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Part 2—Seat Belt, Alcohol, Motorcycle, and Pedestrian Studies

Foreword

This Record, addressing highway safety, is divided into two parts. The first section contains papers about older drivers and the second contains papers about diverse safety topics: seat belts, alcohol, motorcycles, and pedestrians.

Much discussion has been devoted to the problems older drivers face when driving. Lerner and Ratté use existing data plus information from focus groups of older drivers to identify freeway usage and avoidance and specific difficulties encountered when driving on limited-access roads. Looking at the problem from a different perspective, Garber and Srinivasan examine accident data to identify specific problems associated with older drivers at intersections. In a second paper these authors develop statistical models to relate the risk of accident involvement to the traffic and geometric characteristics of the intersection. Staplin and Lyles analyze accident data and use induced exposure methods to identify driving situations in which age differences in motion perception contribute to older-driver overinvolvement in crashes. The actual risk older drivers are to themselves and to other road users is examined by Evans, who suggests that the problem may be as much one of reduced mobility as one of safety.

The second section begins with Carter and Schonfeld describing their evaluation of Maryland's seat belt law in terms of compliance and injury reduction. Then Kim explores the relationship between the 80 percent seat belt use rate in Hawaii and enforcement. Using autoregressive integrated moving average statistical techniques, Rock reevaluates the impact of drinking age laws on traffic accidents in Illinois. By using total accidents, he found that the lower drinking age was responsible for an increase in accidents of 14 percent, or 5,000 per month. The problem of unlicensed and uninsured motorcycle riders in Hawaii was uncovered in a survey of motorcyclists by Kim and Willey. Cheng describes the pedestrian accident problems he found in Utah using more than 10 years of pedestrian accident data. In the final paper Soot describes a method for estimating daily volumes of downtown pedestrian traffic.

Part 1
Older Driver Studies

Problems in Freeway Use as Seen by Older Drivers

Neil D. Lerner and Donna J. Ratté

Limited-access freeways, including the Interstate highway system, are among the safest types of roads; their use is important for achieving full driving mobility. Many features of these high-design roadways address certain age-related changes in physical ability and typical accident scenarios involving older drivers. Freeways are therefore important to the safety and mobility of aging motorists. Yet there is the widespread belief that older drivers as a group avoid freeways. The problem of freeway aversion among older motorists is considered. Existing data are reviewed to determine the extent to which elderly drivers avoid freeways, and new data from focus group discussions are presented that reveal some of the features of freeway driving that older motorists find particularly troublesome. Despite an extensive search of the literature, review of travel data bases, and contacts with many experts and organizations, no objective data on the freeway travel of older drivers were uncovered, and widespread freeway avoidance among older drivers could be neither supported nor refuted. There was evidence, however, that freeway use among the elderly may be increasing and that older drivers generally view themselves as competent drivers on freeways. These findings were supported and expanded by the focus group discussions, which included 65 participants aged 65 to 88. The groups revealed specific difficulties faced in freeway use, including large trucks, traffic speed variance, rudeness of others, signs, merging and weaving lanes, and personal safety. Possible countermeasures to foster greater freeway use were discussed.

Limited-access freeways, including the Interstate system, are important parts of the total highway system; their use is essential for enjoying full driving mobility and safety. The low per-mile accident rates on Interstates show them to be among the safest of all roadway types. Older as well as younger drivers should be able to take advantage of freeways. Yet there is the widespread belief that older drivers tend to avoid freeways. If this is so, the older driver may be limiting personal safety and mobility.

Many physical changes associated with aging can affect driving. Older drivers show patterns of accident involvement that differ from those of other age groups (*1*). Interestingly, freeways possess features that address many of these age-related changes and accident types that characterize older drivers. For example, controlled-access freeways minimize potential traffic conflicts and right-of-way problems, categories in which older drivers are greatly overrepresented in accident statistics. The excellent sight distance along the road ahead provides ample reaction time. The large and legible freeway signs are superior to street signing, which is especially important because of the visual limitations that often accompany aging. Wide, well-delineated lanes of good surface quality minimize tracking demands. The number of decision points and their complexity are minimized, and there is no "visual overload" from roadside signs, signals, stores, pedestrians, and the like. Thus, freeway design provides special safety benefits that may help older drivers in particular. At the same time, freeways have characteristics that may disturb older drivers and cause them to choose other routes.

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The research described was intended to find out why older drivers might show an aversion to freeways. If the reasons are better understood, it may be possible to devise countermeasures that foster greater and safer use of these roads by drivers who may especially benefit from the superior design features.

Implicit in the question of why older drivers avoid freeways is the assumption that as a group they do. However, as work progressed, this stereotype began to appear questionable. Therefore, data were sought that would describe freeway use by various age groups. There is undoubtedly some avoidance of freeways by older individuals, but little objective data were found to support the stereotype of widespread aversion.

Recognizing that at least some freeway avoidance occurs and that fostering greater freeway use may be beneficial to many capable older drivers, it becomes important to determine which problems older drivers find with freeways. This was accomplished by using focus groups in which older people discussed their problems and perceptions.

This paper thus has two general components. First, it describes the effort to determine to what extent older drivers use or avoid freeways, on the basis of available data. Second, it presents new data from the focus groups about the problems of freeway driving seen by older drivers themselves.

OLDER DRIVERS AND FREEWAY TRAVEL

A number of common stereotypes of older people simply are not accurate. Most are active, healthy, and independent. Most of those over 65 live in suburban or rural, not urban, communities. Their preferred mode of travel, by far, remains the personal automobile (*2*). Is the stereotype of freeway avoidance another inaccurate characterization of the older population? Answers were sought in three sources in the literature: (a) information on travel patterns, (b) freeway accident statistics, and (c) driver perceptions of capabilities and risks. A brief overview of the findings is presented here; more detail can be found in Lerner et al. (*3*).

Travel Patterns

The amount and pattern of travel changes with age, and the number of miles traveled (though not necessarily the number of trips taken) drops as drivers become older (*4,5*). But, despite the available information on many travel characteristics, such as trip time, trip length, and trip purpose, there appears to be very little information on the type of roadway used. An extensive effort that included a search of literature, review of travel data bases, and contacts with many experts and organizations was unable to uncover even the most basic data on freeway use by age group. Yet even if such data were available, it would be difficult to interpret any reductions in freeway use as the result of an aversion to freeways and not some other reason. It would be necessary to find some way to account for age differences in confounding factors such as trip purpose, trip time, and residential locations. In summary, no travel data were uncovered that could support or refute the idea that older drivers avoid freeways.

Freeway Accidents

Because of the lack of direct information on freeway travel, another approach was to use accident data as an indirect means of revealing trends in older-driver use of freeways. The assumption is that year-to-year changes in the proportion of accidents on a given roadway type that are attributed to older drivers primarily reflect changes in the proportion of miles that these drivers travel. Table 1 presents data from the Fatal Accident Reporting System and shows the proportion of all fatal accidents attributed to drivers 65 and older, for Interstate and non-Interstate highways. Data are shown for successive 3-year periods. For Interstate and non-Interstate cases, older drivers account for an ever-increasing proportion of the accidents. However, the growth rate of this proportion is much faster for Interstate highways. From the period 1977 to 1979 to the period 1986 to 1988, the proportion of accidents attributed to older drivers on non-Interstate roadways increased by 53 percent (from 6.70 to 10.27). During the same time span, the proportion of accidents attributed to older drivers on Interstate highways grew at nearly twice this rate: it grew 99 percent, from 4.47 to 8.87. Assuming that these changes mainly reflect changes in exposure, the data indicate a dramatic growth in older-driver freeway travel from 1977 to 1988.

TABLE 1 PERCENTAGE OF DRIVERS IN FATAL ACCIDENTS WHO WERE 65 AND OLDER

Years	Interstate % Drivers 65+	Non-Interstate % Drivers 65+
1977 - 1979	4.47	6.70
1980 - 1982	6.17	7.57
1983 - 1985	8.20	9.47
1986 - 1988	8.87	10.27
(Increase from 77-79 to 86-88)	(99%)	(53%)

(Data from Fatal Accident Reporting System)

Similar findings are obtained if interest is confined to drivers 75 and older: the proportion of non-Interstate accidents increased 110 percent, but the proportion of Interstate accidents increased 200 percent. Thus, although they measure indirectly, the data suggest a trend toward substantially greater freeway use by older drivers even during one decade. The image of the older driver as one who avoids freeways may be becoming outdated, if it was ever true.

A review of freeway accident data from various sources (*6–8*) also suggests some interesting aspects of older driver collisions on these roads:

1. The overinvolvement rate of older drivers [based on an "innocent bystander" method of estimating expected involvement rate (*6*)] is not as substantial on Interstate highways as it is on other roadways.
2. Per-mile accident rates increase with driver age for all types of roads, but not as rapidly for Interstate highways as for other roadways.
3. Older drivers in freeway accidents do not appear to differ substantially from other drivers in terms of accident location (noninterchange, interchange, ramp) or intended maneuver (going straight, changing lanes, etc.).
4. Older drivers appear to have relatively more collisions with trucks.

However, it should be noted that the lack of good exposure data seriously hampers the interpretation of age trends in freeway accident findings.

Driver Perceptions of Capabilities and Risks

If older drivers as a group are averse to freeway driving, it should be reflected in their perceptions of their own abilities and in what they see as risky. The literature provided little information that applied specifically to freeways, but a few observations were noteworthy. Yee (*9*) found that only 9 percent of older drivers (which Yee defined as 55 and older) think that their freeway driving ability is worse than it was 5 years ago. Contrast this with the much higher percentage (19 to 25 percent) of older drivers who believe their abilities have deteriorated for driving in other situations, such as during rush hour, when tired, at night, or in glare. However, it should also be noted that only 6 percent said that their city street driving has deteriorated during the past 5 years. Yee also found that 64 percent of older drivers reported that they seldom or never experience difficulty entering or leaving high-speed freeways. However, this was nevertheless a smaller percentage than for younger drivers (84 percent).

In a study of how people perceive driving risk (*10*), subjects used a hand-held dial to continuously rate subjective risk while they were driven over a 26-mi rural route that included a variety of highway types. Generally, older subjects (mean age of 64.5) rated the risk as higher than did younger subjects (mean age of 20.0). However, the segments of the route that were Interstate highways revealed an exception: older subjects rated the risk as lower than did younger subjects. Both old and young subjects saw substantially less risk on Interstate highways than on other rural two-lane highways.

Overview of Literature Findings on Older Drivers and Freeways

There do not appear to be any objective data that adequately support or refute the claim that older drivers as a group avoid freeways in favor of other types of roads. The nearly total absence of data about this issue is perhaps the most striking finding. Some data do suggest that older drivers are increasing their use of freeways, that older drivers suffer less age-related risk on Interstates than on other roadway types, and that older drivers do not see their abilities as especially limited, or the risks as especially high, on Interstates. None of these assertions is based on particularly strong data.

FOCUS GROUPS

It is possible to speculate on many reasons an older motorist might avoid freeways: travel speed, difficulty with certain maneuvers (e.g., merging), traffic mix, conformity with the actions of surrounding traffic, direction finding, perceived hazards, and so forth. One way to find out is to ask the older drivers themselves. Focus group discussions provide a method for doing this.

Method

A total of 65 participants, ranging from 65 to 88 years old, took part in a series of 10 discussion groups held in suburban Washington, D.C. and in southeastern Wisconsin. To minimize any bias toward recruiting only the more active and adventuresome elderly, a variety of recruitment methods and study situations was employed. The final sample included 39 women and 26 men, all but one of whom held a current driver's license. All lived in urban or suburban areas. None worked full time; only four worked part time.

The focus group participants should not be considered a random sample or necessarily representative of all older drivers. The purpose of the focus groups was to bring a generally representative range of older people to the discussions to reveal their problems and perceptions. The findings should be treated qualitatively, not quantitatively.

The focus group technique uses small groups of similar people to discuss carefully defined issues in an informal and nonthreatening environment. Group interaction and exchange are part of the process. A moderator guides the discussion along a predefined question path but does not play an active role in the session. The question path for these focus groups began with a discussion of general feelings about driving and then moved to the roadway types and situations that influence feelings about driving. Freeway driving came up in this context generally. The discussion was then directed toward feelings about freeways in particular. Factors that influence the choice of routes were discussed, and problems and concerns with freeways were explicitly identified. Participants were also encouraged to describe specific freeway situations that they believed to be problems.

After the discussion, each participant completed a brief questionnaire. It requested information about certain driving practices and asked participants to rate their driving ability for six driving situations. Finally, the participant ranked a set of 10 factors related to freeways in order of importance.

Findings

Older drivers represent an exceptionally diverse population, and the focus groups reflected this diversity. There was a wide range of opinion on many aspects of driving, including freeway use.

Freeway Avoidance and Self-Imposed Restrictions

Both the discussions and the questionnaires were in agreement that there is no overall avoidance of freeways by these participants but that attempts are made to avoid certain freeway situations. Many of these drivers restrict their driving, both freeway and nonfreeway, in various ways: they limit night travel, avoid rush hours, and stay away from unfamiliar areas. On the questionnaire, only 6 percent of the participants indicated that they generally avoid freeways, and several more indicated that they avoid them during rush hour (though the discussion session suggested there may be somewhat more restriction than the questionnaire results showed). The drivers in these groups are active freeway users: 31 percent indicated that they frequently use freeways, and only 15 percent seldom or never use them. In fact, in response to one questionnaire item, 70 percent of respondents indicated that they now use freeways as much or more than they did during the periods of their lives when they drove most extensively. Among those using freeways less, the majority were 75 and older, but limited freeway use was not predicted as well by age as it was by the current extent of driving in general (e.g., trips per week).

In summary, there is some selectiveness in the time and place of freeway driving, but for most people, freeway use can hardly be considered restricted. Restricted freeway users tend to be women and those who never used freeways much anyway. Because freeways are more ubiquitous than they were a generation ago, and because women as a group drive more extensively than they did a generation ago, a cohort effect that will reduce self-imposed restrictions on freeway driving can be anticipated.

Perceived Freeway Driving Capabilities

The discussion participants see themselves as very capable freeway users. Table 2 shows the results of one set of questionnaire items, in which the respondents were asked to compare their abilities with the abilities of most other drivers. These ratings were made for the six situations shown in Table 2. Consistent with other research literature on self-rating of driving skill (*11*), people are unlikely to rate themselves as below average. Even recognizing this, however, older drivers as group see themselves as very capable of driving on freeways when traffic is not heavy. More than 60 percent rate themselves as excellent or above average, whereas only 5 percent rate themselves as below average. Even for rush-hour freeway driving, 40 percent rate themselves as better than average,

TABLE 2 PERCENTAGE OF RESPONDENTS RATING THEIR DRIVING ABILITY IN SIX SITUATIONS

Driving Situation	Excellent	Above Average	Average	Below Average	Poor	Total*
Streets	13	48	38	2	0	100%
Country	21	40	40	0	0	100%
Night	3	18	60	11	8	100%
Light Freeway	15	46	34	5	0	100%
Rush Hour Freeway	7	33	51	6	4	100%
Bad Weather	3	28	55	7	7	100%

* May not total exactly 100% due to rounding.

TABLE 3 GROUP MEAN RANKINGS OF FACTORS CONTRIBUTING TO DISLIKE OF FREEWAYS

	MEAN RANK
Large Trucks	3.3
Rudeness or Dangerous Actions of Others	3.6
High Speed of Travel	4.0
Difficult/Confusing Signs	4.3
Difficulty Merging	4.4
Difficulty Maneuvering in Traffic	6.4
Getting Lost	6.7
Things Happen Too Quickly	6.8
Exiting	6.9
Boring View	8.6

and only 10 percent as less than average. Self-perceived ability to drive on freeways during rush hours certainly appears to exceed self-perceived ability to drive at night or in bad weather. Self-judgments for driving on city streets are comparable to those for driving in light freeway traffic.

The focus group discussion supported the conclusion that most older drivers view themselves as capable freeway users. However, some people believe that some physical changes associated with aging cause certain difficulties for them in freeway driving. Some believe that it is difficult to maintain the vehicle headway required by slower reaction times. Others reported that visual deficits make it difficult to read freeway signs. Other factors mentioned include hearing loss, fatigue, medication effects, mobility limitations, tendency to panic or become disoriented, and loss of daring or confidence. Getting lost is a concern for many, and a wide variety of pretrip planning activities was described. However, these issues were not universally seen as problems, and other participants voiced the opinion that their abilities had not changed.

A number of participants also pointed out that older motorists must keep driving on freeways in order to retain ability and confidence. This "use it or lose it" belief seemed to be part of the general philosophy of keeping active and involved: if older people have not engaged in an activity such as driving for a while, they may "feel a little slower getting back at it."

Many believe that they possess virtues of patience, courtesy, and caution, which contribute to their safe driving on freeways as well as in other situations.

Important Factors or Problems in Freeway Use

Several factors related to problems of freeway use came up in the focus groups, and some were discussed with surprising emotional intensity. The discussions were supplemented by a questionnaire item that listed 10 factors and asked respondents to rank them in importance from 1—the factor that they dislike most—to 10—the factor that bothers them least. Table 3 shows the 10 factors and the group mean rank assigned to each. There was a statistically significant degree of agreement among the rankings given by the individual participants (Friedman statistic, $p < .001$).

As Table 3 indicates, the factor rated most important was large trucks. This was an especially prominent problem for those 75 and older, who as a group gave the factor a mean ranking of 2.6. The focus group discussions confirmed the prominence of this issue. Large trucks came up as a major discussion point in virtually every group, and the intensity of feeling expressed left little doubt about the significance of this concern to the older driver. Several participants indicated this is a reason they avoid freeways, and some said they time trips to avoid periods of higher truck traffic. Among the specific complaints are the following: being tailgated by trucks; trucks blocking the driver's view of traffic and signs, both forward and to the side; blinding truck headlights, approaching or in the mirror; speeding, rudeness, and recklessness of truck drivers; spray and gusts from trucks; and the anxiety of feeling the nearness of large trucks.

Speed—more specifically, speed variance from other traffic—is also a concern. A few people are uncomfortable with freeway speeds. However, most judge themselves capable of driving at posted speeds but are uncomfortable with the higher speeds of much of the surrounding traffic, which makes them feel that people "want to push [them] out of the way." Some respond to this situation by taking the attitude that drivers should select their own speed and not worry about that of other drivers; others think that it is very important to "go with the flow."

The rudeness and recklessness of other drivers was a theme sounded throughout the focus groups, with a typical reference to younger drivers in little cars that go zipping in and out of traffic. Instances of rudeness or hostility were mentioned. Such incidents create problems for older drivers in two ways: they reduce the level of control older drivers believe they have over their driving (speed, headway, predicting the actions of others), and they represent social pressure and negative reaction from others. Each of these factors can contribute to discomfort about freeway use.

There were a variety of complaints about freeway and nonfreeway signing, including failure to provide adequate advance warning and confusing or inappropriate sign content.

Merging onto the freeway was clearly the most difficult maneuver discussed; in contrast, there was little evidence that exiting, changing lanes, or passing other vehicles is much of a problem on the freeway. However, many believe that merging is an equally serious difficulty for drivers of all ages, not an age-related issue.

There was a variety of opinion about the lane favored by older drivers. Some prefer the right lane as the slow lane, others prefer the middle lane to avoid conflicts with merging or exiting traffic and to keep options open, and some prefer the left lane because they must worry only about other cars on one side.

CONCLUSIONS

The literature was unable to provide any objective basis for determining the extent of freeway use and route choice by older people. As far as the focus group participants are representative, the conclusion must be that the degree of freeway aversion by older groups is unknown but that it does not appear to be "typical," even for those older than 75. The extent of freeway avoidance is probably overstated in popular opinion. Perhaps such a stereotype was accurate at one time, but it may no longer be accurate now, and it is likely to be even less so in the future.

At the same time, it should be recognized that even if a small proportion of older drivers avoid freeways, there are more than 30 million Americans aged 65 and older, so a small proportion can still be a great number of people. The need to address the problems of older drivers who do not take full advantage of these roads continues. The focus groups revealed a wide range of particular problems suffered by at least some individuals. Overall, the most frequent and emphatic concerns pertained to the traffic operational and social driving climates rather than the physical roadway or personal limitations in ability. A number of people think that the driving climate has changed dramatically over the years; there is now more traffic, more speed, more aggression, and less courtesy. The difficulties people mentioned may be related partly to aging and partly to having developed their driving habits in a less intense driving climate.

The focus groups identified needs and generated ideas for countermeasures that might foster greater, and safer use of freeways by older drivers. These include

1. Lane restrictions, time restrictions, separate truck roadways, and other methods to reduce interaction with heavy trucks;

2. Greater police enforcement, new enforcement technologies such as photo radar (*12*), new traffic-control technologies (*13*), and other methods to reduce speed variability in the traffic stream;

3. Better graphics, greater use of sign panels listing several upcoming exits, and other methods to improve advance signing so that it better meets the visual and information needs of the elderly;

4. Wide, high-quality shoulders; increased police patrol; brightly lit roadside emergency phones; promotion of citizens band radio use; better night lighting; more frequent path confirmation; and other methods to overcome the frequently expressed concerns about personal security;

5. More-legible maps, map-use training in older-driver education courses, in-vehicle guidance systems, and other pretrip planning aids that are designed to be usable by older drivers (*14*);

6. Appreciation of the safety benefits, on-road "refresher" training for those who have not used high-speed roads recently, training in recovery from navigational errors, and other older-driver education specific to freeway use; and

7. Eliminating short merge areas and weaving sections and other methods to improve the interchange geometrics that the focus groups identified as contributing to anxiety.

The demographic changes projected for the United States will result in growing numbers of older drivers, who will increasingly reside in nonurban locales that depend on limited-access freeways for mobility. The needs and perceptions of this group of roadway users must be met if the highway system is to promote full mobility for all drivers.

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Characteristics of Accidents Involving Elderly Drivers at Intersections

NICHOLAS J. GARBER AND RAGHAVAN SRINIVASAN

Statistics indicate that elderly drivers (drivers 65 years and older) are involved in an increasingly high percentage of accidents at intersections. To develop countermeasures to this problem, traffic and geometric characteristics associated with elderly driver accident involvement are identified. The results indicate that the risk of an elderly driver's being in an accident—expressed in terms of an involvement ratio—is higher at intersections outside cities than at those inside cities. It was also found that providing longer amber signal times and protected left-turn phases will help the older driver.

Studies have indicated that significant changes are taking place in the age structure of the U.S. population. This change, which demographers sometimes refer to as the "squaring of the pyramid," is altering the population structure from one in which many young people are at the base and few old people are at the top of the pyramid to one that resembles a rectangle and has an even distribution of the age groups (*1*). In 1900, for example, only 4 percent of the population was 65 years old and older; in 1988, this number had increased to 12 percent, and it is expected to grow to 13 percent by the year 2000 (*1*). In the future, the elderly (defined here as 65 and older) will tend to be more affluent and healthier than the elderly of the past; hence, they are more likely to reside in suburban areas and depend mainly on the automobile for their mobility. This most probably will result in an increase in automobile travel by the elderly.

Unfortunately, statistics indicate that an elderly person has a higher probability of being involved in an automobile accident—particularly a fatal automobile accident—than the average driver or pedestrian. In 1986, there were 5,900 persons 65 and older killed in motor-vehicle crashes; approximately half of them were 75 and older. This is 13 percent of the total traffic fatalities. The elderly represent 12 percent of the population; thus, the proportion of the traffic fatalities for the elderly is approximately equal to their proportion in the population (*2*). It is, however, well known that the elderly travel much less than members of other age groups; thus, they should have a lower percentage of fatal accidents than their proportion in the population. Hence, it is necessary to identify and correct the features of the highway system that create hazardous situations for the elderly.

Previous studies have indicated that a significant percentage of crashes involving elderly drivers occur at intersections. For example, Hauer's analysis of NHTSA data (*3*) has shown that approximately 70,000 elderly drivers are injured and 1,000 killed at intersections every year. These represent 60 and 40 percent of all injury accidents of drivers 64 and older. Hence, this paper will concentrate on the problems of elderly drivers at intersections.

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The scope is limited to intersection accidents occurring in the rural and urban areas of Virginia. The objective is to identify the characteristics of accidents involving elderly drivers at intersections. The specific objectives are

- To identify the causes of accidents involving elderly drivers at intersections,
- To identify intersection geometric characteristics that are predominant in crashes involving elderly drivers, and
- To identify the intersection traffic-control devices that are predominant in crashes involving elderly drivers.

LITERATURE REVIEW

The literature search revealed that much research on the safety of elderly drivers has been undertaken. The following paragraphs summarize the relevant information obtained in the literature review.

Risk of Elderly Drivers in Crash Involvement

Existing data suggest that in general the crash risk for an elderly driver is somewhat higher than it is for the average person, especially the risk of a fatal crash. Evans (*4*) has shown that when the exposure used for calculating fatality rates is the number of drivers in each age group, the risk starts increasing between ages 65 and 70, but, when the amount of miles traveled is used as the exposure, the risk starts increasing at 50. In the former case, the risk for women is half that of men; in the latter case, there is hardly any difference. This shows that the distribution between age and fatality rate depends on the exposure used to calculate this fatality rate.

Type of Collision and Driver Action

A recent study by McKelvey et al. has shown that the elderly are involved in a marginally higher percentage of head-on collisions and a significantly higher percentage of angle collisions than young or middle-aged drivers (*5*). It was also found that elderly drivers are more often charged for failing to yield the right-of-way, turning illegally, and changing lanes improperly than drivers of other age groups.

Intersection Type and Traffic Control

Most of the studies that have considered the effect of intersection type or traffic control have been for all accidents, and the results have not been broken down for different age groups. It can be assumed, however, that most of the intersection traffic and geometric characteristics that have an adverse effect on the safety of the overall driver population will also have an adverse effect on the elderly driver. The following paragraphs summarize studies on the effect of intersection type and traffic control on accidents.

Intersection Type

There are two common types of intersections: cross and T. Cross intersections are much more complex than T-intersections because of the higher number of conflicting traffic streams. Hence, it is possible that cross intersections are not as safe as T-intersections for the elderly. Unfortunately, very few studies have investigated this problem in detail.

Type of Traffic Control

There are four major options for traffic control: (a) traffic signals, (b) stop signs, (c) yield signs, and (d) no control. A specific type of traffic control is used primarily on the basis of traffic volume and delay, not safety. A few studies have investigated the effect of different types of traffic control on safety, but the results are not consistent (*6–8*). Because most of the studies did not consider the effect of traffic volumes in their analysis, their results cannot be generalized.

McKelvey et al. calculated involvement ratios for different types of traffic control for accidents that occurred on highway intersections in Michigan (*9*). They found that there was a large increase in the involvement ratios for drivers over 75 when there were flashing signals. For drivers older than 60, intersections with signals operating on cycles had the lowest involvement ratio. Unsignalized intersections had higher involvement ratios than those with signals operating on cycles, but those with flashing signals had the highest involvement ratios.

COMPILATION OF ACCIDENT DATA

The Virginia Department of Transportation (VDOT) maintains standardized accident data bases for accidents occurring on Interstates and primary, secondary, and frontage roads. Accident data for 1986, 1987, and 1988 were obtained from VDOT. From this data base, accident data on intersections were extracted for further analysis. In addition to the age of the driver or pedestrian, the following variables were extracted: intersection type, traffic control, weather, lighting, type of collision, vehicle zone of impact, major factor, severity, driver sex, driver action, and vehicle maneuver. Accidents were grouped into intersection and nonintersection accidents on the basis of the zone of impact: accidents that occurred within the intersection proper or within 150 ft of the edge of the intersection on each approach were classified as intersection accidents. The compiled accident data covered approximately 26,000 accidents involving drivers 50 and older.

It was expected that city intersections would also have a large number of accidents involving the elderly, so accident data were compiled for a sample of cities in Virginia. Unfortunately, the data on accidents occurring in cities are available not in a standard computer form but as police accident report forms, which are maintained by the Virginia Department of Motor Vehicles. Police accident reports for intersection accidents involving drivers 50 and older were therefore obtained for four randomly selected cities: Virginia Beach, Roanoke, Lynchburg, and Fredericksburg. Relevant accident information from these accident records was then coded into a computer file. The coded accident data base consisted of entries on approximately 7,000 intersection accidents involving drivers 50 and older from 1986 to 1988.

ANALYSIS OF ACCIDENT DATA

Risk of Accident Involvement for the Elderly

The conventional way of expressing risk at intersections, which is based on traffic volume, cannot be used for different age groups because of the lack of adequate data on actual volume distribution by age group. It was therefore necessary to use another definition of risk when comparing age groups.

In this study, risk is expressed in terms of involvement ratio, which is defined as the ratio of the number of accidents attributed to drivers in a given age group to the number of accidents not attributed to drivers in that same age group. Although VDOT does not directly code the responsibility of the driver in an accident, a parameter called driver action is coded. It gives information about whether the driver committed a traffic violation. Hence, in this paper, the involvement ratio for any age group is the ratio of the number of accident involvements by a given age group in which there was a traffic violation to the total number of accident involvements by that age group in which there was no traffic violation.

One assumption is that the police officer who assigns the responsibility for the accident is unbiased with respect to age. McKelvey et al. tested this by analyzing the data for right-angle crashes and comparing the results with those for other crashes. The involvement ratios were found to be quite similar. Because responsibility can be more directly assigned for right-angle crashes, it was concluded that the variation in involvement ratios over age cannot be explained by police officers' biases (*10*).

Accident Characteristics of the Elderly

Driver ages were divided into 5-year divisions. For accidents that occurred in VDOT-maintained intersections, 14 age groups were considered, starting from the 15–19 age group to the above-79 age group. For accidents that occurred in Virginia cities, only 7 age groups were considered because accident data were compiled only for accidents involving drivers 50 and older. Apart from driver age, the following variables were considered: (a) accident location, (b) driver sex, (c) type of collision, (d) vehicle maneuver, (e) driver action, (f) type of intersection, and (g) traffic control.

The two variables considered for comparison between age groups were percentage of involvements and involvement ratio. The proportionality test was used for comparing the percentage of involvements among age groups for accident location, type of collision, vehicle maneuver, driver action, and traffic control, whereas Student's *t*-test was used for comparing the involvement ratios by age groups for all variables considered. A brief description of the theory involved in the proportionality and *t*-tests follows.

Proportionality Test

As the name indicates, this test is used to compare two proportions. The test statistic is the Z value, which is given as

$$Z = (p_1 - p_2)/[p(1 - p)(1/n_1 + 1/n_2)]^{1/2}$$

where p_1 and p_2 are the two proportions to be compared, and n_1 and n_2 are the population sample sizes.

$$p_1 = x_1/n_1 \qquad p_2 = x_2/n_2$$

where x_1 and x_2 are the number of successes in each sample. The pooled proportion of successes is p, defined as follows:

$$p = (x_1 + x_2)/(n_1 + n_2)$$

The null hypothesis that was tested was H_o: $p_1 \leq p_2$, against the hypothesis that H_a: $p_1 > p_2$. The null hypothesis was rejected when the calculated test statistic Z was greater than Z_a, where Z_a is the standard normal variant corresponding to a significance level of a.

Student's t*-test*

The t-test was used in this study for the comparison of involvement ratios. The test statistic is the t' value (14) defined as

$$t' = (X_1 - X_2)/[s_1^2/n_1 + s_2^2/n_2]^{1/2}$$

where

X_1 and X_2 = sample means of the two populations,
s_1 and s_2 = population standard deviations, and
n_1 and n_2 = population sample sizes.

t' is assumed to follow a t distribution with the degrees of freedom given by

$$\text{df} = f(s,n)/g(s,n)$$

where

$$f(s,n) = [s_1^2/n_1 + s_2^2/n_2]^2, \text{ and}$$

$$g(s,n) = [(s_1^2/n_1)^2/(n_1 - 1) + (s_2^2/n_2)^2/(n_2 - 1)].$$

The null hypothesis that was tested was H_o: $X_1 \leq X_2$, against the hypothesis H_a: $X_1 > X_2$. The hypothesis is rejected when t' is greater than t_a^*, where the t_a^* is the standard t value corresponding to a significant level a and degrees of freedom (df).

RESULTS OF ANALYSIS

Percentage of Involvements

Accident Location

Figure 1 shows that the percentage of involvements at intersections increases with age. The results of the proportionality test also showed that the percentage of involvements at intersections for the age group 65 and above was higher than that of the 50–64 age group at a significance level of 0.001 percent (Z = 10.60). This suggests that the elderly are more likely to be involved in accidents at intersections.

Only the VDOT data were used for this analysis because only data on accidents at intersections were obtained for the cities.

Type of Collision

Table 1 shows the percentage distribution of involvements by type of collision for the VDOT data. The results show that not only are angle collisions predominant for all age groups, but this type of collision increases with an increase in age. The proportionality test was again used to determine whether any significant difference existed between the elderly and nonelderly. The results indicate a significant difference at a significance level of 0.001 percent. Table 2 presents the results of the proportionality tests for the VDOT data.

Vehicle Maneuver

Tables 3 and 4 show the percentage distribution of crashes by vehicle maneuver for the different age groups for the VDOT and city data. The predominant crash maneuver for all age groups is that in which the vehicle is going straight. This is because this is the predominant driving maneuver. However, the data indicate that for age groups older than 54 (VDOT

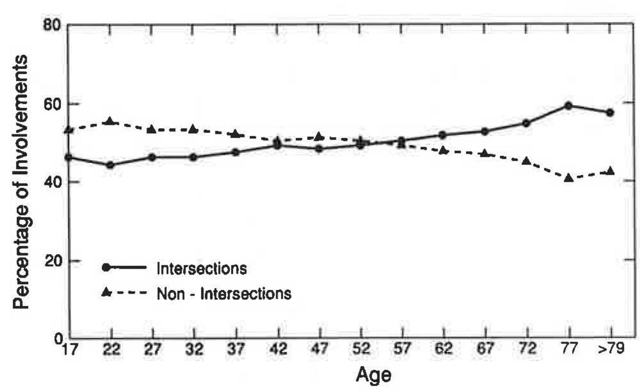

FIGURE 1 Percentage of involvements by location, VDOT data.

TABLE 1 PERCENTAGE OF INVOLVEMENTS BY TYPE OF COLLISION

VDOT Accident Data — 1986 to 1988						
	Type of Collision					
Age Group	1	2	3	4	5	6
15-19	26.0	47.0	1.9	7.4	1.9	15.8
20-24	29.1	46.0	1.7	8.6	1.8	12.8
25-29	30.5	45.2	1.7	8.8	2.0	11.8
30-34	30.3	45.8	1.7	9.5	2.0	10.7
35-39	30.2	47.3	2.0	9.1	1.9	9.5
40-44	30.3	48.3	1.9	8.9	1.9	8.7
45-49	29.9	49.3	1.7	8.8	2.0	8.3
50-54	29.2	49.3	1.7	8.8	2.0	9.0
55-59	26.7	52.5	1.9	9.2	2.1	7.6
60-64	24.7	55.5	1.5	9.2	1.7	7.4
65-69	22.5	57.2	1.7	10.2	1.8	6.6
70-74	19.5	60.4	1.7	9.9	1.5	7.0
75-79	16.5	64.0	1.4	9.2	2.4	6.5
> 79	12.9	67.8	2.3	7.4	1.5	8.1

1 - Rear end
2 - Angle
3 - Head on
4 - Sideswipe same direction
5 - Sideswipe opposite direction
6 - Other (fixed object, noncollision etc.)

TABLE 2 RESULTS OF PROPORTIONALITY TESTS BY TYPE OF COLLISION

VDOT Accident Data — 1986 to 1988			
	Percentage of Involvements		
Type of Collision	50-64	65 and above	Z
Rear End	27.08	19.22	14.52*
Angle	52.14	60.83	13.84*
Head On	1.67	1.72	0.27
Sideswipe Same Direction	9.39	9.56	0.45
Sideswipe Opposite Direction	1.95	1.80	0.85

* Significant at a 5 percent significance level.

TABLE 3 PERCENTAGE OF INVOLVEMENTS BY VEHICLE MANEUVER, VDOT DATA

VDOT Accident Data — 1986 to 1988						
	Vehicle Maneuver					
Age Group	1	2	3	4	5	6
15-19	49.4	4.0	17.4	7.1	1.8	20.3
20-24	52.5	4.0	15.9	6.1	2.1	19.4
25-29	52.3	3.9	15.4	5.0	1.9	21.5
30-34	51.7	3.9	16.0	4.0	1.9	22.5
35-39	50.5	4.2	16.4	3.3	1.9	23.7
40-44	49.6	4.1	16.8	3.2	1.8	24.5
45-49	50.5	3.9	16.4	2.4	2.1	24.7
50-54	47.2	4.6	19.2	2.4	2.1	24.5
55-59	48.0	4.1	20.4	2.5	2.0	23.0
60-64	45.5	5.0	22.2	2.4	2.1	22.8
65-69	44.4	4.5	24.6	1.9	2.4	22.2
70-74	41.5	4.9	28.1	2.2	2.3	21.0
75-79	38.0	5.4	31.6	1.7	2.2	21.1
> 79	37.2	5.7	35.0	2.0	1.9	18.2

1 - Going Straight
2 - Right turn
3 - Left turn
4 - Ran-off-road
5 - Changing lanes
6 - Other (slowing, stopping, backing, passing)

TABLE 4 PERCENTAGE OF INVOLVEMENTS BY VEHICLE MANEUVER, VIRGINIA CITIES DATA

Virginia Cities Accident Data — 1986 to 1988						
	Vehicle Maneuver					
Age Group	1	2	3	4	5	6
50-54	50.9	5.1	17.1	1.1	1.7	24.1
55-59	51.8	5.2	17.4	1.3	1.7	22.6
60-64	54.7	5.7	17.2	0.5	2.2	19.7
65-69	46.7	8.7	21.1	0.5	3.2	19.8
70-74	47.4	5.6	21.4	0.7	3.2	21.7
75-79	45.6	7.2	28.2	0.7	1.3	17.0
> 79	46.5	8.1	26.2	0.5	3.4	15.3

1 - Going Straight
2 - Right turn
3 - Left turn
4 - Ran-off-road
5 - Changing lanes
6 - Other (slowing, stopping, backing, passing)

data) and 65 (city data), there is a consistent reduction in the percentage of crashes in which the maneuver was going straight, whereas there is a consistent increase in the percentage of crashes in which the left-turn maneuver was involved. This suggests that the potential for left-turn accidents involving the elderly increases with age. The results of the proportionality test also show the proportion of left-turn involvements for the elderly to be significantly higher than that for the 50–64 age group at a significance level of 0.001 percent. Although some increase in the proportion of involvements involving right-turn maneuvers was observed for the elderly as age increases, the proportion of accidents involving right turns for the elderly is not significantly different from that for the 50–64 age group at the 5 percent significance level.

