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Foreword

Highway traffic safety is of paramount concern to both the general public and highway and traffic officials. Research efforts have been accelerated in the hope of finding early solutions to many of the problems involved in reducing the ever-increasing number of traffic accidents and fatalities. Highway Research Record 79 presents some of the most recent work sponsored by the Board's Committee on Highway Safety; it will be of general interest to a wide spectrum of researchers concerned with the relationships between drivers, safety and accidents.

The first section offers three papers presented at the Board's 43rd Annual Meeting in January 1964. Concentrating on the problem of the driver, the authors report on the investigation of causes of single-car accidents, the application of factor analysis to accident records, and the study of driving behavior variables.

In a study entitled "Causes and Characteristics of Single Car Accidents," a California researcher applies information from accident reports, driver biographical data, and driver attitude tests to the problem of accident causation. His findings confirm presently held concepts concerning the frequent accident involvement of youths and aged drivers, and establish speed, drinking and drowsiness as major causes of accidents. In addition, the report discusses the extent to which the number of occupants in a car and sex of drivers influence driving behavior.

"A Factor Analysis of Accident Records" reports on the use of a high-speed computer to apply multivariate analysis methods to accident data. Studying 17,400 Michigan accidents, the authors isolated eight independent factors which can be viewed as basic characteristics of accidents. Knowledge of these significant factors makes possible prediction of other characteristics, and it is hoped that information of this nature may eventually contribute to a more comprehensive understanding of accidents.

Driving behavior is studied in "Personality and Biographic Variables in Relation to Driving Item Response." The researchers have correlated verbal responses concerning driving with personality and biographic variables such as competence, sex, and education. They conclude that the relationships correspond with those that would be expected from logical considerations, thus indicating the usefulness of driver responses in the prediction of accidents.

Results of studies of totally deaf drivers in California were presented at both the 43rd and 44th Annual Meetings and are published in this Record. It was found that there are no significant differences in accident occurrences between deaf and non-deaf females, whereas deaf male drivers experienced significantly more accidents than the non-deaf.

The remainder of this publication consists of a series of abridgments of papers from a conference session, "Moving Toward a Safer Highway," held at the Board's 44th Annual Meeting in January 1965. Prominent researchers offered many possible means of making highways safer which will be of special interest to administrative personnel and traffic and safety engineers in state, county, and city highway departments. They include such subjects as the use of computers to detect high-accident locations, proper programming of highway safety improvements, cooperation for safe design and operation, and the future of highway safety research.

Contents

Causes and Characteristics of Single-Car Accidents: Part I

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Two considerations dictated the choice of single-car traffic accidents as a subject for study: (a) this type of accident has shown a steady increase in California, and (b) the driver at fault can be clearly identified.

This survey was designed to determine the approach to the study of accidents that casts the most light on causation. Part I uses the information available from accident reports. Part II will approach the subject via driver biographical data, and Part III through the application of a driver attitude test to a sample of single-car accident drivers. Means of predicting driver accident potential will be explored as the final phase of the study.

●THIS STUDY was initiated early in 1961 by Bradford M. Crittenden, Commissioner of the Department of California Highway Patrol. The immediate purpose of this project was to try to determine the reason for the gravity of the single-car accident problem in California. But other possible by-products emerged from the preliminary work.

The chief of these was the clear insight into accident causation which such a study might yield. In multi-vehicle crashes it is often difficult to fix responsibility for the accident. And even if this responsibility can be determined, elements of partial culpability on the part of the other drivers remain to cloud the issue. In most single-car mishaps, however, the responsibility can more easily be assigned. It would be expected on a priori grounds that the study of a group of such drivers would yield unequivocal information about accident causation.

Because accident statistics commonly embody a mixture of violations, factors and causes, a new set of cause categories was devised in the hope of identifying basic accident sources more clearly.

The cause data which made up the primary material of the study were the opinions and conclusions of the patrolman rather than the formal collision cause, which is usually coded by supervisory personnel. Thus, one possible source of variation was eliminated.

The causes employed herein are speed, drinking or drugs, drowsiness, faulty driving, adverse driving conditions, distraction inside vehicle, distraction outside vehicle, mechanical failure, medical problems, defective vehicle design, unknown vehicle, and miscellaneous. Since most accident causes are complexes of factors, the persons coding the reports were instructed to look for the most cogent factor in each report and to ascribe the accident to that factor ("cause"). For example, an accident involving primarily a lack of manipulative skill combined with high speed would be classed as stemming from faulty driving rather than speed.

The categories are in most cases self-explanatory, the possible exceptions being faulty driving, unknown vehicle, medical problems, and adverse driving conditions. The first grouping embraces accidents arising from lack of manipulative skill—e.g., steering the wrong way in a skid; and from mistakes in judgment—e.g., failure to recognize the end of a dead end street.

"Unknown vehicle" refers to accidents said to be caused by another, unidentified driver, whose actions were responsible for the subject driver's coming to grief.

"Medical problems" includes accidents due to ill health or any medication except narcotics or stimulants.

"Adverse driving conditions" is intended to measure the driver's difficulties in coping with unusual situations in the driving environment. Heavy fog or a detour might illustrate this cause.

A few of the causes are apparently randomly distributed; hence, no correlation with the various characteristics studied is evident. For example, an accident caused by mechanical failure could happen equally well to men or women, at 4 a.m. as well as 4 p.m. These variables are measured only for their gross contribution to the accident totals.

This new cause system was devised on a purely empirical basis, with no previous work to furnish guidelines. Only one of the categories from the original schedule, defective vehicle design, failed to include a substantial number of cases (0.12 percent of the total). In the analysis, these cases were merged into the miscellaneous category.

A rough estimate of the sample size required to limit the theoretical error to 0.01 percent was made from the expression

$$Z = \frac{s}{\sqrt{n}} \tag{1}$$

indicating a sample of 1,500 cases.

But because the cost of extracting a larger sample of reports is negligible, and because a complex selection plan might engender confusion, it was decided to use two complete calendar months of single-car accident production. Each month's report was coded by different personnel so that any biases in classifying might be mutually canceling. An autumn month, September 1961, and a spring month, June 1962, were selected in order to include the effects of seasonal variation.

The number of cases used, about 5,200, is well beyond basic sampling requirements and should assure the validity of the findings as far as accidents are concerned. Some of the victim data proved to be insufficient.

The single-car accident problem is not a transitory one. In the areas of California served by the Highway Patrol, single-car accidents rose from 32 to about 40 percent of all accidents during the period 1950-1960. The single-car proportion has remained at the latter figure during 1961-1962, suggesting that this component of the accident total is approaching stability. Single-car fatals account for approximately 50 percent of fatal accidents of all types.

A comparison of the severity structure of single-car accidents with other motor vehicle accidents (excluding the noncollision, single car and pedestrian categories) shows that other accidents are made up of 65 percent property damage, as compared with 48 percent in the single-car group. Other motor vehicle accidents entail 33 percent of the injury severity, whereas single-car accidents show 49 percent injury. Fatalities occur with greater relative frequency in the single-car than in the other motor vehicle accident grouping—3.1 percent as compared with 1.5. It is a fair conclusion, therefore, that single-car accidents entail graver consequences for the principals than do other types.

Some aspects of the problem were not subjected to detailed analysis because of the absence of significant departures from general accident experience, because the same material was presented in other forms, or because the data were considered inadequate for valid conclusions. Perhaps the most substantial omissions were in the areas of speed and accidents by day of week. Speed was not studied in quantitative form because of the lack of accurate measurements. It appears in the study, however, in qualitative terms—an accident cause as evaluated by the investigating officer. No difference in the weekly distribution between single-car accidents and those of other types was found.

Three commonly used categories of accidents were grouped to form the single-car class: (a) overturned in roadway, (b) struck fixed object, and (c) ran off roadway. The original distributions were subjected to analysis of variance treatment, which showed homogeneity. On the strength of this test, the three types were combined.

