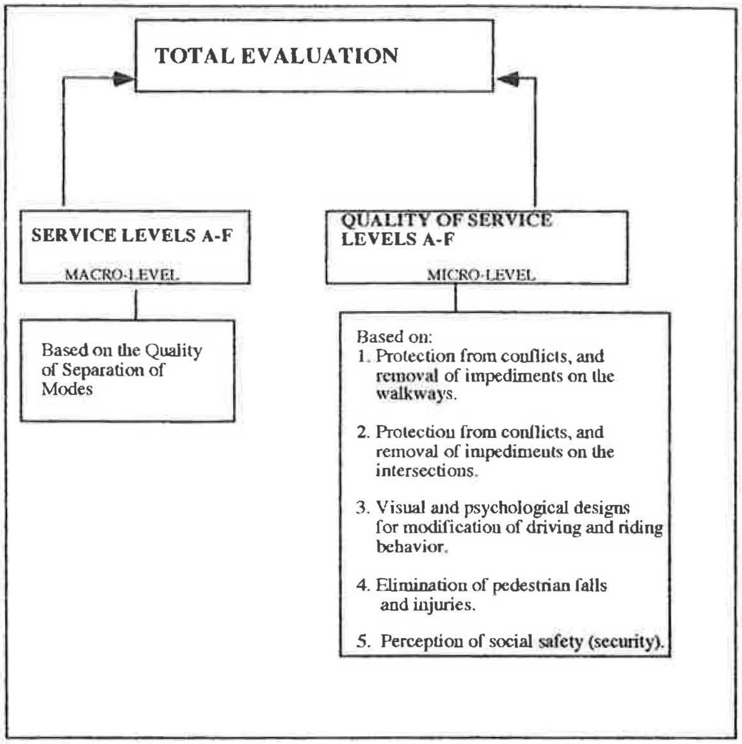

FIGURE 1 A summary of evaluation method.

METHODOLOGIC PROCESS FOR USING SERVICE LEVELS

The process for assigning a service level grade to a walkway requires eight steps, as illustrated in Figure 2. The process starts with a detailed survey of the site, examining the microlevel design, geometric, and operational aspects of the sidewalks and the intersections. To obtain an accurate idea of the weak links on any street, a block-by-block survey is conducted.

The second step results in the systematic itemization of all of the information on the site collected during the survey.

The following step involves an item-by-item comparison of the characteristics of the site, with those items included in the service levels.

The fourth step has two major processes (i.e., identification and elimination). Identification involves scanning the service levels to isolate those that are unsuitable for explaining the site characteristics of the surveyed walkway. Elimination is a decision step that excludes the irrelevant service levels while retaining those whose characteristics are more relevant to the surveyed site.

The fifth step requires a comparison of the characteristics of the surveyed site with the conditions proposed for the remaining service levels.

The next step (sixth) leads to the selection of the service level that meets most of the characteristics observed at the site.

Steps 1 through 6 are repeated for each block on the street.

In the seventh step, the grades assigned to each block on a street are shown together in a tabular form to establish the degree of variation in the safety conditions. The final format would look similar to the one shown for the hypothetical Chester Avenue in Figure 3.

The final step (eighth) requires the assignment of a grade for the entire walkway based on the principle of systems evaluation that states that "minimum capacity of a line defines the capacity of a line." On the basis of this principle, the entire street is assigned an overall grade based on the lowest grade received on any section or block.

EVALUATION USING QUALITY OF SERVICE LEVELS A-D

Service Levels A-F evaluate the macrolevel designs (quality of channelization) only, and they do not assess the microlevel designs or conditions on the walkway that could affect a pedestrian's safety. For example, a sidewalk may be well separated from other modes, but could have large pot holes that could cause injuries, or have poor visibility at intersections, compromising the safety of crossing pedestrians. These problems are not evaluated at a macrolevel, and yet if these quality conditions are ignored, pedestrians' safety is undermined significantly.

The QOS levels also have been developed using grades A through F (excluding "E"), with five levels of variations.

The microlevel components that contribute to the quality of safety are discrete entities, and they cannot be combined together to form one set of QOS levels. Therefore, to assist analysts in conducting accurate microlevel examinations, five disparate QOS levels have been developed using the following criteria:

1. Elimination of conflicts and impediments on the walkways;
2. Elimination of conflicts and impediments at intersections;
3. Visual and psychological designs for modification of driving and riding behavior to ensure pedestrians' safety;
4. Elimination of pedestrian falls and injuries through maintenance and design; and

TABLE 1 Service Levels A-F for Safety: Separation of Modes

Service Level	Pedestrians	Bicycles	Transit	Auto
A	• Exclusive pedestrian facility. • Vehicular intersections and crossings eliminated.	• Bicycles are allowed but only if they have been assigned separate of r/w. *They use the road with transit.* • Bicyclists have separate channelizations at intersections.	• Only Light rail is allowed. • Light rail has defined path.	• Autos are banned. • Autos are not allowed.
B	• Pedestrians have been assigned separate r/w **adequately** separated from bicyclists and vehicles, by bollards, curbs etc. • Pedestrians are provided with **exclusive time separation** at intersections. • They have well defined channelization at intersections.	• Bicycles are assigned with well defined separate r/w, separated by curbs or bollards from pedestrians and vehicles. • Bicycles are controlled by their own traffic signals. • They have separate channelizations a intersections.	• Transit is assigned with separate r/w. • Transit vehicles are controlled by their own traffic signals. • They have separate channel-izations at intersections.	• Autos have their separate r/w. • Autos have their own traffic signals. • They have separate channel-izations at intersections.
C	• Pedestrians have been assigned separate r/w **inadequately** separated from bicyclists. • Pedestrians **face conflicts with right turning vehicles,** and bicyclists, at the signal. • The channelization for pedestrians and bicyclist is **unclear at intersections.**	• Bicycles are assigned with inadequately defined separate r/w. *The bikepaths are placed on sidewalks disting-uishable only by texture.* • Bicycles share signal timing with pedestrians. • The channelization for bicyclists and pedestrians is **unclear at intersections.**	• Transit has separate r/w. • Transit vehicles share the same traffic signals as autos. • They have separate channelizations at intersections.	• Autos have separate r/w. • Auto have their own traffic signals. • They have separate channel-izations at inter-sections.
D	• Pedestrians have been provided with separate r/w **but they are forced to share it with bicyclists.** • Pedestrians face **conflicts with right and left turning vehicles, and bicyclists, at the signal.** • There is no separate channelization for pedestrians and bicyclists at intersections.	• Bicyclists have not been provided with separate r/w. They use the sidewalks. • Bicyclists' behavior is indeterminate at intersections. • There is no separation between bicyclists and pedestrians at intersections.	• Transit is not assigned separate r/w. The share it with vehicles. • Transit vehicles share the same traffic signals as autos. • They have separate channelizations at intersections.	• Autos have more than adequate r/w. • Autos have their own traffic signals. • They have separate channel-izations at intersections.
F	• Pedestrians do not have separate r/w. • Traffic signals have not assigned time for pedestrians. • Pedestrians have no channelization at intersections.	• Bicycles do not have separate r/w. • Bicyclists' behavior is indeterminate at intersections. • Bicyclists use the road with other vehicles at intersections.	• Transit is not assigned separate r/w. The share it with vehicles. • Transit vehicles share the same traffic signals as autos. • They have separate channelizations at intersections.	• Autos have been assigned exclusive r/w. • Autos have their own traffic signals. • They have separate channel-izations at intersections.