Driver Action

Tables 5 and 6 show the percentage distribution of accidents by driver action and age groups for the VDOT and city data. It can be seen that for both sets of data, the predominant violation for the elderly is failure to yield right-of-way. In fact, the percentage of involvements for which the violation is failure to yield right-of-way increases with age not only for those 65 and older but also for those between 50 and 64. This suggests that using traffic control devices that will clearly indicate which traffic stream has the right-of-way will be significant in the reduction of accidents involving the elderly at intersections. Although the predominant violation for all age groups above 50 is failure to yield right-of-way, the results of

TABLE 5 PERCENTAGE OF INVOLVEMENTS BY DRIVER ACTION, VDOT DATA

VDOT Accident Data — 1986 to 1988								
	Driver Action							
Age Group	1	2	3	4	5	6	7	8
15-19	32.9	7.0	21.2	4.5	13.2	2.4	2.5	16.3
20-24	41.8	5.8	15.1	4.5	11.9	2.6	1.9	16.4
25-29	47.3	4.3	14.5	3.9	10.4	2.2	1.7	15.7
30-34	51.5	3.3	14.6	3.8	9.3	2.0	1.3	14.2
35-39	54.1	2.8	15.3	3.4	8.4	1.6	1.4	13.0
40-44	55.3	2.3	16.4	3.1	8.0	1.8	1.2	11.9
45-49	53.4	1.9	15.9	3.1	7.9	1.8	1.3	14.7
50-54	52.9	1.8	18.8	2.8	8.2	1.8	1.6	12.1
55-59	51.6	1.7	20.4	2.7	8.1	2.3	1.4	11.8
60-64	46.9	1.5	24.1	2.6	8.2	2.3	2.4	12.0
65-69	40.3	1.1	29.2	2.8	8.7	2.5	2.4	13.0
70-74	33.7	1.2	35.5	3.1	8.9	2.3	2.6	12.7
75-79	25.2	0.8	43.9	2.5	9.5	3.2	3.0	11.9
> 79	16.6	0.5	48.9	2.7	8.9	3.4	4.0	15.0

1 - No violations
2 - Exceeding speed limit as well as safe speed
3 - Failure to yield right of way
4 - Following too close
5 - Inattention
6 - Disregarded stop-go light
7 - Disregarded stop/yield sign
8 - Other

TABLE 6 PERCENTAGE OF INVOLVEMENTS BY DRIVER ACTION, VIRGINIA CITIES DATA

Virginia Cities Accident Data — 1986 to 1988								
	Driver Action							
Age Group	1	2	3	4	5	6	7	8
50-54	51.9	0.8	14.3	4.7	5.2	1.6	4.1	17.4
55-59	48.0	1.3	16.6	5.5	4.9	2.8	3.5	17.4
60-64	47.9	0.8	18.4	5.6	4.9	2.6	4.5	15.3
65-69	42.8	0.9	22.0	3.5	5.9	2.4	5.4	17.1
70-74	35.7	1.0	26.3	4.3	6.9	2.9	5.2	17.7
75-79	28.4	1.0	33.9	3.5	7.4	3.7	3.7	18.4
> 79	23.7	0.7	35.2	2.7	7.7	5.9	4.3	19.8

1 - No violations
2 - Exceeding speed limit as well as safe speed
3 - Failure to yield right of way
4 - Following too close
5 - Inattention
6 - Disregarded stop-go light
7 - Disregarded stop/yield sign
8 - Other

proportionality tests show that there is a difference at the 0.001 percent significance level in the percentage of involvements between that for the elderly and that for the 50–64 age group. The small percentage of violations by the elderly for exceeding the safe speed limit is expected because this group of drivers tends to drive slower than the other age groups. Table 7 provides the results of the proportionality tests for the VDOT data.

Traffic Control

Table 8 shows the percentage distribution of accident involvements by traffic control and age for the city data. These indicate that there is an increase in the percentage of involvements for the elderly at intersections controlled by stop signs. In fact, the results of the proportionality tests show that the percentage of involvements at stop-controlled intersections

TABLE 7 RESULTS OF PROPORTIONALITY TESTS BY DRIVER ACTION

VDOT Accident Data — 1986 to 1988			
	Percentage of Involvements		
Driver Action	50-64	65 and above	Z
No violation	50.75	32.37	-29.30*
Did not have right-of-way	20.85	36.46	28.04*
Driver inattention	8.17	8.94	2.20*
Following too-close	2.71	2.81	0.48
Disregarded stop-go light	2.11	2.70	3.11*
Disregarded stop/yield	1.76	2.78	9.90*
Speeding	1.68	0.99	- 4.59*

* Significant at the 5 percent significance level.

TABLE 8 PERCENTAGE OF INVOLVEMENTS BY TRAFFIC CONTROL

Virginia Cities Accident Data — 1986 to 1988					
	Traffic Control				
Age Group	1	2	3	4	5
50-54	36.3	19.6	20.3	20.0	3.8
55-59	33.2	20.8	21.4	17.9	6.7
60-64	34.1	22.7	20.1	16.9	6.2
65-69	37.1	21.7	20.2	14.8	6.2
70-74	32.3	21.5	22.0	17.3	6.9
75-79	32.9	27.5	19.8	14.2	5.6
> 79	29.6	27.8	21.7	13.9	7.0

1 - Traffic signal
2 - Stop sign
3 - Traffic lanes marked
4 - No control
5 - Other (slow/warning sign, yield sign, officer, etc.)

for drivers 65 and older is significantly higher than that for drivers 50–64. Table 9 presents the results of the proportionality tests conducted for the VDOT data. Similar results were obtained for the city data.

The increase in percentage of involvements in stop-controlled intersections with age is not surprising considering the fact that there is an increase in failure to yield right-of-way violations with an increase in age.

Involvement Ratio

Accident Location

Figures 2 and 3 show the distribution of the involvement ratios by age for the VDOT and city data. Figure 2 shows that the involvement ratio for intersection accidents initially decreases from a value of about 1.8 for the youngest age group (15–19) to approximately 0.7 for the 45–50 age group. It then increases to approximately 5 for the oldest age group (above 79). It can also be seen that for drivers above 62, the involvement ratio at intersections is higher than the involvement ratio at all locations combined.

Figure 3 shows an increase in involvement ratio from about 0.7 for the 50–64 age group to a maximum value of about 3 for the oldest age group (above 79). The results of the *t* test show that there is a significant difference in involvement ratio between the 50–64 age group and the elderly for both VDOT and city intersection accidents. These results indicate that the potential for a driving violation increases with age for drivers older than 62. The rate of increase, however, is higher for elderly drivers.

Driver Sex

As can be seen from Figure 4, at age 52 and older, the involvement ratio for female drivers is higher than that for male drivers, whereas at 42 and younger, the involvement ratio for male drivers is higher than that for female drivers. The results of *t* tests that were performed show that the involvement ratio for female drivers is significantly higher at a 1 percent significance level than the involvement ratio for male drivers for the 50–64 and the 65-and-older age groups.

Similar results were obtained for the city data. The results of *t* tests also show that the involvement ratio for female drivers is significantly higher than the involvement ratio for male drivers at a significance level of 3.5 percent for drivers 65 and older and 4.5 percent for drivers from 50 to 64.

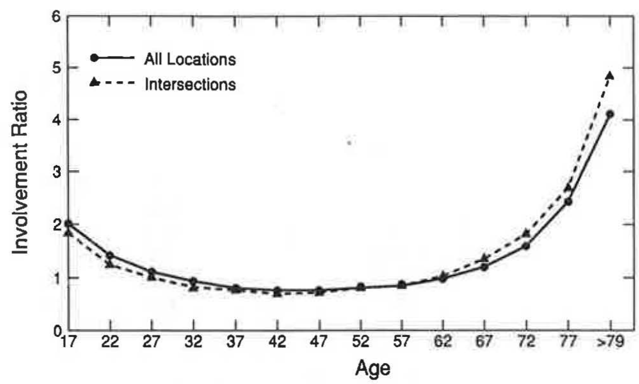

FIGURE 2 Involvement ratio by location, VDOT data.

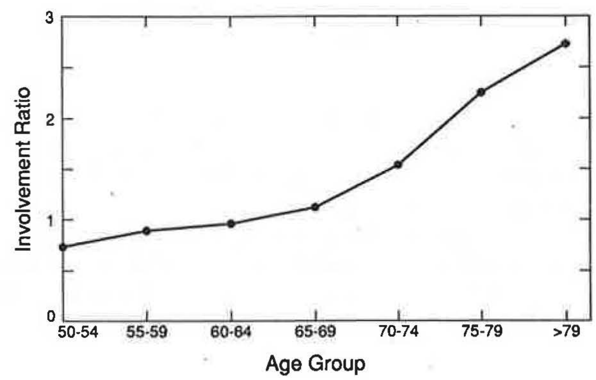

FIGURE 3 Involvement ratio for intersection accidents, Virginia cities data.

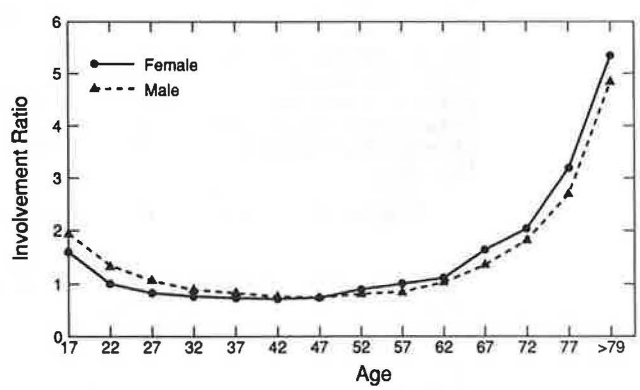

FIGURE 4 Involvement ratio by sex, VDOT data.

TABLE 9 RESULTS OF PROPORTIONALITY TESTS BY TRAFFIC CONTROL

Virginia Cities Accident Data — 1986 to 1988			
Traffic Control	Percentage of Involvements		Z
	50-64	65 and above	
Signal	34.50	33.80	-0.72
Stop	20.94	23.71	2.87*
No control	17.60	15.20	-2.76*

* Significant at the 5 percent significance level.

Type of Collision

Table 10 shows the involvement ratio by type of collision for the VDOT. The results show that for the elderly, there is an increase in the involvement ratio of angle, sideswipe, and head-on collisions with an increase in age. The results of the *t* tests performed on the VDOT data for the 50–64 age group show that the involvement ratios for angle and sideswipe–same-direction collisions are significantly higher than the involvement ratios for read-end collisions (significance levels are 0.3 percent and 0.2 percent, respectively). For the 65-and-above age group, the *t* tests show that the involvement ratios for angle, head-on, and sideswipe–same-direction collisions are significantly higher than the involvement ratios for rear-end collisions (significance levels were 0.01, 4, and 0.56 percent, respectively). The higher involvement ratios for angle and sideswipe–same-direction collisions support the earlier finding that failure to yield right-of-way is a frequent violation for the elderly. Similar results were obtained when the *t* test was performed on the city data. The involvement ratio for angle collisions was significantly higher than the involvement ratio for rear-end collisions for both the 50–64 age group (significance level = 1 percent) and 65-and-above age group (significance level = 0.03 percent).

Vehicle Maneuver

The variations of involvement ratios by vehicle maneuver and age are shown in Figure 5 for the VDOT data. This figure shows that although involvement ratios for accidents involving left-turn maneuvers are the highest for all age groups, significant increases are observed at age 64 and older. Results of the *t* tests performed on the data for the 50–64 and the 65-and-older groups show that the involvement ratios for right- and left-turn maneuvers are significantly higher than those for going straight.

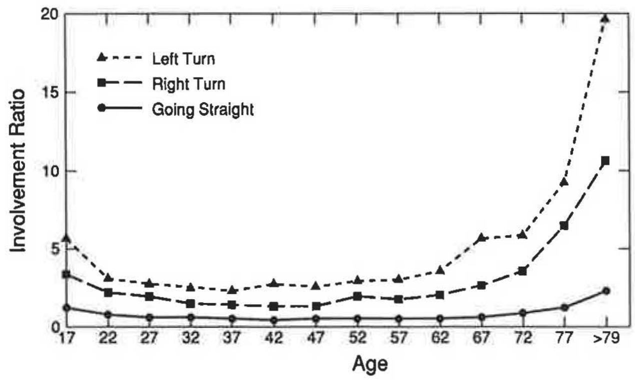

FIGURE 5 Involvement ratio by vehicle maneuver, Virginia cities data.

Traffic Control

Figure 6 shows the involvement ratio for different age groups by traffic control at an intersection. The results of the *t* test performed for the 50–64 age group show that the involvement ratio at intersections with no control is significantly higher than the involvement ratio at intersections with traffic signals (the significance level was 4 percent). When the *t* test was performed on the data for the 65-and-older age group, it was found that the involvement ratio for accidents at intersections with stop control is significantly higher than the involvement ratio for accidents at intersections with no control at a significance level of 2 percent. Also, although the involvement ratio for accidents at intersections with no control is higher than the involvement ratio at intersections with signals, this difference is not significant at the 5 percent significance level.

CONCLUSIONS

- Involvement ratios for the elderly (65 years and older) are significantly higher than those for other age groups.

TABLE 10 INVOLVEMENT RATIO BY TYPE OF COLLISION

VDOT Accident Data — 1986 to 1988					
	Type of Collision				
Age Group	1	2	3	4	5
15-19	1.60	1.64	1.85	1.39	1.57
20-24	1.24	1.02	1.09	1.10	1.14
25-29	0.93	0.86	0.97	0.92	0.90
30-34	0.77	0.77	0.91	0.77	0.86
35-39	0.66	0.74	0.81	0.80	0.56
40-44	0.56	0.77	0.65	0.78	0.53
45-49	0.58	0.81	0.54	0.77	0.53
50-54	0.58	0.95	0.68	0.86	0.78
55-59	0.60	0.99	0.65	1.03	0.46
60-64	0.69	1.21	0.79	1.13	0.61
65-69	0.73	1.71	1.39	1.68	1.42
70-74	0.97	2.28	1.59	2.00	1.50
75-79	1.31	3.61	2.86	2.23	1.88
> 79	1.85	6.34	5.00	6.80	8.00

1 - Rear end
2 - Angle
3 - Head on
4 - Sideswipe same direction
5 - Sideswipe opposite direction

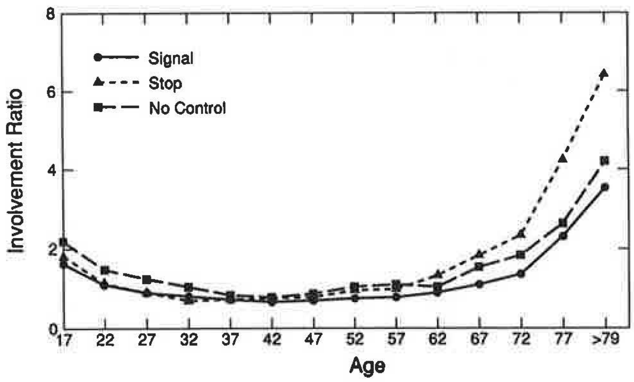

FIGURE 6 Involvement ratio by vehicle maneuver, VDOT data.

- Involvement ratios for the elderly at intersections outside cities are higher than for intersections within cities.
- When the elderly are involved in a crash, it is more likely that they have committed a traffic violation. This likelihood increases with age.
- The probability of the elderly committing a violation at an intersection is much higher than that for other age groups.
- The elderly have a higher potential for committing a traffic violation during a turning maneuver, particularly when making left turns.
- The predominant traffic violation of the elderly is failure to yield right-of-way.
- The elderly are more likely to commit a traffic violation at intersections controlled by stop signs than at any other type of traffic control.
- The provisions of specific countermeasures that will aid the elderly in making turning movements (particularly left turns) will have a significant impact on their crash involvement.

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Risk Assessment of Elderly Drivers at Intersections: Statistical Modeling

NICHOLAS J. GARBER AND RAGHAVAN SRINIVASAN

Advances in medicine and health care have caused an increase in the average life expectancy. This, along with the high birth rate after World War II, has caused an increase in the number of drivers in older age groups. Previous studies have shown that the elderly (defined herein as 65 years and older) are involved in a high percentage of accidents at intersections. Because of the continuous increase in the number of elderly drivers on the roads, it is also highly likely that the number of accidents involving the elderly at intersections will continue to increase, unless countermeasures that will reduce this high rate of intersection accidents are identified and implemented. This paper presents results obtained from a study which had an overall objective to identify intersection design and operation parameters that significantly affect the accident involvement of the elderly and thereby develop guidelines to reduce their accident involvement. Statistical models were developed relating the risk of accident involvement to the traffic and geometric characteristics of the intersection. The primary conclusions are as follows: (a) the elderly are more prone to perform a traffic violation when it is necessary for them to yield to opposing traffic compared with drivers of other age groups; (b) the provision of a protected left-turn phase with left-turn lanes will help in reducing the accident rates of the elderly at signalized intersections; and (c) longer amber times will be beneficial to the elderly.

Over the years there has been an increase in the average life expectancy of individuals because of advances in health care and medicine. There has also been an increase in the percentage of older drivers. This trend is expected to continue at least until the middle of the next century (*1*).

Existing data suggest that the crash risk for the elderly is relatively higher than that for the average person. It has been shown that when the amount of travel is taken as the exposure for calculating the risk, the risk starts increasing at approximately the age of 50 (*2*). Similar results have been obtained when fatal accidents were considered (*3*). These statistics indicate that, considering the increase in the number of elderly drivers and their higher risk of accident involvement, the number of accidents involving the elderly will increase unless suitable countermeasures are taken.

Past studies have shown that a high percentage of accidents involving the elderly occur at intersections (*4,5*). However, very few studies of the specific problem that elderly drivers face at intersections have been carried out. Hence, this study concentrates on the impact of specific traffic and geometric factors of intersections on the risk of accident involvement of the elderly.

Intersection design and operation parameters that significantly affect the accident involvement of elderly drivers at intersections were identified, and algorithms that can be used to assess the crash risk of the elderly were developed. The scope was limited to city intersections in Virginia. The specific objectives were

- To identify a suitable way of expressing the risk of accident involvement for elderly drivers,
- To determine mathematical relationships between the crash risk of elderly drivers and significant traffic and geometric characteristics, and
- To identify changes in design and operation parameters that will enhance the safety of the elderly driver.

COMPILATION OF DATA

Accident Data

The analysis was based on intersection accidents that occurred in cities in the commonwealth of Virginia. Unfortunately, the data on accidents occurring in these cities are not available in a standard computer form. They are available in police accident report forms maintained by the Virginia Department of Motor Vehicles. Police accident reports for intersection accidents involving drivers 50 and older were therefore obtained for four randomly selected cities: Virginia Beach, Roanoke, Lynchburg, and Fredericksburg. Relevant accident information from these accident records was then coded into a computer file. The coded accident data base consisted of approximately 7,000 intersection accidents involving drivers 50 and older in these four cities from 1986 to 1988.

Intersection Traffic and Geometric Data

It was necessary to obtain the specific traffic and geometric data for each intersection selected in the accident data base for the cities, because this information was not included in the police accident reports. This data base was obtained from the answers to questionnaires for each intersection that were sent to the appropriate city engineers. The following information was requested from the engineers:

1. Type of intersection (cross, T, etc.),
2. Traffic control (signal, stop-controlled),
3. Traffic volumes (through volumes, turning volumes),
4. Amber time,
5. Total number of lanes,
6. Approach width,

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7. Presence or absence of right-turn lanes,
8. Presence or absence of left-turn lanes,
9. Divided or undivided,
10. Channelized or unchannelized, and
11. Type of left-turn control (protected, permissive, and protected and permissive).

Questionnaires for about 100 intersections were sent to the city engineers, but complete geometric data were available for only 50 intersections.

Risk of Accident Involvement of the Elderly

The conventional way of expressing risk at intersections based on traffic volumes cannot be used for different age groups because of the lack of adequate data on actual volume distribution by age group. It is therefore necessary to use an alternative definition of risk when comparing age groups.

In this study, risk is expressed in terms of involvement ratio, which is defined as the ratio of the number of accidents attributed to drivers in a given age group to the number of accidents not attributed to drivers in that same age group (*6*). In this report, the responsibility of the driver in an accident is based on the occurrence of a traffic violation, which is coded as a driver action. Hence, in this paper, the involvement ratio for any age group is defined as the ratio of the number of accident involvements in which there was a traffic violation by a given age group and the total number of accident involvements in which there was no traffic violation.

One assumption is that the police officer who assigns the responsibility for the accident is unbiased with respect to age. McKelvey et al. tested this by analyzing the data only for right-angle crashes and comparing the results with those for other crashes. The involvement ratios were quite similar. Because responsibility can be more directly assigned for right-angle crashes, it was concluded that the variation in involvement ratios over age cannot be explained by the bias of the police officer (*7*).

STATISTICAL MODELING

In the modeling task, mathematical relationships were developed between the risk of accident involvement and a set of independent variables considered to be related to the accident. Models were developed only for cross-signalized intersections because sufficient data were not available for other types of intersections. Separate models were developed for drivers between 50 and 64 and for drivers 65 and older.

Models using the involvement ratio as the dependent variable and models using the probability of violation as the dependent variable were developed. In the former case, linear models were developed relating the dependent variable to the set of independent variables. In the latter case, logit models were developed.

The following accident-related variables were considered for the statistical modeling:

- PE—percentage of peak-hour left-turn volume with permissive phasing and without left-turn lane;
- APE—percentage of 24-hr left-turn volume with permissive phasing and without left-turn lane;
- PEL—percentage of peak-hour left-turn volume with permissive phasing and left-turn lane;
- APEL—percentage of 24-hr left-turn volume with permissive phasing and left-turn lane;
- PPL—percentage of peak-hour left-turn volume with protected/permissive phasing and left-turn lane;
- APPL—percentage of 24-hr left-turn volume with protected/permissive phasing and left-turn lane;
- PRL—percentage of peak-hour left-turn volume with protected phasing and left-turn lane;
- APRL—percentage of 24-hr left-turn volume with protected phasing and left-turn lane;
- AMB—average amber time in the four approaches;
- SPAMB—average value of the ratio of speed limit amber time in the four approaches;
- RTV—right-turn peak-hour volume as a percentage of peak-hour approach volume;
- ARTV—right-turn 24-hr volume as a percentage of AADT;
- RVR—percentage of right-turn peak-hour volume with right-turn lane;
- ARVR—percentage of right-turn 24-hr volume with right-turn lane;
- LFV—left-turn peak-hour volume as a percentage of peak-hour approach volume;
- ALFV—left-turn 24-hr volume as a percentage of AADT;
- PKLAN—approach peak-hour volume divided by number of lanes;
- AADAN—AADT divided by number of lanes;
- PKVOL—approach peak-hour volume; and
- AADT—annual average daily traffic.

By definition,

$$PE + PEL + PPL + PRL = 100 \text{ and}$$

$$APE + APEL + APPL + APRL = 100.$$

Initially, two more variables (lane width and presence or absence of right turn on red) were also considered in the statistical modeling. It was found, however, that all intersections considered for the final modeling had 12-ft lanes and all permitted right turn on red. Hence, these two variables were dropped from the modeling.

Criteria for Model Selection

Various criteria have been used in the past to select the best model. These include multiple correlation, adjusted multiple correlation, and maximum likelihood. In this study, the best model was selected based on Akaike's information criteria (AIC) (*8*). AIC for any model can be expressed as follows:

$$AIC = -2 \log L(Lk) + 2k \quad (1)$$

where $L(Lk)$ is Log*e* (maximized likelihood), and k is the number of parameter estimates.

The first term represents the badness of fit, whereas the second term corrects for the complexity of the model. The best model is the one with the least AIC value. A complete derivation of the AIC has been provided by Bozdogan (*9*).

Linear Models

Linear models were developed using the involvement ratio as the dependent variable. Multiple linear regression was performed using the PROC RSQUARE module of SAS. The PROC RSQUARE module provides the best model at each level based on the model with the highest R^2-value, which is also the model with the least AIC. From the best model at each level, the best overall model was selected based on the least AIC value. Models were developed for the two age groups using peak hour as well as AADTs.

Model for 50–64 Age Group Using Peak-Hour Volumes

The model with the least AIC was a four-variable model, which is given as follows:

$$Y = -0.3587 - 0.00576\ \text{PRL} + 0.015353\ \text{PE} + 0.041383\ \text{LFV} + 0.001198\ \text{PKLAN}$$
$$\text{AIC} = -30.79,\ R^2 = 0.75 \quad (2)$$

where Y is the involvement ratio for the 50–64 age group.

This model shows that an increase in PE, LFV, or PKLAN causes an increase in the involvement ratio, whereas an increase in PRL reduces the involvement ratio. Sensitivity analysis was performed by considering an increase of 10 percent of each independent variable over the observed mean values. The involvement ratio corresponding to the mean values of the independent variables is equal to 0.92. An increase of 10 percent over the mean value of LFV increases Y to 0.99, whereas an increase of 10 percent over the mean value of PKLAN increases Y to 0.97. In order to study the effect of left-turn phasing, three cases were considered: PE equal to 100, PEL equal to 100, and PRL equal to 100. When PE is equal to 100, the involvement ratio is equal to 2.2. When PEL is equal to 100 (i.e., PE = 0, PPL = 0, PRL = 0), the involvement ratio reduces to a value of 0.7. When PRL is equal to 100, the involvement ratio reduces further to 0.3. This shows that the provision of left-turn lanes and protected left-turn phases will reduce the involvement ratio of the 50–64 age group at the intersection.

Model for 65-and-Older Age Group Using Peak-Hour Volumes

The model was the least AIC value was a four-variable model, which is given as follows:

$$Y = -10.6619 + 0.040164\ \text{PE} + 0.033648\ \text{PEL} + 0.85830\ \text{SPAMB} + 0.13986\ \text{LFV} \quad \text{AIC} = 9.904,\ R^2 = 0.56 \quad (3)$$

where Y is the involvement ratio for the 65-and-above age group.

This model shows that an increase in PE, PEL, or SPAMB produces an increase in the involvement ratio. This model indicates that although the involvement ratio tends to increase when the percentage of left-turn volume using a permissive phase increases, this effect is reduced when a left-turn lane is provided. The involvement ratio corresponding to the mean values of the independent variables is equal to 1.79. An increase of 10 percent in LFV increased the involvement ratio to 2.03, whereas an increase of 10 percent in SPAMB increased the involvement ratio to 2.6. In order to study the effect of left-turn phasing, three cases were considered: PE equal to 100, PEL equal to 100, and PRL equal to 100. When PE is equal to 100, the involvement ratio is equal to 4.06. When PEL is equal to 100, the involvement ratio is reduced to 3.4. When PRL is equal to 100 (i.e., PE = 0, PEL = 0, PPL = 0), the involvement ratio drops to almost zero.

This model suggests that the involvement ratio of the elderly will increase as the percentage of the left-turn volume increases, but this increase will be reduced if left-turn protected phasing with left-turn lanes is provided for a high percentage of left-turn volumes. Another variable that seems to have a significant effect on the involvement ratio of the elderly is the average value of the ratio of the speed limit and the amber time at all approaches. Because the higher the amber time, the lower the value of the SPAMB for any given speed limit, the model suggests that longer amber times will aid in reducing the involvement ratio of the elderly at signalized intersections. This suggests that the amber period of 3 to 5 sec now used at signalized intersections may not be adequate for the elderly. Also, the reduction in their risk when a left-turn lane is provided on approaches with a permissive phase is less than that for the 50–64 age group. Figure 1 shows the variation of involvement ratio with PE and LFV.

Model for 50–64 Age Group Using 24-hr Volumes

The model with the least AIC was a three-variable model, which is given as follows:

$$Y = 0.2098 + 0.01253\ \text{APE} - 0.00546\ \text{APRL} + 0.04208\ \text{ALFV} \quad \text{AIC} = -28.02,\ R^2 = 0.73 \quad (4)$$

This model shows that an increase in APE or ALFV produces an increase in the involvement ratio, whereas an increase in APRL causes a reduction in the involvement ratio. The involvement ratio corresponding to the mean values of the independent variables was 0.904. An increase of 10 percent in the value of ALFV increases the involvement ratio to 0.97. In order to study the effect of left-turn phasing, three cases were considered: APE equal to 100, APEL equal to 100, and APRL equal to 100. When APE is equal to 100, the involvement ratio is equal to 2.14. When APEL is equal to 100 (i.e., APE = 0, APPL = 0, APRL = 0), the involvement ratio is reduced to 0.88. When APRL is equal to 100, the involvement ratio is reduced further to 0.34. These results are

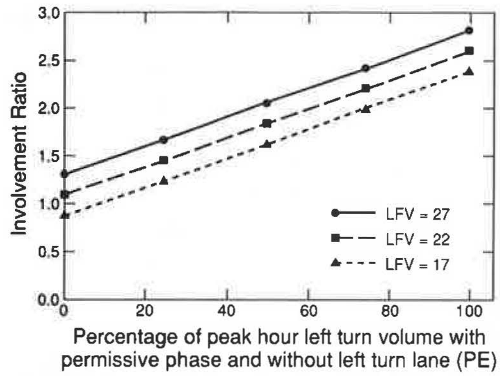

FIGURE 1 Effect of PE and LFV on involvement ratio of 50–64 age group using peak-hour volumes.

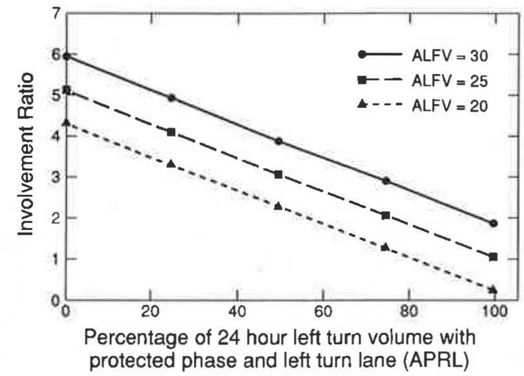

FIGURE 2 Effect of APRL and ALFV on involvement ratio of 65-and-above age group, using 24-hr volumes.

similar to those obtained for the model of peak-hour volumes (Equation 2) in that the provision of protected phasing left-turn lanes will reduce the involvement ratio for the 50–64 age group.

Model for 65-and-Older Age Group Using 24-hr Volumes

The least AIC in this case was obtained for a four-variable model, which is given as:

$$Y = -6.6640 + 0.77154\,\text{SPAMB} + 0.16515\,\text{ALFV} - 0.04063\,\text{APR} - 0.030596\,\text{APPL}$$

$$\text{AIC} = 6.704, R^2 = 0.65 \quad (5)$$

This model shows that an increase in ALFV or SPAMB causes an increase in the involvement ratio, whereas an increase in APRL or APPL causes a decrease in the involvement ratio. The involvement ratio corresponding to the mean values of the independent variables was equal to 1.6. An increase of 10 percent in the value of ALFV increases the involvement ratio to 1.87, and an increase of 10 percent in the value of SPAMB increases the involvement ratio to 2.35. In order to study the effect of left-turn phasing, three cases were considered: APEL equal to 100, APPL equal to 100, and APRL equal to 100. When APEL is equal to 100 (i.e., APE = 0, APPL = 0, APRL = 0), the involvement ratio is equal to 3.46. When APRL is equal to 100, the involvement ratio is reduced to 0. When APPL is equal to 100, the involvement ratio is 0.4. These results are also consistent with those obtained for the model using peak-hour volumes (Equation 3) in that the provision of a protected left-turn phase with left lanes and longer amber times will reduce the involvement ratio of the elderly at signalized intersections. Also, the use of 24-hr volumes seems to provide a better fit (AIC = 6.7, R^2 = 0.65) compared to that obtained for peak-hour volumes (AIC = 9.0, R^2 = 0.56). This may be due to the fact that the elderly travel less during the peak time than other age groups. Figure 2 shows the variation of the involvement ratio with changes in APRL and ALFV.

Logistic Models

As already mentioned, the logistic model was used to relate the probability of violation to the independent variables. The logistic model is based on the binomial theorem, where there are only two possible values for the response (dependent) variable: 1 denoting a success and 0 denoting a failure. In our case, the occurrence of a traffic violation was considered a success and coded as 1, and the nonoccurrence of a traffic violation was considered a failure and coded as 0. The logit model predicts the probability of success, which in our case is the probability of the occurrence of a violation. In a logit model, the relationship between the dependent and independent variables is expressed in this form:

$$P = 1/(1 + e^{-AX}) \quad (6)$$

where P is the probability of success (violation), and AX is defined as $AX = A_1X_1 + A_2X_2 + \ldots + A_nX_n$, where $X_1 \ldots X_n$ are the independent variables.

Logistic regression was performed using the PROC LOGIST module in SAS. A forward as well as a backward stepwise procedure was adopted, and the best model was determined based on the AIC values.

Model for 50–64 Age Group Using Peak-Hour Volumes

The least AIC in this case was obtained for a four-variable model, which is given as follows:

$$AX = -2.49806 + 0.02114\,\text{PE} - 0.009007\,\text{PRL} + 0.00195\,\text{PKLAN} + 0.078203\,\text{LFV} \qquad \text{AIC} = 201.29 \quad (7)$$

This model shows that an increase in PE, PKLAN, or LFV results in an increase in the probability of violation, whereas an increase in PRL causes a reduction in the probability of violation. The probability of violation corresponding to the mean values of the independent variables is equal to .436. An increase of 10 percent in the mean value of LFV increases the probability of violation to .467, whereas an increase of 10 percent in the mean value of PKLAN increases the probability of violation to .457. To study the effect of change in the left-turn phasing, three cases were considered: PE equal to 100, PEL equal to 100, and PRL equal to 100. When PE is equal to 100 percent, the probability of violation is .846. When PEL is equal to 100 percent (i.e., PE = 0, PRL = 0, PPL = 0), the probability of violation is reduced to .40. Also, when PRL is equal to 100 percent, the probability of violation is reduced to .213. These results are also consistent with those given in Equations 2 and 4 in that the probability of violation increases with an increase in left-turn volumes, but this effect is reduced when left-turn lanes and protected phases are provided.

Model for 65-and-Older Age Group Using Peak-Hour Volumes

The least AIC in this case was obtained for a two-variable model, which is given as follows:

$$AX = -2.36491 - 0.0138101 \text{ PRL} + 0.32884 \text{ SPAMB} \qquad \text{AIC} = 134.24 \tag{8}$$

This model shows that an increase in SPAMB produces an increase in the probability of violation, whereas an increase in PRL causes a reduction in the probability of violation. The probability of violation corresponding to the mean values of the independent variables is .61. An increase of 10 percent over the mean value of SPAMB increases the probability to .68. If PRL is changed from its mean value to 0, the involvement ratio increases to 0.702. When PRL is increased to 100, the probability is reduced to .372. These results are consistent with those obtained with Equations 3 and 5. Figure 3 illustrates the variation of the probability of violation with PRL and SPAMB.

Model for 50–64 Age Group Using 24-hr Volumes

The least AIC in this case was obtained for a three-variable model, which is given as follows:

$$AX = -1.42536 - 0.00802 \text{ APRL} + 0.07475 \text{ ALFV} + 0.01475 \text{ APE} \qquad \text{AIC} = 201.44 \tag{9}$$

This model shows that an increase in ALFV or APE causes an increase in the probability of violation, whereas an increase in APRL produces a reduction in the probability of violation. The probability of violation corresponding to the mean values of the independent variables is .46. An increase of 10 percent over the mean value of ALFV increases the probability of violation to .49. When the value of APE increases from its mean value to 100, the probability of violation increases to .776; but, when both APE and APRL are equal to zero (APEL + APPL = 100), the probability of violation is reduced to .44. When APRL is increased to 100, the probability of violation is reduced to .263. These results are also consistent with those obtained previously.

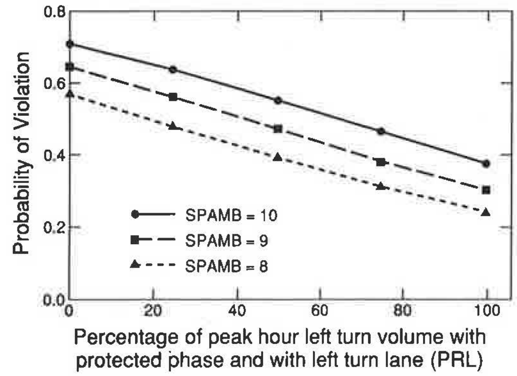

FIGURE 3 Effect of PRL and SPAMB on probability of violation for 65-and-above age group, using peak-hour volumes.

Model for 65-and-Above Age Group Using 24-Hour Volumes

The least AIC in this case was obtained for a three-variable model, which is given as follows:

$$AX = -0.41702 - 0.015789 \text{ APRL} - 0.015116 \text{ APPL} + 0.096615 \text{ ALFV} \qquad \text{AIC} = 133.38 \tag{10}$$

This model shows that an increase in ALFV produces an increase in the probability of violation, whereas an increase in APRL or APPL causes a reduction in the probability of violation. The probability of violation corresponding to the mean values of the independent variables is .606. A 10 percent increase in ALFV over its mean value was found to increase the probability to .642. Increasing APRL from its mean value to 100 decreases the probability to .389. Increasing the value of APPL from its mean value to 100 decreases the probability of violation to .406. These results are also consistent with those obtained using the other models for the 65-and-older age groups. Figure 4 illustrates the effect of APRL and ALFV on the probability of violation.

SUMMARY AND CONCLUSIONS

The complex problem of assessing the risk of elderly drivers was investigated in this report. A detailed study was conducted by investigating the effect of traffic and geometric variables using statistical modeling.

The models developed can be used to evaluate the effectiveness of specific countermeasures, such as providing a left-turn lane or a protected left-turn phase, or both, for different traffic volumes at intersections. The models can therefore be used to evaluate the feasibility of implementing these countermeasures.

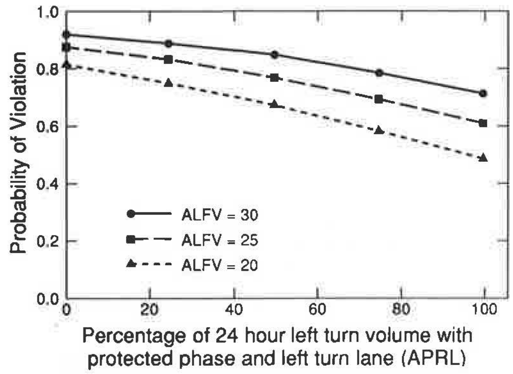

FIGURE 4 Effect of APRL and ALFV on probability of violation for 65-and-above age group, using 24-hr volumes.

