Bicycle Accidents in Maine: An Analysis

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In the United States, little thought has traditionally been given to bicyclists in the design of roadways. Measures to improve bicycle safety should be introduced where they give optimal effect. It is therefore important to know where the problems are the greatest. In total, over 2,000 police-reported bicycle accidents were analyzed. A limited number of hospital-reported accidents were also included. An analysis shows that of 44 patients admitted and treated for major trauma caused by bicycle accidents, only 6 (14 percent) showed up in the police statistics. The vehicle driver involved in a bicycle accident most commonly has not violated any formal highway law, whereas the bicyclist commonly has. There are many reasons for this: lack of knowledge, youth and inexperience, and disrespect for regulations. Bicyclist training and information could influence a high percentage of the accidents (up to 80 percent). Vehicle drivers also need education. Being within the highway code is not always enough to avoid an accident. Nine out of 12 fatal bicycle accidents in Maine during 1988–1991 were caused by collisions with automobiles. Separating bikes and cars from one another is a possible option. Mixed environments can also be made safer, for example, by reducing speed limits or modifying intersections to make them safer for bicyclists. The influence of physical measures is hard to evaluate conclusively because of lacking exposure data. Fatalities are typically caused by head injuries. Increased use of helmets should therefore be a primary short-term safety goal.

Measures to improve bicycle safety should be introduced where they give optimal effect. In order to do this, it is important to know where the problems are greatest and to understand which measures have the potential to be most beneficial. This study focuses on identifying the problematic areas in bicycle safety for a mostly rural state.

BACKGROUND

In the United States, the design of roadways has typically emphasized the safe and efficient movement of motor vehicles. Little thought has normally been given to bicycle riders. In recent years, about 2 percent of all road accident fatalities involved bicycle riders (*1*). This percentage may not seem high, but the risk—measured in fatalities per mile traveled—is high in comparison with other modes of transportation.

In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) was passed by the U.S. Congress. This legislation encourages bicycling and walking as serious transportation options. The result may be that bicycling will become more common. Bicycling is basically a sound and environmentally friendly mode of transportation. However, increased volumes of cyclists may also increase the number of accidents if a safe infrastructure is not provided.

Possible solutions include building bike paths. In order to get a high percentage of bicycle riders to use them, the paths ought to closely follow the roads and highways used by motorists. Otherwise, unprotected road users do not feel safe, especially at night when the risk of being attacked is perceived as high on bike paths that are isolated from major roads. Such bike-roads may also remain unknown to the person who usually goes by car, but who may on occasion want to use his or her bike.

In rural areas bike paths as a rule are beneficial to safety. However, European experience has shown that bike paths along major roads in built-up areas surprisingly often generate more accidents per bicycle-mile than mixed-traffic environments. This is because in urban or suburban areas lacking bike paths, roughly three out of four accidents involving a bicyclist happen at intersections. When a bike path is built, the mid-block risks are generally reduced. What happens at the intersections is quite different. Cycling through a "normal" intersection layout—in which the bike path is about 3 to 6 m (10 to 20 ft) from the parallel road—presents higher risks for the adult cyclist than cycling in mixed traffic. This is partly because turning motorists do not observe the cyclist as easily as when they share the same right-of-way and partly because the angle of collision typically increases from almost parallel to about 90 degrees when the bike path is installed. These differences result in more serious accidents. The overall effect of building bike paths along streets in built-up areas is therefore typically an increase in risk, unless the intersections are grade separated or built in other safe ways (*2,3*).

ACCIDENT DATA

The primary data source is made up of all police-reported accidents occurring in the state of Maine from 1986 through 1991 that involved one or several bicyclists and at least one motorized vehicle, in total 2,059 accidents. According to state law, an accident is reportable to the police if damages are more than $500 or if there is any personal injury and the accident takes place on a public roadway or other place where public traffic may reasonably be expected. These data came from the Maine Department of Transportation's Transportation Integrated Network Information System (TINIS) and were obtained on computer disks and downloaded for analysis. TINIS also gave access to data files containing the geometric layout and vehicle volumes for all locations with reported bicycle accidents. The results presented in this paper are based on the TINIS data base, unless otherwise specified.

Besides the information that can be extracted from this computerized system, a subset of almost 400 actual police reports, which sometimes included supplemental report sheets, was examined. (All fatal accidents and all 1991 accidents were examined in this way.) In these reports, a narrative, as well as a sketch, supplements what is covered in the computerized systems. Besides being more complete, the original reports provide less risk of error. However, it must be kept in mind that even the original data are based on the interpretation of each reporting officer and that

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one of the parties involved in the accident may have had a reason to fabricate a story.