The first grouping of the data to be undertaken was accident cause by degree of severity. On the assumption that a high proportion of property damage accidents may be taken as indicating a minor cause, it was noted that accidents attributable to mechanical failure, unknown vehicle, and miscellaneous factors would be classed as relatively innocuous. The common element in this complex appears to be that though the driver gets into trouble, he retains a considerable degree of control over the vehicle.

In cases where it can be assumed that this degree of control is less—in the case of drowsiness, adverse driving conditions, distractions inside vehicle, and medical problems (where unconsciousness may occur)—the relative incidence of fatal accidents is highest. The same observation applies to a lesser degree in the distraction inside vehicle, and drinking or drugs categories. Here, also, it may be theorized that the driver is sometimes either incapable of recognizing perils or is not looking at the road ahead. In many such cases, there would be no reduction in speed prior to impact and higher proportions of fatalities would be the logical result.

These data may be viewed profitably from another angle—that of the percentage of accidents resulting from each cause. This rearrangement sets forth the overall contribution of each cause to the accident grand total. Here it was seen that faulty driving, which is not usually considered in accident research, is the leading source of single-car crashes, accounting for 25.0 percent of the total, while excessive speed is a close second with 23.6 percent. Other major causes are drinking or drugs, 14.8 percent; and mechanical failure, 10.0 percent.

Another important field of inquiry is that relating to the sex of the driver. Comparing the driving performance of the two sexes with respect to accidents has been attended in the past by the difficulty of equalizing the exposure for the two groups. It is accepted that women's accident experience is much less than that of men. It is likewise recognized that fewer women drive and that their average annual mileage is lower than that of men. An attempt to take these factors into account was made in this study.

Male and female mileage and numerical representation in the driving population were found in earlier studies made by the California Department of Motor Vehicles. The use of these figures gave a multiplier which indicated that if the numbers of men and women drivers were equal and if they drove the same mileage, the women's accident record would be about 75 percent that of men. The same operation performed on comparable single-car data shows that the expected proportion of women's accidents to be 85 percent that of men.

It is seen that the percentages of male and female drivers in the study group are different from the percentages of drivers in all accidents investigated by the California Highway Patrol. The male percentages in the two groups were subjected to statistical tests and showed a significant difference at the 1 percent level. The proportion of male drivers in the single-car sample is significantly lower, and that of the female drivers significantly higher, than the corresponding population proportions.

If we examine accidents distributed in the table of causes according to the sex of the driver, certain interesting observations emerge. Significance tests were applied to accident causes by sex of driver data with the following results: the causes showing significant differences were speed, drowsiness, drinking, faulty driving, adverse driving conditions, and distraction inside vehicle.

In relative terms, therefore, it may be said that men show preferences for speed, drowsiness, and drinking. Women are weaker in the categories of faulty driving, adverse driving conditions (emergency situations in the driving environment), and distraction inside vehicle (stemming possibly from small children). The variables of mechanical failure, unknown vehicle, and miscellaneous could reasonably be regarded as random. Their nonsignificance is therefore not surprising. Distraction outside vehicle apparently also shares this characteristic.

These findings are consistent with the known psychophysical attributes of the sexes. Because of their greater strength and coordination developed by athletics and physical labor, men would be expected to find the management of the vehicle a relatively simple problem. Their more extensive driving experience would also tend to maximize operational skill. The opposite considerations apply generally to women.

On the other side of the coin, men's aggressiveness, daring, and rebelliousness make for reckless and often unlawful behavior. As women's psychological make-up embodies the obverse of these traits, they are comparatively low in accidents due to speed and drinking, and perhaps the aftermath of recreational activities—drowsiness.

Like sex, the age of the driver is strongly interwoven with several aspects of the single-car problem. In the course of the study the number of accidents produced by the various age groups were compared with the corresponding average annual mileages used previously.

Considering numbers of accidents alone, it is notable that more than 40 percent originate in the 15-24 age group. There is a steady decline through the 75 plus group. But if these percentages are related to the percentages of vehicle-miles driven by the various groups, a substantial change is evident. We may consider that if the number of accidents were commensurate with the mileage driven, the ratio of accidents to mileage would be 1.00. Accident experience greater than that which would be expected from mileage alone would give ratios larger than 1.00; experience less than that which mileage would produce would yield ratios smaller than 1.000. Calculations based on this hypothesis are presented in Figure 1.

The accident/mileage ratio in the 15-24 year group is about five times greater than 1.00. The ratio declines to approximately age 50 and then begins to rise. The 75 plus category is the second highest of the distribution. Six major causes by age group are shown in Figure 2.

It is clear that youth is the most dangerous period of life for single-car accidents, middle age the least dangerous, and old age intermediate between the two. Table 1
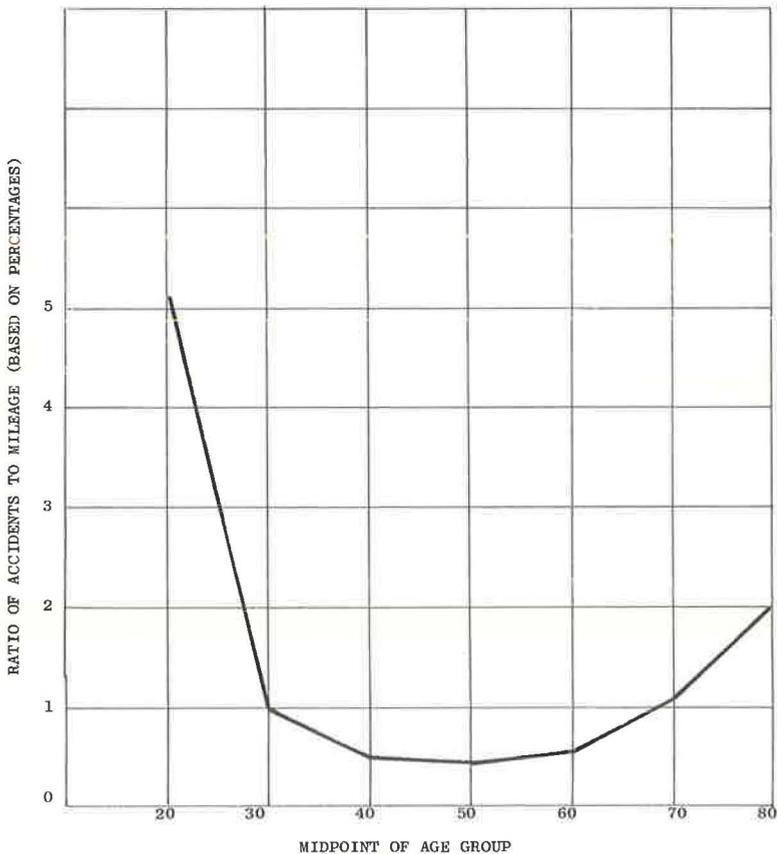