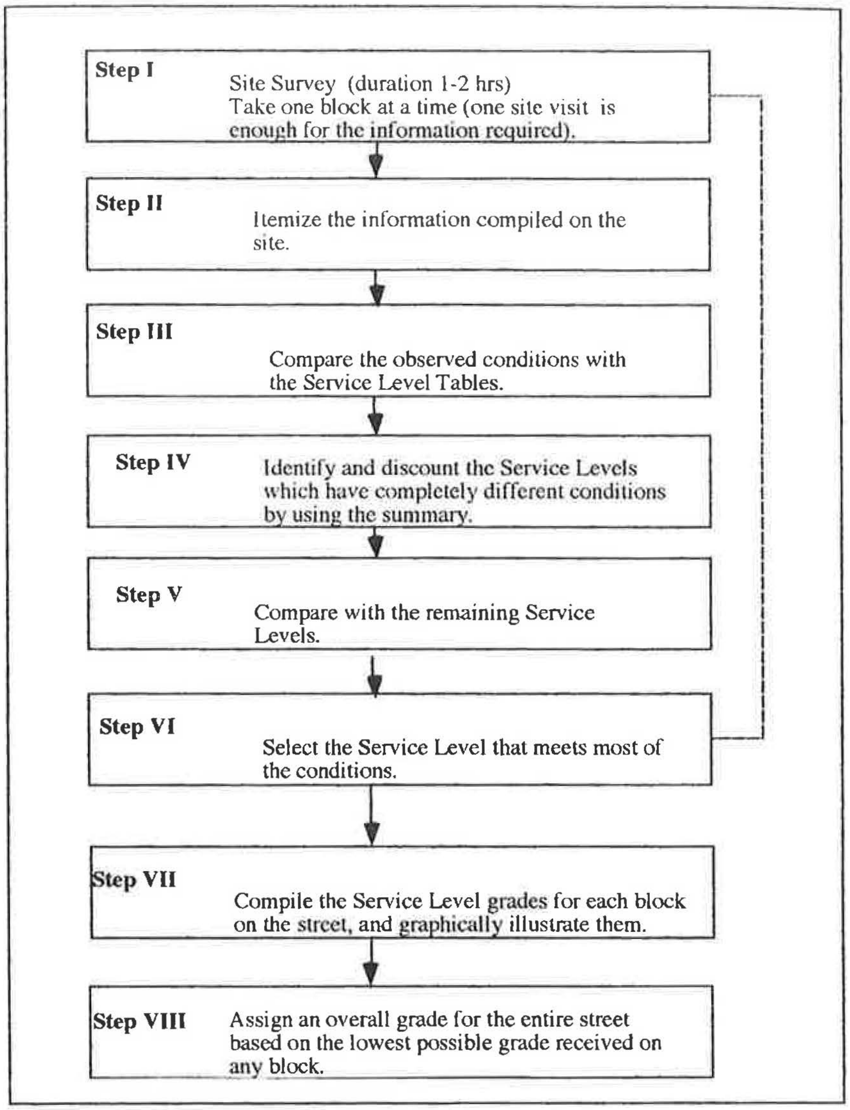

FIGURE 2 Methodologic process for assigning service level grades.

5. Planning and design principles that enhance the perception of social safety (security).

The summary of each of the above five components is as follows.

Elimination of Conflicts and Impediments on Walkways

The level of safety for pedestrians can be compromised by obstructions or barriers along the path.

Researchers such as Fruin (*9*), Braun and Roddin (*2*), Untermann (*13*), Smith et al. (*3*), Whyte (*14*), and Tolley (*16*) have discussed at length the possible barriers or obstructions that pedestrians experience on walkways.

Such impediments may be a result of inadequate ancillary walkway to place street furniture, poor enforcement of regulations to keep the effective walkway free of obstructions because of excessive commercial use, or illegal use of the walkways for parking. The variations in the level of obstruction are explained by the QOS Levels A-F, and shown in Table 2.

Elimination of Conflicts and Impediments at Intersections

Safety problems at intersections have been researched extensively by traffic engineers, planners, and environmental psychologists, such as Sandels (*24*), Mortimer (*25*), Knoblauch (*26,27*), Hauer (*28*), Zegeer et al. (*29*), Cynecki et al. (*30*), Robertson (*31*), and Oliver (*32*). Some of the pedestrian safety issues that have been mentioned consistently by the researchers are as follows:

1. Problems with turning movements concurrent to pedestrians' crossing;
2. Problems with four-way stop signs;
3. Visibility problems at intersections; and

Service Lev. \ Blocks	Chester Ave.(41st &42nd)	Chester Ave.(42nd &43rd)	Chester Ave.(43rd & 44th)	Chester Ave.(44th &45th)
A				
B				
C				
D			✓	✓
F	✓	✓		

FIGURE 3 Graphic representation of evaluation on block-by-block basis on hypothetical Chester Avenue.

4. Effectiveness of traditional speed-reduction measures at intersections, such as rumble strips and pedestrian flashing beacons.

The definition QOS Levels A-F, shown in detail in Table 3, evince a degree of sensitivity to the various nuances and variations of design and regulations on walkways and at intersections.

Visual and Psychological Elements for Modification of Drivers' and Cyclists' Behavior

The importance of visual and psychological designs have been used extensively by urban designers and planners to modify driving and riding behavior. Some of the key proponents of such designs in the U.S. include Brambilla and Longo (*12*), Appleyard (*19*), Untermann (*13*), Homburger et al. (*20*), Whyte (*14*), and Rubenstein (*33*).

In Europe, visual and psychological designs have been used widely for traffic calming. A wide array of literature has been added on the subject, mostly in German, Dutch, and French. Some of the contributions in English have been from Appleyard (*19*), Homburger et al. (*20*), Eubank-Ahrens (*21*), Hass-Klau et al. (*22*), Tolley (*16*), Vahl and Giskes (*23*; interview with Vahl on October 16, 1993, in city of Culemborg, The Netherlands), and Bach and Pressman (*17*).

The QOS Levels A-F have been designed using the concepts and principles proposed by these authors (Table 4).

Elimination of Pedestrian Falls and Injuries on Walkways Through Maintenance and Design

This area has been most neglected. Very little research (*16*) or statistics have been compiled on the falls and injuries that pedestrians have suffered because of the conditions on the walkways, particularly the visually impaired and other physically challenged users.

The key aspects that are relevant to assess the probability of falls and injuries on walkways that have been used to develop the QOS levels are as follows:

1. The condition of the walkway surface;
2. Accommodation of needs of different user groups, such as people with assisting device, etc.;
3. The presence of tactile or sensory cues; and
4. Actions taken to prevent injuries that could be caused by inclement weather, such as excessive snow accumulation or icy patches on the walkways.

Table 5 explains the different QOS levels.

Planning and Design Principles That Enhance Perception of Safety (Security)

Perception of security plays an important role in the decision to walk. Researchers such as Jacobs (*34*), Fruin (*9*), Newman (*35*), Alexander et al. (*36*), Braun and Roddin (*2*), Gehl (*37*), Oc and Trench (*38*), and Rubenstein (*33*) have suggested different design and planning strategies that would improve security on walkways. Some of the frequently mentioned principles are as follows:

1. High levels of activity on the walkways throughout the day and night;
2. Orientation of buildings toward the streets;
3. Regular police patrol and presence of security devices; and
4. Low-level lighting.

All of these principles have been incorporated in the development of the QOS levels for security (Table 6).

METHODOLOGIC PROCESS FOR QOS LEVELS

The process for assigning a QOS level grade to a walkway has nine methodologic steps, as illustrated in Figure 4. The process is very similar to the one for service levels.

Steps 1 through 6 are repeated for each block on the street, and are illustrated graphically in the seventh step. Figure 5 offers an illustration for hypothetical Chester Avenue.

TABLE 2 QOS Levels A-F for Level of Conflicts and Impediments on Walkways

QOS Levels	Illegal Parking of Vehicles	Tactile Guidance to the Visually Impaired	Condition of the Effective Walkwidth	Condition of the Ancillary Walkwidth	Pedestrian -Bicycle Conflicts
A	• None • Vehicles are banned.	• Specially designed sensory cues.	• Free from obstructions.	• More than adequately wide for street furnishings.	• There are no conflicts. Bicycles are adequately separated.
B	• None • Illegal parking is prevented by bollards, landscaping, and curbs over 15 cm or 6".	• Specially designed sensory cues.	• Free from obstructions. • Strict enforcement to keep the effective walk free of commercial and other uses.	• Adequately wide for street furnishings.	• There are no conflicts. • Bicycles are adequately separated.
C	• None • Illegal parking is prevented by curbs over 15 cm or 6".	• Visually impaired guided by texture differences.	• Effective walk is marginally reduced at certain sections by street furnishings or vendors. • The reduction does not affect flow or movements. • Average enforcement to keep the effective walk free of obstructions.	• Adequate, but due to improper placement of street furniture, they encroach on to the effective walkway.	• There are some conflicts with bicycles because bike paths are designed on sidewalks with inadequate separation.
D	• Observed • Illegal parking is observed at certain sections because of low curbs.	• No tactile cues for the visually impaired.	• Effective walk is considerably reduced by street furnishings or vendors. • The reduction affects pedestrian flow and movements. • Poor enforcement to keep the effective walk free of obstructions.	• Ancillary walk is insufficient relative to the observed levels of uses and activities.	• There are frequent conflicts with bicyclists, because they use the walkway without any channelization.
F	• Frequent • Illegal parking is observed because of low curbs, poor design.	• No tactile cues for the visually impaired. • Extremely hazardous for them.	• Effective walk is serving other uses, and not pedestrians (parking). **or,** • The effective walk is missing at sections. • The pedestrians are forced to use the road due to paucity of space. • There is no enforcement to keep the effective walk free of obstructions.	• Ancillary walk is absent.	• There are no conflicts with bicyclists, because they use the roads under mixed traffic conditions.