Hospital statistics provided a final source of information. Two hospitals are currently participating in the Maine Trauma Registry: Maine Medical Center (MMC) in Portland and Eastern Maine Medical Center (EMMC) in Bangor. MMC provided a report covering patients injured in bicycle accidents and admitted to MMC between January 1, 1990, and June 30, 1993. Patients are included if they stay in the hospital more than 3 days, die, or require transfer in or out of the hospital. In total, 42 patients were included in this report. A similar report was obtained from EMMC covering January 1, 1991, to April 30, 1993, which included 10 bicycle victims. MMC also provided a statewide report on 1991 accidents. A special grant enabled the recruitment of emergency nurses in each of 35 hospitals, who voluntarily completed a trauma form on patients identified with major trauma, including 30 patients treated for bicycle accidents in 1991. Information on nine of these was duplicated by information in the MMC and EMMC registries. After these duplicates had been eliminated, the hospital file contained a total of 73 bicycle accidents.

A risk analysis should typically be based on expected accident rates. The denominator for calculating this rate should be number of road users or number of miles traveled. Therefore, to estimate bicyclists' risk with respect to a given factor, it is necessary to know either the number of cyclists passing a location or the number of miles ridden along a section. Because statewide bicycle counts have only been initiated recently, several essential risk estimates cannot be calculated at this time.

ANALYSIS OF BICYCLE ACCIDENT DATA

Number of Accidents

According to TINIS, there were 2,059 bicycle accidents between 1986 and 1991. Fourteen of these were fatal, and 117 were noninjury accidents.

The hospital statistics analyzed in this study show that 22 of 63 admitted patients (35 percent) were treated for collisions with motor vehicles. (The 10 accidents reported by EMMC are of an unknown type.) For these, the average length of stay in the hospital was 9.2 days. The average length of stay in the hospital for patients injured in single-bicycle accidents was 4.6 days.

An analysis of 1990 and 1991 hospital data shows that of 44 patients admitted and treated for major trauma caused by bicycle accidents, only 6 (14 percent) showed up in TINIS. These numbers indicate that the approximate number of severe injury (bicycle) accidents in Maine is around 2,500 per year (2,059/6/0.14), or 0.2 percent of the entire state's population. Of 13 accidents involving motor vehicles, 6 showed up in TINIS (46 percent).

It can therefore be assumed that close to half of the more serious bicycle accidents involving motor vehicles are reported to the police. Whether the portion not being reported is of the same type as those that have been reported can only be left to speculation. Probably the nonreported accidents are somewhat less severe on average and may also be more likely to involve children and occur in rural areas and on private property.

Characteristics of Accident Situation

Population Density

Two of three accidents (68 percent) are reported in an urban environment. A location is classified as urban if it is within a compact area that has a population of more than 6,000. Of the 14 fatal accidents, 9 were rural and 5 urban.

Time of Year

It is natural to assume that most bicycle accidents occur when ridership is high—during the time of year when the weather is favorable to riding a bike, which in most years is from late April through October. The data support this assumption and show that 40 percent of all bike accidents happen in July and August, the vacation months (Figure 1). This indicates that bicycling is primarily a recreational or leisure activity rather than a means for everyday transportation. However, it has to be kept in mind that Maine's population increases considerably during the summer months because of tourism and summer residences.

Weekday of Accident

If bicycling is mostly a leisure activity, the majority of accidents ought to occur on Saturdays and Sundays. Figure 1, however, shows that this is not the case. Saturdays have roughly 20 percent fewer accidents than regular weekdays, and Sundays have 45 percent fewer. This does not necessarily mean that there are fewer people riding bikes on weekends than weekdays. It may also indicate that there is less conflicting vehicle traffic on weekends or that people are in less of a hurry on weekends and therefore are less likely to collide, or both.

Time of Day

Figure 1 also shows that almost half (44 percent) of all accidents happen between 3:00 p.m. and 7:00 p.m. Surprisingly few accidents happen during the morning peak hour.

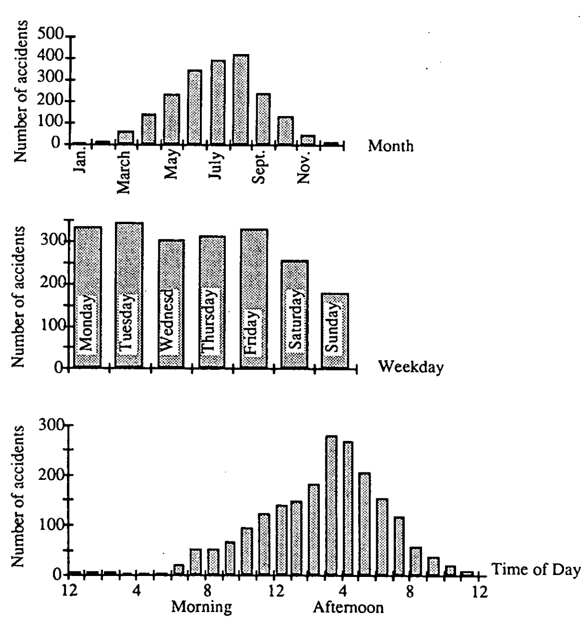

FIGURE 1 Bicycle accidents by time of occurrence.