The following conclusions can be made from the results of the statistical modeling:

1. An increase in the percentage of left-turn volume at an intersection increases the involvement ratio for the elderly. This effect is, however, reduced by the provision of a protected phase with left-turn lanes for a large percentage of left-turn volumes.
2. An increase in amber time for a given speed limit reduces the involvement ratio for the elderly. This implies that the amber period of 3 to 5 sec is probably not sufficient for the elderly because of their longer reaction times.
3. The involvement ratio of the elderly is much more dependent on the AADT than on the peak-hour volumes, probably because the elderly travel less during peak hours than other age groups.

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Age Differences in Motion Perception and Specific Traffic Maneuver Problems

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Studies of age differences in motion perception abilities and accident involvement patterns are reviewed to predict the exaggerated difficulty for older drivers with specific traffic maneuvers and the expected ordering of older-driver accident involvement rates by type of maneuver. A rigorous analysis of police-reported accidents in Michigan and Pennsylvania used induced exposure methods to demonstrate the highest older-driver accident involvement rate for turning left against oncoming traffic; the next highest older-driver accident rate occurred when drivers were crossing or turning into a traffic stream, although the extent of overinvolvement was not as high as the first situation; and the lowest relative involvement rates for maneuvers in which an age-related motion perception deficit may be at issue were in situations in which vehicle headways are critical, such as overtaking. Mitigating factors such as older drivers' slower driving that may compensate for or minimize some of the problems found in laboratory tests are noted. Overall, the present review and analysis supports an interpretation that age differences in motion perception in critical traffic situations is an important factor in older drivers' overinvolvement in particular accident types.

Recent historical accident data, anecdotal evidence, and driver self-reports have suggested an exposure-corrected overrepresentation of older motorists for specific unsafe driving acts. Findings document a decline with advancing age in sensory/perceptual (especially visual) skills, a range of cognitive functions, and the speed of psychomotor responses involved in driving (*1*); however, traffic safety researchers have yet to account for differential accident experience in terms of performance deficits on critical driving tasks. The analyses in this paper are part of a broader effort to investigate the hypothesis that age differences in motion perception can explain older-driver overinvolvement in particular accident categories. On the basis of a review of laboratory tests of the perceptual skills of younger versus older drivers, predictions concerning relative involvement rates among varying types of police-reported collisions in two states are developed and confirmed.

AGE AND MOTION PERCEPTION

Prior investigations have addressed motion perception abilities pertinent to driving, including time-to-collision and gap-acceptance judgments, though only a subset has compared older and younger subjects. In time-to-collision (Tc) estimates, drivers estimate how long it takes them moving at a constant speed to reach specified points in their paths (*2*).

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They are hypothesized to be based either on an optic-flow process, in which the driver's analysis of the relative expansion rate of an image, such as an oncoming vehicle, over time provides the estimate of Tc directly (*3,4*), or on a cognitive process in which Tc is estimated using speed and distance information. In the former theoretical framework, the driver relies on two-dimensional information—that is, angular separation cues (the image gets larger—to estimate Tc; in the latter, the driver calculates Tc on the basis of three-dimensional information. Several studies (*5,6*) have supported the optic-flow model and the idea that two-dimensional, angular separation cues separate from background information suffice to allow drivers to estimate Tc.

Relative to younger subjects, a decline (possibly exponential) for older subjects in the ability to detect angular movement has been reported. Using a simulated change in the separation of taillights, indicating the overtaking of a vehicle, a threshold elevation greater than 100 percent was shown for drivers 70–75 years old versus those 20–29 years old for brief exposures at night (*7*). Older persons may in fact require twice the rate of movement to perceive that an object's motion-in-depth is approaching, given a brief (2.0 sec) duration of exposure. In related experiments, older persons required significantly longer to perceive that a vehicle was moving closer at constant speed: at 19 mph, decision times increased 0.5 sec between ages 20 and 75 (*8*). The age effect was not significant when the vehicle was moving away from the subject.

Next, research has indicated that, relative to younger subjects, older subjects underestimate approaching vehicle speeds (*9*). Furthermore, analysis of judgments of the "last possible safe moment" to cross in front of an oncoming vehicle has shown that older persons (especially men) allowed the shortest time margins at 60-mph approach speeds—older persons accepted a gap to cross at an average constant *distance* of slightly less than 500 ft, whereas younger men allowed a constant *time* gap and, thus, increased distance at higher speeds.

More generally, there is an increased sensitivity across age groups to longitudinal versus tangential movement. However, longitudinal movement is a greater problem for drivers because the same physical displacement of a vehicle has a much greater visual effect tangentially than longitudinally—that is, tangential movement results in greater relative motion (*10*). Other findings relevant to motion perception and accident involvement, though undifferentiated by age in research to date, include the following:

- There appears to be general underestimation of Tc, and as Tc increases, the error increases: in other words, as speeds go up, the error increases (*5*);

- Tc estimates vary between experienced and inexperienced drivers: the former integrate time and distance to provide a safety margin, whereas inexperienced drivers use speed and distance perception alone (*6*);
- Drivers have greater sensitivity to movement toward them than away (*8,11*), and there is high sensitivity to discriminating between directions of movement. This implies that rear-end collisions more likely result from inattention and the inability to judge correctly the magnitude of relative motion rather than from a limitation in detecting its direction. Drivers know when they are gaining on a car, but may be unaware of how fast (*12*);
- An increase in the angular velocity is required for motion detection, with increasing separation between two objects (*11*); and
- Increases in the rate of conflict for merging maneuvers and conflict severity for turning maneuvers are related to increased variance in speeds in the traffic stream for which a driver is making gap-acceptance judgments (*13*) that is, a principal source of risk at intersections is the error of a turning driver in judging gaps in front of fast vehicles.

Collectively, the motion perception literature implies that older drivers should have more difficulty than younger drivers with specific traffic maneuvers: older drivers should have more accidents when (a) turning left against oncoming traffic; (b) when simply crossing or turning into a traffic stream, although the differential should not be as high as the first situation; and (c) where vehicle headways are important (e.g., in overtaking a lead vehicle).

AGE AND ACCIDENT EXPERIENCE BY DRIVING MANEUVER

A broad survey of findings published during the previous decade relating to trends in the accident experience of young and old drivers is summarized; all implied comparisons are typically with the general population.

- California: Men and women drivers older than 70 years had significantly higher accident rates, and right-of-way violations were the leading cause of injury accidents and the primary collision factor in 30 percent of fatal accidents in which older drivers were judged at fault (*14*).
- United States (nationwide): Increased accident rates at signalized intersections following adoption of right-turn-on-red are highest for drivers under 25 or over 55 (*15*).
- Toronto: A survey of motorists indicated that the frequency of collisions under peak-volume urban driving conditions on non-limited-access roadways was reported to be highest for drivers under 21 and over 60 (*16*).
- Iowa: Higher rates were reported for the 65–70 age group, and even higher for drivers 75 and older; the highest percentages of older-driver accidents were in the categories failure to yield, improper turn, and failure to obey traffic signs. Twenty percent of accident-involved drivers over 75 were attempting left-turning maneuvers when the collision occurred (*17*).
- Great Britain (nationwide): Seventeen–19-year-olds had the highest accident rates, although drivers 65 and older had roughly twice the expected number involving failure to obey intersection control and far higher numbers turning across traffic (*18*).
- New Brunswick: Analysis of 30,471 accidents during 10 years showed that drivers 60 and older had accident rates equal or worse than drivers under 25 and a higher at-fault rate; specific problems were failure to yield and improper turning and reversing (*19*).

This overview is a preliminary confirmation of the prediction that the relative accident involvement rates of older drivers can be ordered according to traffic maneuvers in which motion perception difficulties will most strongly influence their safety. The following rigorous analysis of accident data in two states controls for (induced) exposure and accident factors extraneous to driver age to further increase our understanding of these relationships.

OLDER-DRIVER ACCIDENT INVOLVEMENT ANALYSES

Analyses of police-reported accidents in Michigan and Pennsylvania sought to focus on accidents in which drivers' motion perception was a significant contributing or causative factor. Accidents involving drinking drivers or vehicle equipment defects were excluded from consideration. Field reports that coded *Driver 1* as the driver more at fault (or more causative of an accident) and *Driver 2* as the one less at fault formed the basis for calculating relative involvement rates, that is, the cross tabulation of event frequencies as Driver 1/Driver 2 ratios, by driver age group. Four age groups were analyzed: 26 and younger, 27–55, 56–75, and 76 and older.

Michigan Accident Analysis

Michigan accident reports for 1986 through 1988 were examined. Accident report data were merged with other files to create records for analysis that contained entries describing the accident location (e.g., geometry), ambient environmental conditions, the crash occurrence and severity, driver and passenger(s), traffic citations associated with the event, and the vehicles involved and their drivers' intentions. Accident records associated with five specific maneuver types were examined: (a) merging and weaving maneuvers on limited-access highways, (b) lane change maneuvers on limited-access highways, (c) left turns against traffic, (d) crossing (gap-acceptance) maneuvers on non-limited-access highways, and (e) overtaking and passing on two-lane, two-way rural roads. The accident records were analyzed in comparison with base conditions and defined by explicit variable limits.

Merging and Weaving Maneuvers on Limited-Access Highways.

Only accidents that occurred on or near ramps in the vicinity of intersections with the limited-access facility were considered in the analyses for this maneuver. Also, accidents were eliminated, for example, when the vehicles were stopped and in situations in which it wasn't clear what maneuvers were occurring. Finally, driver intentions were also considered. Valid intentions included going straight, passing, changing lanes, and starting up. Eliminated intentions included making a right turn and backing. The resulting analysis set included 1,682 accidents.

Unfortunately, only 27 (1.5 percent) of the 1,682 accidents involved Driver 1s 76 and older. Furthermore, there were only 17 Driver 2s in this age group. In the 56–75 group, there were 174 Driver 1s and 289 Driver 2s. Subject to this caveat, cross tabulations for driver intention (i.e., Driver-1 age by intention) showed that the preponderance of Driver-1 intentions for all age groups was to go straight or change lanes; drivers under 55 showed virtually identical distributions (68 percent straight, 28 percent change); and drivers 56–75 were more likely to have the intention to change lanes (59 percent straight, 40 percent change). However, the distributions for Driver-2 intentions were far more similar to one another (variations on the order of 1 to 2 percent versus 10 percent for Driver 1).

Table 1 presents data in a matrix (cross tabulation) of Driver-1 age by Driver-2 age for specified conditions. If Driver 1 is at fault and Driver 2 is innocent (i.e., Driver 1 caused the accident and Driver 2 just happened to be there), it is argued that Driver 2 characteristics are implicit measures of exposure. Thus, the ratio of Driver 1 to Driver 2 characteristics is indicative of relative over- or underrepresentation (marginal row proportions divided by marginal column proportions); for example, if the proportion of Driver 1s 26 and younger is greater than the proportion of Driver 2s 26 and younger, then this age group is overrepresented in accidents relative to their exposure. This approach is discussed elsewhere in the context of quasi-induced exposure (*20*).

In general, Table 1 data indicate that the 26-and-younger group is overrepresented and the 27–55 and 56–75 groups are underrepresented. The involvement ratios are 1.5, 0.8, and 0.9, respectively, and 2.3 for the oldest group. The small number of older drivers makes conclusions problematic, but the ratio is more than 1.0, indicating overinvolvement.

Of further interest is cross tabulation of violations for Driver 1 by age (Table 2), which shows that different age groups committed different violations. Drivers 26 and under were far more likely to follow too closely and speed than drivers over 26. As older groups are examined, the tendencies shift: speeding becomes less likely, failing to yield more likely, improper use of lanes more likely, and following too closely less likely. Notwithstanding sample size, these trends carry over to the oldest driver group, which was least likely to speed and most likely to fail to yield and to use lanes improperly.

Next, as a comparison to a base condition, merging and weaving accidents were also compared with all accidents that occurred on limited-access highways. Among the most interesting findings, 38.4 percent of merging and weaving rear-end collisions involved Driver 1s 26 or younger, versus 40.8 percent of all rear-end accidents on limited-access highways. The two oldest groups accounted for more rear-end, merging and weaving accidents than they did for all rear-end accidents (11.7 percent versus 9.3 percent). However, for Driver 1s 26 and younger, approximately 4.5 percent of all limited-access highway accidents were classified as merging and weaving accidents; for Driver 1s 27–55, approximately 4.9 percent; for Driver 1s 56–75, approximately 4.8 percent; and for Driver 1s 76 and older, 4.6 percent. That is, merging and weaving accidents do not appear to be overrepresented, in comparison with all accidents on limited-access highways, for any age group.

In summary, notwithstanding the small number of the oldest drivers in this analysis set, drivers in different age groups appear to make somewhat different errors in merging and weaving accident situations: younger drivers are more likely to speed and follow too closely than older drivers, and older drivers are more likely to fail to yield the right-of-way and

TABLE 1 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE, MERGING AND WEAVING ON LIMITED-ACCESS HIGHWAYS

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	155 (24.1)[1]	418 (65.1)	63 (9.8)	6 (0.9)	642 (38.2)
27-55	216 (25.5)	519 (61.2)	110 (13.0)	3 (0.4)	848 (50.4)
56-75	43 (26.1)	103 (62.4)	16 (9.7)	3 (1.8)	165 (9.8)
76-98	4 (14.8)	20 (74.1)	3 (11.1)	0 (0.0)	27 (1.6)
totals	418 (24.9)	1060 (63.0)	192 (11.4)	12 (0.7)	1682

note : [1] cell entries: number of accidents (row percentage)

TABLE 2 CROSS TABULATION OF DRIVER-1 AGE BY VIOLATION, MERGING AND WEAVING ON LIMITED-ACCESS HIGHWAYS

driver-1 age	violation[1]				
	speeding	fail yield	lane usage	following	other
≤26	102 (14.8)[2]	52 (7.5)	152 (22.1)	358 (52.0)	25 (3.6)
27-55	128 (14.3)	96 (10.8)	217 (24.3)	429 (48.0)	23 (2.5)
56-75	21 (12.1)	33 (19.0)	54 (31.0)	60 (34.5)	6 (3.5)
76-98	2 (7.4)	8 (29.6)	9 (33.3)	7 (25.9)	1 (3.7)
totals	253 (14.2)	189 (10.6)	432 (24.2)	854 (47.9)	55 (3.1)

notes: [1] violations: speeding, failure to yield right of way, improper lane usage, following too closely
[2] number of accidents and (row percentage)

use lanes improperly. Moreover, the shift from one violation to another appears to occur with increasing age. However, following too closely is still the most likely violation for all but the oldest drivers.

Drivers 26 and younger and 76 and older are overrepresented in merging and weaving accidents. Although generally underrepresented, the 56–75 group is overrepresented during rush hours and dawn and dusk periods. There is some evidence to suggest that older drivers restrict their driving during poor weather: the magnitude of the involvement ratio remains about the same, but the percentages of older drivers involved as Driver 1 and Driver 2 decrease during adverse weather as measured by road surface condition. There does not appear to be an interactive effect between merging and weaving and weather. Finally, this analysis indicated that older drivers appear to have more problems with trucks than with automobiles in merging and weaving situations.

Lane Changes on Limited-Access Highways.

More than 13,600 accidents occurred away from interchanges after eliminations (e.g., median crossings), but it proved difficult to isolate those that were high-speed lane-change accidents per se. Thus, all accidents occurring at operating speeds were considered relevant in which the accident reports specified intention of a lane change. An analysis set containing 10,398 records was thus defined.

The Driver 1/Driver 2 age matrix for this analysis (Table 3) indicates underrepresentation of drivers aged 27–55 and overrepresentation of the other three groups. An additional matrix for an accident subset predicated on the intention that Driver 1 was attempting to pass was also constructed, but, with only 554 accidents, there were several empty cells. Most interesting, though, was that the involvement ratio increased to 2.0 for younger drivers but dropped to about 0.5 for the 56–75 group. This may be due to the fact that older drivers drive more slowly and attempt to pass less.

The distribution of violations by Driver 1 age is shown in Table 4. Relative to merging and weaving maneuvers, there is a higher proportion of speeding violations for all groups (as expected), lower failure-to-yield violations, and lower lane-usage violations. Following-too-closely violations are about the same. However, age-group differences, versus merging and weaving, are greater: more younger drivers are speeding here, fewer younger drivers have lane-usage violations whereas there is a higher percentage for older drivers, and differences in following too closely are less pronounced for this maneuver.

Finally, when violation patterns for lane-change accidents on limited-access highways versus the base condition—all accidents on limited-access highways—were examined and then compared with the earlier findings for merging and weaving maneuver accidents, a general shift in driver errors was noted with increasing driver age. In maneuvers that involved a lane change, older drivers appeared to have more problems related to tracking and alignment of their vehicles. An alternative explanation for this is that older drivers simply do not drive as fast, so the percentage of involvements for lane-usage violations will increase. However, examination of the ratios of types of accidents to one another suggests that there is still some "real" shifting in the accident distributions that is not explained by older drivers' slower driving. For example, the ratio of following-too-closely to lane-usage accidents for the 26-and-younger group is about 2.7; for the 27–55 group, 1.8; for the 56–75 group, 1.2; and for the 76-and-older group, 0.7. This implies that different drivers are having problems apart from those caused by speed, although the trend is not as clear if the ratios between lane-usage and failure-to-yield accidents are considered.

As noted, the base-condition accidents were simply non-interchange accidents. For all Driver-1 groups, the percentage of accidents accounted for by age group was about the same

TABLE 3 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE, LANE CHANGE ON LIMITED-ACCESS HIGHWAYS

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	232 (28.5)[1]	501 (61.5)	79 (9.7)	3 (0.4)	815 (32.5)
27-55	380 (27.1)	872 (62.2)	139 (9.9)	11 (0.8)	1402 (55.9)
56-75	65 (24.3)	177 (66.3)	24 (9.0)	1 (0.4)	267 (10.7)
76-98	5 (22.7)	16 (72.7)	1 (4.5)	0 (0.0)	22 (0.9)
totals	682 (27.2)	1566 (62.5)	243 (9.7)	15 (0.6)	2506

note : [1] cell entries: number of accidents (row percentage)

TABLE 4 CROSS TABULATION OF DRIVER-1 AGE BY VIOLATION, LANE CHANGE ON LIMITED-ACCESS HIGHWAYS

driver-1 age	driver-1 violation[1]				
	speeding	fail yield	lane usage	following	other
≤26	995 (23.5)[2]	84 (2.0)	797 (18.9)	2131 (50.4)	219 (5.2)
27-55	1036 (18.2)	133 (2.3)	1494 (26.3)	2622 (46.1)	406 (7.1)
56-75	146 (17.0)	36 (4.2)	282 (32.8)	342 (39.7)	55 (6.4)
76-98	17 (20.0)	1 (2.3)	36 (42.4)	28 (32.9)	3 (3.5)
totals	2194 (24.9)	254 (2.3)	2609 (24.0)	5213 (47.2)	593 (5.5)

notes: [1] violations: speeding, failure to yield right of way, improper lane usage, following too closely
[2] number of accidents and (row percentage)

(less than 2 percent different) for both lane-change–related accidents and the base-condition accidents (e.g., the 27–55 group accounted for 52.4 percent of lane-change accidents and 50.7 percent of base accidents). Similar results were noted for Driver 2s. However, it appears that the oldest group of drivers is generally underinvolved in this type of accident. This was determined by dividing the number of lane-change accidents on limited-access highways by the number of base accidents for each group. The results showed that, for drivers 26 and younger, 59.6 percent of all noninterchange accidents were defined as lane-change accidents; drivers 27–55, 63.6 percent; drivers 56–75, 59.2 percent; and drivers 76 and older, 50.0 percent.

Additional results from comparing lane-change accidents and base accidents include (a) Driver-1 violations for lane-change accidents were more likely to be improper lane usage (24.0 percent versus 19.1 percent) or speeding (20.2 percent versus 16.0 percent) and less likely to be failure to yield (2.3 percent versus 5.2 percent) or following too closely (47.2 percent versus 54.2 percent); (b) lane-change accidents are just as likely to occur during the non-rush-day period, but more likely during non-rush-night period (38.5 percent versus 35.0 percent) and less likely during rush hour (29.9 percent versus 33.4 percent); (c) lane-change accidents were more likely to occur at night (72.7 percent versus 66.5 percent), less likely during daylight, and about the same for dawn and dusk; and (d) trucks were slightly more likely to be Vehicle 2 in lane-change accidents versus all accidents (20.4 percent versus 18.5 percent), with a significant shift with Driver-1 age (18.8 percent for 26 and younger, 26.5 percent for 76 and older).

In summary, because the lane-change maneuver on limited-access highways is hard to isolate, accidents that were clearly not lane changes were eliminated and the remainder were analyzed. Notwithstanding the small sample sizes for older drivers, findings and conclusions about lane changes on limited-access highways indicate that (a) drivers in different age groups appear to make different errors when they are involved in accidents: younger drivers tend to speed and follow too closely, older drivers tend to use lanes improperly; (b) the shift from one violation to the other occurs with increasing age, but following too closely is still the most prevalent violation for all age groups but the oldest. Furthermore, speeding violations are more likely than merging and weaving accidents across all age groups; lane usage was less of a problem for the younger drivers than were merging and weaving accidents but more of a problem for older drivers, as was following too closely. Failure to yield was not as much of a problem for any age group for lane-change accidents on limited-access highways.

Drivers 26 and younger and 76 and older appear to be overrepresented for lane-change accidents. Overrepresentation of drivers 26 and younger is about the same as it is for merging and weaving accidents, but older groups appear to have fewer problems with lane-change accidents. Weather and time of day do not seem to have the impact on lane-change accidents that they do on merging and weaving accidents. Similar to merging and weaving accidents, older drivers appear to have more problems with trucks than younger drivers. However, when merging and weaving accidents were considered, there appeared to be a clearer trend with increasing age: with lane-change accidents there were only modest increases for the three youngest groups, and the oldest group had the most problems. However, all age groups have more involvement with trucks in lane-change situations than they do in general on limited-access roads.

Left Turns Against Traffic (Non-Limited-Access Highways).

Given a large sample size, fairly specific accidents in this category can be identified by driver intention; that is, one of the two drivers in an accident was turning left. This resulted in an analysis set containing about 15,500 accidents, and just more than 80 percent of the Driver 1s were turning left. The distribution of combinations of Driver-1 and Driver-2 intentions were (a) Driver 1 was turning left and Driver 2 was going straight (10,708), (b) Driver 1 was going straight and Driver 2 was turning left (1,863), (c) Driver 1 was passing and Driver 2 was turning left (about 600), and (d) both drivers were turning left (about 400). There was a scattering of other combinations. Analysis of only the first two, most frequent combinations in this list is reported. For the most part, signalized and unsignalized intersections were not separated because left turns against traffic involve the same judgments whether the signal is green or not there. Almost 75 percent of the accidents occurred during the day, 20 percent occurred at night, and the rest during dawn and dusk. About 70 percent occurred on dry pavement, more than 80 percent during clear or cloudy conditions. About 56 percent occurred in urban areas. More than 80 percent of the vehicles involved were automobiles, about 12 percent were trucks.

There were fundamental differences in the age distributions for drivers in the left-turn accidents. It may be recalled that for merging and weaving and lane-change accidents on limited-access highways, the Driver-1 age distributions were roughly the same—from the youngest to oldest group they were 38 percent, 50 to 52 percent, 8 to 9 percent, and 0.8 to 1.6 percent—and the first two age groups had accounted for more than 90 percent of the accidents. For left turns against traffic, these two groups account for less than 80 percent. Although it would thus appear that older drivers have substantially more problems with left turns than with merging and weaving and changing lanes, this factor may be tempered by exposure.

Examination of the Driver-2 age distributions shows that they also were virtually the same for merging and weaving and lane-change accidents, but different for left-turn-against-traffic accidents. This is illustrated in Table 5: relative to the maneuvers named previously, the percentages are higher for the 26-and-younger group, lower for the 27–55 group, and similar for the two oldest groups. On the basis of involvement ratios, both groups of older drivers are greatly overinvolved; only the 27–55 group is underinvolved. The net result shows that both groups of older drivers have a more serious problem with turning left than they do with merging and weaving and lane changing, whereas drivers 26 and younger have less of a problem.

The data in Table 6 are for accidents in which Driver 1 was going straight and Driver 2 was turning left. Only drivers 26 and younger appear to be overinvolved. Older drivers do not appear to have a problem with drivers turning left across their paths. Of course, there is a substantial difference in what is required of a given driver in one situation against another.

TABLE 5 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE (DRIVER 1 TURNING LEFT, DRIVER 2 GOING STRAIGHT), LEFT TURNS AGAINST TRAFFIC

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	1752 (39.5)[1]	2251 (50.8)	393 (8.9)	39 (0.9)	4435 (41.4)
27-55	1521 (39.5)	1958 (50.8)	350 (9.1)	26 (0.8)	3855 (36.0)
56-75	663 (38.2)	855 (49.2)	205 (11.8)	14 (0.8)	1737 (16.2)
76-98	249 (36.6)	347 (51.0)	75 (11.0)	10 (1.5)	681 (6.4)
totals	4185 (39.1)	5411 (50.5)	1023 (9.6)	89 (0.8)	10708

note : [1] cell entries: number of accidents (row percentage)

TABLE 6 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE (DRIVER 1 GOING STRAIGHT, DRIVER 2 TURNING LEFT), LEFT TURNS AGAINST TRAFFIC

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	359 (38.7)[1]	464 (50.1)	86 (9.3)	18 (1.9)	927 (49.8)
27-55	271 (36.6)	372 (50.2)	89 (50.2)	9 (1.2)	741 (39.8)
56-75	54 (32.1)	84 (50.0)	25 (14.9)	5 (3.0)	168 (9.0)
76-98	9 (33.3)	11 (40.7)	6 (22.2)	1 (3.7)	27 (1.4)
totals	693 (37.2)	931 (50.5)	206 (11.1)	33 (1.8)	1863

note : [1] cell entries: number of accidents (row percentage)

When Driver 1 is going straight and Driver 2 is turning left, Driver 1 is more likely to be moving and must see the vehicle turning left across his or her path and then decide whether to slow or stop to allow the other motorist to make the crossing maneuver. However, when making the left turn, Driver 1 is likely to be stopped and must estimate time-to-collision, assess whether a gap in the stream exists, then accelerate and turn the vehicle. Both the driver's task loading and frame of reference change from one situation to the other.

When further analysis of violation patterns indicated that the Driver-1 violation was failure to yield or improper turn (no signal), the results were quite similar to those in Table 5, in terms of proportions, indicating that these are high-incidence problems for the older groups. For other violations, older drivers had much lower relative-involvement ratios, though sample sizes were small.

During the non-rush-day period specifically, the two older groups were overrepresented. The 76-and-older group had a ratio more than 6.0, and the 26-and-younger group had an involvement ratio that was just more than 1.0. There was, in essence, a trade-off between these two groups for the rush-hour and non-rush-night periods. For the latter, the ratio of the 26-and-younger group had increased to about 1.2 and the 76-and-older group had decreased to 3.8. The involvement ratios for the two middle groups were roughly the same, regardless of time of day; the 27–55 group was underinvolved and the 56–75 group was overinvolved. The older groups were always overinvolved in left-turn accidents, and the 76-and-older group always had significantly more overinvolvement—especially during the day—with its worst problems occurring during non-rush-day periods. Finally, bad weather and darkness decreased the degree of overinvolvement for drivers 76 and older; involvement ratios were clearly higher for better environmental conditions. Also, older drivers' problems with trucks were not noted here.

A comparison of the left-turn-against-traffic accidents with all multivehicle accidents on US and state numbered routes (including limited-access highways) was conducted as the base-condition comparison. Overall, left-turn-against-traffic accidents accounted for 6.5 percent of the base-condition accidents for drivers 26 and younger, 6.0 percent for drivers 27–55, 8.9 percent for drivers 56–75, and 11.9 percent for drivers 76 and older. Although this comparison is based on frequencies, left-turn-against-traffic accidents are increasingly likely for older drivers.

Summarizing for other variables, left-turn-against-traffic accidents relative to base-condition accidents were more likely during daytime periods (30 percent versus 20 percent and good weather (by about 5 percent, equally likely in urban areas (56 percent), and somewhat less likely to involve trucks as either Vehicle 1 or Vehicle 2.

It must be reiterated that the accidents used for left-turn-against-traffic accident analysis were specifically selected by accident type and driver intention. In general, there was no differentiation made between signalized and nonsignalized intersections or by the number of lanes present. Nevertheless, older drivers evidenced serious problems making left-turn maneuvers against oncoming traffic. Conversely, older drivers confronted with a left-turning vehicle appeared to have no special problem. Interestingly, adverse environmental conditions did not demonstrate a deleterious effect in the accident records on the involvement of the older driver in left-turn-against-traffic–type accidents.

Crossing-Gap-Acceptance Maneuvers on Non-Limited-Access Highways.

For this maneuver, different types of crossing maneuvers were separated. Thus, nonsignalized intersections were isolated and mid-block, nonintersection accidents were not considered.

The difference between the two types of gap-acceptance maneuvers (left turn against traffic and crossing gap acceptance) was of central interest in this analysis. This was examined by first investigating the differences between Driver-1 violations by age. For crossing-gap-acceptance accidents, 90 to 95 percent of all violations were for failure to yield the right-of-way, versus 70 to 75 percent for left-turn-against-traffic accidents. Most of the shift, however, was due to citations for improper signaling of a turn; this was cited for 20 to 25 percent of the left-turn-against-traffic accidents but less than 4 percent for crossing-gap-acceptance accidents. For crossing-gap-acceptance accidents, it was fairly clear that the citations for failure to yield steadily increased with driver age, albeit over a fairly narrow range.

For time of day, the pattern was basically the same as reported earlier: there were differences between the two maneuvers, but the magnitudes and directions of difference were about the same. This leads to the conclusion that there is little difference by time of day. For road surface condition, the results were somewhat different: on dry roads, younger drivers were slightly more likely to be cited for failing to yield but there was little change for older drivers, and on roads that weren't dry, younger drivers shifted toward more speeding citations for crossing-gap-acceptance accidents but there was little change for older drivers.

Comparing results in Tables 5 (left-turn-against-traffic accidents) and 7 (crossing-gap-acceptance accidents) highlights some important differences. The involvement ratios for the left-turn accidents (1.1, 0.7, 1.7, and 8.0 for youngest to oldest age groups) are comparable to those for crossing, which are 1.3, 0.7, 1.2, and 4.6. There is minor unexpected variation in the Driver-2 age distributions: the left-turn maneuver accounts for a higher proportion of the accidents than the crossing maneuver, so turning left across traffic is a more serious problem for the older driver. This may be due to the contexts in which the drivers of the turning and crossing vehicles must perceive and react to the other vehicles: (a) for left turns across traffic, the conflicting vehicle is coming straight toward the turning driver, who must estimate time-to-collision with the oncoming vehicle or a gap between oncoming vehicles; and (b) for crossing maneuvers, the other vehicle is coming from the side. Similar judgments must be made in these situations, the views to the approaching vehicles are different, and angular movement is easier to detect in the latter case.

Examination of the vehicles encountered by the crossing driver revealed a slight tendency for drivers 76 and older to have more difficulties with trucks than with automobiles. The truck percentage (as Vehicle 2) was approximately two points higher than for any other age group (15.6 versus 13.1 to 13.8).

Overall, crossing-gap-acceptance accidents account for 3.1 percent of base condition accidents for drivers 26 and younger, 2.9 percent for drivers 27–55 group, 4.6 percent for drivers 56–75, and 7.4 percent for drivers 76 and older. Though crossing accidents appear to account for a high percentage of all accidents of older drivers, overinvolvement does not appear to be as great as it is for left-turn-against-traffic accidents.

A simple comparison of the percentage of accidents that each age group accounts for also shows that the representation of the two youngest groups is lower for crossing-gap-acceptance accidents than for the base condition (41.6 versus 44.2 percent for 26 and younger and 35.8 versus 41.2 percent for 27–55) and higher for the two oldest groups (15.7 versus 11.4 percent for 56–75, and 6.9 versus 3.1 percent for 76 and older). These percentages are very similar to those for left-turn-against-traffic accidents—about a point lower for the three youngest age groups and somewhat higher for the 76-and-older group. For the Driver-2 age distributions, there are only modest differences between the two maneuvers, less than 2 percent. In general, the involvement ratios are lower for two younger groups and higher for two older groups when crossing-gap-acceptance accidents are compared with the base condition. Compared with left-turn-against-traffic accidents, the involvement ratios for crossing-gap-acceptance accidents are higher for drivers 26 and younger and 56–75 and lower for the other two groups.

Comparisons between the crossing-gap-acceptance accidents and the base condition for other factors showed (a) about 26 percent of the intersection accidents and approximately 30 percent of the base accidents occurred during non-rush-night periods; (b) similar percentages of accidents occurred during clear or cloudy conditions, 81.5 percent for crossing gap acceptance and 78 percent for the base condition, and dry pavement accounted for 70 percent of the crossing-gap-acceptance accidents and 65 percent of base-condition accidents; (c) a somewhat higher percentage (52 percent) were rural accidents, versus the base condition, in which the percentage was approximately 44 percent; and (d) cars accounted for just more than 76 percent of the Vehicle 1s and about 82 percent of the Vehicle 2s in base-condition accidents whereas 83 to 84 percent of both Vehicle 1s and Vehicle 2s were cars for crossing-gap-acceptance accidents; trucks accounted for almost 17 percent of base-condition Vehicle 1s and 15 percent of base-condition Vehicle 2s, versus 13 to 14 percent for crossing-gap-acceptance accidents. Overall, the crossing-gap-

TABLE 7 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE (ANGLE-STRAIGHT ACCIDENTS AT NONSIGNALIZED LOCATIONS), CROSSING TRAFFIC (GAP ACCEPTANCE)

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	986 (33.8)[1]	1542 (52.8)	354 (12.1)	36 (1.2)	2918 (41.6)
27-55	794 (31.6)	1343 (53.5)	334 (13.3)	41 (1.6)	2512 (35.8)
56-75	355 (32.3)	586 (53.3)	132 (12.0)	26 (2.4)	1099 (15.7)
76-98	165 (34.0)	239 (49.2)	77 (15.8)	5 (1.0)	486 (6.9)
totals	2300 (32.8)	3710 (52.9)	897 (12.8)	108 (1.5)	70-15

note : [1] cell entries: number of accidents (row percentage) acceptance accidents (relative to base-condition accidents) tended to be more likely during daytime periods, good weather, and in rural areas, and less likely to involve trucks.

In summary, comparison of the involvement of different age groups of drivers in different types of gap-acceptance accidents showed that the older drivers are relatively overinvolved in both left-turn-against-traffic and crossing-gap-acceptance accidents. However, left turns across traffic appear to present more of a problem for drivers 76 and older than crossing or turning into traffic.

The principal violation for all age groups, increasing by age, is failure to yield right-of-way. There is not, however, the clear shift from one violation to another, as was apparent for the maneuvers on limited-access roads. Time of day appeared to have little importance in explaining differences between age groups, although road surface condition appeared related to an increased likelihood that younger drivers would be speeding. Explicit comparison of driver age group involvement in crossing versus left-turn accidents at unsignalized intersections showed that older drivers had more severe problems with turning left across traffic than with crossing the traffic stream. However, this does not mean that they have no problem with crossing maneuvers; they clearly have problems with both. Other factors that might make crossing gap acceptance more or less difficult were also examined: there appeared to be a volume-related effect, although it was not consistent, and there appeared to be a greater problem for the oldest group when interacting with trucks.

Overtaking and Passing on Two-Lane, Two-Way Rural Roads.

A severe problem with sample size was encountered after the stratifications had been made to clearly define passing accidents. It appears highly likely that there are more passing-related accidents than were isolated, but it is not clear how they can be identified. Of more than 230,000 accidents originally identified as meeting initial criteria, only 2.2 percent (fewer than 5,100) were identified in which Driver 1 intended to pass; after controlling for road type, fewer than 200 remained.

Distributions of Driver-1 age (by intention) show that for the base group, approximately 3.1 percent of the drivers are in the 76 and older group versus only 1.9 percent whose intention is to pass on a two-way, two-lane rural road (similar results were noted for the 56–75 group). This is probably indicative of the fact that older drivers drive more slowly and are less likely to overtake vehicles.

Single-vehicle accidents were also investigated, specifically, those in which the driver's intention was to pass. Sample sizes were small, but it was again clear that accidents in which the intention of Driver 1 was to pass had a far higher representation of drivers 26 and younger than any other. The sample was not stratified (e.g., urban and rural) because of its small size.

In summary, similar to the results for passing and overtaking maneuvers on limited-access highways, younger drivers appear to be overrepresented in these accidents. This is consistent with a distribution of driver speeds that has drivers 26 and younger traveling the fastest and average speeds decreasing by age. This would have the effect of the youngest drivers overtaking and passing drivers far more often than the oldest driver, who, generally speaking, would overtake very few drivers. Because of extreme problems in isolating accidents that clearly involved overtaking and passing maneuvers on two-lane, two-way rural highways, it was impossible to come to any definitive conclusions about problems specific to the older driver.

Pennsylvania Accident Analysis

Police-reported fatal accident records for the period 1977–1986 and nonfatal multiple-vehicle accident records from 1984–1986 in Pennsylvania Department of Transportation (PennDOT) databases served as the basis for a parallel analysis in search of convergent evidence for the accident-involvement patterns documented for Michigan drivers. These incidents were screened to remove cases in which the most-at-fault driver was known to have a blood alcohol content (BAC) of at least 0.10 percent or to have refused a breath test; this was done to focus analyses on driver judgment errors separate from the effects of intoxication. A total of 12,159 records were eligible for analysis under this criterion.

Calculations of relative accident involvement by the same four age groups of drivers examined in the Michigan analysis were performed, reflecting ratios of accident frequency counts for each group in which a group member was the most-at-fault driver (Driver 1) in the incident and those in which group members were the other involved operator (Driver 2, or the "victim"). For example, with respect to the overall accident record data base of 12,159 cases, drivers 26 and younger demonstrated a ratio of Driver 1–versus Driver 2 frequency counts of 4,903 to 3,833, or an overinvolvement rate of 28 percent. By comparison, the 27–55 group was underinvolved by 19 percent, and the 56–75 group was split nearly evenly with Driver-1 and Driver-2 frequencies of 1,722 and 1,742, respectively. For drivers 76 and older, 341 Driver 1 cases and 168 Driver 2 cases on these accident reports described an overinvolvement exceeding 50 percent.

The same cross-tabulation analysis approach was applied to relevant fields in the Pennsylvania accident records denoting sets of "vehicle movement" and "operator performance failure" contributing factors in each accident occurrence. The relative involvement rates by driver age group for accidents represented by vehicle movement categories of interest are shown in Figure 1, also including the "all accidents" trend described above. In Figure 2, relative accident involvement by age group for a range of pertinent operator performance failure factors is presented.