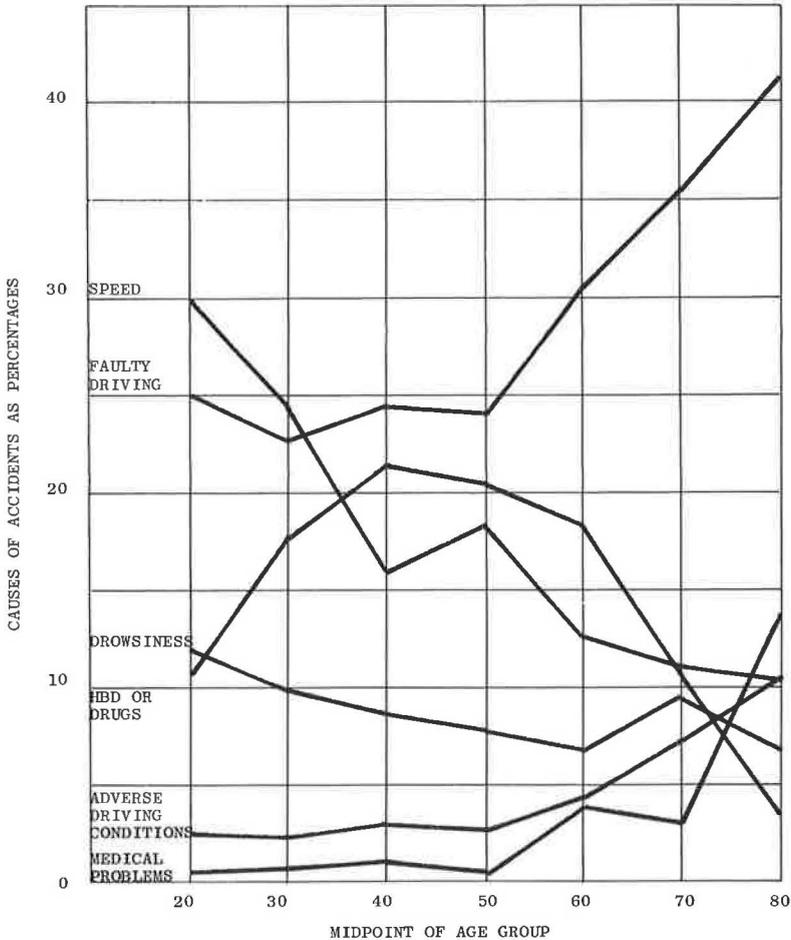Figure 1. Single-car accident-mileage ratios by age of driver.

Figure 2. Selected causes of single-car accidents by age group of drivers.

summarizes data in a youth/middle-age/old-age breakdown giving the causes which appear to be age-connected.

In absolute terms, the 15-24 age group is unquestionably the most dangerous. If an efficient means of accident reduction could be found, its application to this age group should do the greatest good.

If accidents are studied in relation to numbers of drivers or to average annual mileage, the 65-and-over age groups are, by and large, proportionately worse than the others, as suggested in Table 1.

Vehicle occupancy also seems to be strongly linked to single-car accident causation. In the sample studied, about 3,700, or 71 percent, of the drivers involved in single-car crashes were traveling without passengers. On this basis it might be said that the chances of being involved in a solo accident are about 2.5 times greater for the unaccompanied than for the accompanied driver. It cannot be determined, however, whether this is so because there are more one-occupant cars on the road, or whether the accident frequency for such cars is actually higher.

Tests of significance applied to this aspect of the study data showed that speed, drowsiness, drinking, unknown vehicle and miscellaneous influences affect the solitary driver much more strongly than the operator of the multi-passenger car. Attention is claimed by the finding that the number of accidents caused by unknown vehicles is outstandingly high in cases in which the driver is by himself. It may be suspected that the

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TABLE 1

Cause	Period of Life[a]		
	Youth	Middle Age	Old Age
Speed	H	I	L
Drowsiness	H	I	H
HBD or drugs	I	H	L
Faulty driving	I	L	H
Adverse driving conditions	I	L	H
Medical problems	L	I	H

[a]H = high, I = intermediate, and L = low.

"phantom" driver is often the scapegoat for the imprudent actions of the lone vehicular operator.

As would be anticipated, distractions inside vehicle account for a significantly high proportion of accidents involving multi-occupant vehicles. Possibly as a result of interaction with this variable, faulty driving is also shown to be of greater proportions in the "with others" class.

The temporal distribution of single-car accidents in relation to traffic is shown in Figure 3. It can be seen that from 7 a.m. to 6 p.m., the occurrence of accidents follows in a general way the fluctuations in traffic. From 7 p.m. to 6 a.m., accident production is much greater, relatively speaking, than traffic would warrant.
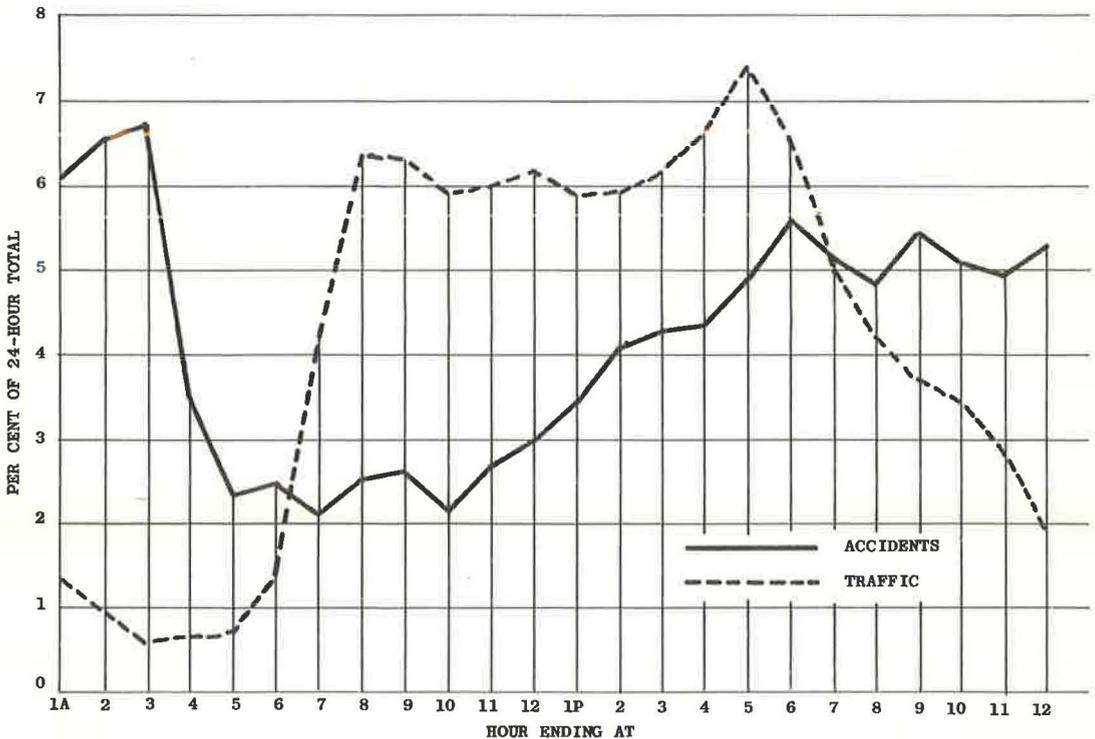