Characteristics of Bicyclists Involved in Accidents

Age

As can be seen from Figure 2, children 10 to 15 years old are especially prone to having bicycle accidents, but many accidents also involve those in their early twenties, as well as younger children. Figure 2 also shows the age of significant trauma patients admitted for care as a result of bicycle accidents. The median age of the 14 fatally injured bicyclists was 16.

Sex

Male bicyclists are involved in 77 percent of all accidents, and 12 of the 14 fatalities were male. According to the hospital statistics, 71 percent of the patients admitted because of bicycle accidents were male.

Type of Injury

The primary analysis covers 58 of the hospital-reported accidents (those reported directly from EMMC and MMC). The most common areas of the body injured were the head, skull, and face [26 accidents, including the only fatalities (*2*)]; chest (9 accidents); legs (7); internal areas (6); arm and elbow (4); entire body (2); spinal cord (2); ankle (1); and hand (1). Data provided indicate that none of the patients seemed to have been wearing a helmet, although in a few cases helmet status was uncertain.

Behavior of Bicyclists Involved in Accidents

Bicyclists' Contribution to Accidents

In 20 percent of the accidents, the police officer did not cite any contributing factor on the part of the bicyclist. In the other 80 percent, the rider contributed to the accident in the opinion of the reporting officer. In 29 percent of the cases, the bicyclist showed inattention or was distracted, and in 18 percent the bicyclist failed to yield the right-of-way. Other common causes were other human violations, 20 percent; driver inexperience, 5 percent; disregard of traffic control device, 4 percent; riding left of center line, 3 percent; unsafe speed, 3 percent; and improper turn, 3 percent. The most common bicycle defect was defective brakes (4 percent). In less than 1 percent of the accidents is it noted that the bicycle had defective lights.

Bicyclists' Movement in Intersection Accidents

It is often assumed that most intersection accidents happen when the cyclist is turning left. The data show that this is not the case. In 84 percent of the cases, the bicycle rider was going straight through the intersection, in 11 percent turning left, and in 5 percent turning right. Note that there are typically more bicyclists going straight through than turning left at an intersection, so the percentages just given cannot be interpreted as risk per bicycle passage. The bicyclist was riding on the sidewalk in about 20 percent of the accidents.

Bicyclists' Choice of Route and Driveway Accidents

A manual analysis of 83 accidents happening at driveways in 1991 shows that of those involving a car entering or leaving the driveway, it was not uncommon that the bicyclist was riding on the sidewalk (29 percent of the cases) or on the left-hand side of the road (18 percent).

Bicyclists Riding With or Against Traffic Flow

One issue often debated among bicyclists is whether it is safer to ride with or against the general flow of traffic. The prevailing opinion is that it is safer to ride on the right side with the general traffic flow. The data here support that opinion.

Since it is not known what percentage of non-accident-involved cyclists ride on the left versus the right side, all that can be done is to study accident numbers. The following analysis is based on 595 accidents—those that were coded in TINIS with respect to

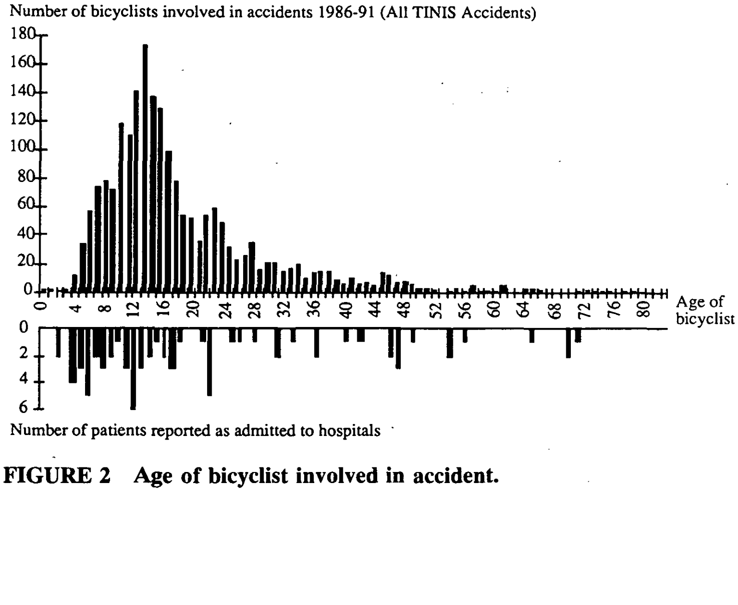

FIGURE 2 Age of bicyclist involved in accident.