The results in Figure 1 demonstrate overinvolvement by drivers 26 and younger not only for all accidents examined, but also for incidents in which the vehicle movement before the "first harmful event of the accident" was described as turning left, changing lanes to the left, and changing lanes to the right, in increasing order of relative (Driver 1 versus Driver 2) involvement. As noted above, drivers 27–55 were proportionately underinvolved with respect to all vehicle movements considered. For the 56–75 age group, there was no

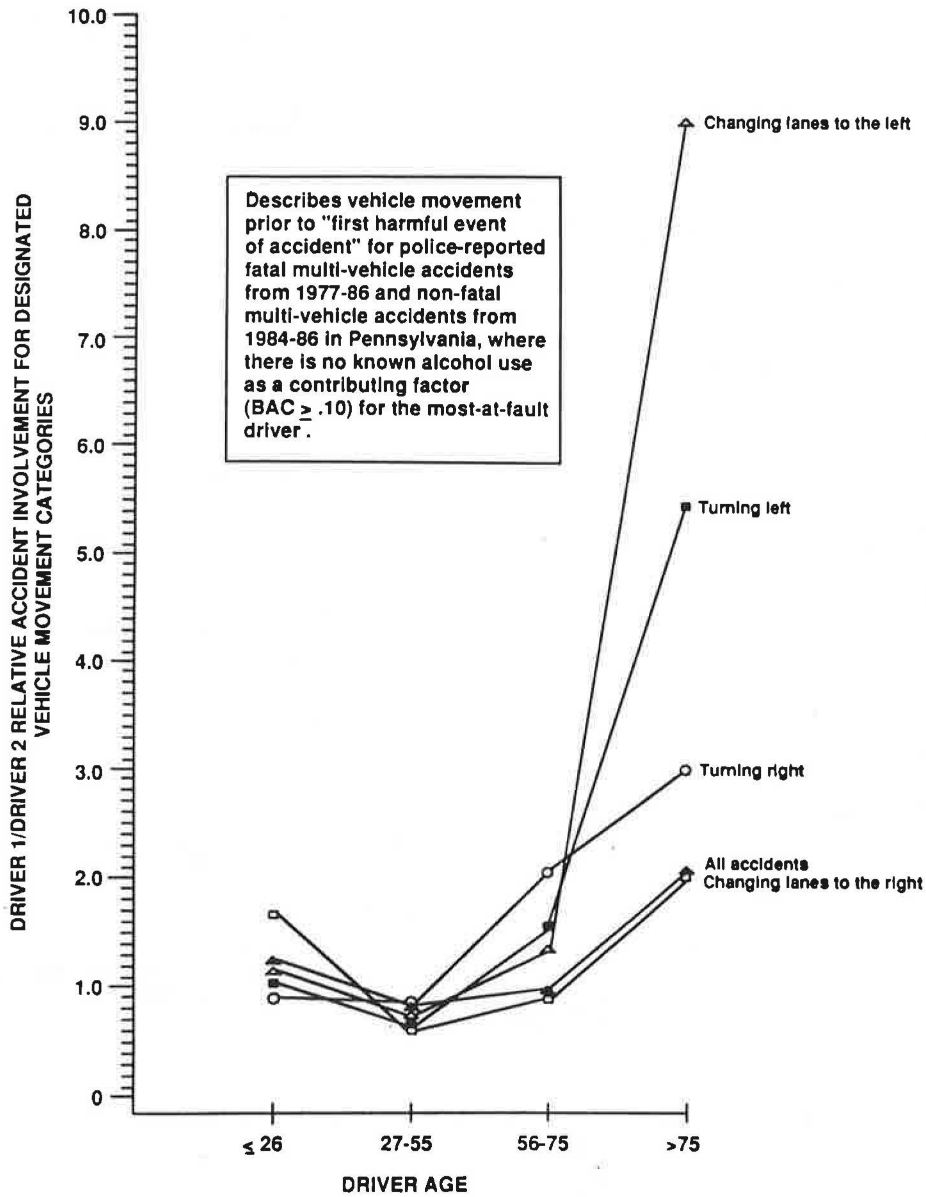

FIGURE 1 Relative accident involvement by driver age according to specified vehicle movement categories.

indicated overinvolvement for the changing-lanes-to-the-right category, but relatively higher Driver 1 frequencies were shown for accidents in which the vehicle movement was changing lanes to the left, turning left, and turning right. The most consistent and extreme overrepresentation in Driver 1 counts was noted for drivers 76 and older; turning left and changing lanes to the left were identified as the most problematic vehicle movements.

In Figure 2, age-related trends are shown for the frequency of involvement in accidents as the most-at-fault operator for whom a contributing factor was noted by police in one of seven categories—improper exit from roadway onto driveway or ramp, improper turning, careless lane change, improper entrance to roadway from driveway or ramp, improper car-following (tailgating), and careless passing—against the frequency of being identified as Driver 2 in such incidents. Considerable similarity to the results presented in Figure 1 is apparent. The 26-and-younger group is marginally underinvolved in improper entrance to and exit from the roadway as well as improper turning, and it is overinvolved in all other operator performance failure categories. Drivers 27–55 are either proportionately represented or underrepresented as driver 1 in all measures. Tailgating and careless-passing relative involvement rates remain low for drivers 56–75, but overinvolvement in all other performance failure categories is indicated, improper turning being the most prominent error. For drivers 76 and older, only the careless-passing relative involvement rate showed an underrepresentation for perfor-

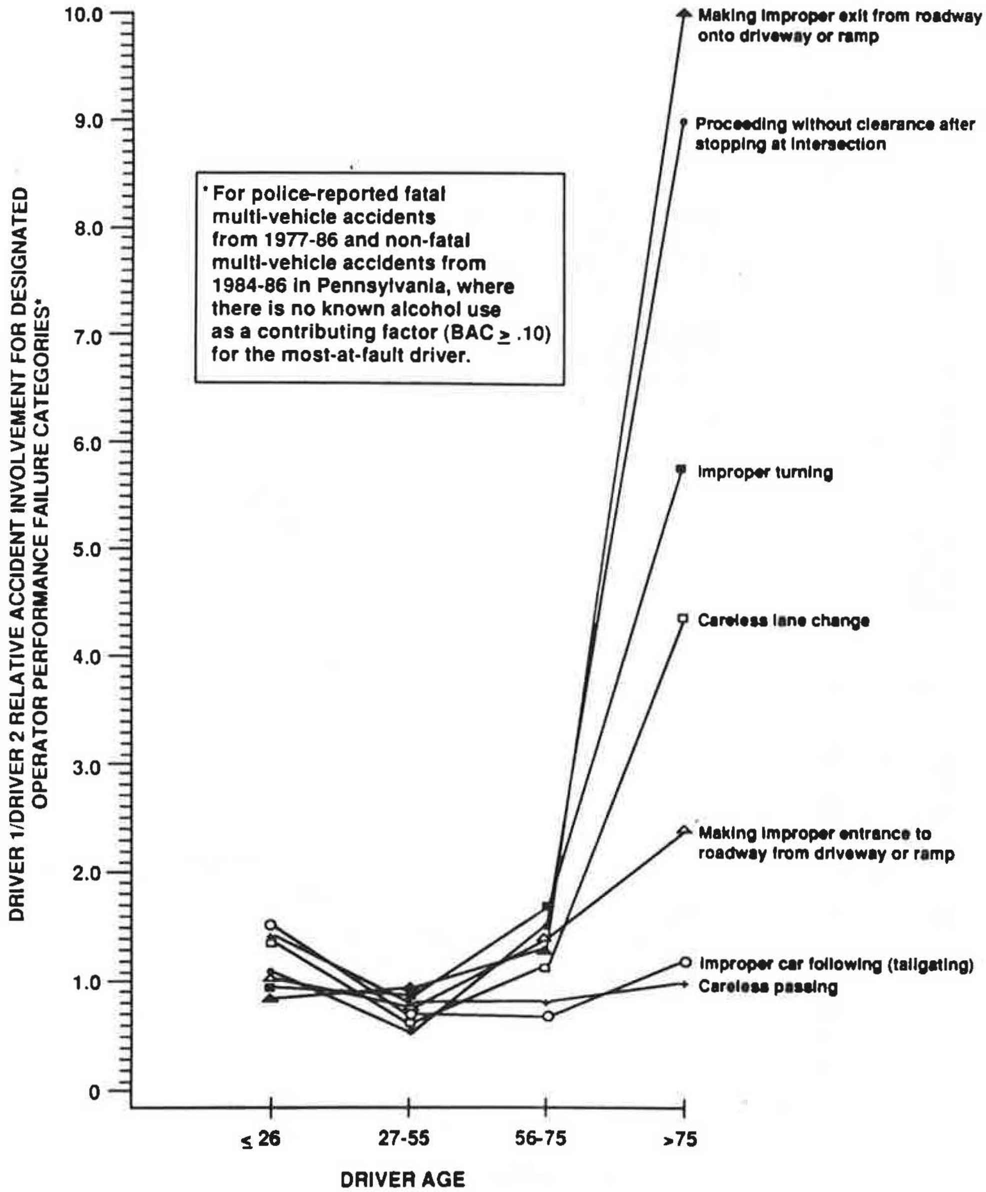

FIGURE 2 Relative accident involvement by driver age according to specified operator performance failure categories.

mance error; a modest increase in the Driver 1/Driver 2 ratio for tailgating and sharp to dramatic increases for all other problem behavior categories were shown for this group.

DISCUSSION AND CONCLUSIONS

The work reported in this paper began with a review of literature that indicated some fundamental differences in errors of motion judgment that drivers of different ages could be expected to make in the highway environment. It was also suggested that a driver's level of experience (and resulting differences in decisions about when and how to operate a vehicle) might compensate for at least some of the apparent differential in functional ability between older and younger drivers. These age differences generated hypotheses about the patterns of older versus younger driver involvement in accidents in which specific maneuvers were attempted by the driver at fault.

Examination of traffic-accident experience by driver age generally verified predictions of age-related overinvolvement in specific types of traffic accidents. The difference in magnitudes was not explicitly compared, but the ordering of the seriousness of the problem (by age) showed some general agreement. For example, where prior research suggested that older drivers would have problems judging left-turn and crossing maneuvers, the accident analysis showed the same results in the same order. The ordering (left-turns being worse than crossing) was expected on the basis of the relative difficulties (in the laboratory) with longitudinal versus tangential judgments of motion.

Left turns are clearly the most serious problem: older drivers have problems judging time-to-collision and acceptable gaps, and these problems are exacerbated by older drivers' generally slower response rates. When the highway environment is degraded, older drivers' experience makes them more cautious, which results in safer outcomes. With crossing maneuvers, older drivers have the same types of judgmental problems, but they are somewhat less severe because of the increased ease of successfully judging vehicle motion. Furthermore, the slower physical response is a little less critical, because the crossing maneuver takes less time to clear the path of an oncoming vehicle than the left-turn maneuver.

The problems older drivers were expected to have with overtaking and passing were not as clearly identified in the field data; this was arguably because of the older drivers' lower operating speeds and, consequently, fewer instances of overtaking other vehicles. Thus, though older drivers may have more serious problems than younger drivers in judging following distances, they simply overtake other vehicles much less often. As the proportion of older drivers in the population increases, however, the situation in which a slower lead vehicle and an overtaking vehicle both are operated by an older driver is likely to rise, and an increasing frequency of older Driver 1s in these accidents may be observed.

The review and analysis presented here serves as the starting point for rigorous laboratory and field testing of older and younger drivers' motion judgment capabilities as required to safely complete specific traffic maneuvers. Given testing situations that preserve an operationally meaningful context for drivers' maneuver decisions, in a realistic driving scene, highway engineering countermeasures and improved older-driver training programs emerging from such work have the potential to reduce older-driver overinvolvement in the accident categories highlighted in this report.

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Older-Driver Risks to Themselves and to Other Road Users

LEONARD EVANS

Risks drivers face themselves and impose on others are examined in terms of the dependence of various crash and fatality rates on age and sex. Some measures of crash involvement increase with age, but their values remain below those for drivers in their late teens and early twenties. If a 16-year-old male driver's crash risk declines by 7 percent throughout his life, his longevity increase will be greater than the longevity increase that a 65-year-old driver obtains by reducing crash risk to zero. Reducing the younger driver's crash risk by 12 percent improves pedestrian safety more than reducing the older driver's crash risk to zero. Compared with the other risks of death as one ages, traffic risk plays an ever-diminishing role; if an 18-year-old dies, the probability that death is due to a traffic crash is almost 50 percent; for a 65-year-old, it is less than 1 percent. Much larger than any increase in driver risk with increasing age is a decline in driving. Thus, the older-driver problem may be one of reduced mobility more than one of reduced safety.

The following three effects appear to be beyond dispute:

1. As drivers age, various capabilities relevant to driving decline: the physical (ability to rotate neck, muscle control), the sensory (visual acuity, hearing), and the cognitive (memory, information processing).
2. As drivers age, their crash rates increase.
3. In the United States, changing demography, increased longevity, and increased universality of driving (especially by women) will result in an enormous increase in older drivers.

These three effects have generated concern that in the future the United States will be faced with a major older-driver problem. The purpose of this paper is to examine the magnitude of this problem, relying mainly on a summary of research findings (*1*) reported in three publications (*2–4*).

Increasing driving risk with increasing age is best separated into two distinct components: (a) increased risks faced by older drivers, and (b) increased risks that older drivers impose on other road users. Legally and philosophically, these risks are of a different nature. There is nearly universal agreement that the measures society takes to prevent its members from doing things that endanger others should be stronger than those to prevent them from doing things that endanger only themselves. Public safety makes a stronger claim on public resources than does personal safety, which can be supported often using personal resources. Differences between the risks we assume ourselves and those we impose on others affect legislation, licensing policies, police enforcement, and so on.

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INCREASED RISKS DRIVERS FACE AS THEY AGE

Figure 1 shows car-driver fatalities per million population in the early 1980s, as determined using data from the Fatal Accident Reporting System (FARS) (*5*) and Bureau of the Census (*6*). It is clear that for men the rate increases steeply at older ages; at 80, the rate approaches the peak value attained at 19. Part of the reason for the increase in the rate for older men but not for older women is the lower percentage of older women who had driver licenses in the period covered by the data (*7*). Note that changes in the proportion of the population that is old, in the absence of other changes, are not expected to change Figure 1 because the rate is already normalized for population.

Figure 2 shows the number of car-driver fatalities per licensed driver. The oldest age plotted, for drivers 70 and older, is the category used in the driver's license data. It is desirable that organizations tabulating data avoid such broad aggregation when substantial quantities of data are available at older ages. Driver fatalities per licensed driver increase for drivers of both sexes at older ages. Rates for men are considerably higher than those for women. Two factors that contribute to this difference are that men traveled more during the period covered by the data and that when men and women traveled together, men were more likely to drive.

Because the patterns in Figures 1 and 2 depend directly on such changing social features as the number of persons obtaining licenses, the amount of driving, and the occupant who is driving, it is preferable to look at the rate per unit distance of driving. This is shown in Figure 3, computed using distance-of-travel estimates from the 1983 Nationwide Personal Transportation Study (*8*). The rate in Figure 3 is not expected to change in any obvious way in response to increasing numbers of older drivers, increasing likelihood of obtaining a license, increasing travel, or increasing tendency for women to drive.

The U-shaped patterns in Figures 1–3 contribute to the general concern about increasing crash involvement with age. Such concern finds additional support in research showing various changes in mental and sensory functions as humans age (*9–11*). Declines with age have been found for such driving tasks as reading signs at night (*12*), perceiving and reacting to roadway hazards (*13*), and general driver performance (*14*). Ranney and Pulling (*15*) find that reaction times for skills related to vehicle control increase with age.

Involvement rates in fatal crashes do not correctly reflect such changes because of the strong influence of age on fatality risk when a crash occurs. The number of drivers killed is the product of two factors: (a) the number of involvements in

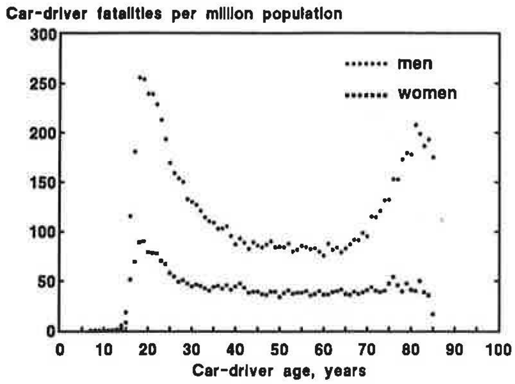

FIGURE 1 Driver fatalities per million population versus age and sex (*1,2*).

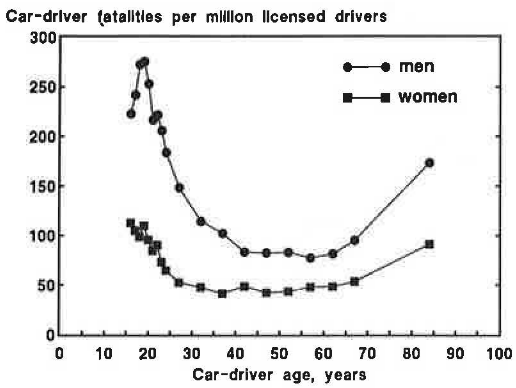

FIGURE 2 Driver fatalities per million licensed drivers versus age and sex (*1,3*).

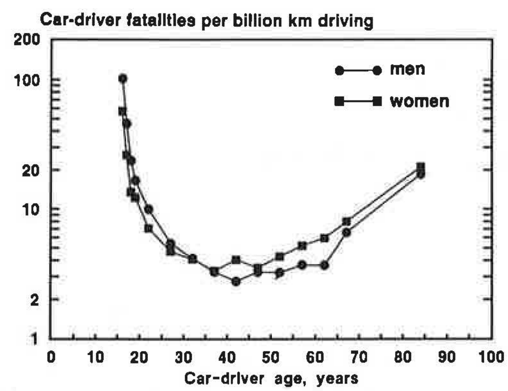

FIGURE 3 Driver fatalities per billion kilometers traveled versus age and sex (*1*).

serious crashes, and (b) the probability that involvement proves fatal. The first factor reflects influences due to all use and behavioral factors, such as type of driving, driver capabilities, time of day, degree of intoxication, and driving risks; it specifically includes all the factors likely to lead to declining driver performance. The second factor is primarily a physiological one. To examine separately the first of these factors, crash involvement, requires quantitative information about the second.

Age and Risk of Death

The effects of age on risk of death were studied using data from more than 80,000 vehicle occupants killed in crashes (*4*). By focusing on vehicles containing two occupants of different ages, at least one of whom was killed, and by using the method described by Evans (*16*), it is possible to extract the influence of age on relative risk of death for similar crash experiences. The results for 10 categories of male occupants are shown in Figure 4; these occupants were killed by a wide range of impact mechanisms. For example, car-occupant fatalities are usually associated with impact on the vehicle interior, but motorcyclist fatalities come from impact with objects unrelated to the vehicle. The absence or presence of steering wheels, safety belts, helmets, cushioning effects of motorcyclist drivers in front, and so on all affect the details of the injury insult. Given these differences, the extent to which the 10 plots in Figure 4 show similar features suggests that the effect displayed is due essentially to differences in basic susceptibility to trauma as a function of age, with the specific nature of the traffic crash being of secondary importance. That is, we expect that fatality risk would similarly depend on age for other types of potentially fatal physical insults, such as severe falls or blows from objects, including vehicles (the present method cannot be applied to investigate pedestrian fatality risk).

Figure 5 shows corresponding results for women; there are insufficient data to perform the analysis for motorcycle drivers; hence the 8 rather than 10 plots.

By collecting data of common ages, the information in Figures 4 and 5 is summarized in Figure 6. These data can be represented in convenient analytical form as

$$R_{\text{men}}(A) = \exp 0.0231\,(A - 20) = 0.630 \exp(0.0231A) \quad (1)$$

and

$$R_{\text{women}}(A) = 1.3 \exp 0.0197\,(A - 20) = 0.877 \exp(0.0197A) \quad \text{for } A \geq 20 \quad (2)$$

where A is age in years and R is the probability that a given impact will prove fatal relative to the probability that the same impact will kill a 20-year-old man. Once age exceeds about 20, fatality risk grows at an approximately uniform rate of 2.3 $\pm$ 0.2 percent per year for men and 2.0 $\pm$ 0.2 percent per year for women. At age 70 the risk is about three times what it is at age 20. Additional evidence supporting the greater fatality risk to women is provided by Foret-Bruno et al. (*17*), who found that women are about 20 percent more likely to be injured than men. They also found explanations of the difference in terms of differences in bone strength in tests using cadavers.

Involvement in Severe Crashes

Fatality rates focus on the outcome, not the severity, of the crash that led to death. Here, involvement rates in crashes of similar severity are examined by considering crashes in a severity range greater than or equal to that sufficient to kill 80-

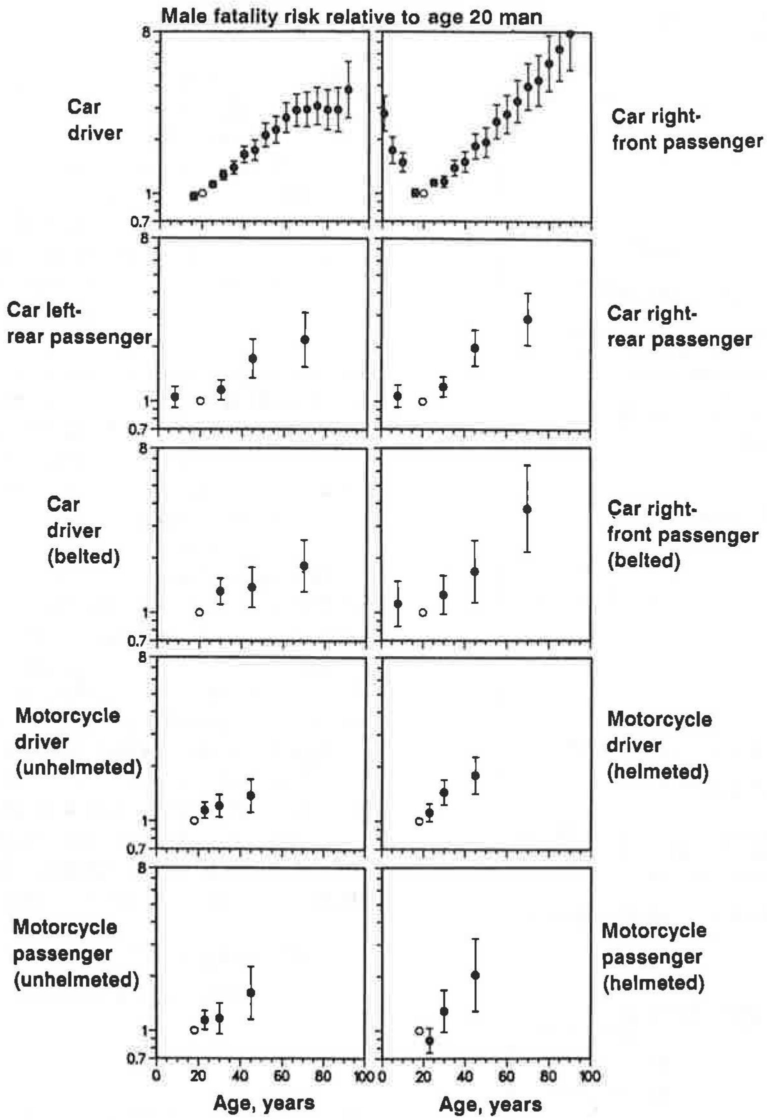

FIGURE 4 Fatality risk from similar physical insult for men of different ages compared with that for men 20 years old (*1*).

year-old men drivers, for which case R has a value of 4.0 (Equation 1). Consider a set of crashes in which N fatalities occur to 80-year-old men. If these crashes were repeated, keeping all factors the same except the drivers, we would expect $0.25N$ fatalities for 20-year-old male drivers and $0.325N$ fatalities for 20-year-old female drivers (Equation 2). To obtain the same number of fatalities, 4.0 times as many crashes by 20-year-old male drivers and 3.1 times as many crashes by 20-year-old female drivers are required. In this way we can use the observed numbers of fatalities to infer involvement rates in crashes in the severity range sufficient to kill 80-year-old men drivers.

Figure 7 shows the number of involvements per capita in crashes severe enough to kill 80-year-old men by driver age and sex. In contrast to Figure 1, there is now only a slight increase with age for older men. Note how much lower the rate at older ages is than it is at younger ages. Thus, a large mechanism generating the upward trend in Figure 1 is the greater likelihood that a crash proves fatal. An increase in crash involvement risk also contributes. Severe crash involvements per licensed driver (Figure 8) barely exceed their minimum values as drivers age.

The rate most indicative of driver behavior is severe crash involvements per unit distance of travel, shown in Figure 9. Here, an increase occurs as drivers increase in age beyond 50 or so. For men and for women, the rate for drivers 70 and older is a factor of about 3 times the minimum rate but still much less than the rates for drivers in their late teens and early twenties. This increase in rate most likely reflects deteriorating skills important for safe driving. Indeed, the increase may underestimate the decline in performance, because one of the most pronounced changes that occurs as drivers age is that they drive less—especially in higher-risk travel, such as at night.

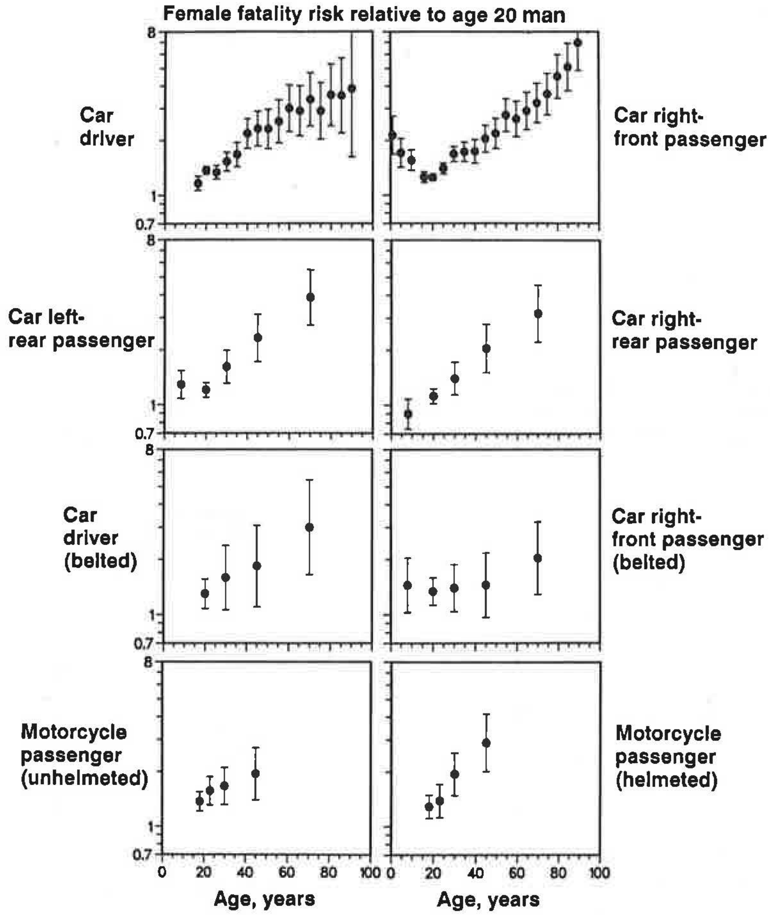

FIGURE 5 Fatality risk from similar physical insult for women of different ages compared with that for men 20 years old (*1*).

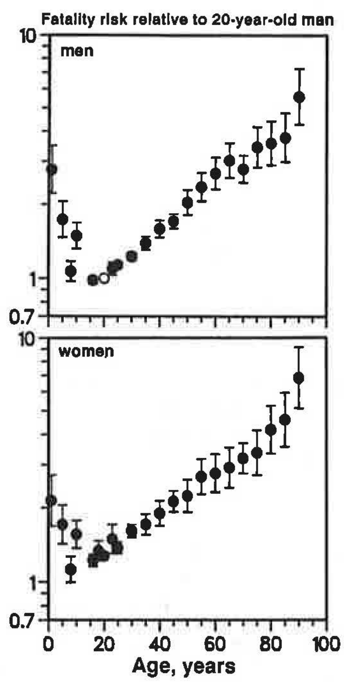

FIGURE 6 Fatality risk from similar physical insult by age for men and women (*1,4*).

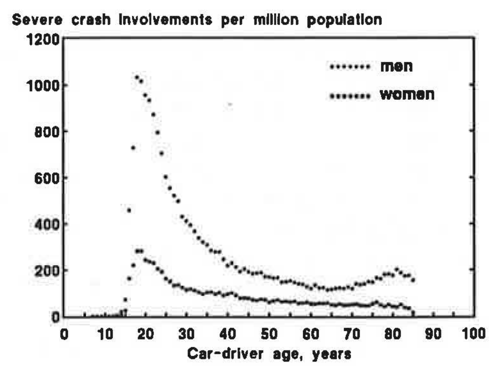

FIGURE 7 Estimated driver involvements per million population in crashes severe enough to kill 80-year-old male drivers versus age and sex (*1,2*).

INCREASED RISKS TO OTHER ROAD USERS

The threat to other road users is investigated by examining the number of crashes in which pedestrians are killed as a function of the age and sex of drivers of any type of motorized vehicle involved in the crashes. Attention is confined to single-vehicle crashes because when more than one vehicle is involved, it is not always possible to determine which vehicle

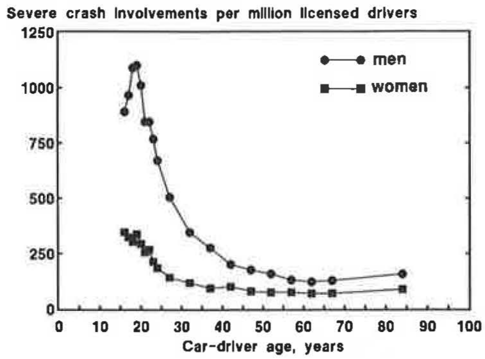

FIGURE 8 Estimated driver involvements per million licensed drivers in crashes severe enough to kill 80-year-old male drivers versus age and sex (*1*,*2*).

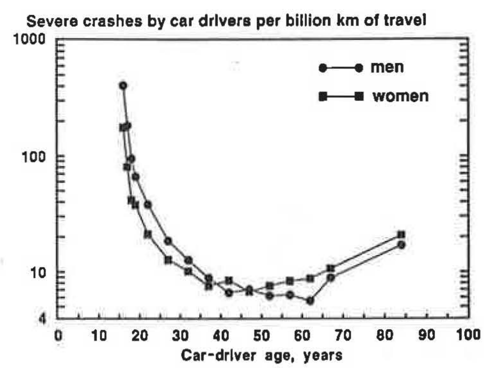

FIGURE 9 Estimated driver involvements per billion kilometers traveled in crashes severe enough to kill 80-year-old male drivers versus age and sex (*1*).

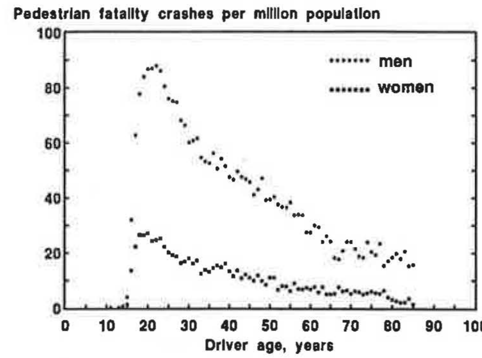

FIGURE 10 Single-vehicle crashes per million population in which pedestrians were killed versus age and sex of driver (*1*,*3*).

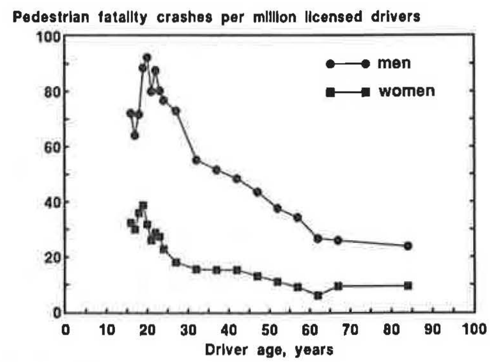

FIGURE 11 Single-vehicle crashes per million licensed drivers in which pedestrians were killed versus age and sex of driver (*1*,*3*).

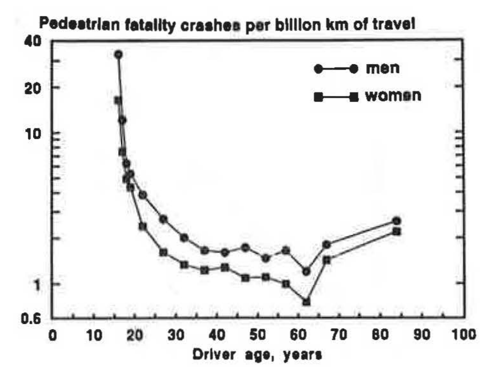

FIGURE 12 Single-vehicle crashes per billion kilometers traveled in which pedestrians were killed versus age and sex of driver (*1*,*3*).

struck the pedestrian. In addition, involvement in multiple-vehicle crashes poses threats to drivers different than those of single-vehicle crashes in which pedestrians are killed; the drivers of cars in single-vehicle pedestrian-fatality crashes usually are not seriously injured. No assumption is made regarding responsibility in pedestrian fatality crashes; about one-third of fatally injured pedestrians have blood alcohol concentrations (BACs) in excess of 0.1 percent (*18*).

Figures 10–12 show the variables for crashes involving pedestrian fatalities corresponding to those for driver fatalities in Figures 1–3. The only curve that suggests any increase in threat to other road users as drivers age is Figure 12, which shows pedestrian fatality crashes per unit distance of travel. Here the increase is small and applies only at ages above about 60; it is overshadowed by the much greater values associated with young drivers of either sex.

TRAFFIC RISKS COMPARED WITH OTHER RISKS AS PEOPLE AGE

A large factor contributing to the increase in driver deaths per unit distance of travel as drivers age is increasing risk of death, given involvement in a crash. The increasing risk of death with increasing age from the same physical insult applies in general, and not just to traffic accidents. Another traffic situation in which increasing risk of death is important is pedestrian accidents; at age 80 pedestrian fatality risk per capita for men and women is more than twice that at any age below 65. At age 70, the number of male pedestrian fatalities is about two-thirds the number of male driver fatalities; for women, the numbers of driver and pedestrian fatalities are similar (*2*).

Although risks in traffic increase with age, they do so much less rapidly than does the risk of death from all other causes combined (*19*). Figure 13 shows the probability in terms of age and sex that a death is any type of traffic fatality. The peak at about age 10 is due primarily to pedestrian fatalities. The difference in Figure 13 between the sexes is small because the increased risk men face in traffic (as pedestrians as well as drivers) is approximately in proportion to the increased risk to men from death from all causes; the greater risk of death for men from nearly all causes leads to male life expectancy at birth being 6 years less than it is for women. If an 18-year-old dies, the probability that death is due to a traffic crash is almost 50 percent. By age 65, the probability that death is due to a traffic crash is less than 1 percent; by age 75 the probability drops to below half a percent.

Figure 14 shows increases in longevity calculated to result if all traffic fatalities were eliminated, without anything else changing (*3,20*). For boys at birth the increase is 242 days, or two-thirds of a year; for girls, 111 days. At age 65 the increases are 15 days for men and 12 days for women; at age 75, 9 days for men and 6 for women.

To place these longevity values in a different perspective, the data in Figure 14 are used for some back-of-the-envelope calculations based on a hypothetical intervention (say, a novel driver training program) that would permanently reduce an individual's risk in traffic by some percentage. The comparisons are confined to male drivers, not only in the interest of simplicity but also because males make up a larger portion of the traffic-safety problem and nearly all are licensed, thereby making present results more representative of likely future results. If the intervention were to generate a lifelong 1 percent reduction in traffic fatality risk for a 16-year-old male road user (that is, at every age his risk would be 1 percent lower than it would have been without the intervention), what corresponding reduction in older-driver risk would be necessary to give that older road user an identical longevity increase? The answer is obtained by taking the ratios of the longevity increases in Figure 14; for a 65-year-old road user, the reduction is 15 percent. That is, reducing a 16-year-old road user's risk by 1 percent gives that individual the same longevity increase as reducing his risk by 15 percent at age 65. Corresponding estimates for ages 70 and 75 are 19 percent and 24 percent, respectively. The longevity increase from eliminating traffic fatality risk at age 65 (an unattainable goal) can be achieved by a reduction in traffic risk of under 7 percent for 16-year-old road users (a possible goal, at least in principle). Confining the analysis to drivers of any vehicle rather than to all road users shows that a 1 percent permanent reduction in risk for a 16-year-old driver produces the same longevity extension as 16, 21, and 28 percent risk reductions for 65-, 70-, and 75-year-old drivers, respectively.

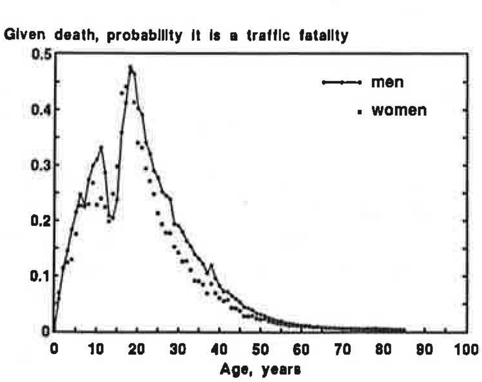

FIGURE 13 Probability that death is due to a motor-vehicle crash versus age and sex (*1,3*).

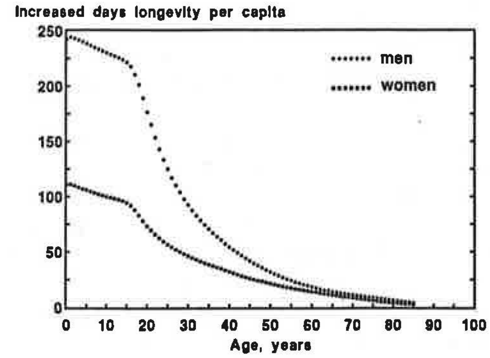

FIGURE 14 Calculated increases in longevity (in days) per capita assuming elimination of motor-vehicle crashes (*1,3*).