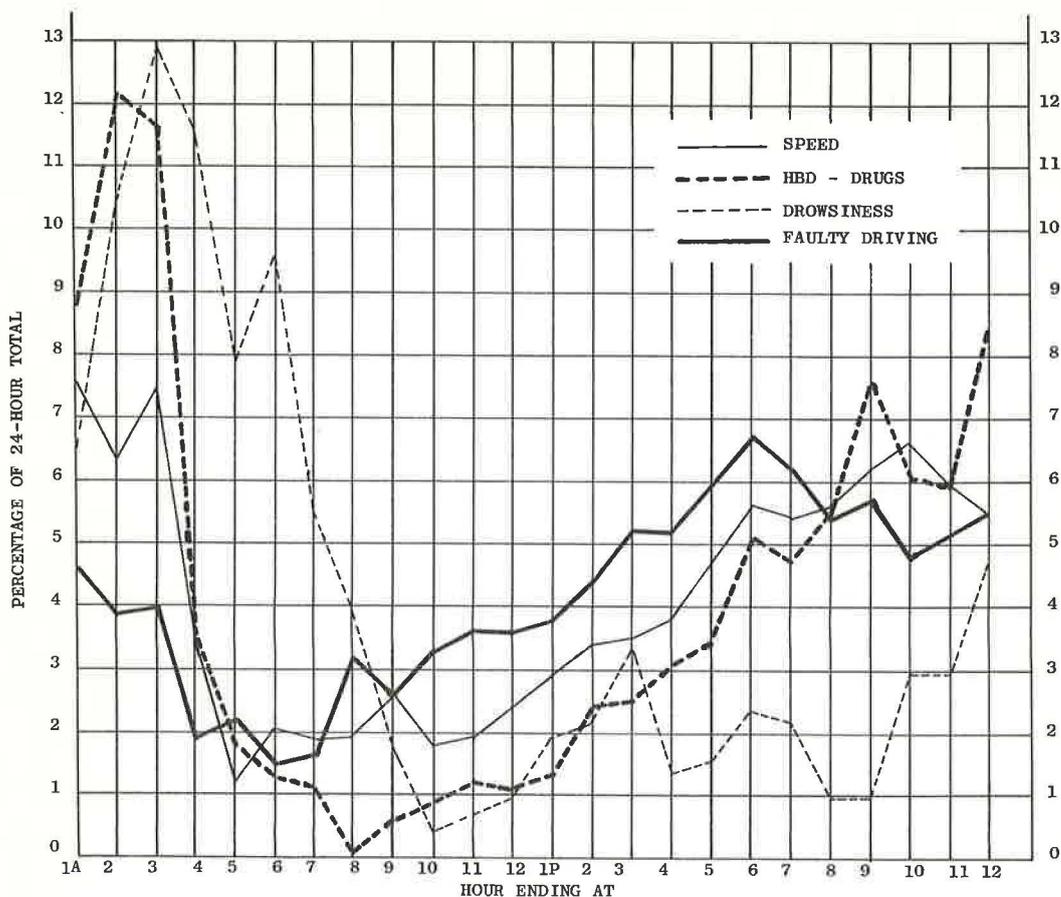Figure 3. Vehicular traffic and single-car accidents by hour of day.

Figure 4. Selected single-car accident causes by hour of day.

Figure 4 presents a graphical portrayal of accidents due to major causes. It may be pointed out that drowsiness as an accident cause reaches the highest point of the day at 3 a.m., with another substantial peak at 6 a.m. Some periodicity throughout the day is evident; other rises take place at 11 a.m., 3 p.m., and 10 p.m.

Speed, being almost as prominent in the evening hours as in those of the early morning, seems to be a function of light traffic volumes. Faulty driving, on the other hand, appears to be distributed more in accordance with traffic, reaching its daily zenith in the 5 to 6 p.m. rush hour. It is the lowest of the four major variables in the dangerous 1 to 3 a.m. period. One might conclude that it is at least partially evoked by the stress and emergencies of heavy traffic.

The general similarity of several of these curves suggests the thought that they could be manifestations of only a few underlying factors. To test this supposition, the technique of factor analysis was applied to five of the variables which show marked patterns of hourly variation (speed, drinking, faulty driving, drowsiness, and distraction inside vehicle) and one which should be considered random—unknown vehicle. The factor containing the latter cause proved to be nondescriptive.

The application of factor analysis, which presupposes linear relationships among the variables studied, may be justified in this case by starting the daily distribution at 5 a.m. instead of 1 a.m. Conditions approaching linearity are then visible. Even so, substantial variances are involved, and the results of the analysis should be regarded only as approximate.

The preliminary correlations were made by the rank correlation method, each hourly total of the variables being assigned a number representing its position in the daily scale. Three factors were extracted from these six variables. The first accounted for 62.9 percent of the total variance, the second 29.5, and the third 7.6 percent. After rotation of the axes, the loadings on the third factor showed an indeterminate pattern. Accordingly, it was excluded from further consideration.

The first factor is heavily constituted of drinking (0.981), speed (0.966), and faulty driving (0.717). Since the major elements represent law violations, this influence in single-car accident causation might be termed "rashness."

The second factor is composed mainly of distraction inside vehicle (0.710), drowsiness (-0.688), and faulty driving (0.585). This grouping suggests lack of attention as a general cause. To connote both diversion of attention and drowsiness, the term "inattention" is proposed for this factor.

An interesting sidelight to the development of these factors is the appearance of faulty driving in both. It is expected that a variable which is highly loaded in one factor will be minimally loaded in the other. The moderately heavy weights of faulty driving in both factors lead to the inference that it partakes both of rashness and inattention.

An examination of the victim data of single-car crashes in general follows the findings of previous parts of the study. It would be expected that the casualty rate in multi-car collisions would be higher than that in single-car crashes because of the greater apparent exposure. But this expectation is not borne out by comparison of the two. For 1961, the deaths per fatal accident in single- and multi-car crashes were much the same, 1.24 as compared with 1.29, respectively. Injuries per injury accident were higher in single-car mishaps—2.24 as against 1.90. This equivalence may stem from the presumed higher speeds in single-car accidents and from differences in the events making up the chain of collision in the two cases. When two or more cars collide, much of the energy of the collision is absorbed. When a car runs off the road and rolls over, however, there is a strong likelihood of multiple contacts of the occupants with objects inside the car and of ejection. A head-on crash with a relatively immovable object also produces greater recoil because of abrupt deceleration, than does a collison with an object which is free to move.

Of the major causes studied in the survey, it was found that speed, drinking and drowsiness produce the highest proportions of deaths and serious injuries. Faulty driving, while contributing heavily to accident totals, is relatively low as a cause of death and injury.

Part II of the study will deal with biographical items—occupation, credit rating, and 3-yr driving records among others—derived from samples of approximately 600 drivers each.

Part III is concerned with the scores of Dr. Donald Schuster's Driver Attitude Survey administered to the same samples.

An overall aim of the investigation is the evaluation of data derived from these three sources. Which one, or which optimum combination of the three, sheds the most light on accident causation? It is possible that some of the measures coming out of this investigation may be efficacious in identifying and predicting accident potential in drivers.

Work on these phases of the project is underway at present.

Discussion

J. STANNARD BAKER, Traffic Institute, Northwestern University, Evanston, Illinois.—
The idea of studying one-car accidents has much to commend it, especially when the objective is to try to determine contributing factors. Important problems are immensely simplified. The study which is the subject of these comments and the two proposed to follow it are, therefore, of great interest.

One-car accidents have been the subject of study before; for example, at Ohio State University as reported by Richard W. Bletzacker and Thomas G. Brittenham in "An Analysis of One-Car Accidents" (Highway Research Board 1958), and by these authors

and Robert F. Baker later in "A Study of One-Car Accidents." They have also been used for study of special aspects of accidents; for example, the present study of vehicle defects contributing to accidents by the Offical Swedish Council on Road Safety Research.

When one studies a report of research, he has to decide to what extent he can believe the data and conclusions presented. He has to do this on the basis of his own knowledge and experience. In this process, ideas develop and questions arise relating to the report and the research it represents. The following comments are some of the ideas and questions generated by study of "Causes and Characteristics of Single-Car Accidents."

Reason for Studying One-Car Accidents

The report implies that the reasons for studying one-car accidents are (a) their increase as a percentage of all, and (b) their severity.

We might ask whether this increase is due to some peculiarity of one-car accidents or to something else. One-car accidents are a much higher percentage of total accidents on limited-access and other divided roads. The percentage of travel on such roads in California probably has been increasing substantially in recent years. Therefore, may it not be that the increase in percentage of one-car accidents is due to improved roads rather than anthing peculiar to one-car accidents? If the road network is constant in quality, true one-car accidents theoretically should be proportional to the mileage traveled. A comparison by years of one-car accidents with miles driven should help us to know whether they are truly increasing in importance.

There is not a better and simpler reason than their apparent increase for studying causes of one-car accidents. In all true one-car accidents, there is no troublesome question of which traffic unit was "responsible" or of the interaction of two or more traffic units. The behavior resulting in injury or damage can therefore be imputed without hesitation to a specific car and driver. Contributing factors can then be deduced from available information with greater confidence.