what side of the street the bicyclist was riding on. Starting with roadway sections between intersections, a total of 128 accidents were recorded in which the bicyclist was riding with the traffic and 41 accidents in which the rider was going against the traffic. For accidents in passing through four-leg intersections, there were 43 in which bicyclists were riding against the traffic and 55 in which they were with the traffic. If it is now first assumed that riding on sections between intersections is equally dangerous on both sides [which is a conservative assumption for cyclists riding on the right side, since many accidents happen when bicyclists are crossing driveways, for which it is definitely safer to be on the right side (*4*)], this means that there are at least 3.1 times (128/41) as many bicyclists using the right side compared with those using the left. If it is next assumed that cyclists stay on the same side of the road when crossing intersections as when riding between them (also a conservative assumption, because cyclists ought to use the right side, particularly in complicated environments with many intersections), going through a four-leg intersection on the left side becomes at least 2.5 times as dangerous as going through on the right side; 43 accidents were reported for cyclists riding on the left, although no more than 17.7 (55/3.1) would be expected if the risk were the same as that on the right side.

Characteristics of Vehicle and Driver Involved in Bicycle Accidents

Type of Vehicle

A question frequently asked is whether trucks often are involved in bicycle accidents. Only 46 of the accidents (2.3 percent) involved a truck or bus; trucks and buses together account for about 9 percent of the miles driven in the state (*5*), although many of these miles are driven on roads with light or no bicycle traffic. Pickup trucks (including larger vans) were involved in 20.7 percent of the accidents and about 26 percent of the miles driven. Motorcycles accounted for 1.3 percent of the accidents and about 0.8 percent of the miles driven in the state. The remaining accidents (75.7 percent) involved a regular passenger car, station wagon, or smaller van. They account for about 65 percent of the mileage driven (*5*).

Age of Driver

Another question often asked is whether older drivers are a threat to bicyclists' safety. Seen from a public health aspect, older vehicle drivers are not a threat. Older drivers (those 70 years and older) may have higher accident rates per mile than middle-aged drivers, but in absolute numbers it is not older drivers but younger ones who typically are involved in bicycle accidents (see Figure 3).

Sex of Vehicle Driver

Male vehicle drivers account for 58 percent of the accidents. The average distance driven by car also tends to be slightly higher for men, so in terms of accidents per mile driven it appears that men and women are approximately equally safe.

Influence of Alcohol or Drugs

According to the information given in the police reports, the vehicle driver was under the influence, had been drinking or using other drugs, or both in only 26 cases. This represents just over 1 percent of the accidents. Typically, a much higher percentage of accidents is attributed to alcohol. One explanation for the low number of accidents reported as alcohol related—with respect to the vehicle driver—is that bicyclists usually ride in the daytime, whereas alcohol and driving is a combination more common in the evening or night. (Over 90 percent of the accidents were reported between 7:00 a.m. and 8:00 p.m.) In 32 cases it is unknown whether the vehicle driver was impaired.

An in-depth analysis of vehicle drivers involved in fatal accidents does not show that these drivers deviate from "good behavior" in any obvious way. The driver in every case was sober and had a valid license and a violation-free driving record.

Behavior of Vehicle Driver Involved in Bicycle Accidents

Vehicle Driver Contribution

In most accidents (60 percent) the police officer has noted "no improper driving" in the report. In 20 percent, inattention or distraction is given as a contributing factor to the accident; in 10 percent, failure to yield the right-of-way; and in 6 percent, obscured vision.

Action of Vehicle Driver Before Accident

In 964 accidents (47 percent of the cases), the vehicle driver was going straight ahead on the roadway. In 293 (14 percent), the driver was turning right, and in 269 (13 percent), the driver was turning left. Other actions resulting in accidents were starting (7 percent), stopping or slowing in traffic (4 percent), avoiding objects or other road users (4 percent), and backing in traffic (1 percent). Legally parked cars were involved in 2 percent of the accidents.