TABLE 3 QOS Levels A-F for Level of Conflicts and Impediments at Intersections

QOS Levels	Conflicts with Vehicles	Conflicts with Bicyclists	Tactile Guidance to the Visually Impaired	Intersection Design	Speed Reduction Measures
A	• None • Vehicles are banned.	• None • Bicyclists use the roads with transit vehicles.	• Specially designed sensory cues.	• Well designed curbs with tactile guidance. • Pedestrian refuges are not needed. • There is no visibility problem as vehicles are banned.	• Speed reduction measures are not required because traffic is banned.
B	• None • Pedestrians have exclusive time separation.	• None • Bicycles have separate channelization, and time separation.	• Specially designed sensory cues. • Pedestrian actuated audible signals.	• Well designed curbs with tactile guidance. • Pedestrian refuges are well designed (with bollards and landscaping) and placed where needed. • High visibility of traffic through extended curbs.	• Speed is reduced using traffic calming measures.
C	• Possible • Pedestrians face conflicts from right turning vehicles.	• Possible • Bicycles use the crosswalks with pedestrians.	• Visually impaired guided by texture differences.	• Curb ramps are adequate and usable, but do not offer any tactile cues. • Pedestrian refuges are placed where needed. • Adequate visibility due to restrictions imposed on parking.	• Speed is reduced using conventional methods -- stop signs, flashing lights, rumble strips.
D	• Possible • Pedestrians face conflicts with right and left turning vehicles at signals.	• Possible • Bicycles use the crosswalks with pedestrians.	• No tactile cues for the visually impaired.	• Ramps are improperly aligned. • Pedestrian refuges are missing where needed. • Poor visibility, vehicles park very close to the crosswalk.	• There are no speed reduction measures.
F	• Very high • There are no traffic control devices, pedestrians are left to fend for themselves.	• Very high • There are no traffic control devices.	• No tactile cues for the visually impaired. • Extremely hazardous situation for them.	• Curb ramps are missing. • Pedestrian refuges are missing. • Extremely dangerous conditions, vehicles park on the crosswalk.	• There are no speed reduction measures.

TABLE 4 QOS Levels A-F for Visual and Psychological Designs to Modify Drivers' and Cyclists' Behavior

QOS Level	Speed Reduction Measures	Compliance with traffic signs and signals *(For every 50 vehicles observed)*	Street Layout and Design	Regulatory Signs
A	• Not required, because vehicles are banned.	• Over 100 percent	• Low level lights (4-5 m or 12-15 ft) • Pedestrian oriented design (wide walkways, landscaping)	• Regulatory signs are clear and prominently placed.
B	• Very effective. • Traffic calming designs -- such as– neck downs, raised crossings, pinch points etc. are placed.	• 80-85 percent	• Low level lights (4-5 m or 12-15 ft) • Completely pedestrian oriented design (wide walkways, landscaping, and traffic calming designs)	• Regulatory signs are clear and prominently placed.
C	• Partially effective. • Traditional methods of speed reduction are used -- such as-- stop signs, rumble strips, flashing beacons etc.	• 70-80 percent	• Moderate level street lights (5-7 m or 15-20 ft). • Partially pedestrian-oriented design (sufficiently wide walkways relative to the street cross-section; one way streets with one or two lanes, less than 3m or 10 ft etc.)	• Messages on the regulatory signs are unclear, although prominently placed.
D	• There are no speed reduction measures.	• 50-70 percent	• High level street lights over 7 m or 20 ft. • Vehicle oriented design (Wide roads and narrow sidewalks).	• Regulatory signs are improperly placed.
F	• Streets have been over-designed with wide lanes encouraging speeding.	• Less than 50 percent	• High level street lights over 7m or 20 ft. • Vehicle oriented design (Multi lane two way roads).	• Regulatory signs are missing.

TABLE 5 QOS Levels A-F for Possibility of Pedestrian Falls and Injuries

QOS Level	Condition of the Walking Surfaces	Conditions faced by Pedestrians with Assisting Devices	Other Hazardous Conditions
A	• Walking surfaces are in excellent condition. They are well maintained and in perfect condition. • There are no chances of tripping.	• Safe and injury free.	• Walkways **are enclosed or canopied,** and do not have: (a) drainage problems; (b) icy patches or snow accumulation; (c) litter.
B	• Walking surfaces are in good condition. Cracks and others problems have been repaired. • There are no chances of tripping.	• Safe and injury free.	• Walkways do not have: (a) drainage problems after rain; (b) icy patches or snow accumulation; (c) litter.
C	• Walking surfaces are in average condition. Uneven surfaces are found in some sections.	• Tripping is possible at certain sections.	• Walkways have: (a) minor drainage problems after rain; (b) icy patches at certain sections during winters.
D	• Walkways are in poor conditions. Broken uneven surfaces are found all along the walkway.	• Pedestrians can trip over or seriously hurt themselves, if they are not careful.	• Walkways have any one of these conditions all the time: (a) drainage problems; (b) slippery icy surfaces at sections; (c) litter -- trash bags or cans blocking walk.
F	• Walkway is unusable at stretches. Broken uneven surfaces with moderate to large pot holes.	• Major injuries can be sustained, particularly by the visually impaired.	• Walkways have any one of these conditions throughout the stretch, forcing pedestrians to use the road: (a) flooding after rain; (b) slippery surfaces and icy patches during winter; (c) uncleared snow during winter; (d) vehicles blocking walks; (e) litter -- broken bottles, glass fragments, sharp objects. (f) litter -- fairly large objects or trash bags blocking walk, furniture, appliances.

TABLE 6 QOS Levels A-F for Perception of Security

QOS Levels	Activity Levels	Lighting	Perception of the Environment	Surveillance
A	• Very high activity levels during the day. • Very high activity levels till late in the evening.	• Well lit by low level lights (4-5m or 12-15 ft).	• The environment fosters a secure image: (Any **three** of the conditions.) (a) various users are observed -- vendors, pedestrians, etc.; (b) stores line the walkways; (c) buildings along the walkways generate high levels of activity and turnover throughout the day till late in the evening; (d) buildings are oriented toward the street/ walk.	• Police surveillance is constant. • There are also security devices on each section of the walk.
B	• High activity levels through-out the day. • High activity levels till late in the evening.	• Well lit by low level lights (4-5m or 12-15 ft).	• The environment fosters a secure image: (Any **three** of the conditions.) (a) various users are observed --vendors, pedestrians, etc,; (b) stores line the walkways; (c) buildings along the walkways generate high levels of activity and turnover throughout the day till late in the evening; (d) buildings are oriented toward the street/ walk.	• Police patrols are frequent by foot or on bicycle. • There are also security devices on each section of the walk.
C	• Moderate to high activity levels during the day. • Sporadic and low during the evenings.	• Moderately lit by lights ranging from 5-7 m (15-20 ft) in height.	• The environment portrays a <u>secure</u> image only during the day: (Any **two** of the conditions.) (a) many users are observed on the walkways during the day; (b) stores close by late afternoon. (c) buildings along the walkways generate moderate levels of activity and turnover throughout the day till late in the afternoon. (d) buildings are oriented towards the street.	• Police patrols regularly in vehicles. • There are no security devices along the sidewalks.
D	• Low to moderate activity levels during the day. • Very low activity levels during the evenings.	• Inadequately lit by high level street lights.	• The environment portrays a negative image throughout the day and evening: (Any **two or more** of the conditions.) (a) few users are observed on the walkways; (b) stores are absent; (c) stores are heavily secured with minimum interaction with their customers; (d) buildings along the walks generate low levels of activity. (e) buildings have no interface with the walkways.	• Police patrols are infrequent and rare. • There are no security devices along the sidewalks.
F	Unfavorable activities observed (drug dealing etc.) especially during the evenings.	Street lights are missing, or broken.	• The environment reflects an unsafe image all the time: (Any **three** of the conditions.) (a) few users are observed on the walkways; (b) stores are absent; (c) stores are heavily secured with minimum interaction with their customers; (d) buildings have very little interface with the walkways; (e) buildings are boarded up; (f) graffiti, and vandalism are rampant.	• Police patrols are infrequent and rare. • There are no security devices along the sidewalks.