We can apply similar calculations to examine how the risks faced by pedestrians are affected by reductions in the crash rates of older and younger drivers. From the data used to produce Figure 10, we calculate that a 1 percent permanent reduction in crash risk for a 16-year-old male driver prevents the same number of pedestrian fatalities as a 9 percent reduction in crash risk for a 65-year-old male driver, an 11 percent reduction for a 70-year-old driver, and a 14 percent for a 75-year-old driver. The unattainable goal of eliminating 65-year-old drivers' crashes into pedestrians is calculated to reduce pedestrian fatalities by a lesser amount than reducing by 12 percent the 16-year-old drivers' rate of crashes with pedestrians.

The differences for female road users are similar to the corresponding differences for men, though in some cases smaller. A cursory examination of Figure 10 shows that eliminating the risks that older female drivers impose on other road users would produce modest benefits compared with reducing by even a small fraction the risks that younger male drivers impose on others.

Those calculations are on a per-driver basis. Even with the demographic changes under way in the United States, there will still be many more younger than older drivers for some time. Hence, reducing the risk for all 16-year-old drivers compared with reducing the risk for all 65-year-old drivers will further increase the already substantially larger safety benefits shown to be associated with reducing younger- rather than older-driver risk.

DISCUSSION AND CONCLUSIONS

Although drivers over about 50 are increasingly more likely to be killed per unit distance of driving than 40-year-old drivers, a large factor contributing to this is not increased crash risk but increased risk of death when a crash occurs. That is, a physiological factor associated with aging plays a role comparable to that due to declines in driving skill (Figures 3 and

6). Although the risk of death from the combined effects of all traffic crashes increases at older ages compared with the other risks of death as one ages, risk in traffic plays an ever-diminishing role.

The graphs that best reflect the behavioral aspects of driving—namely, driver involvements in crashes in the same high severity range per unit distance of travel and in crashes in which pedestrians are killed per unit distance of travel (Figures 9 and 12)—show remarkably similar features. Drivers from about 30 to 60 have the lowest involvement rates. As age decreases below 30, rates increase quickly. For ages greater than about 60, rates increase somewhat, but much less rapidly than as one approaches the younger ages in the graphs.

Taking the most extreme crash-rate comparison, Figure 9 shows that, compared with driving at the age of minimum crash-rate per unit distance of travel, drivers in the 70-and-older age category experience a threefold increase in risk. Similar increases in risk are found by Brorsson (*21*) in Swedish data; indeed, many of the patterns in the Swedish data are similar to those reported here. A factor-of-3 difference in risk is substantial, but it is of a magnitude common to many traffic situations and should not necessarily be viewed as a strong case for denying a driver's license. If having an above-average risk were sufficient grounds to deny a driver's license and each driver's risk were known accurately, such a criterion would inexorably lead to the licensing of only one driver: the one with the lowest risk.

The following examples put a factor-of-3 difference in risk in perspective. A formula (*1*) derived by Nilsson that builds on his earlier work (*22*) indicated that traveling 80 km/hr compared with traveling 60 km/hr increases the fatality risk by a factor of 3. An unbelted driver in a small car is 3 times as likely to be killed in a crash as is a belted driver in a large car (*23*). In the United States, the overall fatality rate was a factor of 3 higher 30 years ago than it is today, and many countries today have rates more than a factor of 3 times the present U.S. rate. Driving 300 km generates 3 times the fatality risk that driving 100 km does. The data of Borkenstein et al. (*24*) indicate that driving with a BAC between 0.05 and 0.09 percent, which is legal in nearly all of the United States, doubles crash risk. Driving with a barely illegal level of 0.1 to 0.149 percent BAC increases risk by a factor of more than 10; driving at above 0.2 percent BAC increases risk by a factor of more than 40.

Much of the data do not depend on demography or social custom in any large or direct way, so their broad qualitative features are expected to remain approximately invariant in time. The effects they represent seem more akin to laws of nature than to observations local to a specific time or place. Their broad features cannot be canceled by interventions—there is no conceivable treatment that would render the graphs of these data straight lines parallel to the age axis. In any event, straightening the curves does not seem a more worthy societal goal than seeking safety measures that reduce risks to all ages in similar proportions if such measures generate greater net reductions in harm.

To acknowledge that the broad shape of Figure 9 is close to being a law of nature is not to conclude that interventions aimed at specific ages cannot make important contributions. Some interventions meant specifically for young drivers have been discussed (*1*), including changes in the advertisement and taxation of beer and in the movies that portray the life-threatening use of vehicles as heroic, humorous, or harmless. These efforts are intended to reduce the magnitude of younger drivers' overinvolvement relative to that of 40-year-old drivers. To expect young-driver rates to drop to the same values as those for 40-year-old drivers in the same society at the same time is unrealistic. Present U.S. rates for 20-year-olds are lower than those for 40-year-olds at earlier periods in the development of U.S. motorization and lower than present 40-year-old rates in many countries.

Corresponding comments apply to older drivers. Research should focus on discovering more specifically why crash risk increases with age and then on formulating specific countermeasures. However, it is unrealistic to expect rates for older drivers to become identical to minimum rates. It might be a law of nature that the oldest drivers have rates well above the minimum, but it is not a law of nature that they should be 3 times the minimum. Any measure that can reduce them to, say, 2.5 times the minimum is of high importance. We already know that the mix of crashes in which older drivers are involved differs substantially from the mix for younger drivers; the older driver's crash is more likely to be multiple vehicle, especially side impact (*25*), but less likely to be a rollover, involve alcohol, or occur at night (*26*). Such differences are relevant to deciding where to focus age-specific interventions.

Many measures for improving older-driver safety may improve safety for all ages in the same proportion. Any such change, no matter how much it reduces older-driver risk, will leave the shape of all the curves displayed in this paper unchanged. Consequently, if the focus is exclusively a comparison with drivers with the minimum risk (the usual metric), the older-driver problem will remain unaltered independent of how much it really changes.

The information presented shows that the major contribution to traffic losses comes from young drivers; the younger-driver component will remain overwhelmingly the major component even after major changes in the demographic composition of the population. Minor reductions in young-driver crash risk generate much larger safety benefits in terms of increased driver longevity and reduced harm to others than do much larger reductions in older-driver crash risk. Thus, whereas there certainly are safety problems associated with driver aging, their magnitude is much less than the problems associated with younger drivers. If limited public resources are available for interventions to reduce driver risk, then the younger-driver problem appears to have a substantially stronger claim. The question of using personal resources, or resources of organizations supported by specific groups of drivers, to reduce the risks to specific groups of drivers is an entirely different matter.

This discussion, being an overview, has focused on how various measures depend on average chronological age. Not only do various measures of driver performance decline with age, but variability among individuals increases (*27*), underlying the importance of not judging an individual's driving ability on the basis of chronological age.

Much larger than any proportionate increase in driver risk with increasing age is the decline in distance of driving. For example, male drivers 70 and over drive, on average, 9300 km/year compared with 31 000 km/year for 35- to 39-year-old drivers; the corresponding values for female drivers are 4300 km/year and 12 600 km/year, respectively (*8*). As mental and sensory abilities decline, the dominant response is to drive less, especially under conditions of elevated risk, rather than a net increase in risk from driving. Largely because of decreased driving, driver fatality risk per year increases only moderately with increasing age, and the threat to other road users declines. The transportation aspect of the problem of aging may thus be one of reduced mobility more than one of reduced safety.

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<u>Part 2</u>
Seat Belt, Alcohol, Motorcycle, and Pedestrian Studies

Safety Belt Use and Highway Safety in Maryland

EVERETT C. CARTER AND PAUL M. SCHONFELD

Lap belts have been required in front seats of automobiles manufactured for sale in the United States since 1964, and lap and shoulder belts have been placed on almost all new cars sold in the United States since 1969. However, availability and use did not match. Several states have enacted mandatory belt use laws (MULs) in the past 5 years. Maryland enacted a MUL in 1986, and an evaluation of its effectiveness in terms of belt use and injury reduction is described. Specifically, 55 observational field studies were conducted at 44 sites in 1987, 32 studies at 26 sites in 1988 (12 of which were the same locations as in 1987), and 16 studies at 16 previous sites in 1989. These studies showed trends as well as usage for different types of highways, times of day, and rural versus urban locations. An analysis of traffic accident victims admitted to Maryland's 11 trauma centers showed a huge increase in serious injury and mortality for unbelted versus belted victims.

Motor-vehicle accidents continue to be a major health hazard in the United States and most developed countries. They are the leading cause of death in the United States for persons 15 through 24 years of age.

Since the early 1960s, safety belts have been widely available in passenger cars. Lap belts have been required on front seats since 1964, and practically all new vehicles sold in the United States since 1969 have been equipped with lap and shoulder belts on outboard front seats. However, because safety belts went largely unused, in the early 1970s NHTSA required vehicle manufacturers to install ignition interlocks to prevent vehicles from being started unless the front-seat occupants' belts were fastened. Bowing to public opposition, Congress soon prohibited such a requirement.

On July 11, 1984, the Secretary of the U.S. Department of Transportation issued the most recent federal regulations on automatic crash protection for passenger cars. These rules affect passenger cars manufactured for sale in the United States on a phased-in schedule that began September 1, 1986. The rule applied to 10 percent of the manufacturer's production the first year, increasing to 25 percent after September 1, 1987, and 40 percent after September 1, 1988. All cars manufactured for the U.S. market after September 1, 1989, were to be equipped with automatic crash protection. However, if states representing two-thirds of the nation's population had enacted mandatory safety belt use laws (MULs) before April 1, 1989, this requirement for automatic protection would no longer apply. This did not occur, and the 1990 model cars were to have either air bags or automatic belts.

The new federal rules for MULs include:

1. Requiring belt use by front-seat outboard occupants, and
2. An enforcement program with
   (a) Penalties of $25 or more for each violation,
   (b) Permissive civil litigation penalties for persons violating the law who are involved in an accident,
   (c) Education and promotion, and
   (d) Evaluation in the state's annual highway safety plan.

In January 1985, New York became the first state to enact an MUL, and it has been estimated that motor-vehicle crash fatalities during the first 9 months of the law were reduced by 9 percent (*1*). Since that time, 35 other states and the District of Columbia have enacted MULs. Three states (Nebraska, Oregon, and Massachusetts) have since repealed their laws. Mandatory use laws generally require outboard front-seat occupants of most personal passenger vehicles to wear safety belts, though the statutes vary in coverage details. Figure 1 shows these states by primary and secondary enforcement status.

Maryland's MUL became effective July 1, 1986. It can be enforced only as a secondary offense when the vehicle is stopped for another action.

Upon enactment of the safety belt use legislation, the Maryland Department of Transportation, with the cooperation of the Maryland State Police, outlined an implementation plan in order to gain public acceptance of the law. A variety of other organizations cooperated in the plan, including segments of the medical community, insurance and other industries, schools, and special interest groups. The implementation plan focused on public information and education; it included mass media, literature, and employers.

With the MUL, the Maryland Legislature requested the Secretary of Transportation and the Insurance Commissioner to submit an annual evaluation report in December 1987, 1988, and 1989.

BACKGROUND

Several studies of the impacts of occupant restraint systems have been documented in the literature and range from statistical analyses to measurements in crash tests (using dummy occupants). Some major conclusions include the following (*2–8*):

1. If all currently unbelted drivers and right-front passengers in the United States were to use lap and shoulder belts

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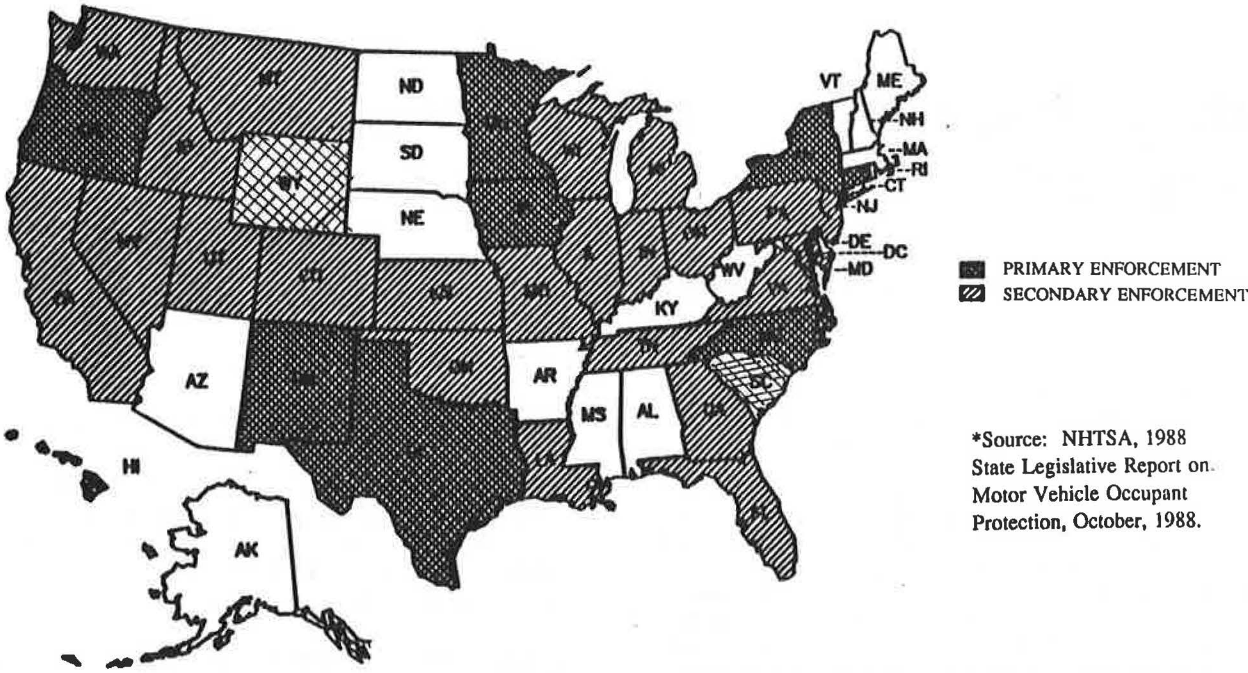

FIGURE 1 States with safety belt laws, showing primary and secondary enforcement as of July 31, 1988.

but not change their behavior otherwise, fatalities in this group could be reduced by approximately 40 percent.

2. Safety belt effectiveness in reducing fatalities is greater for single-car crashes (approximately 60 percent) than for two-car crashes (approximately 30 percent).
3. Safety belt effectiveness is greater for frontal collisions than for side impacts.
4. Lap and shoulder belts provide crash protection superior to that of lap belts alone and present significantly less risk of induced injury for center as well as outboard passengers.

Results reported by before-and-after studies show fatality reductions of only about half that predicted by the research cited previously. One explanation is that the drivers most at risk of being involved in accidents are the least likely to comply with MULs. For example, it has been shown that drivers who were observed violating traffic lights, following other cars too closely, or driving after drinking are less likely to be wearing safety belts than drivers not observed to be committing such violations. Other studies claim that the lower-than-expected fatality reduction is due to a lack of compliance with and enforcement of the law (*9–11*). An August 1986 report by the Insurance Institute for Highway Safety estimated that the safety belt use laws in New York, New Jersey, Illinois, and Michigan were responsible for preventing between 250 and 300 fatalities during 1985 (*1*).

State governments are quite concerned with promoting and enforcing existing safety belt laws in order to achieve maximum compliance, and thus injury and fatality reduction. Much of the relevant literature on occupant restraint systems is dedicated to evaluating the effectiveness of various promotion and enforcement strategies (*12–16*). Such published literature has been effective in communicating what works and what does not.

The literature seems to suggest that safety belt promotion campaigns should be continuous or repeated periodically if they are to be effective in increasing usage rates. The literature stresses the importance of effective enforcement in states with MULs. According to the literature, the support of the enforcement community, including the judiciary, is viewed as the single most critical factor in increasing safety belt use. It is argued that if the public believes that the law will be enforced, compliance will be significantly higher.

BELT USE SURVEYS IN MARYLAND

A primary task in assessing the effectiveness of the Maryland MUL was to measure safety belt use before and after the law was enacted. Of interest was whether use varied with factors such as age, geography, type of highway, and time of day.

The volunteer group, the Maryland Association of Women's Highway Safety Leaders, collected data at 11 sites at 3-month intervals from 6 months before the law through mid-1987. Additional studies were conducted in October 1988 and October 1989 at the same sites. The Maryland State Police have also been collecting belt use data since the law began in July 1986 to document relative changes in use with promotional efforts and over time.

The Transportation Studies Center at the University of Maryland conducted 55 statewide usage observational surveys in 1987 at 44 sites. In 1988, 32 additional studies were conducted at 26 sites (14 new sites); in 1989, 16 studies were conducted at 16 of the previous sites in order to obtain use trends. The locations of the sites are shown in Figure 2. The 1988 studies were made to obtain additional sites in certain categories such as road type and urban or rural location. Table 1 shows the data for all 1987 studies. The sites were stratified

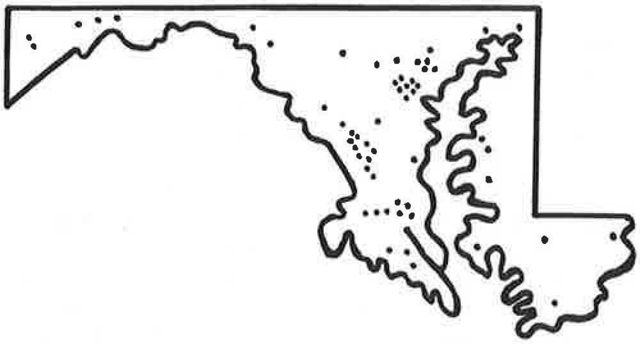

FIGURE 2 Observational survey sites by the University of Maryland.

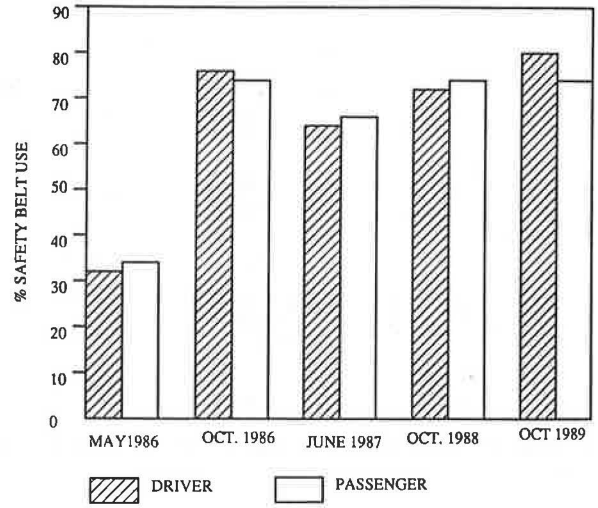

FIGURE 3 Safety belt use by drivers and front outboard passengers, from observations of the Women's Highway Safety Leaders of Maryland.

by geography, time of day, and type of road. At each site the use of safety belts by the driver and outboard front passenger of approximately 400 vehicles was observed.

The results of the observational studies at 11 locations in Maryland by the Maryland Association of Women's Highway Safety Leaders are summarized for five time periods beginning before the passage of the MUL and presented in Figure 3. It is interesting that the use increased immediately after passage of the law, decreased slightly in 1987, and apparently increased again in October 1988 and October 1989. The early increase in 1986 is attributed to wide publicity and strong enforcement (warning tickets for the first 30 days). The second-year decrease has been observed in most other states. The increase in use in 1988 and 1989 is at least partly attributable to stepped-up enforcement and publicity.

Belt use by type of highway and rural versus urban location is shown in Figure 4 for 1987. Similar use relationships for 1988 are shown in Figure 5. The use of belts on freeways was consistently higher than that on major arterials, and the use on major arterials was, in turn, higher than that on minor arterials. Likewise, belt use was higher in urban areas than in rural areas.

INJURIES AND FATALITIES

Preliminary data from a sample of observations of the status of vehicle occupants versus the status of safety belt use obtained in 1987 are shown in Tables 2 and 3. Although these data were drawn from a very small sample of 80 persons, the characteristics definitely indicate reductions in injury severity with belt use. Despite the fact that far more vehicle occupants are restrained than not restrained, according to the use sur-

TABLE 1 PERCENTAGE OF SAFETY BELT USE IN MARYLAND, 1987 OBSERVATIONS

Area Type	Location	Freeway	Major Arterial	Minor Arterial	Total
Rural	Driver	n = 2 mean = 64.14 std = 8.09	n = 2 mean = 54.97 std = 0.23	n = 11 mean = 43.55 std = 14.84	n = 15 mean = 47.81 std = 15.03
	Passenger	n = 2 mean = 64.45 std = 8.10	n = 2 mean = 48.51 std = 3.00	n = 11 mean = 43.168 std = 18.51	n = 15 mean = 46.07 std = 16.78
Semi Urban	D	n = 1 mean = 67.90 std = 0	n = 20 mean = 60.61 std = 7.82	n = 5 mean = 46.65 std = 9.79	n = 26 mean = 58.63 std = 10.10
	P	n = 1 mean = 65.28 std = 0	n = 20 mean 57.63 std = 12.49	n = 5 mean = 44.05 std = 11.09	n = 26 mean = 55.17 std = 13.23
Urban	D	n = 1 mean = 60.33 std = 0	n = 24 mean = 50.94 std = 11.02	n=0	n = 25 mean = 51.31 std = 10.95
	P	n = 1 mean = 65.05 std = 0	n = 24 mean = 46.16 std = 11.76	n=0	n = 25 mean = 46.92 std = 12.10
Total	D	n = 4 mean = 64.13 std = 6.31	n = 46 mean = 55.32 std = 10.589	n = 16 mean = 44.52 std = 13.54	n = 66 mean = 52.94 std = 12.36
	P	n = 4 mean = 64.86 std = 5.74	n = 46 mean = 51.25 std = 13.11	n = 16 mean = 43.21 std = 16.34	n = 66 mean = 49.78 std = 14.49

n = No. of observation periods - each site had over 200 observations (many over 400) mean = arithmetic average
Std = standard deviation - a measure of dispersion or spread of observations. About 68% of the observations are within plus or minus one side of the mean. For example, seat belt use by front seat passengers on major arterials averaged 48.5% with 68% of the observations between 45.5 and 51.5 (± 3.0).

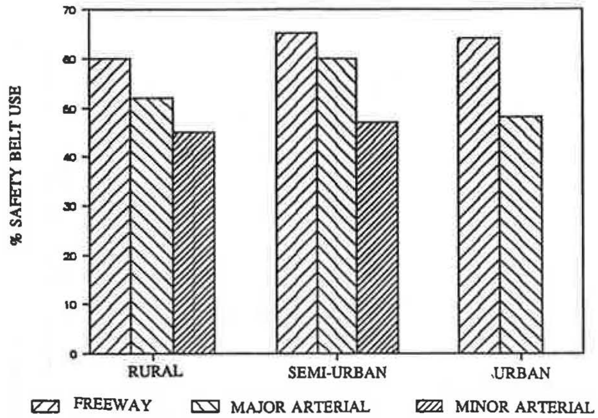

FIGURE 4 Safety belt use by type of highway and location, 1987.

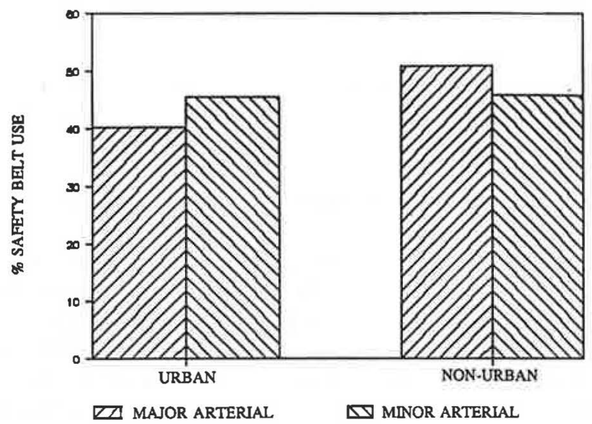

FIGURE 5 Safety belt use by type of highway and location, 1988.

TABLE 2 STATUS OF VEHICLE ACCIDENT VICTIMS AND SAFETY BELT USE

Status	Driver	Passenger	Unknown	Total
Belted	19	7	0	26
Unbelted	32	16	0	48
Unknown	5	0	1	6
	56	23	1	80

TABLE 3 ADMISSION DISPOSITION OF TRAFFIC ACCIDENT VICTIMS AND SAFETY BELT USE

	Disposition				
Status	Intensive Care	Nonintensive Care	Other	Deaths	Total
Belted	13	6	8	0	26
Unbelted	37	6	2	3	48
	50	11	10	3	74

veys, more unbelted than belted individuals were admitted to trauma centers. It is interesting to note the dramatic difference in admission to intensive care: 13 of 26 belted survivors as opposed to 37 of 45 unbelted survivors. Also, all three fatalities in the sample were unbelted. In 1988 data were obtained on admission and disposition of accident patients from the 11 trauma centers in Maryland from July 1987 through June 1988. Also obtained were data on safety belt use by these patients. It must be noted that this is a preselected group in the sense that these were all patients who were taken to trauma centers because of either evidence of severe injuries at the scene of a vehicular crash or a suspicion of severe injuries on the basis of assessment in the field, including mechanism of injury. Therefore, the spread between belted and unbelted individuals is not as great as what one might expect from a general population, because all of these patients were suspected of having injuries serious enough to warrant referral to a trauma center.

Of 3,281 trauma admissions who were victims of car and truck crashes in 1988, 843 were noted to be belted, 1,668 were noted to be unbelted, 8 were in the "other" category, and 762 were in the "unknown" category. The mortality for belted victims was 2 percent and the mortality for unbelted victims as 5.2 percent, almost a threefold rate. The unbelted individuals had a slightly higher injury severity score of 11.9, which compared with 10.5 for the belted individuals. Likewise, the mean length of stay for unbelted victims was 9.08 days and for belted victims, 7.11 days. The information is summarized in Table 4. Table 5 shows the same data base for 1989 (July 1988 through June 1989) with very similar results. Because only summary data were available, no statistical analysis was conducted with the data.

These data suggest that, for this population, unbelted patients had more than twice the mortality, higher injury-severity scores, and longer hospital stays. Once again, it is important to emphasize that these observations are suggested despite the fact that the registry is composed entirely of individuals suspected of serious injury. This suggests that even within a population of trauma patients, there continue to be significant protective benefits from safety belt use. Because only 33 percent (in 1988) and 36 percent (in 1989) of the victims were using safety belts compared with more than 60 percent of the drivers and front outboard passengers, the population of unbelted occupants is greatly overrepresented in trauma center admissions.

Promoting safety belt use has been a major activity for the past 4 years in Maryland, but no studies of effectiveness have been conducted.

ENFORCEMENT

It should be possible to determine the effectiveness of enforcement in increasing safety belt use by comparing use in locations with little or no enforcement activity with use in locations with high enforcement activity. The Chief's Challenge program began November 1, 1988, and concentrated for a month on a highly publicized campaign to promote safety belt use through intensive enforcement measures. Most large and many small county and municipal police agencies participated. This high emphasis on enhanced enforcement should

TABLE 4 REVIEW OF CAR AND TRUCK TRAUMA ADMISSIONS: FY 1988

Safety Device	Frequency of Use	Mortality (%)	Mean Injury Severity Score	Mean Length of Stay (days)
Belt	843	2.0	10.5	7.11
No belt	1,668	5.2	12.0	9.08
Other	8			
Unknown	762			

SOURCE: Maryland Trauma Registry.

TABLE 5 REVIEW OF CAR/TRUCK TRAUMA ADMISSIONS: FY 1989

Safety Device	Frequency of Use	Mortality (%)	Mean Injury Severity Score	Mean Length of Stay (days)
Belt	1,057	1.9	9.8	8.2
No belt	1,871	4.6	11.9	8.4
Unknown	722			

SOURCE: Maryland Trauma Registry.

result in increased safety belt use. However, field measurements of use were not conducted to ascertain the effect.

The Maryland State Police has been active in enforcing the MUL since July 1986. Table 6 shows the activities by quarter for 1986 and 1987, the total for 1988, and the first three quarters of 1989. As shown in this table, more than 110,000 citations and more than 20,000 warnings had been issued through September 1989. In 1988 local police began actively issuing citations for nonuse of safety belts. No numerical data are available for local police.

The state police conducted a seminar for top local police officials in February 1989 to teach the benefits of safety belt use and obtain a commitment to encourage belt use and more aggressive enforcement by all police officers. The seminar was followed by a course on the training of personnel for each local police department on this matter. They will, in turn, train police officers in their unit. This and other activities strengthened the relationship between enforcement strategies and safety belt use in 1989.

The high belt use in Maryland can be attributed partly to the high enforcement level and to the high percentage of non-Maryland drivers on Interstate routes who probably do not know that the MUL is enforceable only as a secondary offense.

TABLE 6 ENFORCEMENT OF MARYLAND MUL BY MARYLAND STATE POLICE

Time		Citations	Warnings	Total
7-1 to 9-30	'86	3,726	6,138	9,864
9-30 to 12-31	'86	4,801	3,787	8,588
Total 1986		8,527	9,925	18,452
1-1 to 3-31	'87	4,599	3,291	7,890
4-1 to 6-30	'87	7,214	4,621	11,845
7-1 to 9-30	'87	5,948	3,696	9,644
10-1 to 1-30	'87	9,742	-	9,742
Total 1987		27,503	11,618	39,121
1-1 to 12-31	'88	41,106	--	41,106
1-1 to 9-30	'89	33,181		33,181
TOTAL		110,317	21,543	131,860

CONCLUSIONS

The use of safety belts increased significantly after the Maryland Safety Belt Use Law was enacted, especially in the driver and right front-seat passenger positions. As shown in Figure 3, use increased from an average of 32 percent to 73 percent, (May versus October 1986), and then declined slightly to 66 percent (June 1987). October 1988 and October 1989 data show increases to 73 percent and 78 percent, respectively. These data are from the Maryland Association of Women's Highway Safety Leaders. The University of Maryland 1987, 1988, and 1989 data are similar but show a consistently lower use rate (Table 1).

Data from the 11 Maryland Trauma Centers show that a small percentage (33 percent in 1988 and 36 percent in 1989) of the admitted traffic-accident victims are belted. However, the mortality rate for unbelted victims is more than 2.5 times that of belted victims. And the severity of injury and the length of hospital stay are higher for unbelted patients.

In summary, increases in reported safety belt use (Maryland is one of the highest belt use states) and decreases in fatalities occurred after the law, specifically among the occupants of the seating positions affected by the Maryland law. Persons who were wearing safety belts in fatal crashes were less than half as likely to be killed as those not restrained. The Maryland MUL is a popular well-publicized law. An amendment to the MUL making it a primary offense would be significant in enabling enforcement. The MUL has proved to be a great safety benefit, reducing the severity of injury to accident victims and saving the lives of many who would have been fatally injured.

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Effects of Enforcement on Seat Belt Use in Hawaii

KARL KIM

Hawaii leads the nation in seat belt use compliance. The use rate for front-seat occupants of passenger vehicles in daylight exceeds 80 percent. After the results of observational studies on seat belt use conducted in Hawaii are described, the relationship between enforcement levels and seat belt use is explored. Some of the relevant literature and some of the different approaches to explaining driver behavior are reviewed, and a statistical model relating levels of enforcement and rates of seat belt use for the city and county of Honolulu is presented and discussed. A variation of the regression model that uses cumulative citations standardized by the estimated number of drivers in the county is shown to explain more than half of the monthly variation in seat belt use. Enforcement is shown to be an important factor in Hawaii's success with its mandatory seat belt law, but other factors such as public education (though difficult to quantify) are examined. Finally, the relevance of these findings to other states is discussed.

Since the passage of its mandatory belt use law in 1985, Hawaii has consistently led the nation in seat belt use compliance. The most recent observational studies show that front-seat occupant daylight use of passenger restraints in Hawaii exceeds 80 percent (*1*). In the state's largest city, Honolulu, the use rate is 85.2 percent, approximately twice the average use rate (42.3 percent) in most U.S. cities (*2*). Further evidence of Hawaii's lead in seat belt use compliance comes from the federal government's Fatal Accident Reporting System (FARS), which showed that Hawaii had the highest restraint use of all states for drivers and passengers involved in fatal accidents (*3*).

After a description of Hawaii's environment and some patterns in belt use before and after the enactment of the Hawaii law, an effort is made to explain the success of the Hawaii law. In particular, the relationship between enforcement and compliance is examined. A statistical model relating levels of enforcement and compliance is presented and discussed. The relevance of Hawaii's experience to other states is also discussed.

BACKGROUND

Created by volcanic activity that began some 30 million years ago, the Hawaiian archipelago comprises seven inhabited islands and numerous uninhabited smaller islands, atolls, and shoals. The state is organized into four counties: Honolulu, Hawaii, Maui, and Kauai. With a resident population of just more than 1 million, Hawaii is the 39th largest state in the nation. But in terms of land area, it is the fourth smallest. Its 4,100 mi of roadway is the least amount of roadway of all 50 states. It is also last in the nation in terms of drivers per 1,000 people of driving age (*4*).

The major economic activity in Hawaii is tourism. More than 6 million visitors come to Hawaii each year. The trade and services sector accounts for more than 50 percent of the state's total employment. Defense activities also figure heavily in the Hawaiian economy. Approximately 134,000 members of the armed forces and their dependents are stationed in Hawaii. Although less dominant than it was a quarter-century ago, agriculture is still an important part of the state's economy. Major agricultural products include sugar, pineapples, flowers, macadamia nuts, and coffee.

Changes in land use and settlement patterns (the shift from agricultural to urban uses, increased densities, and continued growth in population and automobile use) are reflected in the increase in traffic accidents. In 1967 there were only 11,529 accidents in Hawaii. By 1987 the total number of accidents in the state grew to 23,618; in those accidents, 138 persons were killed and approximately 12,000 were injured.

Hawaii's Mandatory Seat Belt Use Law

During summer 1985, Hawaii became the 10th state in the nation to enact a mandatory seat belt law. The Hawaii law—Hawaii Revised Statutes (H.R.S.) 291-11.6—took effect December 16, 1985, after a 45-day warning period. The law was written to cover only front-seat occupants of motor vehicles because most people killed in crashes are front-seat passengers (between 1979 and 1984, 88 percent of motor-vehicle crash fatalities were front-seat passengers). Legislators also believed that a law covering rear-seat passengers would be difficult to enforce and more intrusive. Hingson (*5*) has noted that intrusiveness of seat belt laws has been a major reason for public opposition. In addition, Hawaii legislators amended the law regulating insurance rates (H.R.S. 294-13) and required all insurance companies to provide a 10 percent reduction in premium charges for all policy holders with vehicles equipped with seat belt assemblies. Unlike many other states with seat belt laws, the Hawaii law gave police the power of primary enforcement, under which police have the authority to stop and issue citations to any motorists not in compliance with the law. Under secondary enforcement, police can issue belt use citations only if the vehicle has been stopped for another traffic violation. The fine for violating the seat belt law was $15. Legislators argued for setting the fine at less than $25 in order to avoid supporting the federal rule that would have made it unnecessary for automobile manufactur-

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ers to provide automatic passive restraints if two-thirds of the U.S. population resided in states that had passed seat belt laws meeting certain federal requirements, including the $25 fine (*6*, p. 889).

In the context of other traffic safety initiatives enacted in Hawaii, it is not surprising that Hawaii was one of the first states to adopt a seat belt law and one of the few to grant police the power of primary enforcement. Williams and Lund (*7*) report that 8 other states (New York, Texas, North Carolina, Connecticut, New Mexico, Iowa, Minnesota, and Oregon) have primary enforcement laws and 25 states have secondary enforcement laws. Besides its seat belt law, Hawaii also has a mandatory child restraint law. It was enacted in 1983 and carries a $100 fine for first-time violators. In 1986 the state raised the minimum age for alcohol purchase from 18 to 21. In addition, the police departments routinely use sobriety checkpoints as a way to curb drunk driving. Other initiatives under consideration by the legislature include adopting administrative revocation of licenses of drunk drivers, banning passengers in the cargo area of pickup trucks, and restoring the mandatory helmet use law for motorcyclists. At present, there is little, if any, interest in raising the state's maximum speed limit above 55 mph.

Compliance with Hawaii's Mandatory Seat Belt Law

Soon after the law was enacted, the Motor Vehicle Safety Office of the State Department of Transportation contracted with the University of Hawaii's Department of Urban and Regional Planning to develop a system for monitoring, recording, and reporting on seat belt use in Hawaii. The university developed a procedure using observers at 118 fixed locations throughout the state. Each observer was trained and tested to ensure a high degree of consistency. The sites were chosen to ensure that major population centers and travel corridors and a variety of settings (urban, rural, suburban, commercial, etc.) were covered. A microcomputer-based data base management system for inputting, editing, and compiling the data was developed. Analysis of the data was conducted on the University of Hawaii's IBM 3081 mainframe computer, using the SPSSx statistical package.

Since 1985 a total of 393,021 persons have been observed during 11 separate periods. The earliest observations were conducted in November 1985, before the law took effect, and the most recent were completed in January 1990.

Over the period 1985 to 1990, total statewide seat belt use increased from 33 percent 1 month before the law took effect to higher than 80 percent in January 1990 (Figure 1). Belt use increased immediately after the law took effect to more than 72.6 percent in January 1986. The use rate dropped during the first year of the law to 66.7 percent in July 1986 and even further to 66.1 percent by January 1987. Hawaii experienced a continuing decrease in belt use through October 1987, when the lowest use rate (63.5 percent) was recorded. By January 1988, however, compliance began to increase and has climbed steadily ever since. By June 1989 seat belt use in Hawaii had surpassed even the high levels set immediately after the law took effect. This has surprised some observers who thought that the high levels of compliance achieved just after the law was implemented would be difficult to surpass. Hawaii's high

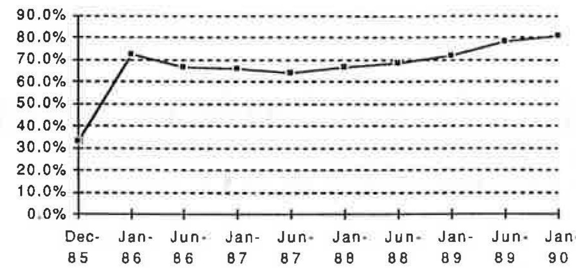

FIGURE 1 Seat belt use rate for Hawaii, 1985–1990.

and increasing rate of compliance with its mandatory seat belt law means that the state has not only passed all other states in the United States, but has begun to approach the high levels of compliance (80 to 90 percent) reported in many European countries (*8*, p. 89).

Hawaii's initial rate of compliance, 73 percent, was one of the highest levels of compliance achieved in the United States, according to a survey of states conducted in 1987 (*9*, p. 2). Only two states (North Carolina and Maryland) have ever reported use rates higher than Hawaii's. The reported increase in belt use in Hawaii immediately after the law took effect was 40 percentage points, but the actual increase attributable to the law may have been much greater. Surveys conducted in 1983 revealed a use rate of approximately 17 percent (Hawaii Department of Transportation, unpublished data).