Intersection Accidents and Movement of Vehicle Hitting Bicyclist

A specific analysis of movement was done for accidents occurring at intersections. In more than half of these, the vehicle was turning (in 27 percent to the left and in 30 percent to the right). Manual

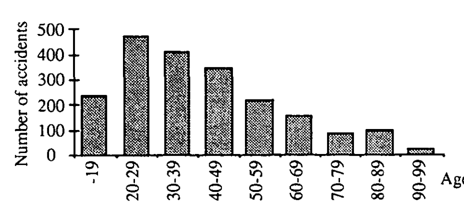

FIGURE 3 Age of vehicle driver colliding with bicyclist.

analysis of 205 accidents reported at intersections in 1991 shows that the two parties entered the intersection at right angles in the majority of cases (70 percent). About 10 percent of the accidents were caused by left-turning cars colliding with bicyclists riding in the opposing direction. Right-turning cars cutting off bicyclists going straight through the intersection accounted for 9 percent of these accidents.

Characteristics of Accident Location

Accident Distribution at Intersection or Roadway Section

Roughly half of all accidents occurred at intersections (48 percent according to TINIS; 55 percent according to a manual analysis of 370 accidents from 1991). Of these, about 55 percent occurred at three-leg intersections, 42 percent at four-leg intersections, and 3 percent at five-leg intersections. Roughly half of the accidents between intersections involved a vehicle or bicycle moving in or out of a driveway (50 percent according to the manual analysis of the 1991 accidents). Only 9 percent of all accidents involved a bicyclist and a motorist traveling along the road in the same direction away from intersections and driveways. In 3 percent, the parties were traveling in opposing directions away from intersections and driveways. The bicyclist was crossing the road away from intersections and not coming from a driveway in 10 percent of all accidents. An analysis of 1991 accidents that occurred at a driveway entrance or exit shows that most often the accident involved a car that was leaving the driveway (34 percent of the cases) or just entering the driveway (26 percent). There were also many cases involving bicyclists who were riding into the street from a driveway (34 percent) compared with heading for the driveway (6 percent). However, some of the accidents that seem to have happened away from intersections and driveways may have involved a bicyclist crossing the road with intent to go into a driveway. This intent is usually impossible to determine from the police report.

Out of the 14 fatal accidents examined in depth, only 3 accidents happened at intersections. In three cases the bicyclist was crossing a major road coming from a driveway, and in two other cases the bicyclist was crossing a major road away from any intersection or driveway. In one case the bicyclist rode along the road in the direction opposite to the vehicle traffic, and in three other cases, the bicyclist was going straight along the road in the same direction as the vehicle. In two of these cases, the bicyclists for some reason lost their balance and fell in front of the vehicle.

Intersection Control

In the state of Maine, the practice is to have Stop signs on nearly all minor approaches at nonsignalized intersections. Four-way and other all-way stop controls are uncommon. Yield signs are used very sparingly, mostly for right-turn-only lanes in rural environments. Only very minor streets intersecting with other local streets have no signed control.

At three-leg intersections, 1 percent of the accidents occurred at all-way stops, 50 percent at other stops, 2 percent at Yield signs, 8 percent at traffic signals, and 37 percent where there was no control. At four-leg intersections, 3 percent of the accidents happened at four-way stops, 43 percent at other stops, 38 percent at

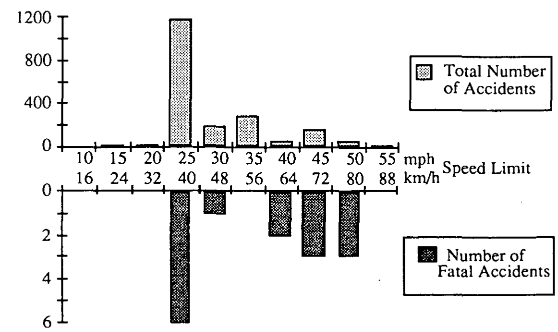

FIGURE 4 Speed limit on road where accident took place.

signalized locations, and 14 percent where there was no control. At intersections with more than 25,000 vehicles entering per day, 51 out of 57 accidents happened at signalized intersections. Although the lack of bicycle counts again makes it impossible to calculate risks, they may be higher at signalized intersections because of higher traffic volumes and speeds, as well as an increase in turning movements.

Accident Frequency and Speed Limit

A distinction must be made among frequency of accidents, rate of accidents, and severity of accidents. Figure 4 shows that the majority of accidents happen on roads with speed limits of 40 km/hr (25 mph) or less. This does not mean that roads with lower speed limits are less safe than others, but that the majority of biking takes place on urban streets with low speed limits. Consequently, to reduce the number of accidents, measures aimed at increasing the safety on these streets are necessary. However, the most serious accidents typically occur on roads with relatively high speed limits. Half the fatalities occurred on roads with a speed limit of 64 km/hr (40 mph) or higher.