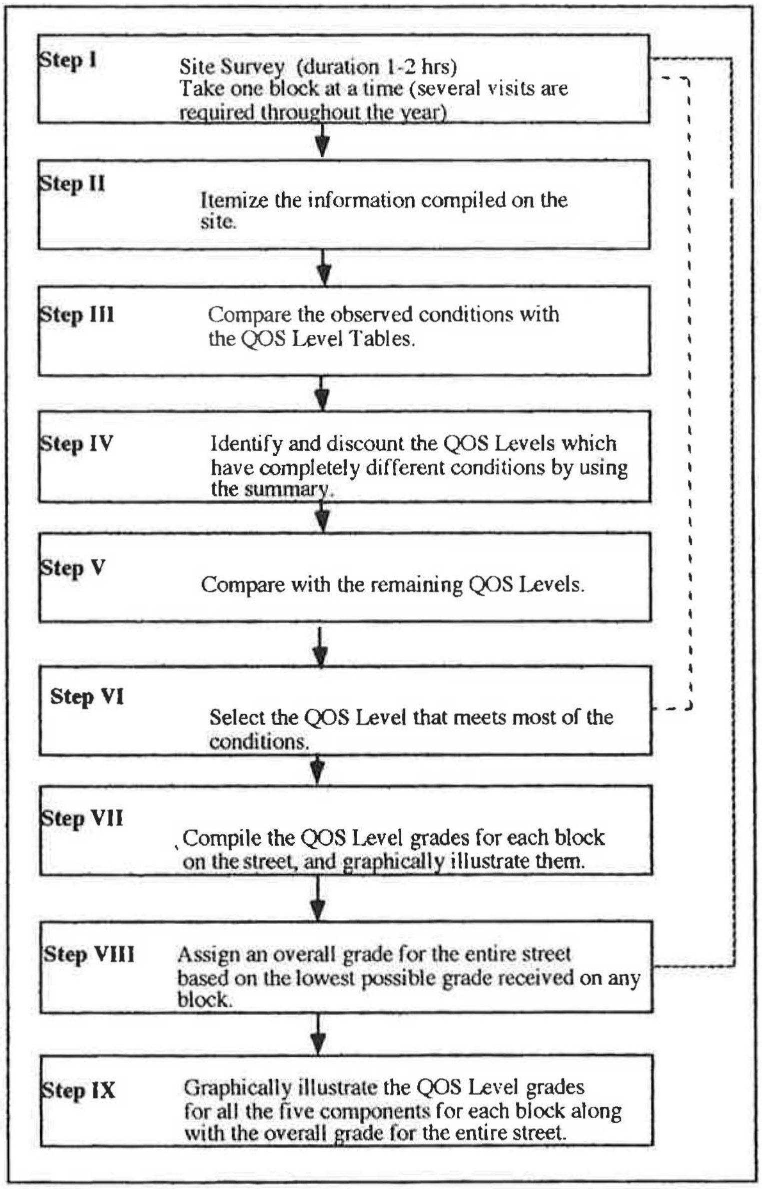

FIGURE 4 Methodologic process for assigning QOS level grades.

The eighth step involves assigning an overall grade for the entire street. The entire street is assigned a grade on the basis of the lowest grade received on any section or block.

The entire process is repeated for all of the five components mentioned earlier and shown in Figure 5.

In the last step, the grades assigned for each of the five components for each block are shown along with the overall street grade, similar to the one shown for the hypothetical Chester Avenue in Figure 5.

ASSESSMENT OF METHOD

The proposed method evinces both positive and negative attributes, as discussed next.

The advantages of the method are as follows.

Provides In-Depth Analysis of Macro- and Microlevel Conditions on Walkways

The evaluation of safety at both macro- and microlevels would enable planners and designers to obtain a more comprehensive picture of the conditions on the walkways. The grade on macrolevel conditions will indicate the quality of channelization for each mode to ensure a general level of safety, particularly for the pedestrians. At the microlevel, each of the five independent components, such as perception of security, or level of maintenance for elimination of falls and injuries, will indicate the qualitative conditions of these components in ensuring a conflict-free, safe pedestrian environment. By studying these microlevel elements separately, we can identify those that are independently influencing (positively or negatively) the safety of the pedestrians.

Elements \ Blocks	41st-42nd	42nd-43rd	43rd-44th	44th-45th			(n-1)-nth	Overall Grade for the Street
Barriers and Impediments on Walkways	C	C	D	C			B	D
Barriers and Impediments at Intersections	C	D	C	C			C	D
Elimination of falls and injuries	D	D	C	C			C	D
Design for Drivers' Behavior Modification	D	C	D	D			C	D
Perception of Security	C	D	C	D			D	D
Service Level Grade	D	D	F	D			D	Overall SL F

FIGURE 5 Graphic illustration of QOS level grades and overall grades for hypothetical Chester Avenue.

Enables Faster Decisions on Actions to be Taken

A graphic representation (Figure 5) of the inventory on the strengths and weaknesses of each block of walkway on a street enables professionals to:

1. Make swifter decision on the actions to be taken.
2. Identify the sections or blocks that require immediate attention. For example, on the basis of the information provided in Figure 5, the block between 43rd and 44th streets on hypothetical Chester Avenue requires immediate attention because, compared with other sections, it received the lowest grades (three QOS D grades, and SL F for the type of separation).

Enables Professionals to Prioritize Work on Entire System of Walkways in a City

The tabulation of the overall street grade helps in prioritizing work on those streets that have received the lowest grade. In Figure 6, the hypothetical streets that have been evaluated for the quality of channelization (service levels) and elimination of conflicts and barriers on the walkways have been placed in the appropriate square in the matrix on the basis of their grades.

On the basis of these grades, Chester followed by Baltimore will need immediate attention, both at macro- and microlevel conditions.

DRAWBACKS OF METHOD

The proposed method does have some weaknesses.

Method Requires Considerable Amount of Financial Commitment and Manpower Resources

The block-by-block survey for large sections of the city using the service levels and the five disparate QOS levels require: first, a large number of skilled personnel, and second, several visits to each site. The involvement of a large number of surveyors is also necessary to complete the evaluation within a relatively shorter period.

After survey, the grades from all of the sites must be compiled and then graphically shown.

Unfortunately, all of these processes depend heavily on the availability of skilled manpower, and sufficient finances are required to pay for labor and other expenses. One way of alleviating the financial and manpower dependence would be by evaluating smaller sections of the city that are traversed frequently by pedestrians and contain at least one major origin and destination point.

Method May Suffer From Some Level of Subjectivity

Although effort has been made to reduce the level of subjectivity, it is very difficult to completely eliminate it. Because it is a qualitative evaluation of the conditions present at each site, the grade assigned by each surveyor can be colored to a certain extent by his or her personal perception of the conditions.

The problem of subjectivity can be mitigated to a large extent by sending different surveyors to the same site to gather the necessary information. This would not require additional work or manpower, because the evaluation of the five QOS levels (which are most prone to subjectivity) do require several site visits.

CONCLUSION

The proposed method attempts to evaluate safety on the walkways from different dimensions. First, different components of safety, such as conflict-free environments on the walkways and intersections, elimination of falls and injuries, and security, have all been included in the evaluation method to obtain a holistic view of the conditions of the walkways. Second, pedestrian mode has not been treated in isolation. The safety problems that result from interfaces

Elimination of Conflicts and Barriers on the walkways

Separation of Modes

Service Levels \ QOS	A	B	C	D
A				
B				
C		Walnut Spruce	Chestnut	
D				Baltimore
E				Chester
F				

FIGURE 6 Qualitative evaluation of hypothetical streets using QOS and service levels.

with other modes along the walkways and at intersections are incorporated in the method.

In addition, the methodologic process discussed in this paper will enable the user of the method to derive the grades for service levels and QOS levels systematically, and then show the assessment for the street (on a block-by-block basis) and the entire network of streets in a city, through clear and useful graphic illustrations.

The method does evince some amount of subjectivity, as it is basically a qualitative evaluation. But it offers an alternative way of studying and evaluating walkways to enable traffic planners and engineers to plan and design a better and safe network of walkways for all types of users.

ACKNOWLEDGMENTS

The author is deeply grateful for the comments and suggestions given by Dr. Anthony R. Tomazinis, which helped in arriving at the final draft of this paper. The author also thanks Dr. Vukan R. Vuchic for his constructive criticism of the proposed method.

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Driver and Pedestrian Comprehension of Pedestrian Law and Traffic Control Devices

JOHN E. TIDWELL AND DEVIN P. DOYLE

A nationwide survey was conducted to identify how well people understand pedestrian safety issues. The study focused on the respondents' assessment of pedestrian involvement in traffic accidents and knowledge of pedestrian-related traffic control devices and pedestrian-related laws. Responses from both pedestrians and motorists were included in the findings. Questionnaires were distributed at driver's license examination stations in each of the 48 contiguous United States. The American Association of Retired Persons (AARP) also distributed questionnaires to many of its members participating in a defensive driving course offered by the organization. From the examination stations, 3,595 completed questionnaires were returned, while 1,231 completed questionnaires were returned from the AARP. The surveys were disaggregated based on the personal experience and demographic characteristics of the respondents. These groups were tested using the chi-square method to identify statistically significant differences. The study found that a high percentage of the respondents are knowledgeable of proper pedestrian-vehicle interaction. Many of the respondents, however, appear to have a poor understanding of many of the pedestrian-related traffic control devices and issues related to safe pedestrian habits. While many of the disaggregated groups showed statistical differences, few showed practical differences that would justify the development of special programs to target specific groups, such as the elderly.

Pedestrian safety issues are particularly important to the transportation community because of the vulnerability of individuals using this mode of transportation. In 1992, the NHTSA reported that 5,546 pedestrian fatalities and an estimated 94,000 pedestrian injuries had occurred in the United States (*1*). The gravity of the results of pedestrian accidents can be seen in the disparity between pedestrian fatalities as a percentage of all traffic-related fatalities and pedestrian injuries as a percentage of all traffic-related injuries. In 1992 pedestrians accounted for 14.1 percent of all traffic fatalities, while pedestrian injuries accounted for only 2.8 percent of all traffic-related injuries (*1*).