Severity

How real is the apparently greater severity of one-car accidents? Is there anything about them that makes them more severe or could some or all of the greater severity be the result of less complete reporting of minor single-car accidents? In multi-car accidents, there are approximately twice the number of people involved per accident and, therefore, a much greater chance of some one person being injured or killed. This would lead us to expect greater severity for multi-car accidents. How then, do we explain the higher percentages of fatal and injury accidents among one-car accidents?

We can be sure that fatal accidents are completely reported. But there is good reason to believe that minor one-car accidents are much less fully reported than multiple-car accidents. When two or more cars are involved in even a very minor accident, it will be reported so as to be on record for claim settlement purposes. But a driver in a one-car accident of the same severity often may not take the trouble to report; it would only be an unwanted encumbrance on his driving record. Furthermore, in one-car accidents where there is no chance of filing claims for injuries, fewer injuries will be reported, especially fewer Class C injuries. For two years, damage to frequently repaired guardrails, posts and trees at a sharp right-angle turn in a state highway were regularly noted by the writer. This damage suggested that about 20 cars had suffered sufficient damage by collision with fixed objects to produce reportable one-car accidents. Yet official records showed only three acidents at this point, all involving two cars and none with injury. Can we not, therefore, question the conclusion that "drivers in 'solo' crashes are exposed to greater risk?" Might it not be equally possible to conclude "minor 'solo' crashes are less likely to come to the attention of the authorities?" Would it not be likely also that on rural roads reporting of minor one-car accidents would be less complete than in built-up areas because bypassers and those living nearby would be fewer and less likely to report and because patrolling is less frequent and so police are less likely to come on the accident without being summoned?

The surprising differences shown between single-car and other accidents of deaths per fatal accident and injuries per injury accident can perhaps best be accounted for by less need to report injuries in one-car accidents in which possible damage suits are far less likely to be involved. There seems to be no other really good explanation.

Definition of Single-Car Accident

The definition of single-car accidents as "those in which the sequence of events starts with a driver losing control of his vehicle" seems to be a theoretical one rather than the definition actually used. Was an actual determination made in each case that the driver "lost control," whatever that means? If so, how and by whom was the determination made? Actually three types of accidents seem to have been accepted as representing and defining single-car accidents: (a) "running off roadway" (Does this mean road or roadway as defined in "Manual on Classification of Motor Vehicle Traffic Accidents?"); (b) striking a fixed object; and (c) overturning in the roadway.

Classification by these types is simple and reasonably reliable. For the purpose of this study these groups would seem to be adequate.

But these three types of accidents should not be equated with true one-car accidents. True one-car accidents should surely not include those in which a vehicle runs off the road or hits a fixed object to avoid striking another vehicle. The fact that 5 percent of the single-car accidents are attributed to "unknown vehicle" suggests at least that a small percentage of the accidents in this study are not true one-car accidents.

Collisions with properly parked vehicles as well as with fixed objects and other objects should also be included among one-car accidents. The addition of "collision with parked vehicle" as a type of accident in the most recent edition of the "Manual on Classification of Motor Vehicle Traffic Accidents" will enable these to be separated from other two-car accidents and included with one-car accidents.

If leaving the road and crossing a narrow median to collide with an oncoming vehicle in the opposite direction is a true one-car accident—as it would be by using existing accident classifications—why would not crossing a barrier line to encroach on the path of an approaching vehicle also be a one-car accident? Then how about crossing a center line? Thus, there are real problems in defining one-car accidents. One should be careful in a definition to indicate exactly what are actually accepted and used as single-car accidents as contrasted with what might be theoretically included.

Cause Classification and Determination

The problem of classifying "causes" is formidable, especially if this has to be done from information supplied by others. It is obviously simpler for statistical treatment to have only one cause for each accident. Hence the idea of a "precipitating incident" which "triggers" the accident is convenient. But it is not easy to set up rules for dedermining which of several apparently co-existing factors triggered the accident. Such rules have almost built-in bias. For example, if preference is given consciously or unconsciously to law violations, some other factors are sure to be suppressed. Eleven "causes" including "miscellaneous" are used. These are used as though they were mutually exclusive. But are they really so? For example, do "drinking or drugs" not often contribute to accidents by way of "faulty driving?" Can drinking not also contribute through speed? Speed is one of the categories for which the title is "in most cases self-explanatory." Yet all accidents involve some speed. One wonders what speed is related to. The speed limit? Too fast for conditions? Is it determined by accident severity or by possibility of taking successful evasive action?

Under the circumstances one cannot avoid a definitely uneasy feeling that some, perhaps much of the variation among "causes" may be the result of methods of data reporting and interpretation. This would be especially true of minor differences.

Some Special Problems

Examining the data, therefore, raises some interesting questions that one would like to have answered.

For example, if mechanical failure and medical problems are both single "precipitating" conditions (they can hardly be called incidents), why do accidents caused by medical problems seem to be so much more severe than those due to mechanical failure? Surely, a driver would have more forewarning of a medical problem than of a mechanical failure. Presumably, except in rare cases, medical problems would be less difficult to cope with. Could it be that some medical problems were really causes of death and "injury" than causes of the accident? What would these figures look like if injury and death of drivers only were considered? Or passengers only if car occupancy were known well enough?

"The number of accidents caused by unknown vehicles is outstandingly high in cases in which the driver is by himself." Can this be a result of accident reporting? Information about the unknown vehicle in one-car rural accidents is almost invariably the report of a driver. It explains his accident. Would he not be more likely to explain it as an "unknown vehicle" when alone than when there were others in the vehicle who might not corroborate his report? The single occupant could never report this condition if the accident were fatal, but he would be highly likely to do so in a property-damage collision. Would this not possibly explain why, for unknown vehicles, the percentage of property damage accidents is highest for any cause and the percentage of fatalities is lowest?

What percentage of the one-car fatal accidents involved no passengers is not stated, but about 70 percent of all one-car accidents did so. Therefore, it can be assumed that in half or more of the fatal one-car accidents there would be no survivor to tell about the accident. Then in more than half of the one-car fatal accidents there would be virtually no way of knowing it if the "cause" was drowsiness, distraction inside, distraction outside or unknown vehicle. It would be difficult, in many cases, to detect drinking, faulty driving, mechanical failure, and medical problems. Consequently, underclassification would result in these categories and overclassification in speed, miscellaneous and perhaps adverse driving conditions. Many serious injury accidents would present the same difficulty because of loss of memory. Consequently, the relative seriousness of accidents related to various causes may be modified appreciably by the limitations of sources of information.

Of 164 fatal accidents, 39—or 24 percent—were attributed to drinking or drugs. Presumably nearly all were drinking. On the accident reports a certain number were indicated as having been drinking. We do not know in how many of these cases drinking was determined to be the "trigger" event and in how many this was rejected in favor of one of the other eleven categories. However, autopsies of drivers killed in accidents in New Jersey showed 58 percent had been drinking, Delaware autopsies showed 39, Maryland 62. In New Jersey, accident responsibility was "indicated" for 85 percent of the drivers who were alcohol positive on autopsy. It would seem, therefore, that on the basis of autopsies about half of the accidents might be considered as "caused" by drinking. This is twice the number indicated in the report. Does this mean that in perhaps a half or a third of the cases in California in which there was an indication that the driver had been drinking, those who classified the accident decided some other factor "triggered" the event? Does it mean that in California a great many fewer drivers had been drinking than on the East Coast? Or does it mean that reports of one-car accidents, like most accident reports, apparently do not detect and report nearly all of the drivers who had been drinking?

Possible Testing of Data for Accuracy of Reporting

We would like to have methods for testing the reliability of original data as easily applied as those for testing the significance of statistical inferences.

Lacking them, methods of collecting and interpreting the data must be carefully evaluated to appraise the value of conclusions drawn from them by statistical manipulation!

Examination of the conclusions in the light of past experience, logic, and other similar studies, as has been done above, may also suggest certain weakness in the original data.