Accident Severity and Speed Limit

Figure 5 shows the likelihood of a reported accident's ending up as a fatality. The "most likely ratio" is calculated as the recorded number of fatal accidents for a given speed limit divided by the recorded total number of accidents for that speed limit. The high

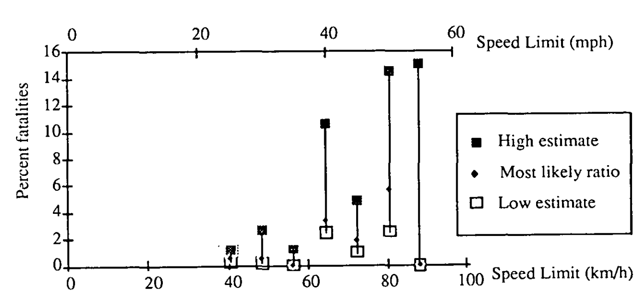

FIGURE 5 Number of fatal bicycle accidents per reported accident for different speed limits.

and low estimates are the maximum and minimum ratios that can reasonably be obtained, assuming that the observed numbers follow a Poisson distribution around true means. There is a 5 percent risk that the true ratio is lower than the low estimate, and a 5 percent risk that it is higher than the high estimate. As can be seen, the likelihood of a fatality is much higher for accidents on roads with speed limits above 56 km/hr (35 mph) than on those that have lower speed limits. The χ^2-test gives a statistically significant difference ($p < 0.1$ percent).

Furthermore, accidents may be less likely to be reported on low-speed roads since the bicyclist may not be injured at all. Therefore, the true ratio of fatalities to accidents in reality may increase even more with increased speed.

Vehicle Volume

Most accidents happening between intersections were reported on low- and medium-volume roads. Only 3 percent were recorded on roads with average annual daily traffic (AADT) above 25,000 and 45 percent where AADT was above 5,000; 16 percent happened on roads with AADT less than 500 and 37 percent with AADT less than 2,000. It may seem surprising that low volume is not a guarantee of safety on roadway sections. Bicycle counts have not been taken. This means that there can only be speculation as to the risk per cyclist on a busy road versus that on a residential street with very low vehicle volumes. European research reveals no strong correlation between the number of accidents per mile cycled and motor vehicle volume (*4,6*). These studies show that the risk—measured as bicycle accidents per mile ridden—may even decrease with increasing vehicle volume. At least four factors may help explain this paradox: (*a*) bicyclists become more careful when they ride on high-volume roads, (*b*) less skilled bicyclists do not attempt to ride on high-volume roads, (*c*) high volumes may keep motor vehicle speeds low, and (*d*) high-volume roads may have wide lanes and better overall design to accommodate motor vehicles and bicycles. It should be noted that intersection accidents are not included in this discussion.

One reason so many accidents happen on low-volume roads is that these typically are local access roads on which children are allowed to ride. The upper part of Figure 6 shows the relationship between the age of bicyclist involved and motor vehicle volume for accidents occurring away from intersections. This confirms that young children have most of their accidents on low-volume roads, whereas teenagers and adults have accidents on somewhat busier roads as well as on the ones with the lowest volumes. There is a very distinct peak around 15,000 to 20,000 vehicles a day for teenagers, indicating that this age group may have difficulties coping with such heavy flows (about one vehicle every other second during the peak hour). The reason that there are fewer accidents reported on roads with 20,000 vehicles per day and up is probably that there are not many roads in Maine with those traffic volumes.

A similar analysis including age of the injured bicyclist was made for intersection accidents (see lower part of Figure 6). Again the tendency for young bicyclists to be injured at low-volume intersections—where they are allowed to ride—may be seen, whereas teenagers and adults have more accidents at higher-volume intersections.

Width of Road

Most bicycle accidents between intersections happen on two-lane roads. Only 7 percent of them are reported on roads with more than two lanes. This does not show that multilane roads are safe, since most bicycling takes place on two-lane roads.

A question to ask is, "How much safer is a road with shoulders versus one lacking shoulders?" This question cannot be answered without access to bicycle counts. What can be determined is that half (51 percent) of all links with bicycle accidents lack shoulders completely, and 54 percent lack a shoulder on the right side. Only 13 percent of the roads had a right shoulder of 6 ft (1.8 m) or more.

Roadway Construction and Maintenance

In only 1 percent of the accidents was it noted that there was roadway construction going on. In less than one-fourth of a percent did the accidents take place in a maintenance area or utility work area.