Over the past two decades, several studies have analyzed pedestrian collision and conflict data. This research was conducted to study target groups for pedestrian safety, such as those by Knoblauch (*2*) and Reiss (*3*). Other researchers, such as Robertson (*4*) and Zegeer (*5*), have tried to determine the effectiveness of alternative pedestrian sign and signal messages. So far, little attention has focused on the comprehension of current pedestrian-related traffic control devices and laws. In 1980 and again in 1990, the Pedestrian Safety Committee of the Transportation Research Board identified "pedestrian comprehension of traffic control devices" as a priority issue (*6*). This study addresses this issue, as well as issues related to laws that involve pedestrian and vehicle interaction. If pedestrians and motorists do not understand the rights and obligations they have concerning their interaction, serious consequences may result.

Two government documents address the issues of traffic control devices and traffic laws. The FHWA periodically updates the *Manual on Uniform Traffic Control Devices* (MUTCD), which establishes guidelines for the installation of all traffic control devices throughout the United States. States are required to adopt this manual or develop and adopt one that closely conforms to it. The manual is the basis for the installation and use of all pedestrian-related control devices. The Highway Safety Act of 1966 made all states responsible for developing and implementing "a program to achieve uniformity of traffic codes and laws". The *Uniform Vehicle Code* (UVC), maintained by the National Committee on Uniform Traffic Laws and Ordinances, was selected to serve as the guide for the development of states' motor vehicle and traffic laws. For this study, the section of the code titled, "Rules of the Road," serves as the guide to issues related to pedestrian and motorist laws.

It is widely accepted that two pedestrian groups need special attention: the young and the old. While neither has received much attention with regard to traffic control devices, both groups demand consideration in the area of pedestrian safety. In 1992, pedestrians under the age of 16 had an estimated injury rate of more than 57 injuries for every 100,000 individuals. This rate is much higher than that of any other age group. For pedestrians over the age of 54, the fatality rate is 3.28 fatalities per 100,000 people and is nearly one percentage point higher than the next highest age group.

Unfortunately, the study and evaluation of younger pedestrians (15 years and under), is a complicated task, as indicated in a study conducted by Reiss (*3*). This study involved a series of detailed question-and-answer-sessions. While collecting information on the knowledge and level of understanding of pedestrian issues by the younger groups is important, the effort involved was deemed beyond the scope of this study. Instead, this study focuses on the driving population and places special emphasis on older Americans.

STUDY OBJECTIVES, METHODOLOGY, AND ANALYSIS

Two brief questionnaires were used to evaluate the respondents' understanding of safe pedestrian and motor vehicle interaction. The major objectives were (*a*) to identify specific traffic control devices that may be misunderstood by a number of respondents and (*b*) to evaluate the knowledge or awareness of various issues and traffic laws related to pedestrian safety. The methodology consisted of the development, distribution, and analysis of two questionnaires addressing these issues.

The research team was particularly interested in gathering the opinions of a diverse group of respondents. It was decided that the

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investigation should be conducted in each of the 48 contiguous United States. To execute the study on a national level, two types of facilities were selected in each of the states as questionnaire distribution centers. The first of these involved the use of driver's license examination stations in cooperation with each state's department of motor vehicles (DMV). This type of facility was selected because it would ensure responses from both the driving and the walking public. The second type of location included 55 Alive training courses offered by the American Association of Retired Persons (AARP). This would provide the analysts with a set of responses from older citizens, who have been identified as a high-risk group for fatal pedestrian collisions.

Questionnaire Development

The questionnaire was designed to focus on a variety of pedestrian safety issues. The initial analysis involved an in-depth review of previous pedestrian studies, pedestrian-related traffic control devices addressed in the MUTCD, and pedestrian traffic laws provided in the UVC. Input also was sought from the following transportation safety groups: the American Automobile Association (AAA) Foundation for Traffic Safety, FHWA, and NHTSA. Using the information collected from those sources, a draft questionnaire was developed containing 25 questions. The questionnaires were then reviewed by the three safety groups, and contacts were established in each state's DMV. A large percentage of the comments received mentioned the length of the survey and the complexity of several of the questions. The safety groups agreed that a shorter questionnaire posed in simple language would assure a higher response rate. Based on these suggestions, a decision was made to use two survey forms. Respondents were neither asked nor expected to complete both forms. While some questions are identical on both the forms, most address unique pedestrian safety issues. The questionnaires are shown in Figures 1 and 2.

Each of the questions was carefully selected based on one of four types of information collected: (*a*) demographic characteristics, (*b*) problem assessment, (*c*) knowledge of pedestrian laws, and (*d*) knowledge of pedestrian traffic control devices. The first set of questions addresses the personal characteristics and experiences of each of the respondents. These questions are common to both Surveys I and II and ask for the respondent's gender, age, personal experience, and safety education. The responses were later evaluated to determine whether statistical differences exist between the various groups. The next set of questions is related to the respondents' assessment of various pedestrian safety issues. Topics include the use of alcohol by pedestrians, the significance of pedestrian fatalities, and the education of younger pedestrians. The third set of questions involves issues of pedestrian laws. State laws related to pedestrians, right-of-way at both midblock and intersection crossings and issues related to walking on or along roadways are addressed. The final set of questions deals with the respondents' knowledge and comprehension of various traffic control devices, including advance pedestrian crossing signs, pedestrian signals, and pedestrian signs in school zones.

After applying many of the changes suggested by the questionnaire reviewers, three pretests were conducted at two sites. These pretests included brief interviews with the respondents in order to evaluate any difficulty they may have understanding the questions. After each of the tests, observations and comments made by the respondents were weighed, and changes were made when deemed appropriate. These tests, conducted to identify any complex or poorly worded questions, were considered important because the research team could not provide the staff to distribute the questionnaires and answer questions at the various sites around the country.

Data Collection

Because the purpose of this study was to collect information that could be applied on a national level for the development of safety planning and programming projects, data were collected from each of the forty-eight contiguous United States. The research team chose drivers license examination stations to distribute questionnaires to the public. The use of these facilities yielded a large volume of data without a large staff and provided a survey of both the driving and the walking public.

The DMV in each state was contacted before proceeding with the selection of the various sites. After contacts were established, each was asked to identify two examination stations in the state where the surveys could be distributed. The selection was based on criteria established by the research team. Because more than 75 percent of all pedestrian injuries and fatalities occur in urban areas, the contacts were asked to select at least one site within the state's largest metropolitan area (*7*). The remaining site was to be located in a separate city large enough to demand a need for pedestrian safety. The second criterion called for the selection of full-time examination stations. It was believed that full-time facilities would have a larger volume of customers, assuring a higher response rate and a more timely completion of the questionnaires for analysis.

The AARP was selected to assist in the distribution of questionnaires to the older group. Respondents were limited to participants in the AARP 55 Alive safety course. The task of selecting specific groups to be surveyed was given to the 55 Alive coordinators in each state. The coordinators were asked to apply the same criteria as was applied to the selection of the examination stations. Participants in the courses were asked to voluntarily complete the questionnaires.

Data Analysis

The questionnaires were sent to the examination stations and the AARP groups in late summer of 1992. The completed forms were returned over an eight-month period from September 1992 to April 1993. After the surveys were returned they were entered into a computer software program for analysis, Statistical Analysis Software (SAS). From the examination stations in the 48 contiguous states, 3,595 completed questionnaires were returned. From the AARP 55 Alive courses, 1,231 completed surveys were returned. There was a concern among the research team that the groups responding to the two questionnaires may be statistically different based on the demographic questions. Using SAS it was determined that no significant statistical differences exist between the groups responding to Surveys I and II.

After all the questionnaires were completed, summary statistics were calculated. The responses were disaggregated based on the responses to the demographic questions to create analysis groups. These analysis groups include the following:

- Experience or knowledge of a pedestrian collision,
- Pedestrian safety education,

Survey I

CITY ________________
STATE ________________

PEDESTRIAN SAFETY QUESTIONNAIRE

WE NEED YOUR HELP!

This questionnaire is part of an effort to reduce pedestrian injuries and deaths. The project is funded by the AAA Foundation for Traffic Safety. The Pedestrian Safety Institute of The University of Tennessee's Transportation Center is the research agency.

Please note that your participation is entirely voluntary. It will not in any way affect the outcome of your drivers license test. Please do not put your name on the questionnaire. Your completing and returning this questionnaire will be considered your informed consent.

If you are willing to help us improve pedestrian safety, please answer these questions to the best of your ability. Thanks for your help.