Special comparisons can help test the data indirectly. A few of these appear in the report but when a "curious consideration emerges," deficiencies in original data are not suggested as a possible explanation.

An example of such a test will illustrate. Some of these "causes" would be randomly distributed with vehicle travel and not affected by time of day. The best example of this would be mechanical failure. There is no important logical reason why vehicles should fail more at night than by day or in the rush hour than at other times. Therefore, the hourly distribution of mechanical failures ought to correspond closely to hourly distribution of traffic. All single-car accidents were compared with volume of traffic by hour of day (Fig. 3), but this includes important causes, such as drinking and drowsiness, which our common experience tells us are influenced indirectly by hour of day. If percentage of mechanical defects by hour of day had approximately the same distribution as traffic volume, one would feel some confidence that data collection methods were reliable. However, if the distribution of mechanical defects as causes of accidents corresponded more nearly to that of drowsiness or had been drinking, one would be suspicious. Perhaps mechanical defects are reported to explain circumstances that the reporting driver would consider more culpable: intoxication and falling asleep.

Uses of Data

Data in this report do, in many respects, usefully confirm data from other sources. The distribution of accidents by age of driver corresponds well with data on all accidents from other sources indicating that age is not a significantly different factor in one-car accidents than in others.

When traffic-accident research reports are received by those responsible for some phase of preventing accidents, they are examined for clues as to what might be done differently as a result of new knowledge from the report. Research reports individually are rarely the basis for new lines of activity. This is no exception. But taken with other people's reports accumulating over many years, this will add to a better understanding of accidents and consequently of their prevention.

GENE MILLER, National Safety Council. — The opening remarks in the "Discussion" indicate good general knowledge of the importance of the single-car accident problem in terms of frequency, severity, and trend, and the analysis of the data, including preparation of charts and tables generally is excellent.

In any study of this kind, though, the conclusions should be of paramount importance. But the conclusions can be no more reliable than the data which are analyzed, and it is in this area that a question seems appropriate.

The report contains no statement bearing on the reliability of the basic data. There is a statement that the "preparatory work was a Patrol project," and that reclassification of the report "was done in the Patrol's Operational Planning and Analysis Division."

One introductory statement concedes that interpretation of the same data by different persons usually varies. And another statement concedes that biases in classifying probably do occur, and as a possible way of correcting for this, "each (of two) month's reports were coded by different personnel so that any bias in classifying might be mutually canceling." It would seem better to have set up controls to insure uniformity in classification.

The reputation of the California Highway Patrol apparently is offered as assurance of reliability of the data, and while it is quickly admitted that some of the best motor vehicle data now available are collected by the California Highway Patrol, it would still seem that a special analysis such as this one should contain evidence of unquestioned reliability and validity in the basic data. Instead, validity of the data is suggested in at least one place in the report because it confirms "a priori expectations."

It is even possible that the analysis should have been the second part in the series of studies, and that the first part should have been a determination of the reliability of

the data, or if necessary, the design and collection of new data under conditions sufficiently controlled to insure their validity and reliability.

The report states that "a new set of cause categories was devised in hope of identifying accident causes more clearly," and further, that "this new cause system was devised on purely a empirical basis, with no previous work to furnish guidelines." Again, a test or study of this new "cause system" might well have been the subject of the first in a series of studies, but apparently the study under review includes both some testing of the new cause system, as well as an analysis of data collected for the first time under the system.

Frequently in the report, references to the data include statements such as: "Statistics are not available," "If more data were available," "Recent data are not available," "It is assumed," etc.

This may appear to be undue concern over the basic data, but unless such data truly reflect the accident situation, and are properly identified and classified, the most advanced and precise analytical methods can only produce questionable results. If the analysis is based on data previously collected, and it is not possible to introduce additional reliability checks, perhaps the title of the study should be changed to "Reported Causes and Characteristics of Single-Car Accidents."

Regarding the author's new "cause system," I feel that he should be commended for his efforts along these lines. Committees have struggled with this problem for a long time, but they have been hampered in their efforts by a requirement that such a system have majority acceptance. This has ruled out experimentation, and has kept any agreed upon system simple to the point of being almost useless as far as accident analysis is concrened.

But the author's cause classification system raises questions about the techniques employed to insure proper classification of the accident circumstances. For example, he comments that data on speed, prior to impact, are derived from participants' and witnesses' statements, and from estimates by investigating officers, and that the data "are necessarily of a low order of reliability." But he then lists speed as one of the cause items, and includes analyses of it throughout the entire report, without any further evidence of the reliability of this statistic.

The same concern exists regarding the definition of the other cause factors. For example, how is drowsiness determined? Were doctors consulted regarding the medical problems category? Was HBD data taken from reports on accident forms (long suspected of being unreliable), or was it determined from autopsies, blood, breath, or behavioral tests? The literature suspects that because of the stringent requirements for evidence in court, when in doubt about the involvement of alcohol, investigating officers will avoid assigning accidents to this category. The drug item may be equally questionable; and wouldn't it be desirable to separate HBD and drugs?

Faulty driving would seem to contain the ingredients for wide variations in the actions to be included, and for possible nonuniformity in the data. What does the category contain, and how was it determined? Was mechanical failure determined by a mechanic? What was the basis for determining that vehicle design was faulty, and who made this diagnosis?

Distraction inside and outside the vehicle should contribute to a better understanding of accident causes, but this item, as well as some of the other items in the new cause system are not generally included on routine accident reports. Were special supplementary investigations made to get this information?

Even more important than questions about the definition and source of the cause items is the basis for assigning a single cause to each accident. In view of multiple causation of most accidents, and general agreement that several factors must co-exist to produce an accident, why was only one cause selected to describe each accident? And what criteria were used for selection?

Admitting a possible advantage for analysis purposes of describing each accident with a single cause, there must be many where more than one cause could as easily have been selected. For example, if a driver was distracted while speeding, and ran off the road, what would be the criteria for selecting one or the other as the single cause? Neither one of these causes by itself may have produced the accident; each may be equally important.

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On sex of driver, the author quite properly attempts to equalize the exposure of male and female drivers, introducing travel data from an earlier department study. The technique is generally satisfactory, but conclusions should be handled cautiously since quantitatively equal exposure is not necessarily quantitatively equal. A study by National Family Opinion showed that while males did 73 percent of all driving, their proportion increased to 76 percent in rural areas where the mileage death rate in 1961 was 6.9, and their proportion was down to 69 percent in urban areas where the death rate was only 3.1. The male proportion of driving is also higher after dark when the mileage death rate is three times higher than during the day. In rural areas at night, when death rates are the highest, 80 percent of the driving is done by males, according to this survey.

It is possible that if the quality of exposure could be equalized as well as the quantity of exposure, women may not prove to be better drivers than men. They may even prove to be poorer drivers than men, a fact that could influence the approach to this phase of the problem.

In the factor analysis, since drinking, speed, and faulty driving all represent law violations, use of the general term "rashness" seems quite mild. Possibly a term such as "irresponsible driving" might be more descriptive.

And, since there is reason to suspect that males and females drive differently, drive in different environments, and have different accident experiences, it seems possible that combining them into a single factor analysis might fail to reveal significant differences in the management of the motor vehicle by each sex.

The motor vehicle accident problem is a highly complex one that I feel will not be corrected with a generalized approach. Every opportunity should be used to reveal contributing cause data in as detailed and specific form as possible, again keeping in mind that the principal purpose for studies such as this one should be to identify information which can be useful in preventing accidents.

Unfortunately, studies such as this one, which have great potential for revealing new and useful information on motor vehicle accidents, often must be done with data already in existence, or under other handicaps arising out of data deficiencies. The comments in this report on the study are not intended to be critical of the study itself, which in general is excellently done, but rather are made with the fervent hope of offering encouragement for upgrading the quality of source information.