Hawaii is unique in that there are relatively few governmental jurisdictions. There are only four counties and no other units of local government. Use rates for the four county jurisdictions and the state as a whole are contained in Table 1. Honolulu has maintained an average use rate much higher than 70 percent during the entire period in which the seat belt law has been in effect. The neighboring island counties have all had use rates lower than Honolulu's both before and after the law took effect. In general, use rates have been much more unstable in the neighboring island counties. During the period after the law took effect, Hawaii's use rate has ranged between 55.4 and 78.9 percent; Maui's, between 43.5 and 77.3 percent; and Kauai's, between 64.8 and 73.5 percent.

The most recent observations (January 1990) show that belt use in Hawaii varies not only by county but also by position in the vehicle, posted speed limit, urban versus rural location,

TABLE 1 SEAT BELT USE RATE: PERCENTAGE BY COUNTY

Date	Honolulu	Hawaii	Maui	Kauai	State
12/85[a]	37.4	26.0	26.0	28.8	33.0
1/86	76.5	64.0	67.3	70.7	72.6
6/86	71.9	59.6	57.7	64.9	66.7
1/87	68.9	63.2	54.8	65.6	66.1
6/87	70.7	59.3	44.5	66.8	63.8
10/87	70.6	55.4	43.5	65.0	63.5
1/88	71.2	69.9	50.1	64.8	66.5
6/88	72.8	65.6	59.3	68.5	68.5
1/89	72.5	77.0	64.6	69.3	71.5
6/89	81.9	73.6	74.0	68.9	78.3
1/90	82.3	78.9	77.3	73.5	80.5

[a]Represents the pre-law observations.

and time of day. The use rate for drivers was 82.6 percent, but the use rate for front-seat passengers was much lower—75.0 percent. Belt use among both drivers and passengers increased with the posted speed limit. The highest use rates (86.1 percent for drivers, 78.6 percent for outboard passengers) were observed on roadways in which the posted speed limits were 50 mph or greater. The highest use rates in the state occurred in the most urbanized areas. For example, the use rate in Honolulu's primary urban center was 85.2 percent; in the rural areas of the island, use rates ranged between 69.6 percent (Waianae) and 79.2 percent (Waialua). Similarly, on each of the three other islands where observations were taken, the highest use rates occurred in the urbanized areas (Kihei and Wailuku on Maui, North Hilo on Hawaii, and Koloa and Lihue on Kauai). The highest use rates also occurred during the morning, from 8:00 to 10:00.

EXPLAINING THE SUCCESS OF HAWAII'S SEAT BELT LAW

Interest in explaining seat belt use is not new. Fhaner and Hane, for example, have reviewed the studies conducted before the enactment of mandatory seat belt use laws in the United States (*10*). There are, therefore, several hypotheses that might explain Hawaii's high and continuing rate of compliance with its mandatory seat belt law. For example, the decision to use a seat belt might be modeled as a benefit-cost problem. Graham (*11*) has estimated that the benefits of using seat belts range between 3 to 25 cents per trip, which should be compared with the costs (time, inconvenience, discomfort, etc.) of using seat belts. By adding the costs of a fine—the dollar amount as well as the additional costs and aggravation associated with receiving a citation—one could argue that passage of Hawaii's mandatory seat belt law changed the economic incentives such that the perceived benefits of seat belt use outweighed its costs. This perspective presumes rational behavior on the part of motorists and their passengers. The reality may be that people are incapable of making such benefit-cost comparisons, particularly when such small probabilities may be involved. Slovic et al. have argued that behavior is more likely to be influenced by the probability of the hazard than the magnitude of its consequences (*12*). Traffic safety specialists, let alone motorists, vary widely in terms of the perceived effectiveness of seat belts in reducing fatalities and injuries as well as in assigning a probability to the likelihood of an accident's occurrence. The problem is compounded by the phenomenon, observed by Svenson and others, that most drivers may regard themselves as more skillful and less risky than average (*13*). Another view of the problem suggests that the failure to use seat belts results primarily from a failure to make use of seat belts a habit rather than any "distrust of seat belts or any very deep-seated systems of attitudes and beliefs" (*14*). The question as to how habits are formed opens some larger psychological questions that may involve the influence of personality types, such as introversion-extroversion (*15*), or certain driver and vehicle characteristics that Evans and Wasielewski (*16*) have related to risky driving practices. Also, there are various theories and counterarguments involving the "danger compensation" principle or "Peltzman effect"—whereby it has been argued that drivers compelled by law to use seat belts or other safety measures increase their risk-taking behaviors and unsafe driving practices. The presence of many different theoretical perspectives complicates the explanation of Hawaii's success with its mandatory seat belt law.

Enforcement and Compliance

What is apparent from Hawaii's experience is that there has been a radical change in behavior in comparison with past levels of belt use in the state and in terms of Hawaii's overall level of compliance vis-à-vis other states in the United States. What explains the high and lasting levels of compliance in Hawaii? One might examine the relationship between levels of compliance and enforcement. Compared with some of the strategies used to increase seat belt compliance (public education, media campaigns, public service announcements, etc.), enforcement is a visible and measurable intervention. The numbers of traffic citations for seat belt law violations are compiled monthly by state and local governments.

One might hypothesize that seat belt use in Hawaii is a function of enforcement levels. In terms of the relationship between seat belt enforcement and compliance, one study has found that belt use in primary enforcement states is at least 13 percent higher than it is in secondary enforcement states (*9*, p. 16). Two other studies—Evans and Graham (*17*) and Wagenaar et al. (*18*)—have found a reduction in traffic fatalities that is higher among those states with primary enforcement than those with secondary enforcement. However, the work by Shinar and McKnight suggests that the major determinant in compliance behavior is "not necessarily what the police do, but rather, how it is perceived by the road users" (*19*, p. 386). It is interesting to note that Shinar and McKnight identify two variables associated with the perceived risk of apprehension: threat (degree to which the driver sees visible enforcement units as a threat of apprehension) and density (the number of enforcement units per mile of driver travel).

Because Hawaii is an island state with a limited amount of roadway, it is not unreasonable to expect that the threat of apprehension and the density of police units would be greater in Hawaii than elsewhere. The geography in Hawaii makes it relatively easy to establish a strong police presence. Hawaii is composed of volcanic mountain ranges that dominate the interior of each island, so most development has concentrated in the low-lying coastal areas. Narrow transportation corridors have evolved that connect the major nodes and population centers. As a result, it is easy not only to monitor motor vehicle movements, but also to set up enforcement strategies covering a large proportion of the driver population. Anyone who has lived on an island for any extended period of time understands the notion that the threat of apprehension in Hawaii is greater than it is elsewhere. Moreover, because Hawaii's system of government is highly centralized, it is easier to mandate policies regarding belt use, training, and enforcement. Enforcement of the seat belt law in Hawaii has been strong, consistent, and more uniform than in other places that have multiple, overlapping jurisdictions. In addition, a strong public information program has helped to increase public perception of the risks associated with nonuse.

Testing the Hypothesis

To test the relationship between seat belt use and enforcement, data on seat belt citations and observed belt use rates in Honolulu were compiled each month. More than 70 percent of the state's population lives in Honolulu. Selecting one county eliminates some of the differences between counties that may exist in terms of enforcement practices. Table 2 contains a summary of seat belt citations issued in Honolulu from 1985 through 1989. The number of annual citations has grown steadily, from 12,347 in 1986 to more than 18,500 in 1989. In the city and county of Honolulu alone, 64,900 citations have been issued since the seat belt law took effect.

Two data sets were pooled. The observational data on belt use were collected by the University of Hawaii; the data on seat belt citations were collected by the Honolulu Police Department and furnished to the Hawaii Department of Transportation. Information about numbers of licensed drivers was obtained from the Honolulu Department of Data Systems.

Several steps were taken to transform these different data elements into usable variables. Citation data were available monthly, but data on seat belt use were available only biannually (January and June). A smoothing technique (running averages) was used to estimate the monthly use rates between the observation periods. A similar technique was used to transform the annual data regarding motor vehicle licences into monthly totals. In this manner, a monthly time series for licensed drivers, seat belt citations, and seat belt use rates was derived. Summary descriptive statistics are provided in Table 3.

Two approaches were taken. The first approach (Equation 1) viewed the potential relationship between enforcement and compliance on a month-to-month basis. Several regression models were developed. Of the models tested, the one (Equation 2) with greatest explanatory power (R^2-value) used the number of belted drivers as the dependent variable (Y) and a ratio of the drivers to citations issued as the independent or explanatory variable (X). The number of belted drivers was derived by applying the observed use rates to the total number of estimated drivers. The ratio of drivers to citations was determined by dividing the number of drivers by the number of citations issued each month. This figure increases during those months in which few citations are issued and decreases during those months in which many citations are issued. The resulting equation can be expressed as

$$Y = 367{,}441.5 - 63.24X \quad (-5.06) \qquad (1)$$

$R^2 = .348$, F-statistic $= 25.5$

with t-statistic values in parentheses. The t-statistic value is significant at the .05 level, as is the F-statistic. With an R^2-value of .348, more than one-third of the total variation in belt use is explained by the single citation variable. It is also important to note that the sign of the regression coefficient is negative, as expected. The citation variable is expressed as ratio of drivers to citations, so that as the number of citations increases, the value of this variable decreases. This suggests that, for Honolulu, enforcement has had a significant influence on observed belt use.

The second approach attempted to account for the cumulative effects of enforcements on compliance. Under this approach, the dependent variable (Y) remains the same as before, but the independent term (X) is the cumulative number of monthly citations divided by the monthly number of drivers. The assumption here is that with each passing month, a larger and larger proportion of the driving population in violation of the seat belt law has been cited. The equation can be expressed as follows:

$$Y = 288859.4 + 598535.4X \quad (7.18) \qquad (2)$$

$R^2 = .518$, F-statistic $= 51.59$

In this formulation, the R^2 is higher, explaining more than half of the total variation in monthly belt use. In addition, the t-statistic on the citation term is highly significant. These results suggest that the relationship between enforcement and compliance is best viewed in a cumulative manner. Although the month-to-month approach can explain approximately one-third of total variation, the cumulative model performs substantially better.

The technique relies upon a number of important assumptions. First, in constructing the monthly time series, the variation over the 6-month intervals is assumed to be small enough that the averaging technique provides a good approximation of use rates for individual months. Similar assumptions regarding the smoothing of licensing data are also implicit in this analysis. Second, it has been assumed that standardizing citations by dividing them into the approximated monthly totals of licensed drivers gives a reasonable approximation of the enforcement effort. Although using an exposure variable such as total front-seat occupants on the road for a given month would have been a better way to standardize this variable, such data are not readily available. The third major assumption in this analysis involves the use of a simple linear

TABLE 2 SEAT BELT CITATIONS, CITY AND COUNTY OF HONOLULU

Date	Total Annual Citations
December 1985	210
December 1986	12,347
December 1987	15,182
December 1988	18,661
December 1989	18,500
Total	64,900

TABLE 3 SUMMARY STATISTICS, MONTHLY TIME SERIES DATA (DECEMBER 1985–JANUARY 1990)

Variable	Mean	Standard Deviation	Range
Belt use (%)	73	6.5	37.4–82.3
Citations	1,319	631.3	210–2,840
Drivers	460,794	9,954.2	441,278–479,140
Belted drivers	337,948	34,584.2	165,039–394,332
Cumulative citations	30,498	19,801	210–65,950[a]

[a] Includes January 1990.

regression model. Several other curvilinear regressions of transformed variables were tested, but none provided greater explanatory power than the one presented. The model explains almost half of the total variation in monthly belt use, but it is important to recognize inherent deficiences with a pooled, cross-sectional analysis such as the one presented. One basic problem is that, though all the data come from Honolulu and cover roughly the same time period, the observations are not pure time-series data. For example, the same members of the sample of automobile occupants may or may not have been observed over the 4-year period. Similarly, the citation data do not distinguish between first-time and repeat offenders. These are important aspects of the analysis that need to be controlled in a strict time-series study of the relationship between enforcement of and compliance with the mandatory use law.

Nonetheless, the results suggest that enforcement has been an important factor in encouraging seat belt usage in Honolulu. Several federal grants have been used to pay for seat belt enforcement, but the responsibility for maintaining enforcement levels still rests with each local government. Although enforcing the seat belt law is expensive, the results suggest that enforcement levels should be maintained or perhaps increased to ensure growing compliance with the mandatory restraint law.

The model also fails to account for saturation effects or potential differences between the resilient nonuser of seat belts and one who changes behavior after being cited. Further research is needed, and plans to examine more closely the background and demographic characteristics of those who have received seat belt citations are under way. Of special interest are studies on rates of repeated offenses, tourists versus residents, and relationships between violations of the seat belt law and violations of other traffic safety laws.

Other Factors Related to Hawaii's High Rate of Compliance

Whereas the cumulative model was able to predict approximately half of the variation in belt use in Hawaii, it is clear that there are other factors related to Hawaii's high rate of compliance. Public education about the benefits of seat belt use might have played a part in Hawaii's success. Such efforts are difficult to evaluate, but it is important to note that Hawaii's campaign to increase seat belt use involved broad sectors of the community. Besides the Hawaii Coalition for Safety Belt Use, several other state and local groups were formed to share information and promote traffic safety. A "Saved-by-the-Belt" Club was formed; newsletters, bumper stickers, buttons, grocery bags, key chains, posters, and brochures with printed messages about seat belt use were developed and distributed. The national organization Traffic Safety Now spent an estimated $350,000 over 4 years. In addition to funding a newsletter sent to more than 700 people, funds were used to produce local radio and television spots promoting seat belt use. Activities were also undertaken by health educators, police officials, and others—such as car rental agencies and airlines that provided information and reminders to tourists. A public relations firm was hired to coordinate such activities as interviews with key public officials and production of press kits for local media. A combination of paid and nonpaid advertising was used. The public relations firm worked out an arrangement in which local stations ran one free public service announcement for each paid broadcast. Several hundred roadway signs proclaiming "Buckle up, it's the law" were placed at strategic locations throughout the state.

The observation data collected by the University of Hawaii have proved to be an integral part of the public education campaigns in Hawaii. The biannual data were distributed to local police departments and used by health educators in targeting areas for increased activity. Because the data were collected by the university on a scheduled basis, the information served to promote some competition between various communities and local agencies around the state. In addition, the results of the observational studies were reported by news media and incorporated into public service announcements.

RELEVANCE OF HAWAII'S EXPERIENCE TO OTHER STATES

Although the voluntary adoption of passive restraints and airbags by automobile manufacturers may eventually eliminate much of the need for studies on seat belt use, the data and results on seat belt compliance from Hawaii are interesting for several reasons. First, Hawaii has achieved extraordinarily high rates of compliance with its seat belt use law. Just 1 month before the law took effect, belt use was approximately 37 percent; it has more than doubled during the past 4 years. The actual increase or change in behavior may have been much greater, because earlier surveys in Hawaii reported use rates of only 17 percent.

The second point is that seat belt use in Hawaii—though it dropped during the initial period in which the law was implemented—has continued to increase steadily since October 1987 to the point that it has even surpassed the initial high levels set immediately after the law took effect. Use rates in Hawaii are high and are continuing to grow.

A third point is that there does appear to be a relationship between enforcement levels and seat belt use, particularly when accounting for the cumulative number of citations issued for seat belt law violations. More than half of the monthly variation in belt use could be explained by the cumulative number of seat belt citations. Enforcement has been an important factor in Hawaii, but the effects of public education and public service announcements, though difficult to measure, should not be overlooked. A challenge to traffic safety researchers may be to develop an appropriate evaluation technique for measuring the impact of these efforts. In Hawaii, the fact that the seat belt law was able to generate such broad involvement is evidence of community support and acceptance of the law.

Hawaii provides an ideal setting for the testing of hypotheses regarding driver behavior. In addition to being a nearly closed system because of its location in the middle of the Pacific Ocean, Hawaii has only four units of local government, which correspond to the major islands, so many of the problems associated with multiple or overlapping jurisdictions do not exist. Both Hawaii's law and the programs (enforcement and public education) that have evolved here should be scrutinized by other states in search of greater success in implementing mandatory seat belt use laws.

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Reexamination of Impact of Drinking Age Laws on Traffic Accidents in Illinois

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Previous studies of the impact of drinking age laws on traffic accidents have often used statistical techniques or short data sets that can lead to misleading conclusions. Studies generally have focused on fatalities or surrogate variables or both. Using autoregressive integrated moving average techniques and total accidents by month over a 20-year period, the experience in Illinois is reexamined. The lower drinking age in Illinois from October 1973 to January 1980 was responsible for an increase of more than 5,000 accidents per month, a 14 percent increase. When the age was raised back to 21 in 1980, the figures reversed a similar amount. More than 1,000 additional 18- and 19-year-old drivers were involved in accidents each month with the lower age limit, a 20 percent increase. It was also found that total monthly property-damage-only accidents were highly positively correlated with wet or snowy pavement and negatively correlated with dry pavement; fatal accidents behaved in the opposite way. The techniques used can be used to analyze the impact of other public policies on accidents.

Government policies are enacted to accomplish goals. Whether they are successful is typically difficult to determine. In the scientific world, variables can be controlled precisely; in the real world, many influences apply simultaneously. Whether the impact of a public policy can be sorted out from the dynamic interaction of other variables is problematic.

One area that has been studied for some time is the effect on traffic accidents of changes in the minimum drinking age. In the early 1970s, a number of states lowered the minimum age in response to the trend of promoting adulthood at an earlier age. This trend was in conjunction with the lowering of the voting age to 18 in 1971 and the involvement of those under 21 in the armed forces during the Vietnam War. States subsequently reassessed their policies, because alcohol-related accidents in this age group skyrocketed. This reversal was reinforced at the federal level by an amendment to the Surface Transportation Assistance Act of 1982 to withhold federal highway funds after mid-1986 from any state with a minimum drinking age under 21.

The impact on traffic accidents of changes in the drinking age in Illinois was studied. There are a number of motivations for this study. First, many of the statistical techniques used in previous research are suspect. Second, enough time has passed to allow for a substantial number of observations after the policy enactment. Third, most studies have researched the impact of either the lowering or the raising of the drinking age; both are combined in this effort. Fourth, studies have differed in their focus: the majority have used driver fatalities; some have concentrated on injuries, injuries and fatalities, or all accidents. Because of the difficulty in measuring alcohol involvement, proxy or surrogate variables have been employed. The accuracy of these measures is of interest.

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THE ILLINOIS SITUATION

In October 1973, Illinois lowered the minimum legal drinking age for beer and wine from 21 to 19. In addition, home rule laws made it possible for some jurisdictions to allow purchase of all alcoholic beverages at a lower age (*1*). In January 1980 the uniform statewide drinking age of 21 was restored.

A data set suitable to analyze the impact of these changes is compiled monthly by the Illinois Department of Transportation (IDOT) (*2*). For the entire state from 1970 to mid-1989, traffic accident totals (also broken down by fatal, injury, or property damage only), age of drivers involved, and road conditions were selected. The state totals came from police accident reports filed for all accidents with fatalities, injuries, or property damage over a dollar limit (currently $250).

As would be expected, accident figures show much month-to-month variation. In Table 1, the mean, standard deviation, minimum, and maximum values are presented. The age breakdown by IDOT is less than ideal: 11 brackets are used; 18- and 19-year-old drivers are combined as well as those aged 20 through 24.

PREVIOUS RESEARCH

A survey by the Government Accounting Office (GAO) (*3*) located 32 studies on raising the drinking age and traffic accidents, of which 14 were summarized. Many of these were before-and-after comparisons of ratios, often using as little data as 1 year before with 1 year after. Such short time periods make it virtually impossible to separate potential impacts of other variables (rival causes). Attributing all of the changes in the dependent variable to a single causal variable is at best misleading and at worst incorrect. The classic example of such an error was pointed out by Campbell and Ross (*4*) in their study of a Connecticut speeding crackdown: politicians attributed all of a 1-year decline in fatalities to their policy, but it was determined that the decline may have been due to nothing more than a regression to the mean. The year before had seen an unusually high fatality rate; the decline would have been likely to occur with or without the crackdown.

Use of ordinary least squares (OLS) regression analysis in many studies for longer time-series data is also subject to misinterpretation. Using a time series, the inherent OLS as-

TABLE 1 MONTHLY ILLINOIS TRAFFIC ACCIDENT STATISTICS, 1970–1989 (*2*)

Variable	Mean	Standard Deviation	Minimum	Maximum
Total Accidents	40,475	7,065	27,998	84,153
Fatal Accidents	144	33	73	220
Injury Accidents	9,572	1,386	6,506	14,704
Property Damage Accidents	30,760	6,300	21,227	72,360
18-19 Year Old Drivers	5,038	1,218	3,010	11,991
20-24 Year Old Drivers	11,378	2,327	7,688	26,750
25-34 Year Old Drivers	16,479	3,376	10,406	37,605

sumption of uncorrelated error terms is routinely violated (*5,6*). As a result, estimated variances of coefficients are too small, making variables appear significant when they may not be. Most time series have trends (regular or seasonal or both) that need to be removed or modeled (*7*). OLS trend estimates are sensitive to outliers and cannot be estimated with accuracy. To have any reliability, studies using before-and-after or OLS techniques must also include controls—either other age groups or other states.

Traffic accident data are likely to contain patterns of autocorrelation (*8*). If a relatively long series is available, the techniques of Box et al. (*9,10*) provide a superior method to prepare the data for impact analysis (*7*). Comparative studies have found that in most cases these techniques more accurately account for regularities in time series than do alternative strategies of analysis (*11*). This approach is particularly appropriate for identifying significant shifts in accident involvement associated with legal changes independent of observed regularities in the history of the dependent variable.

However, a number of studies using this approach have had relatively few observations after a policy intervention. For example, Hilton (*8*) and Maxwell (*12*) used 12 monthly observations, and Wagenaar (*11*) used 12 months in 1 state and 25 in another. Again, this shortness increases the possibility that other influences will be misconstrued as the interventions. In most states, the after intervention period (higher drinking age) was a time of pervasive awareness and concern about drinking and driving. Police activity was increased and stronger penalties were passed. Because these time periods ran coincidentally, it might be incorrect to attribute any changes to the drinking age alone. A longer after period would allow more confident conclusions. For this study, 45 months before, 75 months during, and 103 months after are available.

All of the studies analyzed in the GAO report (*3*) examined the impact of increases in the drinking age. The report cites a list of works that looked at the result of lower drinking ages, but all such reductions occurred before 1975. GAO believed that data and analytical techniques at the time were less sophisticated and that the issue was less relevant to policy. With a longer time period, and a state that lowered and then raised the drinking age, one dummy variable can account for the presence and absence of a policy (e.g., lower drinking age) rather than two separate intervention variables.

The focus variable for measuring the impact of changes in the drinking age in previous literature has varied considerably (*3*). Direct indications of drinking may come from police observations and tests and in the case of fatalities, coroner's reports. Police observations can lead to bias, because police judgment of intoxication can be subjective and reporting can be incomplete. A coroner's report is more objective, but it constrains impact analysis to accidents involving driver fatalities.

A common proxy for alcohol involvement is the three-factor surrogate: male driver, single-vehicle accident, at night. This measure has been popular, because the probability is above average that crashes meeting these conditions involve alcohol. But this measure will be reliable only to the extent that the ratio of alcohol-related surrogates to the total class of surrogates remains constant (*3*). This measure would attribute to alcohol other causes, such as falling asleep at the wheel (which is certainly more likely at night), acute medical condition, or suicide (*13*). Multiple-car crashes, the impact of "happy hours" earlier in the day, and women's drinking are ignored.

As an alternative, the influence of changes in the drinking age can be measured as a deviation from total accident trends. This measure is suitable with a statistical technique available that uses a long time period to account for trends and other potential influences; it is the one used in this study. Cook and Tauchen (*14*) believed that total accidents would be insensitive to interventions targeted at drunk drivers because such drivers constitute only a small fraction of those involved in crashes. Their view today seems controversial, and the results of this study suggest that the measure is adequate.

MODEL AND RESULTS

The analysis involved the development of an autoregressive integrated moving average (ARIMA) model. This model describes the stochastic autocorrelation structure of the data series and in effect filters out any variance in a dependent variable (e.g., monthly traffic accidents) that is predictable on the basis of the past history of that variable. Remaining variance can then be related to the effects of an intervention variable.

One implication of this approach is that any regular pattern in the dependent variable over time that is similar to the pattern of potential independent variables over time is not considered as a possible causal effect between the variables; such intraseries regularities are filtered out first. This procedure has several advantages (*15*): effects of many exogenous variables are controlled, independent error terms are obtained, and these procedures are a conservative test of the causal connection between two variables.

Examination of the autocorrelation function (ACF) of monthly traffic accidents revealed the presence of regular and seasonal nonstationarity. As a consequence, it was necessary to difference the series both regularly ($Y_t - Y_{t-1}$) and seasonally ($Y_t - Y_{t-12}$). This accounts and corrects for trends from observation to observation and from year to year.

The differenced data were analyzed using the ACF and partial autocorrelation function (PACF) to identify any autoregressive and moving average patterns. The model (0,1,2) $(0,1,1)_{12}$ was identified. Parameters were estimated and are presented in Table 2. The residual ACF and PACF were small and exhibit no patterns. At 24 lags of the ACF, the Ljung-Box *Q*-statistic was 11.8, which was not significant at the .05 level (the critical chi-square value with 20 degrees of freedom is 31.4). The Akaike information criterion (AIC) and Schwartz Bayesian criterion (SBC) suggested that this model was preferable to other models examined. It can be concluded that the model fitting is adequate for the data; the residuals of the model are distributed as white noise.

It is assumed that a change in the drinking age would have an immediate, permanent effect on accidents, which would be reversed if the policy were reversed. The response function is $w_o I_t$, where w_o represents the impact of the change and I_t is 0 when t is less than 46 (October 1973) or greater than 121 (January 1980) and 1 when t is between 46 and 121. The parameter values and model diagnosis statistics for the series including the intervention effects are noted in Table 3. The results suggest that when the lower drinking age was in effect, monthly accidents in Illinois increased by (w_o =) 5,700. This was statistically significant ($p < .01$). This represented a 14 percent increase from the mean level of accidents.

One concern with the data is that IDOT changed the threshold for reporting property-damage-only accidents from $100 to $250 in October 1975. Because this could have affected total accidents reported, a second intervention was added, $w_1 J_t$, where J_t is 0 when t is less than 70 (October 1975) and 1 when t is greater than 70. This model produced similar results to the previous one; the w_1 coefficient was not statistically significant for either total accidents or property-damage-only accidents.

It is difficult to compare the results of this study with earlier ones of Illinois because of the differences in dependent variables. However, in all cases the direction of impact is identical. Using an ARIMA model, Maxwell (*12*) estimated that single-vehicle, nighttime, male-driver crashes decreased by 8.8 percent with a higher drinking age. With the same surrogate but using before-and-after comparisons, Schroeder and Meyer (*1*) obtained a slightly higher reduction. Williams et al. (*16*) estimated a reduction in nighttime fatal crashes of 23 percent.

EXTENSIONS

The focus of the research to this point is the impact of the drinking age on the total number of monthly accidents. It is

TABLE 2 ARIMA PARAMETER VALUES AND MODEL DIAGNOSIS STATISTICS, TOTAL ACCIDENTS

Parameter	Order	Value	Std. Error	t-Statistic
Moving Average	1	.41	.06	6.72
Moving Average	2	.36	.06	5.90
Seasonal Moving Average	12	.87	.06	14.99
Constant		-5	16	-0.32

Ljung-Box Q Statistic at 24 lags: 11.8 AIC: 4399 SBC: 4413

TABLE 3 ARIMA PARAMETER VALUES AND MODEL DIAGNOSIS STATISTICS INCLUDING INTERVENTION EFFECTS, TOTAL ACCIDENTS

Parameter	Order	Value	Std. Error	t-Statistic
Moving Average	1	.45	.06	7.20
Moving Average	2	.39	.06	6.35
Seasonal Moving Average	12	.85	.06	15.18
Intervention (W_O)		5767	2007	2.87

Ljung-Box Q Statistic at 24 lags: 15.1 AIC: 4394 SBC: 4412 hypothesized that changes in accidents because of changes in the drinking age were caused by 19- and 20-year-olds. Their changed accident rates would necessarily affect drivers in other age groups. Because accidents can involve two or more drivers, the total number of drivers in accidents exceeds the total number of accidents in a month. Thus, it would be expected that drivers of all ages experience a change in number of accidents. However, it is reasonable to expect that 19- and 20-year-olds would experience a greater percentage effect and other age groups a lesser percentage effect. To test this, the number of drivers involved in accidents in different age brackets was examined. Because 19- and 20-year-olds were not combined by IDOT, three age brackets were selected: 18–19, 20–24, and, as a control group, 25–34. If the hypothesis is correct, the 18–19 group would experience the greatest percentage change, followed by the 20–24 group and finally those 25 through 34.

Using the same time period (1970–mid-1989), the monthly number of 18- and 19-year-old drivers involved in accidents was modeled using ARIMA methods. This was repeated for drivers 20 through 24 and again for those 25 through 34. The $(0,1,2)\ (0,1,1)_{12}$ specification again proved adequate. The response function was $w_o I_t$ as defined earlier. As noted in Table 4, the lower drinking age was associated with more than 1,000 more 18- and 19-year-old drivers' being involved in accidents each month. From an average base of about 5,000, this represented a 20 percent change. Also noted in the table are the percentage changes for the 20–24 group (16 percent) and the 25–34 group (13 percent). The results are consistent with the hypothesis.

Traffic accident literature has indicated the impact of weather as being an exogenous influence (*17–19*). An ARIMA model accounts for seasonal patterns. The influence of weather in this model can be inferred by correlating accidents by type with road surface conditions (dry, wet, or snow and ice). It is noted that the data are monthly totals and not linked to individual accidents. Table 5 shows that dry pavement is associated with fewer property-damage and total accidents but more fatal and injury accidents. Wet pavement is positively correlated with all measures except fatal accidents. Snow or ice has a strong negative association with fatal accidents. This suggests that bad weather is linked to more accidents overall but fewer accidents that involve death or injury.

TABLE 4 ARIMA INTERVENTION EFFECTS FOR DRINKING AGE CHANGES, BY AGE OF DRIVERS INVOLVED IN ACCIDENTS

Age Bracket	Change in Accidents[a]	Percentage
18-19	1005	20
20-24	1835	16
25-34	2153	13

[a] All results statistically significant at the .01 level

TABLE 5 CORRELATIONS BETWEEN ROAD SURFACE CONDITIONS AND TRAFFIC ACCIDENTS

Accident Type	Pavement Condition: Dry	Wet	Snow/Ice
All Accidents	-.14	.39	.62
Fatal Accidents	.55	-.21	-.45
Injury Accidents	.52	.13	-.10
Property Damage Only	-.27	.41	.72

FUTURE RESEARCH

The Illinois data set could be used to examine other areas of interest and controversy. For example, it is alleged that those immediately under the drinking age are more likely to obtain alcohol illegally than those who are farther below (*3*). With an increase of the drinking age to 21, one could examine the percentage reductions in accidents in the younger age groups.

Unusual months of weather could be identified and included in the model for more explanatory power. A variety of other public policies could be examined for their impact. For example, during the past 20 years, laws enacted in Illinois have allowed right turn on red (1973), lowered the maximum speed limit to 55 mph (1974), raised the maximum speed limit on most Interstate highway segments to 65 mph (1987), and mandated the use of seat belts (1985).

In addition, the impacts of economic conditions and gasoline prices and availability are of interest. Changes in the drinking age in bordering states are relevant; for a number of years the lower drinking age in Wisconsin attracted many younger drivers from Illinois. Looking at the short- versus long-term effects of a higher drinking age is a challenge. Wagenaar (*20*) noted that they can differ: short-term impacts can dissipate if below-age drinkers obtain alternative sources of alcohol, or they can be reinforced if new cohorts of younger drivers do not develop patterns of driving after drinking. In Wagenaar's study of Michigan, long- and short-term effects were not very different.

An alternative hypothesis, that raising the drinking age does not reduce fatalities, has been proposed (*21*); more lives are lost among older drivers than are saved among younger drivers. An extension to this considered by Asch and Levy (*22*) was that inexperience in drinking, independent of age, was the major hazard. These results go against the conventional wisdom, but they should be researched further.

SUMMARY AND CONCLUSIONS

The lower legal drinking age that prevailed in Illinois from late 1973 to 1980 caused an increase of more than 5,000 traffic accidents a month, a 14 percent change. This result was obtained using more relevant statistical techniques and avoiding surrogate and proxy variables. The data extended over an unusually long time period for greater validity.

Could changes in accidents be attributable to some other "rival" causes? ARIMA intervention analysis is probably the most appropriate statistical technique for ruling out other causes. Its modeling accounts for (filters out) trends (in population, traffic volumes, safety improvements) and regularities or seasonality (weather, traffic). It asks the question, Was there a statistically significant change in the filtered time series that corresponds with a particular time period? In this case, a change began in October 1973 and ended in December 1979. The data suggest that the answer is yes. Other public policies or events began or ended during this period, but either they were permanent or the time periods did not correspond exactly with the drinking age changes. This increases the confidence in concluding that changes in the drinking age led to changes in the number of accidents.

Reducing traffic accidents saves money. It is estimated that the average traffic accident (a weighted average of fatal, injury, and property damage costs) costs more than $7,000 in 1980 dollars (*23*). Updated to current dollars, the higher drinking age in Illinois saves more than $50 million a month.

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Improving Motorcycle Safety in Hawaii: Recommendations Based on a Survey of Motorcycle Owners and Operators

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A study on motorcycle safety was conducted for the Hawaii Department of Transportation by the Department of Urban and Regional Planning, University of Hawaii. The study is based on a telephone survey of 494 motorcycle owners and operators that was conducted in August 1989. Trends in motorcycle accidents are described, results from the attitudinal study are given, and several legislative, administrative, and programmatic recommendations for improving motorcycle safety in Hawaii are proposed, including restoring Hawaii's mandatory helmet law and requiring motorcycle safety education courses for all new riders. A disproportionately large share of those involved in fatal motorcycle accidents was found to be neither licensed nor insured. Some ways that licensing and registration systems might be enhanced to improve motorcycle safety in Hawaii are suggested.

After the problem of motorcycle accidents in Hawaii is described, trends in motorcycle crashes and motorcycle-related deaths are discussed. Then a survey of motorcycle owners and operators conducted by the Department of Urban and Regional Planning, University of Hawaii, is described. An examination of licensing and registration laws in Hawaii is also included. It is concluded that there are three types of actions that can be taken to improve motorcycle safety in Hawaii: legislative actions refer to the enactment of new laws such as mandating helmet use or motorcycle education; administrative actions involve improving or enhancing current regulatory actions already in place, such as improved licensing and enforcement of existing traffic safety laws; and programmatic actions refer to the creation and enhancement of a variety of programs on education, public information, and further study and analysis of motorcycle accidents in Hawaii.

MOTORCYCLE ACCIDENTS IN HAWAII

In 1988 there were 11,544 registered motorcycles in Hawaii and 21,940 licensed operators. Motorcycles made up approximately 5 percent of all registered motor vehicles and accounted for 2.2 percent of major traffic accidents (damage over $300). However, a disproportionately large share of all traffic fatalities, 11 percent, resulted from motorcycle accidents. This percentage has grown greatly since the mandatory helmet law was repealed in 1977. At that time, only 4 percent of all traffic fatalities resulted from motorcycle accidents.

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In Hawaii, motorcyclists face twice the risk of being involved in an accident than the average automobile driver. Data in 1981 showed 251 accidents per 10,000 automobiles and 502 accidents per 10,000 motorcycles. Although this ratio narrowed by 1987 to 295 accidents per 10,000 automobiles and 442 accidents per 10,000 motorcycles, the accident ratio for motorcyclists was still far greater than that for other motor-vehicle operators.

There is also reason to believe that the problem of motorcycle accidents in Hawaii is more serious than it is in other states. In 1987 there were an estimated 509 motorcycle accidents in Hawaii, resulting in 13 fatalities. This amounted to 442 accidents and 11.3 fatalities per 10,000 motorcycle registrations. These figures are both above the 1987 national averages of 305.5 and 8.65 (*1*).

As shown in Table 1, the current fatality rate per 10,000 motorcyclists is 2.5 times greater than the average fatality rate recorded during the 9 years that Hawaii had a mandatory helmet law. The repeal of the helmet law in Hawaii has meant an increase in the number of fatalities due to lack of helmet use. In the 4 years before repeal of the act in 1977, there was not one fatality from failure to use a helmet. In the years following repeal there has been a 900 percent increase in fatalities without helmets. Average annual fatalities among helmet users, on the other hand, increased only 16 percent. The 250 percent jump in fatality rates among the total motorcycle population has been largely due to lack of helmet use.

Historically, the majority of persons killed in motorcycle accidents have been young men. The 25-years-and-under age group accounted for only 6.8 percent of Hawaii's licensed motorcycle operators (median age 39 years) but 65.5 percent of all motorcycle fatalities. In addition, since repeal of the helmet law, the proportion of unlicensed operators killed in motorcycle accidents has increased greatly. The proportion of fatalities attributed to head injury also has increased, as has the proportion of those killed while under the influence of alcohol. These findings are summarized in Table 2.

The increase in unlicensed operators is troubling, for it means that there are many untrained and uninsured motorcyclists on the road. Approximately 16 percent of those killed in motorcycle accidents died within the first 11 months of having a motorcycle license (Table 3). Lack of training and inexperience are significant factors contributing to the overall motorcycle accident rate in Hawaii.