1. Have you or someone you know ever been involved in a pedestrian accident, either as a pedestrian or as a driver?
____ I have ____ A family member has ____ Someone else I know has ____ No one I know has

2. Do you believe children are being taught about pedestrian safety in their school?
____ Yes ____ No

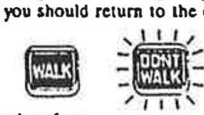
3. Pedestrians account for about what percentage of all traffic related deaths?
____ 1% ____ 5% ____ 10% ____ 15% ____ 20%

4. What do you believe is the single most likely reason why pedestrian accidents happen?
____ Driver error ____ Alcohol ____ Poor visibility
____ Pedestrian error ____ Other (specify) ________________________________

5. In the downtown area of a large city you may legally cross a street only at a traffic signal or where there is a painted crosswalk.
____ TRUE ____ FALSE ____ DON'T KNOW

6. If a pedestrian is just beginning to cross the street in a crosswalk that does not have a pedestrian signal, you must slow down or stop to let the person finish crossing the road.
____ TRUE ____ FALSE ____ DON'T KNOW

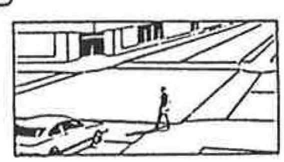
7. Assume you have just started crossing a street on a "WALK" signal, but the signal quickly begins flashing "DON'T WALK". This means there isn't enough time to cross, and you should return to the curb.
____ TRUE ____ FALSE ____ DON'T KNOW



8. If sidewalks are provided, you may not legally jog on the road surface.
____ TRUE ____ FALSE ____ DON'T KNOW

9. Assume you are at an intersection with a pedestrian signal that has a button labeled "Push Button for WALK Signal". The signal will immediately change to "WALK" when you push the button.
____ TRUE ____ FALSE ____ DON'T KNOW

10. Assume you are at an intersection that lets you turn right on red after you stop. The pedestrian in the figure has just begun to cross at the crosswalk. He must wait and let you turn before he finishes crossing.
____ TRUE ____ FALSE ____ DON'T KNOW



11. This sign is placed approximately 200 ft. in advance of a crosswalk.
____ TRUE ____ FALSE ____ DON'T KNOW

12. Are you:
____ Male ____ Female

13. Your age is:
____ Under 20 ____ 20-29 ____ 30-39
____ 40-49 ____ 50-64 ____ Over 64

14. Have you reviewed your state's drivers license manual recently?
____ Yes ____ No

Please return this completed questionnnaire to the person who gave it to you. We appreciate your help very much.

FIGURE 1 Pedestrian safety questionnaire, Survey I.

Survey II

CITY ____________
STATE ____________

PEDESTRIAN SAFETY QUESTIONNAIRE

WE NEED YOUR HELP!

This questionnaire is part of an effort to reduce pedestrian injuries and deaths. The project is funded by the AAA Foundation for Traffic Safety. The Pedestrian Safety Institute of The University of Tennessee's Transportation Center is the research agency.

Please note that your participation is entirely voluntary. It will not in any way affect the outcome of your drivers license test. Please do not put your name on the questionnaire. Your completing and returning this questionnaire will be considered your informed consent.

If you are willing to help us improve pedestrian safety, please answer these questions to the best of your ability. Thanks for your help.

1. Have you or someone you know ever been involved in a pedestrian accident, either as a pedestrian or as a driver?
   ____ I have ____ A family member has ____ Someone else I know has ____ No one I know has

2. Who do you feel should teach children about safe pedestrian habits?
   ____ School ____ Private Safety Organization
   ____ Home ____ Police
   ____ Church ____ Other (specify) ________________________________

3. Have you ever received any advice about pedestrian safety either in school, on television or on the radio, in newspapers or in magazines, or in brochures or pamphlets?
   ____ Yes ____ No

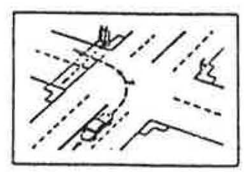
4. About what percentage of all pedestrian deaths involve drunk pedestrians?
   ____ 5% ____ 10% ____ 20% ____ 40% ____ 50%

5. If there are no sidewalks, you should always walk on the right-hand side of the road with the traffic.
   ____ TRUE ____ FALSE ____ DON'T KNOW

6. If you are standing on the sidewalk at a painted crosswalk not at an intersection, traffic is not required to stop to let you cross the road.
   ____ TRUE ____ FALSE ____ DON'T KNOW

7. A "WALK" signal at an intersection means that you may cross the road safely because no cars will be driving through or turning into the crosswalk.
   ____ TRUE ____ FALSE ____ DON'T KNOW

8. Assume you are a motorist waiting to turn left at an intersection that does not have a left-turn arrow. When the light turns green, the pedestrians in the figure step into the crosswalk as you are turning. You must let the pedestrians finish crossing before you finish your turn.



   ____ TRUE ____ FALSE ____ DON'T KNOW

9. When you are driving in a school speed zone, you may resume your speed as soon as you can see the "END SCHOOL ZONE" sign.
   ____ TRUE ____ FALSE ____ DON'T KNOW

10. This sign is placed approximately 200 ft. in advance of a pedestrian crossing used by children to go to and from a school.
    ____ TRUE ____ FALSE ____ DON'T KNOW

11. Most pedestrian accidents in cities happen while a person is crossing the road at some place other than an intersection.
    ____ TRUE ____ FALSE ____ DON'T KNOW

12. If you wear white clothing while walking along a roadway at night, drivers will be able to see you from a safe distance.
    ____ TRUE ____ FALSE ____ DON'T KNOW

13. Are you:
    ____ Male ____ Female

14. Your age is:
    ____ Under 20 ____ 20-29 ____ 30-39
    ____ 40-49 ____ 50-64 ____ Over 64

15. Have you reviewed your state's drivers license manual recently?
    ____ Yes ____ No

**Please return this completed questionnaire to the person who gave it to you.
We appreciate your help very much.**

FIGURE 2 Pedestrian safety questionnaire, Survey II.

- Gender of respondent,
- Age of respondent, and
- Knowledge of the driver's manual.

The chi-square method was used to analyze the responses to these questions. It was deemed an appropriate statistical tool because of the categorical, non-normal nature of the questions. The statistic was used to determine whether significant differences exist between the groups. The SAS tests were conducted using a 95 percent level of confidence to assure that a Type I error did not occur. The correct answers to the questions, against which the responses were tested, were determined by surveying the state DMV contacts, and by reviewing each state's codes and statutes, the MUTCD, and the UVC.

SURVEY RESULTS

The research team received 4,826 completed pedestrian questionnaires. The distribution of these questionnaires by type and source is shown in Table 1. Seventy-seven examination stations in rural and urban areas participated in the study. These areas ranged in population from 3,500 to 8.8 million and included: New York City, Los Angeles, Chicago, Boston, Detroit, and Atlanta. Of the AARP groups, representatives from 20 states assisted in the study.

Based on the demographic information provided by the respondents, the surveys were disaggregated to determine target groups that may have a misunderstanding of pedestrian laws and traffic control devices. The summary of these responses is provided in Table 2. The remaining questions on the two surveys are subdivided into one of three groups. These groups include questions related to the respondents' perception and assessment of pedestrian issues and problems; the UVC; and the MUTCD.

Respondents' Assessment of Pedestrian Issues

Seven questions on each of the two questionnaires asked the respondent to provide an assessment or perception of the current condition related to specific pedestrian issues. These issues include the education of children on pedestrian safety, general pedestrian collision issues, drunk pedestrians, the location of pedestrian accidents, and walking at night. The total number of responses to each of these questions is shown in Table 3.

Safety Education of Children

Question 2 on Surveys I and II involves the education of children on pedestrian safety issues. On Survey I this question asked respondents if they think schools are taking responsibility to inform children about safe pedestrian habits. A large percentage of respondents felt that schools are educating children about pedestrian safety. On Survey II the question asked respondents who they think should be responsible for providing pedestrian safety training to children. The majority indicated that children should be taught about this issue in the home and in school.

TABLE 1 Distribution of Questionnaires by Type and Source

	Driver License Examination Station	AARP	Combined Responses
Survey I	1,832	489	2,321
Survey II	1,763	742	2,505
Total Responses	3,595	1,231	4,826

General Pedestrian Issues

The remaining questions deal with general pedestrian issues and include the assessment of all pedestrian collisions and fatalities and drunk pedestrian fatalities. An attempt was made to determine whether the respondents are aware of dangerous pedestrian locations and the dangers of walking at night. Question 3 on Survey I asked the respondents to estimate what percentage of all traffic fatalities are pedestrians. The research team was interested in finding out if the respondents would underestimate or correctly identify the percentage of 15 to 20 percent. Nearly one-third of all respondents believe that pedestrians account for 10 percent or less of all traffic fatalities. The female respondents had a higher statistically significant number of correct responses to this question. An effort also was made to determine the respondents' general perception of the pedestrian safety problem by asking their opinion of the typical causes of pedestrian collisions in Question 4. By an overwhelming margin, respondents in both groups believe that collisions occur because of simple driver or pedestrian error or because of the involvement of alcohol.