Other Contributing Factors

Weather and Road Surface Conditions

Most accidents happen in clear weather on dry roads. Only 12 of the 2,059 accidents took place on icy or snow-covered roads. This,

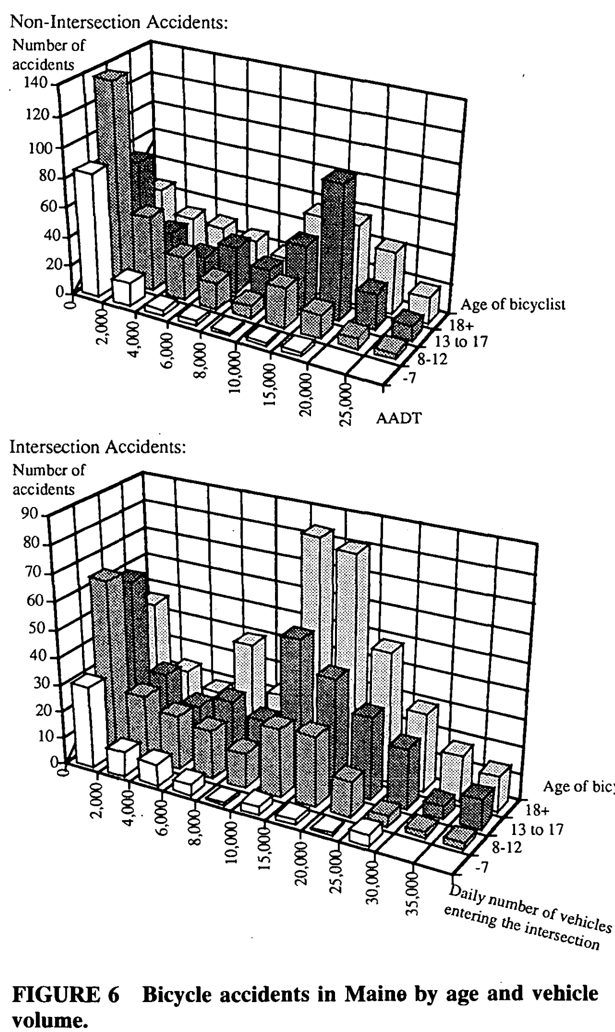

FIGURE 6 Bicycle accidents in Maine by age and vehicle volume.

of course, reflects the fact that very few bicyclists ride in bad weather or on snow-covered or icy roads. Six percent of the accidents happened during rainfall.

Light Conditions

Most accidents happen in daylight (83 percent) or at dawn or dusk (8 percent). Of those that happen when it is dark, over 80 percent happen on streets with street lights lit. The quality of this lighting may vary, however.

CONCLUSIONS AND RECOMMENDATIONS

The results show that a typical bicycle casualty in Maine is a 13-year-old boy riding his bicycle straight across a low-volume road and colliding with a four-door passenger car driven by a young male at around four o'clock on a sunny afternoon in early August.

Even though Maine is a fairly rural state, two out of three bicycle accidents are reported in urban areas. Nevertheless, the majority of the fatal accidents occurred in rural areas.

Fatalities are typically caused by head injuries. Increased use of helmets should therefore be a primary short-term safety goal.

One relationship clearly demonstrated is that the number of serious accidents increases significantly with higher speed limits.

According to the police reports, the vehicle driver involved in a bicycle accident has most commonly not violated any formal rule of the road. However, the driver may still have failed to detect the cyclist or to "use utmost care." The bicyclist commonly has violated a formal law, at least in the eyes of the police officer. There may be many reasons for this: lack of knowledge, youth or inexperience, and disrespect for regulations. Bicyclist training and information could influence a high percentage of the accidents (up to 80 percent). Increased enforcement could also reduce the accident number, but probably not as dramatically as education. Enforcement has to focus on relevant problems. For example, lack of nighttime equipment is not a major contributor to the accidents since less than 9 percent of the accidents happen when it is dark and only 1 percent of the accidents happen in darkness on streets lacking street lights or having the lights off. Teaching riders to observe traffic control devices, to yield the right-of-way, and always to ride on the right side of the road with the flow of the traffic is probably best achieved through a combination of education and enforcement. Not all violations can be eliminated with either of these methods. Everyone has at some time violated a highway code by mistake. It is human to miss a sign, even to run a red light once every few years. There will always be motorists and bicyclists making mistakes no matter how well trained they are and irrespective of how efficiently enforcement patrols work. Therefore, if the goal is the ultimate safety level, other measures have to be used as well, including engineering measures. Bicyclists are one of the most unprotected road-user categories, even if they wear helmets. Separated bike paths can be used to create a safer riding environment. Most fatal bicycle accidents are caused by collisions with automobiles. Separating cars and bicyclists also lets the biker breathe somewhat fresher air, which is another important aspect of public health. The question is how much can be spent in order to safeguard the small but growing number of bicyclists.