C. F. McCORMACK, U. S. Bureau of Public Roads.—I sympathize with Mr. Penn. He has encountered the continuing difficulties of accident cause investigators attempting to utilize data and opinions provided by routine accident reports of police officers not fully trained in accident investigation.

Deficiencies in basic data describing circumstances surrounding, actions during, and participants in the accidents surveyed have lead the researcher into some rather questionable observations. (I prefer not to call them conclusions.)

According to the 1961 Inventory of Traffic Safety Activities, California had a reporting ratio of 42 nonfatal accidents to each fatal accident. The true reporting ratio is probably more than three times this much according to an analysis of accident reporting in HRB Bulletin 158. The 1961 ratio ignores as inconsequential, accidents resulting in low property damage even though such accidents may be of significance in discussing contributing causes of accidents, particularly those during inclement weather. Thus, the sample can be said to be too small although the number of accidents studied is twice what statistical analysis required.

The analyses discussed are predicated on conclusions reported by traffic officers who investigated the accidents and interpretations of causative circumstances by personnel of the central office who set up the data for analysis. Both are judgment procedures and both can lead to erroneous results because of the unreliability of judgment decisions made by a large number of individuals. This is particularly noticeable in observations as to speed and faulty driving. Both of these terms, if defined at all,

must be loosely defined and, therefore, subject to wide variation in their assignment as actions contributing to accidents.

Several observations are at variance with what has been accepted in the past. While these variances do not make present observations wrong, they certainly require more documentation than the data upon which they are based will permit. As an example, the report stressed the purported fact that solo crashes are more severe than multiple-car crashes. While not attributable directly to the author, the implication that coffee breaks are likely to reduce driving efficiency, certainly is at variance with the "frequent-stop" policy safety promoters have been urging on motorists.

Not all observations are based on the source data available to the study. What, for instance, leads to the observation that male drivers are unsafe because they have aggressive tendencies while female drivers lack manipulative skill? Are all distractions within the vehicle attributable to other occupants of the vehicles? Should not there be consideration of such actions as lighting cigarettes, tuning radios and fumbling in glove compartments? It would appear that the author may be jumping-the-gun on the second and third parts of his research.

Relating sex of drivers to miles driven is an advance over most studies of this type. However, simple miles driven are not a complete measure of exposure. A more accurate measure would be miles driven related to daylight and darkness, bad weather, and highway and traffic conditions.

Perhaps some of these difficulties will be overcome in the next two parts of the study dealing with biographical data and attitudes of drivers.

I hope these comments do not discourage Mr. Penn—rather, I hope, they will encourage him. In fact, Mr. Penn is in a unique position. Gathering together into one highway transportation agency, as they have in California, the department of highway patrol, the department of motor vehicles, and the division of highways should permit more thorough examination of all conditions and circumstances involved in motor vehicle accidents. Specifically, data on driver characteristics and highway and traffic conditions should be more readily available to him in the continued examination of highway accidents.

HUGH S. PENN, Closure.—There were obviously too many points raised by the panel to discuss each specifically. However, to cover some of the more telling criticisms, I might discuss two of the topics raised by Mr. Baker. One concerns tests of the temporal distribution of some of the variables studied. While the work was being done, tests of randomness were made of the variables, but because the report was originally intended for local consumption, a statement regarding this phase of the investigation was not included. It can be made part of any future versions of the study.

Mr. Baker's remarks about single-car accidents possibly being a function of highway improvements is quite apropos. It is quite conceivable that when drivers cannot find cross traffic to run into, they will collide with guardrails, bridge abutments and the like.

In general, the criticisms of the panel covered three general areas: the limitations of the accident report as a source of information, the reliability of this study, and the nonuse of population values in evaluating some of the findings of the study.

I have worked with accident reports for many years, and I agree wholeheartedly with criticisms of them as a source of data. But what is the alternative? Virtually the only other means of obtaining accident information are costly, time-consuming, on-the-scene investigations. Few agencies are equipped or funded to make such investigations. At present, virtually all approaches to the traffic problem utilize the accident report in one way or another.

On the score of reliability, I would like to observe that I, and other persons who have looked into the subject, know that policemen tend to report events in stereotypes. This should not be interpreted as meaning that guardians of the law are not capable of

independent thought but that the list of approved motives of public conduct is rigidly defined, and many of the categories become catch-alls.

This study was based on an attempt to get behind these stereotypes and to see whether a more revealing view of accident causation might not result from using a fresh cause schedule.

The work was done as carefully as possible. Those supervising the coders were given written instructions, training sessions were held, and difficult decisions were brought to me for determination. As is the case in any endeavor using people, all with varying backgrounds and capabilities, it is certain that there will be minor inconsistencies. However, this is true of the more conventional accident statistics: they are derived mainly from the accident report; they are coded, tabulated, and summarized; and then are received as authoritative.

In regard to the use of population values to evaluate research findings, I assure you that I would be most happy to use them if they were available. Many of the statistics presently compiled seem to have little or no relation to accident causes. For example, in California, we compile every year the number of drivers in accidents who have valid licenses. But if one looks for, say, the annual mileage of 17-year old boys, or the number of vehicular occupants exposed to death or injury in crashes, or even the number of women in the driving population, he will look in vain.

I should like to thank the members of the panel for their thoughtful review of this part of the study. However, I feel that many of the weak points they have pointed out are due to deficiencies in the material available for making such studies.

A Factor Analysis of Accident Records

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If statistical summaries of traffic accidents published yearly by most states and by the National Safety Council are interpreted in the obvious way, conclusions are likely to be erroneous because the age or sex of the driver may be attributed to extraneous factors such as the proportion of driving done in rural areas where high speeds are common, or to similar factors such as night driving, conditions that prejudice the results in terms of the drinking driver, and related characteristics of the driver, his vehicle, and his environment. For this reason, the factor analysis procedure has proved to be useful as a means for better understanding of a multivariable situation, as the traffic accident is.

In this study, eight major factors have been analyzed for their contribution to accidents. In addition, a separate factor analysis was conducted on a random sample of 1,000 fatal accidents. An elementary linkage analysis was also supplied to the data, primarily to group individuals into various classes, and this adds confidence to the results obtained.

It was found that most of the common variance among the 23 variables studied is accounted for by 8 independent factors. The report on this investigation explains the nature and the strength of the association of these eight factors with the accident event. It is quickly admitted that the inclusion of still further variables could result in other factors being identified with traffic accidents, as well as with a better definition of the ones that were isolated. It is important to recognize that particular combinations of a number of variables are probably of much greater importance in understanding the accident event than the effects of variables taken singly or in pairs.

•ALTHOUGH most people are aware that it is erroneous to think of accidents as having a single cause, most of the analysis of accident data is congruent with a single-cause theory of accidents. Consider the yearly statistical summaries of traffic accidents that are published annually by most states, and published for the nation by the National Safety Council. These tabulations convey the magnitude of specific problems, such as accidents involving excessive speed, alcohol, or pedestrians, and convey changes in the general accident problem and specific accident problems from year to year. However, it is difficult to make valid inferences regarding causation from such tabulations of one variable at a time. In addition, such summaries often include cross-tabulations conveying the relationship between two factors of interest, such as sex of drivers and number of accidents involving high speeds or alcohol. Although we may be aware that if we interpret such tables in the obvious way our conclusions are likely to be erroneous—sex of driver may be related to extraneous factors, such as the proportion of driving done in rural areas where high speeds are common, or to factors such as the proportion of driving done at night when drinking is more common—out methods of analysis typically do not take into account more than two variables at at time. Similarly, our studies relating characteristics of drivers, vehicles, and highways to accident rates typically treat variables two at a time. With such methods, only interpretations based on a

single-cause theory (tempered by judgment) are possible. There is need for the application of methods of multivariate analysis which are congruent with a multiple-causation theory of accidents. In the same way that the development of punched-card methods made it possible to record and tabulate data on many variables, the availability of modern computers makes possible multivariate analysis of such data.