A report generated by NHTSA titled, *Traffic Safety Facts* (*1*), indicates that over the past 10 years the percentage of pedestrian fatalities involving pedestrians with blood-alcohol concentration levels (BAC) of 0.10 or higher has ranged from 35 to 39 percent. The BAC scale is used in many states to determine if driver is legally intoxicated. Question 4 on Survey II was asked to determine whether the respondents recognize the danger of being a drunk pedestrian. The answers indicate that the respondents may not be aware of the extent of this problem.

Another important issue is whether most pedestrian collisions occur at intersections or away from intersections. The purpose of Question 11 was to determine whether the respondents perceive one location more hazardous than the other. According to 1992 injury and fatality statistics, the number of non-intersection pedestrian collisions exceeds those at intersections for all age groups with the exception of the 65 years and over group (*1*). The majority of the respondents correctly perceived non-intersection locations to be more hazardous. A significantly higher percentage of respondents 50 years and over and respondents having recently reviewed their state's driver's license manual answered this question correctly.

In 1992 more than 82 percent of all pedestrian fatalities occurred between 6 p.m. and 6 a.m., and more than 46 percent occurred between 9 p.m. and 3 a.m. Because a higher percentage of fatalities occur during hours of darkness, it is important to determine the respondents' perception of danger while walking at night. One study conducted for NHTSA by Blomberg (*8*) found that white clothing worn at night was detectable from a distance of only 68.3 m (224 ft). The average stopping distance for an automobile travelling 56.3 km/hr (34.9 mph) is 68.6 m (225 ft); for higher speeds this distance increases significantly. Other studies by Allen (*9*) and Hazlett and Allen (*10*) found that wearing white does have some benefit in low-speed conditions, but for higher speeds it may not

TABLE 2 Summary of Responses: Demographic

	Examination Station (%)		AARP (%)	
	Survey I	Survey II	Survey I	Survey II
Have you or someone you know been in a pedestrian accident (Nos. 1.1 and 2.1)				
I have	8	10	9	11
Family member	9	11	9	9
Aquaintance	21	18	15	17
No one I know	62	61	67	63
Have you ever received pedestrian advice (No. 3)				
Yes		74		73
No		26		27
Your gender (Nos. 1.12 and 2.13)				
Male	50	39	48	44
Female	50	61	52	56
Your age (Nos. 1.13 and 2.14)				
Under 20	11		10	
20-29	25		26	
30-39	26		24	
40-49	20		21	
50-64	13	24	14	28
Over 64	5	76	5	72
Have you reviewed your state's driver's manual (Nos. 1.14 and 2.15)				
Yes	45	47	42	50
No	55	53	58	50

provide a motorist with adequate stopping distance. Blomberg's study found that retroreflective material worn at night is detectable from distances over 226.8 m (743.9 ft). The results of these studies were used to determine the correct response to Question 12, FALSE. Wearing white at night only provides a marginal increase in pedestrian safety and only in low-speed situations. A significantly higher percentage of respondents who had not reviewed their state's driver license manual responded correctly. In addition, a significantly higher proportion of respondents at the examination stations responded correctly when compared with the AARP responses.

Questions Related to the UVC

It is important that pedestrians and motorists be aware of their rights and responsibilities as road users, particularly for situations involving the interaction of these groups. In each of the two questionnaires, seven questions were asked related to issues addressed by the UVC. These issues include questions related to midblock crossings (MBCs), right-of-way at intersections, and walking along or on the roadway. The results of these questions are provided in Table 4.

Midblock Crossings

Question 5 of Survey I asked respondents about their obligation to cross at intersections or painted MBCs in the downtown area of a large city. The legal element of this question is addressed in Section 11-503(c) of the UVC and states that between adjacent operating signalized intersections, "pedestrians shall not cross at any place except in a marked crosswalk." Because most downtown intersections are signalized, the correct response is TRUE. The overwhelming majority of respondents answered this question correctly. It should be noted that the state codes in South Dakota and Wisconsin appear to allow midblock crossings at locations away from crosswalks while the Massachusetts and New York state codes do not address this issue. Statistical differences were detected between the responses from the AARP group and the examination station group.

The research team was also interested in determining who the respondents believe has the right-of-way when a pedestrian is standing on the curb at an MBC. Section 11-502(a) of the UVC states that motorists must yield the right-of-way to pedestrians crossing the road within a crosswalk. It does not state that motorists must stop or slow down to allow a pedestrian on the curb to cross. The correct response to Question 6 on Survey II therefore is TRUE. Based on the responses it appears that about 69 percent of the respondents do not understand their obligations in this situation, which could potentially be very dangerous. A significantly higher percentage of respondents having remembered receiving safety information responded correctly. This issue is also addressed in Question 6 of Survey I. Respondents appear to understand their obligations as motorists to grant the right-of-way to pedestrians crossing within a marked crosswalk. A significantly higher proportion of respondents who had recently reviewed their state's driver's license manual responded correctly.

Right-of-Way at Intersections

Question 8 on Survey II and Question 10 on Survey I asked to determine whether the respondents recognized the obligations of motorists making turns at intersections. The issues of turning left on

TABLE 3 Summary of Responses: Pedestrian Issues

	Examination Station (%) Survey I	Survey II	AARP (%) Survey I	Survey II
Do you think children are being taught in school about safety (No. 2)				
Yes	66		73	
No	34		27	
Pedestrians are what % of traffic fatalities (No. 3)				
1%	6		10	
5%	25		23	
10%	32		29	
15%	22		21	
20%	15		17	
Why do pedestrian accidents happen (No. 4)				
Driver error	27		23	
Alcohol	24		22	
Poor Visibility	9		15	
Pedestrian error	27		38	
Other/Combin.	13		2	
Who should teach children on pedestrian safety (No. 2)				
School		36		32
Pvt. Safety Group		6		6
Home		36		41
Police		16		16
Church		5		4
Other		1		0
What percentage of fatally injured pedestrians are drunk (No. 4)				
5%		18		20
10%		19		23
20%		23		25
40%		21		16
50%		19		16
Most pedestrian accidents happen away from intersections (No. 11)				
True		69		73
False		14		12
Don't Know		17		15
White clothing is visible from safe distances (No. 12)				
True		69		73
False		14		12
Don't Know		17		15

green and turning right on red are addressed in Sections 202(a)(1) and 202(c)(3), respectively. These sections state that turning vehicles must give the right-of-way to pedestrians lawfully within a crosswalk. A high percentage of respondents to both questions selected the correct response, that the pedestrian has the right-of-way. A significantly higher percentage of correct responses come from the respondents who had been exposed to safety-related material and who had reviewed their state's driver's license manual.

Walking Along or on the Roadway

Two questions address the issue of walking along or on the roadway: Question 8 of Survey I and Question 5 of Survey II. The research team wanted to find out if the respondents recognized their

TABLE 4 Summary of Responses: Knowledge of Legal Requirements

	Examination Station (%) Survey I	Survey II	AARP (%) Survey I	Survey II
In the city you must cross at a signal or crosswalk (No. 5)				
True	86		94	
False	8		4	
Don't Know	6		2	
You must let pedestrians in crosswalks finish crossing (No. 6)				
True	92		97	
False	5		1	
Don't Know	3		2	
If there are sidewalks, you may not jog in the road (No. 8)				
True	54		61	
False	18		14	
Don't Know	28		25	
When turning right on red, pedestrians must wait for vehicles (No. 10)				
True	16		13	
False	79		82	
Don't Know	5		5	
You should walk on the right with traffic (No. 5)				
True		31		14
False		64		83
Don't Know		5		3
Traffic is not required to stop if you are waiting at a crosswalk (No. 6)				
True		31		31
False		61		59
Don't Know		8		10
When turning left on green, vehicles must wait for pedestrians (No. 8)				
True		92		95
False		4		3
Don't Know		4		2

responsibilities while walking along the road. Question 8 concerned the growing use of the roadway by joggers even where sidewalks are provided. While the UVC does not specifically address jogging, it is assumed that the definition of a pedestrian in the UVC includes this group of individuals. Section 11-506(a) states that pedestrians shall not walk on or along the roadway when a sidewalk is provided and when its use is practicable. The only variation from this law found in the state responses came from Rhode Island. Section 31-18-10 of its law says that an individual may run or jog on the road surface even when sidewalks are available. However, if that person shall begin to walk, "he/she shall walk upon an available sidewalk" (*11*). The law does require the use of retroreflective materials by joggers and runners during hours of darkness. About 39 percent of the AARP respondents and 46 percent of the examination respondents did not select the correct response, that joggers may not use the road surface when sidewalks are provided. A statistically significant higher number of correct responses came from male respondents and older respondents.

