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-

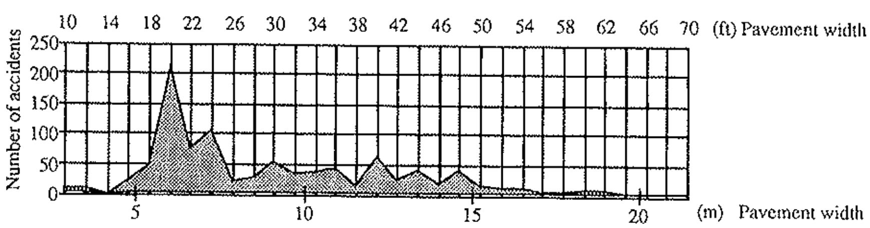

FIGURE 1 Pavement width of link with bicycle accident. (Note that intersection-related crashes are not included.)

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-

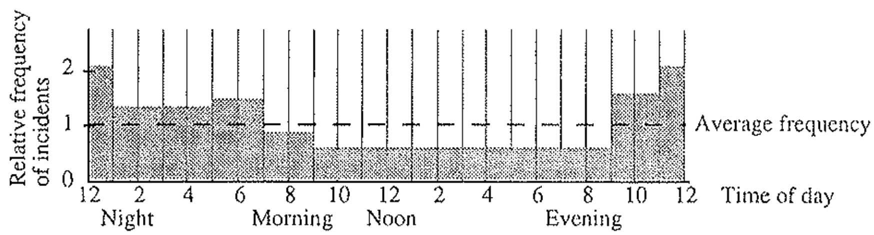

FIGURE 2 Time of day when most severe incident occurred. Relative frequency of incidents is defined as share of incidents reported during a specific time period divided by the portion this time period constitutes. The fact that traffic volumes vary between these time periods is not taken into account.

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

	morning						afternoon			evening		
Time of day	0-2	2-4	4-6	6-8	8-10	10-12	12-2	2-4	4-6	6-8	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) $\approx$ 10 percent, 30 km/h (19 mph) $\approx$ 20 percent, 50 km/h (31 mph) $\approx$ 60 percent, and 80 km/h (50 mph) $\approx$ 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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Publication of this report sponsored by Committee on Bicycling and Bicycle Facilities.