These observations about motorcycle accidents and fatalities suggest a number of problems. The first problem relates to the effects of repealing the helmet law. Helmets are de-

TABLE 1 MOTORCYCLE STATISTICAL SUMMARY FOR HAWAII

Year	Motorcycle Registration	Number of Accidents	Accident Rate*	Number of Fatalities	Fatality Rate*	Accident/ Fatality Ratio
1962	4,173	213	510	10	24.0	21.3
1963	5,590	313	560	5	8.9	62.6
1964	7,270	428	589	9	12.4	47.6
1965	9.827	512	521	13	13.2	39.4
1966	12,016	643	535	20	16.6	32.2
1967	10,558	575	544	8	7.6	71.9
1968[a]	9,646	543	563	8	8.3	67.9
1969	8,579	346	403	5	5.8	69.2
1970	10,834	429	396	6	5.5	71.5
1971	10,033	427	426	6	6.0	71.2
1972	10,321	446	432	4	3.9	111.5
1973	10,343	417	403	3	2.9	139.0
1974	10,447	386[b]	369	4	3.8	96.5
1975	8,373[c]	396	473	9	10.7	44.0
1976	9,134	444	486	6	6.6	74.0
1977[d]	9,408	518	551	11	11.7	47.1
1978[e]	9,771	619	634	23	23.5	26.9
1979	9,986	599	600	20	20.0	30.0
1980	9,696	562	580	10	10.3	56.2
1981	10,700	537	502	15	14.0	35.8
1982	11,317	508	449	13	11.5	39.1
1983	8,563	481	562	19	22.2	25.3
1984	10,199	409	401	15	14.7	27.3
1985	10,607	412	388	10	9.4	41.3
1986	11,055	463	419	12	10.9	38.4
1987	11,515	509	442	13	11.3	39.1
1988	11,544	702[f]	608[f]	18	15.6	39.0[f]

* Rate per 10,000 motorcycles

[a] 1968, the year mandatory helmet use was implemented

[b] 1974, the year reportable accident damage was increased from $100 to $300

[c] 1975, the first year under no-fault insurance

[d] 1977, motorcycle helmet use law repeal effective June 8, 1977

[e] 1978, the first complete year after motorcycle helmet use repeal

[f] Accident estimates assuming 1 fatality per 39 accidents

signed to protect the motorcyclist from injury and death; increased nonuse has meant increased injury and death. A second problem relates to issues of licensing, training, enforcement, and operator skill. There are many factors associated with motorcycle safety. A mandatory helmet law is only part of the picture. The data on motorcycle deaths show that younger, more inexperienced, and unlicensed operators account for a disproportionately larger share of accidents and fatalities. A third type of problem relates to the disproportionate costs associated with the higher fatality and injury rates likely to result from operating a motorcycle.

UNIVERSITY OF HAWAII STUDY

The major data source for the University of Hawaii study was a telephone survey of motorcycle owners and operators conducted in 1989 between August 14 and September 14. Participants were drawn from two data files: motor vehicle registrations and operator licenses (supplied by the state of Hawaii and city and county of Honolulu). A combined data set listing those registered owners with active operator licenses was also constructed. The purpose of the study was to address the following areas: (a) questions about motorcycle registration,

TABLE 2 CHARACTERISTICS OF FATAL MOTORCYCLE ACCIDENTS IN HAWAII (5)

Variable Category	Before Repeal (1973-1976)	After Repeal (1977-1988)	Total (1973-1988)
Male	100%	95.9%	96.0%
Age	21.5 years	23 years	23 years
Licensed	72.7%	48.5%	51.0%
Owners	45.5%	62.1%	61.4%
Helmet Used	100%	37.4%	42.6%
Speeding	53.8%	42.6%	40.6%
Drunk	31.8%	39.6%	38.0%
Head Injury	50.0%	56.2%	54.0%

TABLE 3 LICENSING OF PERSONS KILLED IN MOTORCYCLE ACCIDENTS IN HAWAII, 1973–1988

Number	Time with License	%
92	no license	45.5
33	less than one year	16.3
70	over one year	34.7
7	unknown	3.5

licensing, and use; (b) questions about attitudes toward helmet use and helmet laws; and (c) questions about improving motorcycle safety in Hawaii.

Several methodological issues were identified. The first was the large number of military personnel in Hawaii who must follow helmet use regulations. The rules that the military has adopted are stricter than the voluntary helmet use laws for the state of Hawaii. Therefore, active duty military personnel were excluded to prevent a possible bias of the results in favor of helmet use.

A second problem arose during the attempt to match registered owners with those having active operator licenses. Given the different data entry procedures and systems used by the separate agencies handling licensing and registration, it was impossible to compile a complete computerized list of the registered owners who have operator licenses. Such a compilation would have required that names and addresses be exact matches or that there be some identification field or code, such as Social Security number, common to both files. This was not the case.

An inherent problem in this survey was that it was limited to those listed in a telephone directory. Names were verified directly by matching addresses or at least by matching the last names. Under this procedure, owners and operators who live with people who have the same last name and are listed in a telephone directory were also included. Because there was no means of tracking those whose last names and addresses are not listed in telephone directories, a possible bias of this survey was that it reached an older, more stable population. The more transient, usually younger, groups perhaps were not sampled adequately. However, when compared with other methods of sampling, such as direct observation or personal interviews, the telephone survey was the only cost-effective method that could guarantee an adequate sample size in an unbiased, geographically proportional manner.

Characteristics of Respondents

There were 494 respondents who completed the survey. The composition of the main sample by sex is 94.1 percent (n = 465) men, 5.9 percent (n = 29) women. The age of the respondents ranged from 15 to 72, with the mean, median, and mode being 38 years (n = 28) (on the basis of the city and county of Honolulu's motorcycle license tape, the average motorcycle operator in Hawaii is 40 years old, and the median and mode ages are 39 years).

The ethnic makeup of respondents includes Caucasian (51.8 percent), Japanese (19.0 percent), Hawaiian (9.9 percent), Chinese (7.7 percent), and Filipino (5.5 percent). No other group makes up more than 2 percent.

A large proportion of the respondents are professionals (28.5 percent). Blue-collar workers constitute only 27.3 percent of the sample, which compares with 43.3 percent nationally. Approximately 24 percent of the sample reported yearly earnings between $35,000 and $50,000 ($n$ = 118). The mean income is $31,811 a year, and the median $28,128 a year. The income mode is $36,000 a year ($n$ = 40).

Motorcycle Ownership, Registration, and Use

Excluding military personnel living either on bases or with ship addresses, there are 8,514 registered motorcycle owners and 13,595 licensed operators on Oahu. Of those, only 2,970 were matched through the original data tapes as having both licenses and registrations. This means that only 34.9 percent of Oahu's registered motorcycle owners have licenses, although 90.3 percent of those from the registration list reported on the survey that they have active motorcycle licenses. Of licensed drivers, only 21.8 percent of those on the license data tape were traced as having a registered motorcycle, although 56 percent of those contacted from the same list reported having a registered motorcycle. All subgroups reported high compliance with Hawaii's mandatory insurance law; it is 85.8

percent among registered licensees, 87.5 percent among licensed operators, and 88.1 percent among registered owners.

Honda is the most popular motorcycle (35.8 percent), as it is nationally (50.8 percent), followed by Kawasaki (18.8 percent), Yamaha (15 percent), Harley-Davidson (14.8 percent), and Suzuki (8.5 percent). BMW, Triumph, and other makes account for 5.4 percent of the market.

Most respondents reported having motorcycles with large engine displacements: 34.2 percent have motorcycles with between 450 and 749 cc, and 31.8 percent have motorcycles with more than 750 cc. This is the opposite of the Motorcycle Industry Council data (*1*), which shows that most of the nation's motorcycles (57 percent) have engine displacements smaller than 350 cc.

The data collected show that the major purpose for motorcycle use is commuting to work and school (42.9 percent), which is followed by recreational use (40.5 percent). The average number of miles traveled in a week is 92.25. The mean is 70 mi and the mode, 100 mi (n = 86).

Of the main sample, 87.2 percent (n = 431) reported having motorcycle insurance. Reasons for not having insurance included expense (32.8 percent), lack of necessity (18.8 percent), lack of motorcycle ownership (10.9 percent), and difficulty of obtaining it (7.8 percent). Of those with insurance, 72.9 percent said that they have it because of the law (n = 304), and 27.1 percent said that they have it to protect themselves against liability. Average insurance costs per year were reported as $442.06; median payments are $363, and the mode is $300 ($n$ = 55).

Attitudes Toward Helmet Use and Helmet Laws

When asked about use of helmets, 60.1 percent reported wearing their helmet all the time (n = 297), 13.4 percent stated that they never wear a helmet (n = 66), and 26.5 percent said that they wear it some of the time (n = 131). Of the third group, the average percentage of time that helmets are worn is 54, and the median and mode (n = 29) are 50 percent.

Subjects were asked to give reasons they do or do not wear a helmet. Table 4 shows reasons helmets are worn, and Table 5 shows reasons they are not. Of those who wear helmets, 74.7 percent said that the reason is safety. An additional 9 percent think that they run a higher risk without one, and 6.9 percent stated that the helmet protects them against the elements.

TABLE 4 REASONS GIVEN FOR WEARING A MOTORCYCLE HELMET

Reasons	n	%
Safety Aspects	316	74.7
Higher Risk Without	38	9.0
Protection from Elements	29	6.9
Required to Use	24	5.7
Other Reasons	16	3.8
Total	423	100.0

TABLE 5 REASONS GIVEN FOR NOT WEARING A MOTORCYCLE HELMET

Reason	N	%
Uncomfortable	91	28.4
Impairs Visibility	55	17.2
Inconvenient	50	15.6
Impairs Hearing	32	10.0
Little Risk of Accident	31	9.7
Reduces Pleasure	29	9.1
Helmet is Ineffective	13	4.1
Personal Freedom	12	3.8
Other	7	2.2
Total	320	100.0

Of those reporting that they never or only sometimes wear a helmet, 28.4 percent said that helmets are uncomfortable, 17.2 percent think helmets impair visibility, 15.6 percent called them inconvenient, 10 percent reported that helmets impair hearing, 9.7 percent perceived that there is little chance for an accident, and 9.1 percent said that the helmet reduces the pleasure of riding. Of the remaining responses, 4.1 percent cited the helmet's ineffectiveness and 3.8 percent stressed the need for personal freedom.

In this sample, 60.7 percent reported carrying passengers (n = 300), and 39.1 percent said that they do not. Of those carrying passengers, 226 reported that their passengers wear helmets (77.7 percent).

When asked specifically if Hawaii should require all motorcycle riders to wear a helmet, 45.7 percent answered yes (n = 226), and 53.8 percent responded no (n = 266). On the other hand, when asked if they would support a helmet law if it would lower the costs of motorcycle insurance, 68.8 percent responded yes (n = 340) and 31 percent said no (n = 153). As to what they think can be done to increase helmet use in Hawaii, 44.2 percent said that reduced insurance premiums or other monetary incentives would help, and 43.1 percent said that increased public education about the benefits of helmet use would suffice.

To more closely examine the relationships between the variables, a number of cross tabulations were run comparing frequency of self-reported helmet use and various attitudinal and self-reported behaviors. Chi-square statistics were calculated, and only those results significant at the $p < .05$ level (or below) have been reported.

Attitudes of the subjects about whether Hawaii should have a mandatory helmet law were significantly related to the level of helmet use. Those who reported wearing helmets all the time are more in favor of a helmet law and reduced insurance premiums for helmet users; those who do not wear helmets disagree with both. Helmet use is also significantly related to compliance with the state's insurance requirements.

The frequency of helmet use is considerably higher among subjects who operate Japanese motorcycles (Kawasaki, Honda, Yamaha, and Suzuki) than those who operate Harley-Davidson, BMW, or Triump motorcycles. Engine displacement also has a significant, although less marked, impact on the frequency of helmet use. Subjects reporting larger engines are somewhat more likely to report a lower frequency of helmet use than those operating small to mid-size motorcycles.

Those who took a motorcycle safety course are also more likely to be helmet users than those who did not receive formal training. Safety helmet use was also significantly related to the sex of the respondent. Women are more likely to wear helmets consistently than men are.

Helmet use is significantly related to the geographic area of residence of Oahu. Use is higher in the urban areas of Honolulu and Ewa, but decreases in the more rural North Shore and Waialua areas of the island.

To check the attitudes of the subjects toward risk-taking behaviors, a series of questions was asked about whether drivers engage in hazardous behaviors. Helmet use is significantly related to five of these questions. Operators who reported actions such as accelerating the motorcycle suddenly, cutting in and out of traffic, driving after consuming three alcoholic beverages, having more than five drinks a week, and riding on the median strip are also more likely not to wear helmets. This corroborates earlier studies by Allegrante (*2*) and Hemmerling (*3*), which explained helmet use as a function of attitude and behavior. This finding must also be seen in light of Goeller's work (*4*) in explaining accidents in terms of vulnerabilities. Increasing vulnerabilities and exposure increases the chances that an accident will occur.

One risk-taking behavior—speeding—is not related to helmet use. An explanation is that few people recognize speeding as risky behavior, and the practice is widespread among motorcyclists. Racing was not found to be significantly related to helmet use because neither subgroup admitted doing it.

Attitudes Toward Increasing Motorcycle Safety in Hawaii

In response to a question about the likelihood of being injured in a motorcycle accident, 44.5 percent think it is unlikely, and only 25.9 percent think it is likely or extremely likely. This variable is also significantly related to the respondents' self-assessment of their driving habits: cautious drivers believe their chances of an accident are not likely, but thrillseekers admit that they feel a slightly higher chance that an accident is likely. The most likely accident thought to occur to motorcycle drivers (81.4 percent) is that of being struck by another vehicle. Subjects think that the most common cause of accidents is another person's not seeing them (38.7 percent). Recklessness of the motorcycle operator was the second most stated reason for accidents (35.2 percent). But examination of the Fatal Accident Reporting System (FARS) statistics (*5*) from the Hawaii Motor Vehicle Safety Office shows that the motorcycle operator is responsible for 77 percent of motorcycle fatality accidents. The major cause is speeding or carelessness by the motorcycle operator (54.4 percent).

When asked what can be done to improve motorcycle safety and education in particular, 36 percent said that the state should require a safety education course before licensing (n = 178), and 32.2 percent (n = 159) said that greater public awareness through publicity campaigns is all that is necessary.

Problems in Enforcement of Licensing and Registration Laws

In addition to the telephone survey, an analysis of motorcycle licensing and registration laws was conducted. FARS data (*5*) show that in the 4 years before the mandatory helmet law repeal in 1977, 100 percent of motorcycle fatalities were wearing helmets and 72.7 percent had valid motorcycle licenses. In the last 3 years these numbers have reversed: only 26.8 percent of fatalities were wearing helmets and 29.3 percent had licenses. Further data show that the major causes of accidents have been speeding and losing control of the motorcycle. Both causes of accidents are typical of inexperienced drivers and add credence to studies that link a lack of license to inexperience, and inexperience to increased accident rates (*6–8*).

The problem of unlicensed operators is a matter of law enforcement. Motorcycle riders without licenses are not easy to detect or stop without cause. Currently, under Hawaii Revised Statutes (H.R.S.) 286.132, the penalty for driving without a license is not less than $250 and not more than $1,000, or not more than 1 year in prison.

Under H.R.S. §431:10C-501, no motorcycle is to be driven on any public roadway at any time unless the motorcycle is insured. To obtain insurance, one must have a valid motorcycle license or a valid motorcycle learner's permit and a certificate of successful completion from an approved motorcycle education course (§431:10C-504). Upon obtaining insurance, one is given a liability insurance card that has the name, make, year, and factory number of the motorcycle; policy number; name of the insurer; name of the insured; and the effective dates of the coverage. Under §431:10C-502, this card is to be carried on the person operating the insured motorcycle at all times. To prove that a motorcycle is properly insured, the insured must present this card at the annual safety inspection check, under H.R.S. 286-26. If this insurance card is not displayed, the safety sticker will not be affixed to the vehicle and the certificate of inspection will not be issued. This certificate of inspection is a requirement for registration. The penalty for noncompliance is a fine of not more than $1,000, 30 days' imprisonment, or a 1-year driver's license suspension, or any combination thereof.

Under the current H.R.S. provisions, the procedure exists to give police officers sufficient reason for stopping motorcyclists suspected of driving without licenses and insurance. This just cause is the lack of a current safety sticker on the motorcycle license plate. A related issue would be those without insurance who somehow receive a certificate of inspection. Again, this is an issue of enforcement, for certainly under the H.R.S. provisions it is illegal to approve a safety check without insurance.

A general lack of enforcement throughout the entire system toward motorcycles, the lack of effective punitive measures, and the lack of prosecution for offenses (on the part of operators and inspectors) may have contributed to the increase in unlicensed and uninsured operators.

RECOMMENDATIONS

Three types of recommendations come from this study: legislative, administrative, and programmatic.

Legislative

The major legislative recommendations involve restoring the mandatory helmet law and mandating motorcycle safety education courses for new riders.

According to the telephone survey results, 60.1 percent of the motorcyclists on Oahu always wear their helmets. At the same time, there is more opposition to than support for mandatory helmet laws. Among owners and operators, 53.7 percent oppose a mandatory helmet law, and 45.7 percent support such a law. However, support for the law increases to 68.8 percent if, as a result of the law, motorcycle insurance premiums are reduced. The study found that fatality rates have increased by more than 2.5 times since repeal of the helmet law. These findings suggest that although enactment of a mandatory helmet law may encounter opposition, there might be added support if the helmet law were linked to reduced motorcycle insurance premiums.

According to the survey, opposition to the helmet law is most likely to come from nonusers of helmets and owners and operators of larger motorcycles. Another possible area for legislative action involves mandatory motorcycle education for new riders. In reviewing the fatality data, it was determined that a disproportionately large share of the fatal accidents involved inexperienced, younger operators. Finally, this study has determined that there has been a significant increase in the proportion of unlicensed operators killed in motorcycle crashes. Approximately 45.5 percent of all fatalities involved those without motorcycle licenses.

The fact that younger, inexperienced operators have a higher chance of being killed or injured in a motorcycle accident points to the need for mandatory education for new riders. Operating a motorcycle is, by nature, a complex and dangerous activity requiring an adequate skill level, so there may be cause for legislation requiring that younger, inexperienced riders receive more training and education.

When owners and operators were asked what could be done to increase motorcycle safety in Hawaii, the most popular answer (36 percent of all respondents) was to require education courses. Although most owners and operators think that the most common cause of a motorcycle accident is that of being struck by another vehicle, data show that the motorcycle operator is usually at fault. Mandating motorcycle education courses would be effective if in fact the skill levels were to increase. Education courses are required for motorcycle insurance, and they should be required for licensing, building the licensing procedures into the course.

Administrative

There are two types of administrative actions that could contribute to improved motorcycle safety in Hawaii. The first pertains to licensing and registration procedures and laws already on the books, and the second relates to data and information management.

Enforcement of motorcycle safety laws in Hawaii is weak. Laws require that operators be licensed and insured, but there is substantial evidence that these laws are routinely broken. First, there is a large and growing number of fatalities involving unlicensed and uninsured riders. Second, about 10 percent of those with registered motorcycles admit that they do not have a license. Approximately 88 percent of the registered owners reported having motorcycle insurance. These self-reported estimates may actually overstate the true amount of licensing and insurance.

Police departments need to step up enforcement of a variety of motorcycle and traffic safety laws. The survey found that motorcyclists admit to a variety of risky and illegal driving actions including speeding, driving under the influence, and cutting in and out of traffic. Although unlicensed operators are difficult to detect, stopping operators of motorcycles without current safety stickers may be a way to identify uninsured or possibly unlicensed operators.

Much has also been said about Honolulu's motorcycle licensing procedures, mainly centering on the administration of the test and the general perceived unfairness of the instructors. Critics have cited these concerns as reasons for Hawaii's high number of accidents involving unlicensed drivers. However, this low license rate is a national trend and can be viewed as an attitudinal shift related to the overall risks of enforcement and penalties.

Yet Hawaii still has much room for improvement in its motorcycle licensing procedures. One alternative is the complete adoption of the Motorcycle Operating Licensing Plan developed by the Motorcycle Safety Foundation and NHTSA. A major component of this plan is the Motorcycle Operators Manual, a 35-page manual providing applicants with information ranging from basic preriding cycle inspection and protective gear to how to deal with dangerous road surfaces and how to handle on-street emergency situations. Also included are licensing and safety requirements specific to each state. In comparison, Hawaii currently offers only six pages on motorcycle information in the Hawaii Drivers Manual (*9*). Only four of those six pages cover basic rules for operating a motorcycle. Forty-nine sample test questions are included in the manual 70 pages behind the section on motorcycles, and 15 pages in the front of the manual describe the current skills test. Also lacking is mention of the mandatory insurance requirements or the availability and advantages of the Motorcycle Safety Course.

Although already listed under programmatic recommendations, it is again necessary to recommend administratively that licensing procedures be incorporated into the Motorcycle Safety Foundation's education course as much as possible. This action can be seen as streamlining the current system and providing the necessary checks on both skill levels and insurance requirements in a more timely and convenient manner to persons either taking or administering the tests.

The second administrative recommendation involves improving the data management system with which to check and cross-check consistency in terms of licensing, ownership, and insurance. This would be facilitated by the addition of a unique field—such as a Social Security number—that appears on the ownership record and the operator's license record. This would enable a more accurate matching of owners and operators. Computerized matching could also be used to confirm that registered motorcycles are also insured.

Programmatic

Three types of programmatic recommendations emerge: (a) the state would improve and expand the Motorcycle Safety Foundation educational program currently administered through the University of Hawaii, (b) the state should promote motorcycle safety awareness and initiate a public information campaign to increase awareness of penalties for violating motorcycle licensing, registration, and insurance laws and (c) the state should fund further research and evaluation of motorcycle safety issues in Hawaii.

The results of this survey and others show that motorcycle crashes are related to risk-taking behaviors. Existing motorcycle education programs should be improved and expanded as a means of improving the operating skills and performance of motorcyclists. The education courses should be targeted toward younger, inexperienced operators. More research would be useful in terms of analyzing the types of behavioral patterns that younger, inexperienced operators are likely to exhibit. Motorcyle education courses may need to address both operating skills and risk-taking behaviors among operators.

The expansion of motorcycle education programs in Hawaii is seen to have short- and long-term effects. In the short term, a mandatory education program would send a strong message to new and experienced riders that safety is important. In the long run, such a course could help change some of the dangerous practices among motorcycle operators.

Certainly, major new initiatives or programs must be planned and coordinated with the participation of Hawaii's motorcyclists. A general motorcycle safety awareness campaign might also help in the development of effective programs and partnerships among government traffic safety officials, the motorcycle industry, and motorcyclists. Such a partnership is likely to have lasting effects in education, public awareness, and improvements in motorcycle safety laws and programs.

Finally, additional research on the causes of motorcycle accidents and strategies for prevention may be useful. In addition to correlation with other risk-taking behaviors, some further research might also examine concerns such as speeding, alcohol or drug involvement, and the effects of growing traffic congestion and urbanization on motorcycle crashes. Effects to improve the collection of accident and injury and fatality data go hand in hand with the proposed new topics of research. The call for a broadened research agenda implies more than the expenditure of more resources into basic data collection. The motorcylist population is not nearly so large as the automobile-driving population, but the increased risk and severity of injuries associated with motorcycle accidents suggest that additional, detailed studies of causes and remedies are warranted.

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Pedestrian Accidents in Utah

ERIC YUAN-CHIN CHENG

The objectives are to investigate the trend of Utah's pedestrian accident rate and to analyze and discuss some of the factors involved in Utah's pedestrian accidents. The results show that Utah's accident rate for fatally injured pedestrians decreased in 1980 but held fairly constant after that with minor fluctuations. It appears that Utah's accident rate for nonfatally injured pedestrians increased steadily over the same 9-year period with the exception of 1985. The analysis also indicates the following (a) age 5–10 is the major grouping involved in Utah's pedestrian accidents; (b) most pedestrian accidents occurred in daylight and in the peak from 3:00 p.m. to 7:00 p.m.; (c) the majority of pedestrian accidents are caused by pedestrian error; (d) pedestrian accidents tend to be more serious—about 4 percent are fatal; (e) more pedestrian accidents occurred between intersections than at intersections; (f) men and boys are involved in more than twice as many pedestrian accidents as are women and girls; (g) adverse road, weather, and light conditions are not a factor in most pedestrian accidents; and (h) traffic-control devices do not guarantee a safety zone for pedestrians. The analysis for school-age pedestrian accidents reveals similar findings. Because most pedestrian accidents are caused by pedestrian error, more emphasis must be placed on modifying the training and behavior of pedestrians in crossing techniques, particularly for school-age pedestrians.

According to national accident reports (*1*), nearly 45,000 Americans die each year in traffic-related accidents. Approximately 16 percent of these victims are pedestrians. It is widely accepted that pedestrian-involved accidents tend to be more severe than vehicle-with-vehicle accidents because of the lack of protection for pedestrians. For years, traffic engineers and researchers have made a great effort to identify and analyze pedestrian accidents and recommend countermeasures. The efforts have been successful in the United States as shown by the declining trend in accident rates of both the fatally and nonfatally injured pedestrians (Figures 1 and 2).

The accident rate is a better indicator of trends than simple numbers in analyzing accidents because it takes into account exposure to traffic. The relatively small percentage of pedestrian accidents at a location, particularly at an intersection, makes it difficult to predict potential accident locations using historical accident data. Normally, improvements at pedestrian crossings are based on the amount of traffic and the number of pedestrians. Accident history is usually used to justify additional improvements, particularly when accidents result in public outcry. It is the safety engineer's responsibility to analyze available data at pedestrian-crossing locations and to make recommendations. The objectives of this study are to investigate the trend of Utah's pedestrian accident rate for the period 1979–1987 and to analyze and discuss some of the factors involved in Utah's pedestrian accidents. School-age pedestrian accident statistics are also reviewed and discussed.

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TREND OF UTAH'S PEDESTRIAN ACCIDENT RATES

The accident data used come from FHWA and cover 1979 through 1987 (*1*). Review of Utah's accident rates for fatally injured and nonfatally injured pedestrians (Table 1) indicates that the rate for fatally injured pedestrians decreased in 1980 but held fairly constant after that with minor fluctuations. It appears that Utah's accident rate for nonfatally injured pedestrians increased steadily over the same 9-year period with the exception of 1985.

Regression analysis was used to formulate a relationship between vehicle-miles and the number of fatally and nonfatally injured pedestrians in Utah. The result reveals very little relation between vehicle-miles and the number of fatally injured pedestrians. However, the R^2-value of .68 indicates that the number of nonfatally injured pedestrians is moderately dependent on the number of vehicle-miles. If fatally injured and nonfatally injured pedestrians are combined as a dependent variable, the R^2-value of .66 indicates that the total number of fatally injured and nonfatally injured pedestrians has a moderate relationship with the vehicle-miles. Because the regression equation is valid only in the range of the data set used to construct the relationship, use of increasing vehicle-miles jeopardizes predictions made with this relationship.

PEDESTRIAN ACCIDENTS IN UTAH

The Traffic and Safety Division of the Utah Department of Transportation is maintaining a centralized accident records system. The following accident statistics and review are based on the pedestrian accidents that occurred during the period from 1984 through 1988. This paper's purpose is to identify factors involved in Utah's pedestrian accidents.

Figure 3 shows that Age 5–10 is the major grouping involved in Utah's pedestrian accidents, accounting for approximately 28 percent of the total. Figure 4 indicates a peak from 3:00 p.m. to 7:00 p.m., which may be the result of the conflict between the school-age and adult pedestrians and the increased exposure to peak-hour traffic.

Figures 5–14 show statistics of the 5-year average for some factors involved in Utah's pedestrian accidents. The following findings can be obtained from these figures:

1. Most pedestrian accidents occurred in daylight conditions (Figure 5).
2. Only 30 and 18 percent of drivers were cited for violation in pedestrian-related accidents at intersections and between intersections, respectively (Figures 6 and 7).

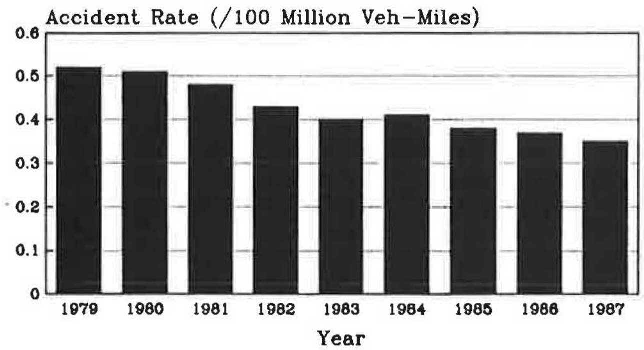

FIGURE 1 Fatal pedestrian accident rate in United States.

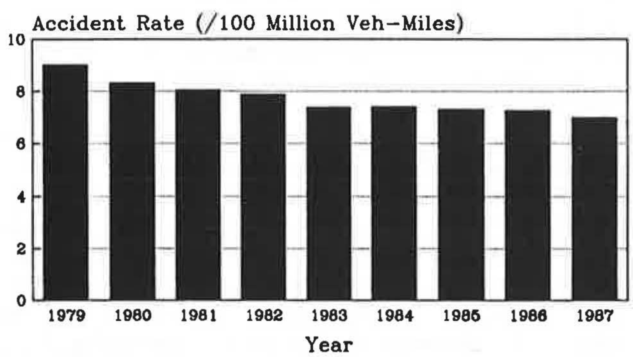

FIGURE 2 Nonfatal pedestrian accident rate in United States.

TABLE 1 PEDESTRIAN ACCIDENT RATES IN UTAH

Year	Fatally Inj	Non-fatally Inj
1979	0.81	11.60
1980	0.52	10.21
1981	0.49	11.61
1982	0.40	12.45
1983	0.54	12.39
1984	0.45	12.30
1985	0.46	10.63
1986	0.38	13.22
1987	0.50	13.78
Average	0.51	12.07

NOTE: Rate is Acc/100 Million Veh-Miles

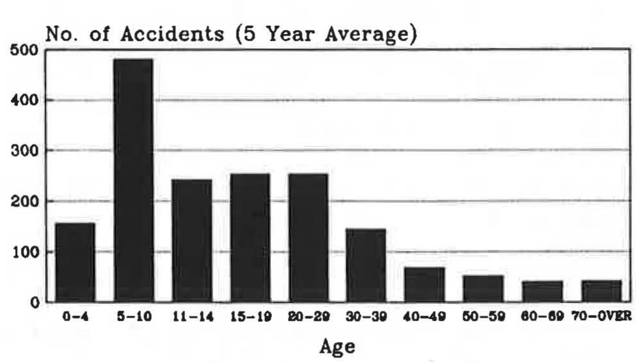

FIGURE 3 Pedestrian accidents by age group.

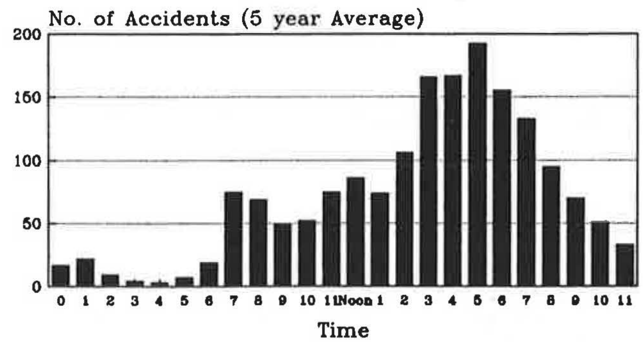

FIGURE 4 Pedestrian accidents by time of day.

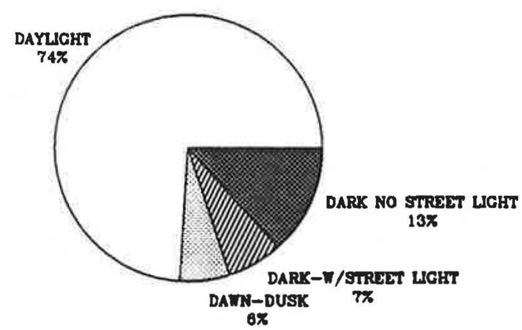

FIGURE 5 Pedestrian accidents by daylight conditions (5-year average).

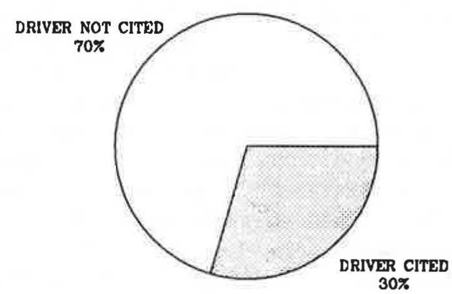

FIGURE 6 Pedestrian accidents by driver violation at intersections (5-year average).

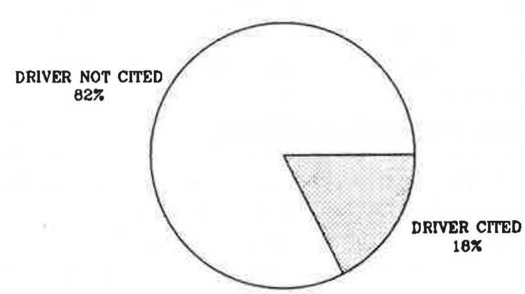

FIGURE 7 Pedestrian accidents by driver violation between intersections (5-year average).

3. Pedestrian accidents tend to be more serious—about 4 percent of them are fatal (Figure 8).
4. Traffic-control devices, such as traffic signals and signing, do not guarantee a safety zone for pedestrians (Figure 9).
5. Seventy-eight percent of the pedestrian accidents occurred between intersections without traffic-control devices (Figure 10).
6. Men and boys are involved in more than twice as many pedestrian accidents as are women and girls (Figure 11).
7. Adverse road, weather, and light conditions are not a factor in most pedestrian accidents (Figures 12–14).

The study also found that about 23 percent of the pedestrians killed had been drinking (*2*). However, fatalities linked

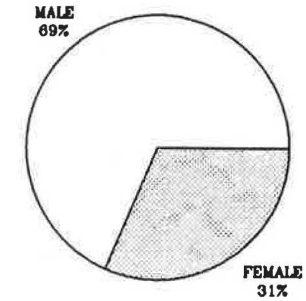

FIGURE 11 Pedestrian accidents by sex (5-year average).

FIGURE 8 Pedestrian accidents by severity (5-year average).

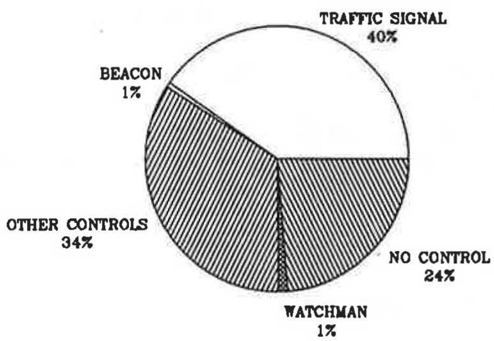

FIGURE 9 Pedestrian accidents by traffic-control devices at intersections (5-year average).

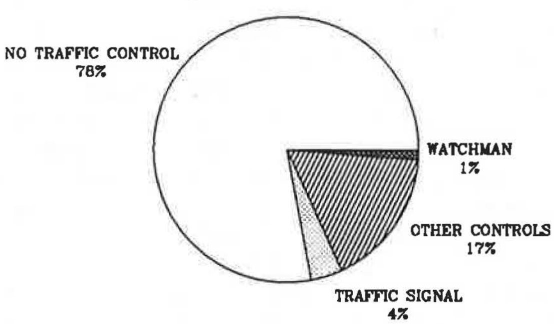

FIGURE 10 Pedestrian accidents by traffic-control devices between intersections (5-year average).

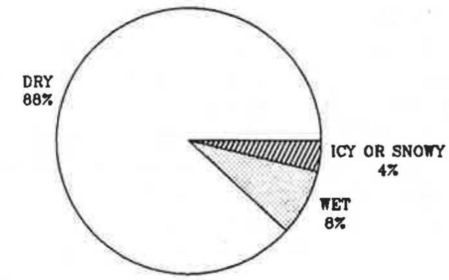

FIGURE 12 Pedestrians accidents by road surface conditions (5-year average).

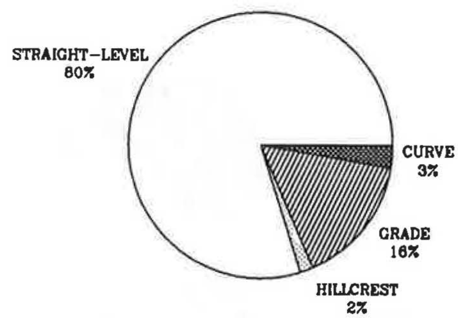

FIGURE 13 Pedestrian accidents by roadway alignment (5-year average).

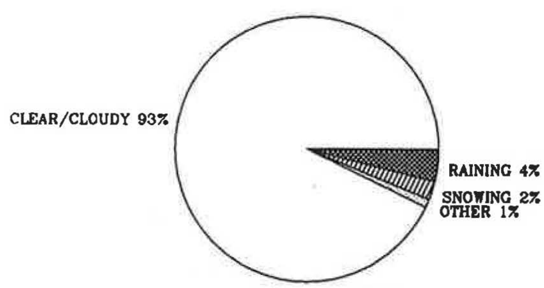

FIGURE 14 Pedestrian accidents by weather conditions (5-year average).

to drinking decreased steadily from 36 percent in 1984 to 7 percent in 1988. About 7 percent of the pedestrians were killed in crosswalks.

SCHOOL-AGE PEDESTRIAN ACCIDENTS IN UTAH

School-age pedestrian accidents have long been a major concern of traffic safety engineers. The following statistics are also based on data from 1984 through 1988. School age as used herein is defined as 5 to 18 years old.

The review of the school-age pedestrian accident data revealed pertinent information and several conclusions.

1. The age group 5–10 is involved in most school-age pedestrian accidents (about 52 percent). The percentage of involvement decreases as the age range increases (Figure 15).
2. Male children are involved in more than twice as many pedestrian accidents as female children (Figure 16). This mirrors the information in Figure 11.
3. Only 20 and 13 percent of drivers were cited in school-age pedestrian accidents at intersections and between intersections, respectively (Figures 17 and 18).
4. More accidents occurred between intersections than occurred at intersections. Traffic signals do not prevent school-age pedestrian accidents at intersections. Traffic-control devices cannot be placed at all locations between intersections where pedestrians cross or interact with traffic (Figures 19 and 20).
5. School-age pedestrians suffer 75 percent serious injury (Figure 21).
6. Adverse road, weather, and light conditions, again, are not major contributors to child pedestrian accidents (Figure 22–25).

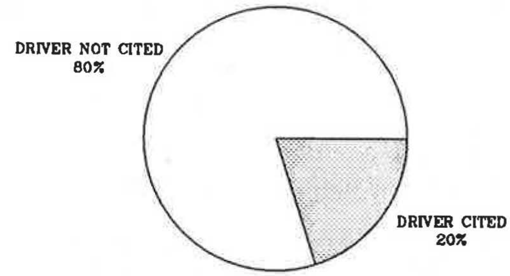

FIGURE 17 School-age pedestrian accidents by driver violation at intersections (5-year average).

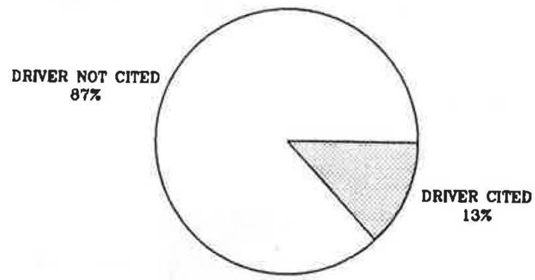

FIGURE 18 School-age pedestrian accidents by driver violation between intersections (5-year average).