Question 5 addresses the issue of walking along the roadway when sidewalks or shoulders are unavailable. The UVC states in Section 11-506(c) that if a pedestrian is walking on a roadway that has two-way traffic and no sidewalks or shoulders, that individual shall walk on the left; thus, the correct response to this question is FALSE. The reason for this requirement concerns the importance of visual and audio cues pedestrians receive from approaching vehicles. Pedestrians with their backs to oncoming traffic are dependent solely on audio cues, which may or may not provide adequate warning. Using the UVC as the standard for correctness, it was found that 36 percent of the examination station respondents are not aware of this responsibility. Only 17 percent of the AARP respondents did not select the correct response. Both male respondents and those who had been exposed to pedestrian safety advice had a statistically higher percentage of correct responses, as did the older respondents.

Questions Related to the MUTCD

In addition to determining the comprehension of various pedestrian traffic laws, the research team wanted to evaluate respondents' knowledge of pedestrian traffic control devices. These devices aid in the safe interaction of pedestrians and motorists. If the meanings of these devices are misunderstood, traffic engineers are not properly serving the community. The remaining portion of the two questionnaires involved six questions related to pedestrian signals and signs. Both the MUTCD and the UVC were used as guides for determining the correct responses to these questions. Because pedestrians are much more likely to sustain serious injuries when a collision occurs, it is important that they understand the meaning of the signals provided in the MUTCD. A summary of the responses to these questions is provided in Table 5.

Pedestrian Traffic Signals

Questions 7 and 9 on Survey I and Question 7 on Survey II concern pedestrian signals. Question 7 addresses the use of the flashing DON'T WALK symbol or message. Section 4D-7 of the MUTCD states that the pedestrian clearance interval should be designed such that a pedestrian who has just stepped into the crosswalk has enough time to travel to the center of the farthest travel lane. According to Section 11-203(b) of the UVC, the upraised palm, or DON'T WALK message, means that pedestrians shall not begin crossing, but that pedestrians already crossing should continue to a sidewalk or raised median. Nearly half of all respondents answered this question incorrectly and may not clearly understand the meaning of the flashing DON'T WALK message. The test for statistical significance indicated that a higher percentage of female and younger respondents answered this question correctly.

TABLE 5 Summary of Responses: Knowledge of Traffic Control Devices

	Examination Station (%)		AARP (%)	
	Survey I	Survey II	Survey I	Survey II
A flashing DON'T WALK means to return to the curb (No. 7)				
True	42		46	
False	51		48	
Don't Know	7		6	
The WALK signal appears immediately, at an actuated signal (No. 9)				
True	10		10	
False	84		80	
Don't Know	6		10	
Pedestrian sign (with lines) is placed in advance of a crossing (No. 11)				
True	59		53	
False	17		18	
Don't Know	24		29	
A WALK signal means there are no turning conflicts (No. 7)				
True		47		47
False		51		51
Don't Know		2		2
You may resume your speed when you see the END SCHOOL ZONE sign (No. 9)				
True		66		74
False		30		23
Don't Know		4		30
School pedestrian sign (with lines) is placed in advance of a crossing (No. 10)				
True		72		74
False		12		7
Don't Know		16		19

The significance of Question 9 on actuated pedestrian signals is that it gives the research team an idea whether respondents understand how the pedestrian signal is coordinated with the traffic signal phasing. As required per Section 4B-28 of the MUTCD, pedestrian-actuated signals are installed at locations where traffic control timings may not provide the opportunity to cross without excessive delay. The signal that controls vehicle traffic must be allowed to complete its cycle and then provide a clearance interval before allowing pedestrian movements. Most pedestrian signals will not immediately change to WALK when actuated. Between 16 and 20 percent of the respondents did not know the correct answer and thus may be inclined to assume that a button or signal is malfunctioning if the change does not occur immediately.

A study by Zegeer (*12*) of more than 2,000 pedestrian accidents found that more than 37 percent involved collisions with either left- or right-turning vehicles. Pedestrians are often given a false sense of security by the presence of a steady WALK symbol or message. Question 7 on Survey II was asked to determine whether the respondents are aware of conflicts that may still occur with turning vehicles during the presence of a steady WALK signal. Section 4D-2(3) of the MUTCD stresses that there may or may not be conflicts with turning vehicles. While the 1978 MUTCD allowed the use of a flashing WALK message to warn pedestrians of turning vehicles, this practice has been eliminated in the 1988 publication because it was determined to present an unclear message. Just under one-half of all respondents answered this question incorrectly, which suggests that many of the respondents may not be cognizant of potential conflicts with turning vehicles. A significantly higher percentage of male respondents and respondents who remembered receiving pedestrian safety advice answered this question correctly.

Pedestrian Traffic Signs

Of the final three questions to be discussed, two deal with the use of the pedestrian crossing signs. Question 11 on Survey I and Question 10 on Survey II are similar and are an attempt to determine whether the respondents can differentiate between the use of crossing signs and advance crossing signs. The questions displayed graphics of the W11A-2 and the S2-1 signs provided in the MUTCD. Section 2C-32 of the MUTCD states that crossing signs are distinguished from advance crossing signs by the presence of crossing lines. Only 17 percent of the respondents to Question 11 and between 7 and 12 percent of the respondents to Question 10 answered correctly. The large percentage of DON'T KNOW responses may indicate that the respondents are not aware that two crossing signs are used or that some uncertainty exists about the indicated distance of 200 ft. Statistical tests indicate that a significantly higher proportion of male respondents, younger respondents, and respondents having reviewed their state's driver's license manual answered these questions correctly.

The final question, Question 9 on Survey II, deals with the use of the END SCHOOL ZONE sign (S5-2). The MUTCD in Section 7B-12 states that this sign or a standard SPEED LIMIT sign shall be used at the precise location where speeds at the end of a school zone are to change. This indicates that motorists must wait until after they have reached or passed this sign before resuming their speed. Motorists may not resume their speed simply because the sign is within sight distance. If the driver believes he or she may do so when the sign becomes visible, the vehicle may reach unsafe speeds long before leaving the school speed zone. Of the respondents at the examination stations, 66 percent answered incorrectly, while 74 percent of the AARP respondents answered incorrectly. Both male and younger respondents had a significantly higher percentage of correct responses. Those respondents having received pedestrian safety advice and having reviewed their state's driver's license manual also had a higher proportion of correct responses.

CONCLUSIONS AND RECOMMENDATIONS

After evaluating the results of the questionnaires, the research team reached the following conclusions:

- The level of firsthand knowledge or experience in a pedestrian accident is relatively low.
- The majority of respondents believe children should be taught about pedestrian safety at home and in school.
- The majority of respondents underestimated the true ratio of pedestrian fatalities to all traffic fatalities.
- The respondents appear to understand the right-of-way issues when a pedestrian is in the crosswalk but not when the pedestrian is standing on the curb.
- A significant proportion of respondents do not understand the flashing DON'T WALK signal.
- A large percentage of respondents do not know that joggers must use sidewalks when provided.
- The advance crossing and school crossing signs are misunderstood by the majority of respondents.
- A significant number of respondents do not know to walk against traffic when no sidewalks are provided.
- A significant number believed that a WALK signal means no turning vehicles will cross their path.
- Most respondents believe they may resume their speed before reaching the END SCHOOL ZONE sign.
- The majority of respondents believe that wearing white at night will enable them to be seen from a safe distance.
- Several of the state contacts' official responses were incorrect concerning the rules of the road, which may indicate the confusion over pedestrian laws.

Based on these conclusions the research team developed several recommendations. These recommendations are divided into three categories: (*a*) pedestrian safety programming, (*b*) traffic engineering, and (*c*) enforcement.

Pedestrian safety programs should include the following elements:

- One in six traffic fatalities is a pedestrian.
- The flashing DON'T WALK symbol means not to start crossing but to continue if you've already begun.
- It is illegal to jog on the road surface when adequate sidewalks are provided.
- The difference between pedestrian crossing signs and advance crossing signs is that pedestrian crossing signs show the crossing lines.
- Walk on the left facing traffic when sidewalks are not provided and when walking along a two-way road.
- Pedestrians should be aware that a WALK message means that vehicles may still turn into the crosswalk.
- A motorist may not resume speed until reaching the END SCHOOL ZONE sign.

- Retroreflective materials should be worn or a flashlight should be carried when walking at night because of increased hazards.

Traffic engineering recommendations include:

- The current distinctive features between crossing signs and advance crossing signs should be evaluated, perhaps using heavier lines or different colors. The use of supplemental distance plates also may prove useful.
- The use of informational signs indicating the meanings of the WALK and flashing DON'T WALK symbols at intersections should be considered.

Law enforcement activities should consider the following:

- Drivers who do not yield the right-of-way at the appropriate times should be given citations.
- Pedestrians who behave in an unsafe manner should also be given citations, particularly in corridors or areas that have traditional pedestrian safety problems.
- Review of the obligations at MBCs should be administered. The research indicates that some confusion still exists about the right-of-way issue when pedestrians are standing on the sidewalk waiting to cross. This may require a close review of Section 11-502 of the UVC.

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