Realistically, total separation cannot be achieved, and many bicyclists may prefer the greater mobility offered on the existing road network. (Locally, for example, in Davis, California, the bicycle roads are spaced closer together than streets open to motorists, but this will remain the exception rather than the rule.) Mixed environments can, however, be made relatively safe. The data clearly demonstrate that the risk of fatality decreases with a lower speed limit. A German study (*7*) 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/hr (12 mph) ≈ 10 percent, 30 km/hr (19 mph) ≈ 20 percent, 50 km/hr (31 mph) ≈ 60 percent, 80 km/hr (50 mph) ≈ 98 percent. The data in this study do not indicate that Maine bicyclists should have a survival rate very different from that of German pedestrians.

There is usually a correlation between actual speed and speed limit, but it is not always possible to get a desired level of speed through posted speed limits alone. Complementary measures may have to be used to make residential streets safer for all age groups, including young children. One solution is to rebuild local streets so that different traffic categories can relate to each other under conditions appropriate for the weakest in the chain—the playing child. This concept started in the Netherlands with the *Woonerf*. Here sidewalks are eliminated and the whole roadway becomes the domain of the resident. Car drivers always have to yield to playing children and if necessary get out of the car and ask the child to move in order to proceed. The roadway is "furnished" in such a way that the maximum vehicle speed cannot exceed a fast walking speed. This concept spread to Denmark [*Stillevej*, designed for 30 km/hr (20 mph) maximum speed, and *Opholds og Legeområder*, for 15 km/hr (10 mph)]; to the rest of Scandinavia; and to Germany (*Verkehrsberuhigung*), translation of which produced the British term "traffic calming." These measures have also been tried, for example, in the state of Washington. These concepts form a good basis for reducing the risks on residential streets. Stop signs are also very effective devices for reducing speed (*8*). Traffic signals, on the other hand, do not reduce top traveling speeds. This probably has contributed to the fact that 35 percent of all bicycle accidents at four-leg intersections occurred at signalized locations.

Outside residential and downtown areas, traffic calming can typically not be used, but separation can be used. To be effective, intersections have to be separated as well (by tunnels or overpasses). Where this is not feasible, reliance on selective improvements to accommodate bicycles on roads open to motor vehicles has been necessary. The data indicate that measures to improve safety for adult cyclists should focus on high-volume intersections, because on roadways between intersections, volume is of less importance to adults. Teenagers, however, should have access to a bicycle road network connecting high schools, malls, and so on, with residential areas excluding roads with volumes of more than 10,000 vehicles a day.

The fatal accidents analyzed here involved 12 males of varying age and 2 adult females. Both women lost their balance and fell onto the roadway in front of vehicles. The typical male accident involved a high degree of risk taking (e.g., riding at a high speed across a road from a blind driveway) rather than lack of skill. It is hard to generalize from such small numbers, but to reduce the number of similar accidents through education, the education should not focus on technical aspects of how to handle a bike but on a form of defensive driving—not to take risks when crossing a street, to assume that there will be a car coming and that the driver does not see you. How to reach bicyclists with this information is important. Children can be reached through school, and this is already being done in Maine. Eventually everybody could be reached this way, and it is hoped that the knowledge would stay with the person through old age. Nevertheless, could the process be speeded up by aiming campaigns toward adult bicyclists? Adult bicyclists are probably harder to influence because their habits are more set. Are television and radio commercials effective? Can adults effectively be reached when renewing their driver's licenses? Only in one case was it known that the bicyclist killed had a valid license. In at least two cases, the fatally injured bicyclist lacked a valid license (ages 19 and 22). One bicyclist had a police record including eight violations for operating motor vehicles without a valid license, failure to report an accident, and speeding. In four cases it was unknown whether the bicyclist had a license or not. In the remaining seven cases the bicyclist was below the age of 17.

A main conclusion of this study is that bicycle exposure data are lacking in the state of Maine. A risk analysis should typically be based on expected accident rates. The denominator for calculating this rate should be the number of road users or number of miles traveled. To estimate bicyclists' risk with respect to a given factor, it is necessary therefore to know the number of cyclists living in the area, the number passing the location, or the number of miles ridden along the section. Statewide bicycle counts are just now being initiated. This means that several essential risk estimates cannot yet be calculated. This analysis should be followed with a more comprehensive study once results from these bicycle counts are available.

During the writing of this paper, several serious accidents involving bicyclists occurred in the area. Educating motorists would probably have been the most efficient measure for avoiding these accidents. Reading police reports forces the conclusion that most often the bicycle rider is at fault, so teaching bicyclists to comply with the rules becomes the obvious first thought. Education and training probably should be directed at both bicyclists and motorists. Motorists need to be reminded that bicyclists have the legal right to operate on the public roadway and that they have essentially the same rights and responsibilities as other vehicle operators. Motorists should also be reminded to actively search for bicyclists in the traffic environment.

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