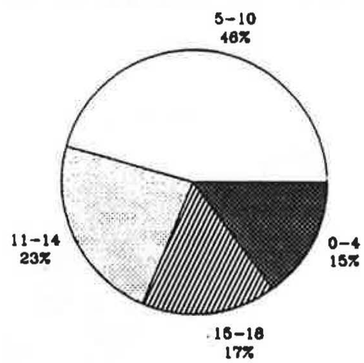

FIGURE 15 School-age pedestrian accidents by age group (5-year average).

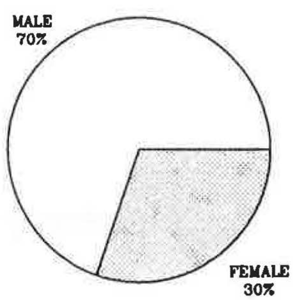

FIGURE 16 School-age pedestrian accidents by sex (5-year average).

DISCUSSION OF RESULTS

Most previous studies, nationwide and worldwide, have concluded that the majority of the pedestrian accidents are caused by pedestrian error. Utah's statistics confirm this finding. Because school-age children make up the majority of victims in pedestrian accidents, more emphasis must be placed on teaching school-age pedestrians correct crossing techniques. Parents and teachers may be the best sources of such instruction. However, a long-range continuing safety program that involves all pedestrian age groups is necessary. A national pedestrian safety program called Walk Alert, initiated in 1986, has been implemented in at least 10 states. Many agencies from different government levels and community organizations are involved in this program (*3*).

Pedestrian safety is a major field of traffic safety. It can be greatly improved by the cooperation of pedestrians, traffic engineers, enforcement officers, drivers, parents, educators,

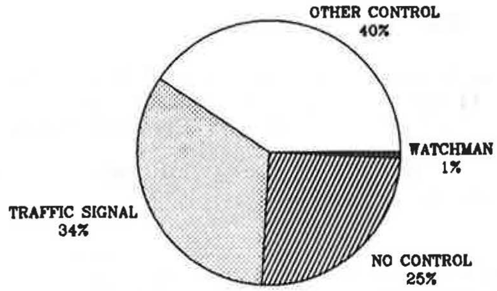

FIGURE 19 School-age pedestrian accidents by traffic-control devices at intersections (5-year average).

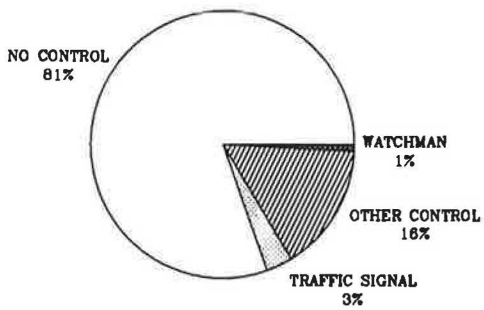

FIGURE 20 School-age pedestrian accidents by traffic-control devices between intersections (5-year average).

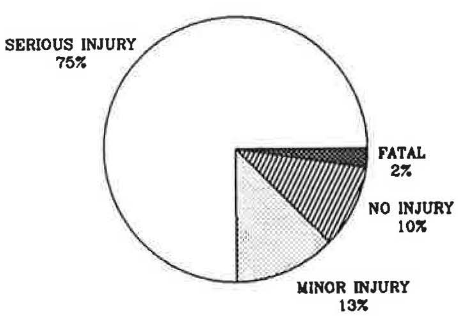

FIGURE 21 School-age pedestrian accidents by severity (5-year average).

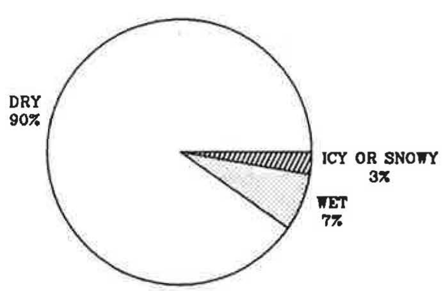

FIGURE 22 School-age pedestrian accidents by road surface conditions (5-year average).

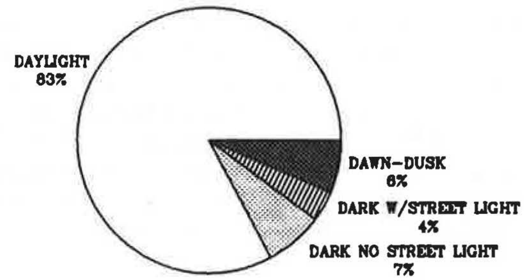

FIGURE 23 School-age pedestrian accidents by daylight conditions (5-year average).

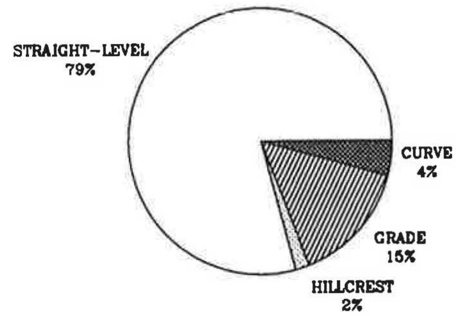

FIGURE 24 School-age pedestrian accidents by roadway alignment (5-year average).

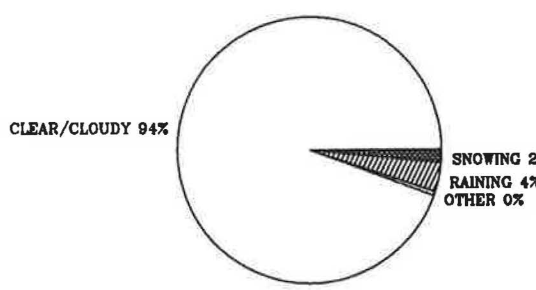

FIGURE 25 School-age pedestrian accidents by weather conditions (5-year average).

and so on through an effective program. Traffic engineers should use safety studies and design to provide a safe walking environment for pedestrians. Some essential improvements should be considered, such as lighting systems, sidewalks, overpasses, pedestrian signals, warning devices, and original geometric design. However, improvements in geometrics are meaningless unless the pedestrian's behavior is safety-oriented, particularly for school-age children.

Utah Department of Transportation (UDOT) has recently standardized the signing and regulation for school crossing zones. It is one of UDOT's efforts in improving safety for school-age pedestrians. New rules set differing distances for signing in advance of school zones, depending on the posted speed of the highway at that point. It also requires that a crossing guard, who should carry stop paddles instead of flags, be employed with the flashing yellow sign. Statewide standard signing and regulation for school crossing zones will give drivers uniform expectations and allow them to take appropriate action as they approach school zones. Hence, a reduction in school-age pedestrian accidents can be expected.

ACKNOWLEDGMENT

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The contents of this paper reflect the views of the author, who is responsible for the conclusion and accuracy of the data presented. The contents do not necessarily reflect the official views and opinions of the Utah Department of Transportation.

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Trends in Downtown Pedestrian Traffic and Methods of Estimating Daily Volumes

Siim Soot

This study examines the pedestrian traffic changes in the Chicago central business district from 1981 to 1989, dates of two major pedestrian traffic surveys. Each interviewed more than 1,400 and counted more than 3 million pedestrians. Pedestrian flows have changed with land use changes and the growing importance of the two major train stations on the west side of downtown. Office space has increased and retailing has moved north. Some areas have experienced declining pedestrian traffic as pedestrian traffic generation rates of downtown office space declined. Some basic characteristics of pedestrians and their traffic patterns have not changed. The stability in the daily pattern of pedestrian traffic, even when volumes rise or fall, leads to a method to estimate 10-hr pedestrian volumes. This method is proposed because it is easy to use, it requires little data, and existing Milwaukee and Los Angeles models do not work well without recalibration.

In the past few decades, most major American downtowns have experienced dramatic changes. Although skylines reflect the growth of office space and the concomitant employment, many historically important shopping streets no longer have the vibrancy that they did during the middle of this century. At the same time that resident populations continue to decentralize into the suburbs, the immediate fringes of the central business district (CBDs) enjoy an increase in high-rise residences. These trends have had major impacts on downtown pedestrian traffic.

Recently, pedestrian traffic has been studied from a variety of perspectives from pedestrian characteristics to planning issues (*1–3*). Many studies have also focused on trip characteristics, distance traveled being a common theme (*4–6*). Several studies have gone beyond the necessary descriptive works to model pedestrian traffic with intersection models (*7*) and automobile traffic flow relationships (*8*). All the studies recognize that data collection is key, and several authors have focused on data collection methods. Partly to avert the resource-intensive aspects of manual data collection, surrogate methods have been explored as a means of estimating pedestrian volumes; Ness et al. (*9*), the Los Angeles Department of Traffic (*10*), and Patel (*11*) focus on the interrelationship between downtown land use and pedestrian traffic.

All these studies, which have substantially advanced the knowledge of downtown pedestrian traffic, have one thing in common: data are examined for one or more cities during a short time window, generally less than a few months. In contrast, in this paper data collected for two Chicago pedestrian studies in 1981 (*12*) and 1989 (*13*) are used. Both represent major efforts in which several million pedestrians were counted and approximately 1,500 were interviewed. Where appropriate, reference is also made to the 1963 Chicago data used by Rutherford and Schofer (*2*).

The purpose of this paper is to (a) discuss the characteristics of current pedestrian activity, (b) identify the major changes in the decade of the 1980s, and (c) suggest how the data can be used to estimate pedestrian volumes in downtown areas. Existing methods to estimate pedestrian volumes appear to be inadequate for the task because they require too much data or they do not yield satisfactory results. Therefore, a simple procedure is proposed until more sophisticated methods are developed.

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DATA COLLECTION

Pedestrian Count Data

The data from the two studies used here were collected using the same methodology and were supervised by the same personnel. The first study (*12*) was conducted in 1981 and included 332 10-hr mid-block counts for the Chicago CBD, also known as the Loop; the 1989 study (*13*) covered a larger area and therefore more locations. About 300 sites were common to both studies. Each study counted more than 3 million pedestrians, many individuals more than once as they passed several mid-block sites. In both cases data were collected on summer days without rain.

Pedestrian Interviews

Both studies included pedestrian interviews using a spatial and temporal sampling design. On the basis of land use, the downtown was divided into 16 zones: a primary retail zone, a specialty retailing zone, a government zone, a financial zone, and so on. Within each zone a random sample of five block faces was selected for interview sites. The day was divided into three periods: peak, lunch, and off-peak. The basic interview design then had 48 spatiotemporal cells (16 zones times 3 time periods), with 30 interviews in each, resulting in 1,440 interviews. The larger 1989 study area had 17 zones yielding 90 additional interviews.

This interview design accomplished two things. First, it provided the desired breadth, covering the entire study area and the 10-hr day. Second, and equally important, it allowed the computation of a scaling factor for each interview. From the count data it was possible to determine the number of pedestrians in each zone during the respective interview period, yielding the scaling factor. Thus, the scale weighted interview should better reflect the entire pedestrian population, reducing bias.

EMPLOYMENT, RETAILING, AND OFFICE SPACE TRENDS

Employment has been increasing in Chicago's downtown for more than a decade. In the 1970s, when the metropolitan area employment increased by approximately 300,000 jobs, a third of this growth took place in the CBD. This yielded an average rate of 10,000 new CBD jobs per year in the 1970s. Employment growth has slowed slightly in the 1980s, increasing by 40,000 from 1980 to 1985 (*14*), bringing the total jobs to approximately 450,000 in the 1 mi^2 Chicago Loop. Employment growth trends tend to be cyclical, however, and could have changed before the end of the decade. The 1990 census will provide more current data.

Two major retailing changes have occurred during the study period. First, State Street, the traditional downtown shopping street, has had a decline in the number of anchor stores from six to two: Sears, Montgomery Ward, Goldblatt's, and Wieboldt's have closed. These multifloored stores each occupied either half or full blocks. At the same time major department stores, such as Marshall Field's, Neiman Marcus, and Bloomingdale's were built on North Michigan Avenue, just beyond the study area. Second, and just as important for this study, is the diffusion of retailing throughout the downtown area. Building lobbies now contain restaurants and convenience stores; the range of goods is limited but certainly greater than a decade ago. A good example is the new State of Illinois Building, in which the first floor is devoted to retailing. In contrast, the Daley Center, a 30-story city office building built in the mid-1960s, is devoid of street-level retailing.

The growth in employment has been facilitated by the increase in office space in the downtown area. During the 8-year study period between 1981 and 1989, 1.93 million m^2 of office space (20.7 million ft^2) was added in the immediate study area and another 0.46 million m^2 (4.9 million ft^2) within a few blocks of the study area boundary. This resulted an increase of approximately 25 percent in the general downtown area.

PEDESTRIAN TRAFFIC

High-Density Travel

Because high pedestrian densities often contribute to movement conflicts, the relationship between density and conflicts has been studied frequently. The Chicago studies shed some light on where and why some of these high densities develop.

The 1989 summer study reveals that 10-hr mid-block volumes vary from more than 30,000 to less than 1,000. In both the 1981 and 1989 studies, the highest volumes—the only ones over 30,000—were at major retailing sites. Because much of the retailing in the greater downtown area has shifted to North Michigan Avenue, the highest volumes are now outside the traditional Loop (beyond the area of Figure 1). Intensively used retailing areas result in high daily totals because they are not characterized by sharp drops in traffic found in office space environments, where sidewalks are quiet when workers are on the job. In retailing areas, traffic builds rapidly when stores open and is busy throughout the day. The lunch period has significantly higher volumes, but retailing districts have no other distinct pedestrian traffic peaks. If more distinct peaks of traffic were to occur, there would be more potential for pedestrian congestion and movement conflicts.

The area of greatest pedestrian intensity is found in the West Loop near the commuter rail stations (Figure 1). Two of the bridges crossing the Chicago River near these stations have more than 2,000 pedestrians (on one side of the bridge) during peak 15-min periods. The traffic there, approximately 300 m (1,000 ft) from the trains, comes in waves, and there is little activity between waves. Two factors tend to keep this area from being one of serious concern. First, despite the high densities of traffic, the great majority is destined to or from the train station and walks at a brisk and steady pace. Visual observation suggests that differential speed among pedestrians is only a minor problem. Second, the stream moves overwhelmingly in one direction, minimizing the number of conflicts caused by opposing traffic. Anyone walking counter to the main flow will experience difficulty maintaining a steady pace.

The contribution of the two largest downtown structures to pedestrian traffic also merits examination. Both the Sears Tower and the Merchandise Mart have more than 300,000 m^2 (3.1 million ft^2) of office space (Figure 1). One might think that such buildings would generate large amounts of traffic. The pedestrian data do not show unusually high levels near these buildings. The Sears Tower has two main entrances, east and west. The 10-hr mid-block counts are approximately 17,900 and 15,700, respectively. The other two block faces (the building occupies the entire block) have volumes under 15,000. None of these numbers suggests congested sidewalks.

Moreover, the combined 1989 street counts at the entrances—33,600—are very close to the 1981 combined totals of 33,000. The area around the Sears Tower has grown during this time, but this has not translated into many more people on the street.

Because it is relatively isolated, the Merchandise Mart better reflects its impact on pedestrian traffic volumes. The 10-hr volumes near the Mart are unimpressive (Figure 1). Neither side of the two bridges connecting the Loop with the Mart carries more than 5,000 pedestrians per day. The area north of the Mart has even lower volumes. These lower volumes imply that a large building by itself does not necessarily lead to overly crowded sidewalks. Even if everyone decided to leave the building at 5:00 p.m., it is logistically infeasible that everyone would reach the sidewalk at the same time. The delays associated with elevator use within the building play a major role in spreading out the pedestrian traffic. The use of the rail rapid transit directly connected to the second floor of the building and the use of taxis minimize the effect on nearby sidewalks.

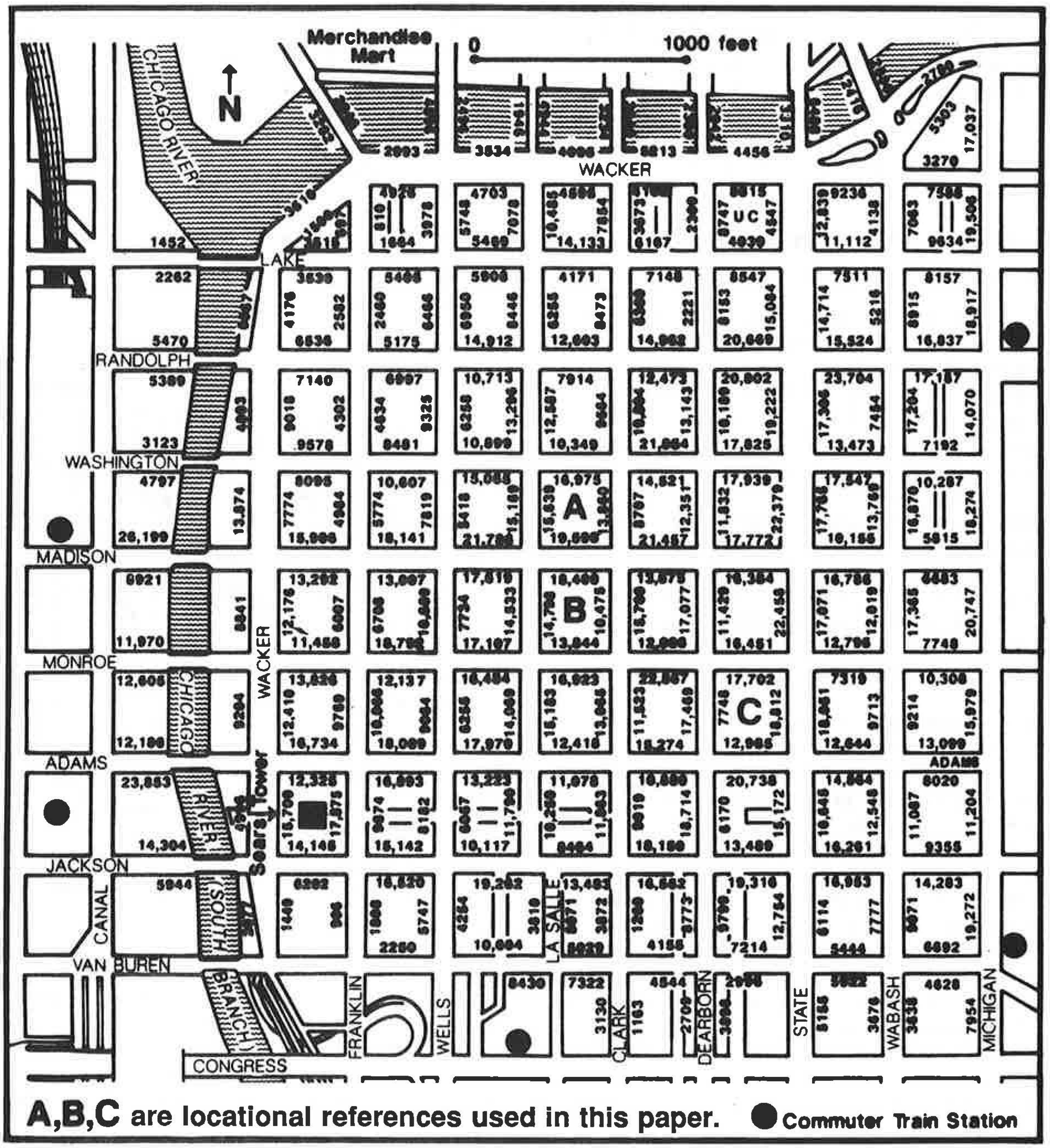

FIGURE 1 Weekday 10-hr pedestrian traffic, 7:45 a.m.–5:45 p.m., 1989.

Changes in 1981–1989 Daily Volumes

One major change is apparent in contrasting the two studies: the number of very high and very low volume sites has declined. At the high end, the number of Loop locations (Figure 1) with more than 25,000 pedestrians has declined from eight in 1981 to just one in 1989 (Table 1). The drop can be attributed to the decline in shoppers evident from the locations of these sites and the interview data discussed below. The traditional shopping district—State Street—had seven of the eight 1981 sites over 25,000; currently, there are none on State Street. Aggregating the top two categories (more than 20,000 pedestrians), 12 sites have been lost from 1981 to 1989. Eight of those sites were lost from State Street alone. The remaining four are scattered, and little can be concluded about their decline. Three of the four are in commercial areas where office space is on the increase but pedestrian traffic apparently is not. This seeming paradox will be addressed later.

At the lower end of the pedestrian volume table, there are also declines. The number of sites with 5,000 or fewer pedestrians daily has decreased by 16. Many of these sites are in a three-block-wide north-south band in the West Loop.

After 20 locations found west of and including both sides of Wells Street moved out of the 5,000-or-fewer class, a few other locations also dropped down to this class (Table 1).

As a generalization, the pedestrian traffic volumes declined in the east and increased in the west (Figure 2). Enjoying increased popularity, Michigan Avenue at the far east fringe of Figure 2, is excluded from this generalization.

Relationship Between Change in Pedestrian Traffic and Building Construction

In a broader sense the declines in traffic cannot be attributed only to the decrease in shoppers. The decline or lack of growth in pedestrian traffic characterizes the southeastern part of the Loop. This area has had very little new office construction, as Figure 2 shows. On the other hand, the western and northwestern parts of the Loop have had a significant increase in both new office space and pedestrian traffic.

There is nothing remarkable about the growth in pedestrian traffic in the northwestern corner of the Loop, but the lack of pedestrian growth on LaSalle street—the financial street—is noteworthy. With two new buildings having a combined total of 0.17 million m^2 (1.6 million ft^2) and high occupancy rates, one might expect to see an increase on LaSalle, but most of the block faces in a three-block expanse in the core of LaSalle Street have experienced declines of more than 10 percent.

There are several places in this study where sidewalk pedestrian traffic generation per square foot of office space has declined. Whatever the reason, this phenomenon calls for further study. There are a few plausible explanations. First, it is possible that as Rutherford and Schofer conjectured (*2*), buildings are less intensively used. Second, flex time and alternative work schedules cause more traffic to miss the 10-hr time window (7:45 a.m. to 5:45 p.m.). Third, many more buildings provide services within, reducing the necessity to go outside. Fourth, advances in telecommunications designed to decrease the need for person trips may be beginning to have an effect. Fifth, in some areas the downtown may be overbuilt, resulting in high vacancy rates.

Effects of Train Stations

Still, it is apparent that pedestrian traffic has grown in the western part of the study area. This is attributable to the office space completed in the 1980s and the increased use of Metra, the commuter rail service (Figure 2). Many developers have sought sites close to the commuter rail stations on the western fringe of the Loop. Because the expense of parking in the Chicago downtown for most commuters is significantly more than the cost of a round-trip train ticket, approximately a quarter of the CBD workers arrive by commuter rail as do more than half of all suburban commuters who work in the CBD. Between 1983 and 1989 all but one of the five commuter rail stations shown in Figure 1 experienced at least a 25 percent increase in patrons. Though much of this came from lower fares, the train station locations are still important, especially the two west of the Chicago River. In 1989 these two stations accounted for 66 percent of the five-station total.

TABLE 1 AGGREGATED 10-hr PEDESTRIAN VOLUMES, 1981 AND 1989

Number of Pedestrians	Number of 1981 Sites	Number of 1989 Sites	Difference 1981 - 1989
Over 25,000	8	1	-7
20,001-25,000	17	12	-5
15,001-20,000	57	62	5
10,001-15,000	66	80	14
5,001-10,000	87	96	9
0- 5,000	86	70	-16

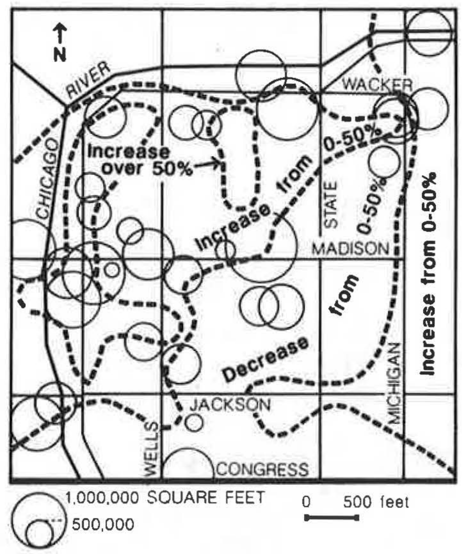

FIGURE 2 Changes in pedestrian traffic and office buildings completed, 1981–1989.

Interview Data

The interview data corroborate some of these findings. They verify that the CBD is a place to which people come to work but less often to shop. Since 1963 the proportion of those who came for the primary purpose of shopping has declined about 10 percentage points from 14.3 to 8.0 percent in 1981 and to 4.5 percent in 1989. Interestingly, the percentage who indicated that they came downtown to work has essentially not changed, remaining at approximately two-thirds of all pedestrians. In the 1980s, of the remaining trip purposes, the greatest increase was for leisure activity. Leisure is a category that includes those walking for exercise or pleasure, as well as some homeless or others who may have provided this as a convenient response.

The distances pedestrians walk has changed little. The median distance was about two blocks in 1963 (*2*) and is about the same today. Many in 1989 were walking for exercise, accounting for long trips and a higher mean than median.

Last, the interviews show that the downtown still has a male majority. Men account for approximately two-thirds of the 1981 and 1989 weekday downtown pedestrians and in both years outnumbered women in all trip purposes except shopping.

ESTIMATION OF PEDESTRIAN VOLUMES

These data suggest that, in order to adequately estimate the traffic at a given location, a model must incorporate two key elements: the land use in its immediate vicinity and its location relative to major CBD entry points.

Estimates Based on Land Use Data

The Toronto work of Ness et al. (*9*) considers these elements. Their calibrated model is specific for either journey-to-work trips or lunch-hour trips. Because it is calibrated on a 9 percent and 5 percent sample of these trips, respectively, it has significant data requirements. The data were collected with a mail-back survcy of Toronto's downtown labor force. Although satisfactory results were found in Toronto, the model is resouce-intensive.

Because of these requirements for the Toronto model, a more basic model was developed for Los Angeles (*10*). A multiple regression equation was estimated for the number of downtown pedestrians in which the combined four-block-face pedestrian total was used as the dependent variable. The independent variables included a list of land uses ranging from office space to parking space. The approach was logical, but two of the land uses—hotel-institutional and manufacturing—had negative coefficients. And, because the constant in the equation for a 12-hr day was 19,980, the equation appeared to be more of a description of downtown Los Angeles than a model usable elsewhere. As expected, the model fits the high-traffic blocks—more than 15,000 pedestrians—better than the low-volume blocks.

A similar model was used in Milwaukee by Behnam and Patel (*11*), relating the land use in a block to the total traffic on the four block faces. The availability of land use data highlights its ease of use. Whereas the derived regression equation fits the Milwaukee data well, several disadvantages become apparent. First, some model parameters are not intuitively appealing. They suggest that commercial space generates more traffic per square meter than office space, which the Chicago data support, but both are outpaced by the traffic-generating rates of vacant space. In the application described, 1,022 m^2 of vacant space generates more traffic than 3,251 m^2 of commercial space and the 3,948 m^2 of office space combined (*11*). Second, of the four directly comparable coefficients, vacant space had the highest traffic-generating rates, higher than land uses for storage and maintenance, residences, and cultural activities and entertainment. It should be cautioned that when this was verified, the Milwaukee examples were presented in the original work with land use expressed in square meters, but the model coefficients were given for data expressed in square feet. In the computations above, data were converted to square feet before the model estimates were derived.

Although neither the Los Angeles nor Milwaukee study makes any claims of geographic transferability, it is tempting to observe how well these models perform in Chicago. Several sites were tested: the Sears Tower, the Merchandise Mart, and two blocks on LaSalle Street. The LaSalle Street blocks are marked with the letters *A* and *B* on Figure 1. Both models overestimate the two large-building traffic volumes, the Sears Tower and the Merchandise Mart, but underestimate the traffic for the LaSalle Street blocks. The Los Angeles model (*10*) does best for the Sears Tower, estimating 72,000 in comparison with the actual of 60,000, but it misses each of the other three sites by more than 25,000 pedestrians. Not surprisingly, the Milwaukee model (*11*) does very well for one of the LaSalle blocks. Because of the logarithmic comparisons of the model, however, it estimates more than a million pedestrians at the Sears Tower. Because only one in eight estimates for the two models is within 20 percent of the actual level, it is apparent that they must be recalibrated for Chicago. These models would probably yield better results if the land use within a two-block radius were used, the median Chicago CBD walking distance. This would make data manipulation more demanding, but it would recognize the immediate surrounding environment.

Estimates Based on Samples

It is clear that existing models calibrated for other cities either do not provide satisfying estimates of pedestrian traffic in Chicago or are difficult to use. One then reaches the conclusion that there exists a solid, fundamental base for modeling pedestrian traffic but that the model has not yet been generalized.

In the meantime, the emphasis has been on extrapolating daily totals from samples (*15*), a strategy used here. The reasons for sampling are amply outlined by Davis et al. (*16*). By testing short sampling periods, they obtained satisfactory results for a variety of largely non-CBD land use settings in Washington, D.C. Their objective was to estimate 1- to 4-hr counts from samples of 5 to 30 min. They concluded that the sample period should be in the middle of the period being sampled and that the longer the sample period, the more accurate the estimate.

Their method holds considerable promise but needs modification for the Chicago downtown. The principal reason is that the Chicago volumes are much higher and the major fluctuations in pedestrian traffic during the day require that the sampling period take into account the time of day, absent in the Washington study. To apply the Washington technique properly, samples must be drawn from several times during the day, requiring that the design of when and where data are to be collected be well thought out. Moreover, the field operatives must be well qualified to follow directions and move from place to place in a timely fashion. In general, the more elaborate the sampling scheme, the greater the potential for time savings—but also greater the potential for error while transferring a greater share of the design and extrapolation work to more highly paid individuals in the office. This is not always cost-efficient. Therefore, a system is advocated that minimizes both sampling and mathematical work.

An Alternative Approach

The method relies on knowing or estimating the daily pattern of traffic and then sampling during just 1 hr. Data need to be available on how pedestrian traffic fluctuates by time of day in different land use environments, because each environment has a distinct daily pattern (*13*).

Typically, data are collected and recorded every 15 min throughout the day, as suggested by Haynes (*17*), and graphed as a percent of the daily total. This graph of the daily pattern of pedestrian traffic is unique to every block face, and is thus here called the block-face pedestrian signature, or merely signature. These signatures reflect the land use in the immediate area; though they are unique, they can be classified into distinct groups (*13*).

Examples of 10-hr signatures can be seen in Figure 3, which shows the 1981 and 1989 signatures for a selected block face. Because the land use in the immediate area has not changed, the signature remains largely unchanged. The location is on a block face with office buildings that is very close to the traditional State Street shopping district. Note that despite the constancy in the signature, the total 10-hr pedestrian volume has declined by more than 2,000 pedestrians to 12,795. This may reflect higher office-vacancy rates or fewer shoppers at the nearby stores.

For most sites, the 1981 and 1989 site signatures are similar, but this may not be true for sites experiencing major land use changes. In 1981 the selected site in Figure 4 was typical of the West Loop in which much of the pedestrian traffic passed during the two peak periods to and from the nearby commuter train station. By 1989 a new 0.11 million-m^2 (1.2 million-ft^2) office building was added to this location, and the signature changed dramatically.

In places where the signature has not changed, it would be possible to sample a few 15-min segments and extrapolate the 10-hr total. Few Loop sites show the minor changes seen in Figure 3. Still, so many sites show sufficiently little change that it is worthwhile considering use of 1981 signatures and 1989 samples as a means of estimating 1989 totals. For this purpose a block bounded by State, Adams, Dearborn, and Monroe was selected (*C* in Figure 1). This block was selected for two reasons: it is located near the center of the Loop, and it has experienced a dramatic change, the closure of the Montgomery Ward store sited on the southern half of the block. By 1989 the store was razed and the site was left empty. Traffic

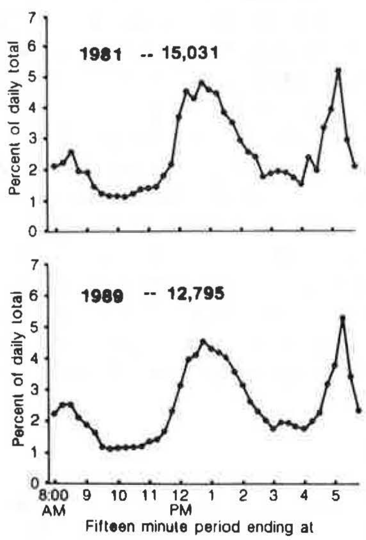

FIGURE 3 Signatures for north side of Monroe between State and Wabash, 1981 and 1989.

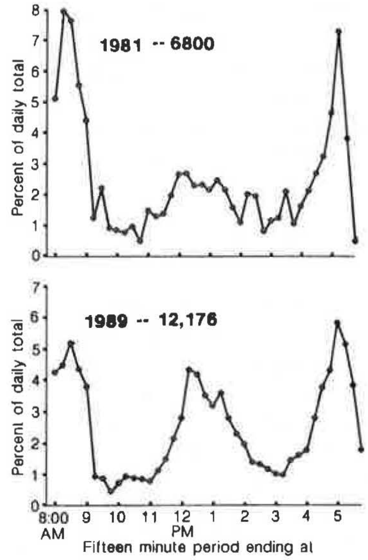

FIGURE 4 Signatures for north side of Wacker between Madison and Monroe, 1981 and 1989.

dropped by approximately 10,000 pedestrians on the east and west sides of the block. One might expect the store closure to have affected the signatures, but because the area remains a mixed office and retailing area, the effect should not be great. Overall, the 1989 signatures resemble the 1981 signatures, even on the west side where the 10-hr volume has dropped by more than 50 percent (Figure 5). On the south side (Figure 6), where the drop in pedestrians was only about 1,500, the signature, with high levels of morning activity for both years, is different from the west-side signature (Figure 5).

The lack of change over time in the signature suggests that the 1981 signatures and 1989 samples can be used to estimate 1989 totals. Table 2 summarizes this effort. It would be easier to take a 1-hr sample than to take three or four 15-min samples scattered throughout the day, so each estimate was derived from one sample. In the majority of cases (23 of 36) the estimates were within 10 percent. It is quite possible that even day-to-day variations would fluctuate this much.

The method can be summarized in the following steps. First, selected signatures must reflect the land use in the area. Most places where pedestrians are being counted have a record of previous counts, and signatures can be obtained. A guide is

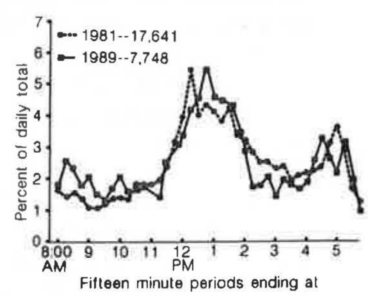

FIGURE 5 Signatures for west side of Block C on Figure 1, 1981 and 1989.

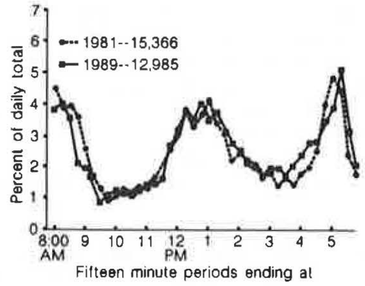

FIGURE 6 Signatures for south side of Block C on Figure 1, 1981 and 1989.

TABLE 2 ACTUAL AND 1989 ESTIMATED 10-hr PEDESTRIAN VOLUMES FOR FOUR BLOCK FACES IN DOWNTOWN CHICAGO

	North	East	South	West
1981 Actual	19,888	29,028	15,366	17,642
1989 Actual	17,702	18,812	12,985	7,748
1989 Estimates Based on One-Hour Samples				
Sample period	Estimates			
8 A.M. - 9 A.M.	16,429*	24,155	11,020	12,352
9 A.M. - 10 A.M.	16,855*	18,872*	12,877*	10,034
10 A.M. - 11 A.M.	19,376*	16,514	12,776*	7,694*
11 A.M. - 12 Noon	19,608	16,044	12,563*	7,045*
12 Noon - 1 P.M.	19,529	17,462*	12,813*	8,114*
1 P.M. - 2 P.M.	18.665*	18,274*	13,930*	7,938*
2 P.M. - 3 P.M.	20,939	20,018*	12,869*	5,325
3 P.M. - 4 P.M.	20,399	18,617*	16,643	6,534
4 P.M. - 5 P.M.	16,270*	17,767*	12,421*	7,236*

Block identified on Figure 1 with the letter C.

* Estimate within 10% of the actual volume.

being compiled for those circumstances in which signatures are not available. Second, a 1-hr sample must be collected. Third, from the signature, the percent of the daily total accumulated during the sample period is determined; fourth, the sample is factored up to derive the estimate.

The technique is simple, and it holds promise. It would not work as well in areas such as the site used in Figure 4, but even in this case a different signature can be assumed and a longer sample period can be used.

CONCLUSIONS

Significant changes have occurred in the patterns and volumes of pedestrian traffic in downtown Chicago. The main changes include a decline of traffic in peak retailing areas and an increase in the West Loop. Also, because of the move toward the development of mixed-use office buildings (that is, more self-contained units with retailing), there are fewer sidewalk pedestrians per square foot of office space. Many new retailers primarily serve building traffic and do not generate sidewalk traffic in the manner common to large retailers on State Street or Michigan Avenue.

The consequence is the emergence of a CBD with fewer places that have exceedingly high pedestrian volumes and therefore potentially fewer pedestrian conflicts in movement. Even the largest office buildings do not generate the volumes of traffic that overburden sidewalks.

The areas with the greatest intensity of traffic per 15-min period are associated with the two principal commuter rail stations. Parking lots and subway stations do not have the same effects. Mercifully, these stations are located on the fringe of the CBD, so the traffic moves in largely one direction, causing fewer pedestrian conflicts than would be the case if the stations were located near the core of downtown.

These changes have taken place, but some fundamental things have not. During the 8-year period, retailing areas are still retailing areas, and the financial district is still the financial district. Despite the fact that some areas have higher or lower pedestrian volumes, it is remarkable that the pattern of daily traffic—the pedestrian signature—has changed very little. This lack of change provides an opportunity to estimate traffic by using sample counts. This has the distinct double advantage of minimizing both field sampling work and the conversion of these data to daily estimates. The method is simple.

There are still many questions. With all the increase in office space, why are the pedestrian traffic totals not higher? Are telecommunication systems having an effect? It would appear that increases in downtown office space may burden the transportation systems that bring these workers into the CBD, but, with the exception of the immediate commuter rail station areas, the sidewalks do not appear to be suffering the same fate.

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