Only a few applications of multivariate methods have been reported. Multiple-correlation and partial correlation methods have been used to a limited extent, such as to study the effects of roadway characteristics on the accident rates of sections of highway in Oregon (1, 2). Goldstein and Mosel (3) factor-analyzed attitude items and related the factors to self-reported accidents and violations, and Versace (4) factor-analyzed a portion of the Oregon data. There seems need for a multivariate attack on the large quantity of data available in accident records. The purpose of this study is to make a small beginning in that direction.

<div align="center">PROCEDURE</div>

Accident Data

With the cooperation of the Michigan State Police, punched-card records were obtained on the fatal and injury accidents in Michigan for 1957, over 18,000 in total. Since it was impossible to analyze all of the data recorded for such accidents, 23 variables were chosen such that each accident could be coded by the presence or absence of each of 23 characteristics, and such that the characteristic not be so rare that very few accidents would be coded for it, or so common that almost all accidents would be coded for it. A conversion program was prepared so that the computer would make a card for each accident, recording only the data on these 23 variables. The characteristics are given in Table 1.

Reduction of the data to this form certainly leaves out much information of importance. In addition to data not recorded at all, the data on the variables chosen were not complete. For example, drivers' age was reduced to a simple dichotomy, whether driver under 25 was involved or not; information regarding ages over 65, or the age of the other driver, if any, was lost. A more complete analysis to recover such information is planned in a later study.

Factor Analysis as a Method

The principal multivariate method used in this study was a factor analysis of the correlation coefficients among the 23 variables which had been chosen and coded. This procedure was developed in the 1930's by Thurstone (5) and others for the study of psychological abilities. The basic idea of factor analysis can be illustrated by its most important early application. A large number of tests existed measuring various aspects of mental ability. Most of these tests had high correlations with some of the others. It was reasoned that there may be only a small number of basic factors of mental ability, and that each of the many tests was measuring one or more of these factors. Factor analysis was a means of deriving such factors inductively from the correlations among the tests. A small number of such factors were found, which made a basis for the further development of the theory of mental ability. The various intelligence tests in use today, and the interpretation and use of these tests, has been heavily influenced by factor analysis. Factor analysis has since been applied to diverse areas, and has proved its usefulness both in providing a means for better understanding of the variables involved, and in the practical development of efficient measuring instruments.

Correlation Matrix

The data with which factor analysis begins are given in Table 2. The table of the correlation coefficient of each variable with every other variable is known as a correlation matrix. In the case of dichotomous variables, the correlation coefficient reduces to what is called a phi coefficient, ϕ. It is related to the chi-square statistic,

TABLE 1
ACCIDENT CHARACTERISTICS STUDIED

1. Female driver involved or not
2. Driver under age 25 involved or not
3. Driver with less than one year's experience involved or not
4. Fatal accident or not
5. Alcohol involved or not
6. Accident at intersection or not
7. More than one vehicle involved vs single vehicle
8. Vehicle other than passenger car involved or not
9. Speed greater than 50 involved or not
10. Vehicle defect recorded or not
11. Out-of-state vehicle involved or not
12. Vision obscured or not
13. Daylight or not
14. Weather clear or cloudy vs other weather
15. Surface dry or not
16. Paved road or not
17. Road defect recorded or not
18. State or U. S. highway or not
19. Traffic control devices present or not
20. Open country vs built-up or urban area
21. Weekend (5 pm Fri. 12 pm Sunday) or not
22. Rush hour (7-9 am or 4-6 pm) or not
23. Summer or not

χ^2, commonly used to test for a significant relationship between two dichotomous variables, as follows: $\phi = \pm \sqrt{\chi^2/N}$, where N is the sample size, and the sign of ϕ reflects a positive or negative relation between the variables.

To interpret Table 2, observe for example the top of column 1, which corresponds to "Female Involved." We see that accidents in which a female is involved are slightly less likely to involve a driver under 25; accidents involving a female are less likely to have a mention of alcohol on the accident record; they are more likely to be accidents involving more than one vehicle; they are more likely to involve an inexperienced driver, etc. The coefficients in Table 2 are based on 17,400 accidents (the number remaining after cards with incomplete data were eliminated, and when the number had been further randomly reduced to facilitate feeding cards into the computer in batches of 200), so that even very small coefficients are statistically significant. Examination of the matrix may reveal relationships of interest, but it is beyond human capacity to comprehend the matrix as a whole. Factor analysis may be viewed as a means of summarizing all of these coefficients in a way that the mind can grasp.

Methods of Analysis

The use of factor analysis is not an exact science, and opinions differ on a number of questions of procedure. The author's approach to the use of factor analysis is an empirical one; results which hold up over several methods of analysis are accepted, while those that do not are regarded as questionable. Accordingly, additional analyses were carried out, and their results used to guide the interpretation of the primary analysis.

For the primary analysis, factors were extracted by the principal components method (6), and rotated by the quartimax method (7) and the varimax method (8). Since the two methods yielded almost identical results, only those for the quartimax method are reported. Since these methods require orthogonal (independent) factors, the biquartamin method (9) was also applied. Again, almost the same solution was obtained. Since criteria for the number of factors to include in the rotation process did not lead

TABLE 2
INTERCORRELATION MATRIX

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																							
2	-012																						
3	-148	-060																					
4	+111	+039	-083																				
5	+143	+068	-056	+470																			
6	+102	+207	-100	+024	+017																		
7	-073	+079	+107	-075	-045	-005																	
8	+168	-071	-304	+126	+131	+056	-039																
9	-026	+023	+050	+040	-024	+020	+119	+069															
10	+011	+018	-045	-036	-093	+047	-030	+037	+035														
11	-027	+027	+058	+031	-011	+019	+108	+043	+603	+029													
12	+006	-036	+045	+063	+123	-043	+048	-013	-022	-270	+016												
13	+009	-007	-070	+022	+025	+002	-052	+027	-224	+038	-158	-058											
14	+009	-038	+043	+153	+210	-043	+069	-027	-045	-189	-004	+380	-058										
15	-050	-002	+037	-206	-134	-026	+212	-053	-028	+072	-014	-055	+002	-038									
16	-017	+017	+001	-005	-012	+031	-011	+011	+036	+015	+033	+005	-019	-012	+002								
17	-052	-012	+000	-048	-037	-034	+042	-054	+003	-023	+021	+015	+016	+035	+077	-016							
18	-016	-020	-027	+014	+111	-010	+041	+021	-007	-020	+011	+034	-005	+070	+081	+001	+033						
19	-053	-015	-063	+099	+270	-017	-041	+087	+001	-016	+025	+017	+016	+039	-016	+029	+011	+107					
20	+001	+039	-021	+011	+014	+038	+045	+120	+105	+038	+199	-030	-012	-040	+012	+008	-014	+045	-008				
21	+076	-042	-143	+061	+065	+006	-034	+342	-006	+026	-026	-012	+025	-019	-041	-018	-034	-005	+030	-019			
22	-067	+040	+110	-018	+015	-007	+023	-090	-015	-018	-030	+008	-001	+027	+034	-001	+005	-006	-088	+012	-064		
23	+002	-048	+014	+020	+204	-070	+129	-031	-081	-138	-033	+232	-039	+397	+116	-017	+043	+162	+054	+016	-016	+015	

to a clear decision in this case, solutions were obtained for six through ten factors. Although factors seven and eight were of a doubtful status on the basis of the additional analyses below, it was felt that the eight-factor solution was most meaningful. Since the factor loadings on the first six factors were almost the same regardless of the number included in the rotation or the rotation method used, these loadings are considered reliable.

Results

The results of the factor analysis are given in Table 3. The principal results are the factors, indicated by roman numerals. The entries in the table, the factor loadings, measure the correlation between each variable and each factor. The person not acquainted with factor analysis will not be seriously in error if he thinks of a factor as a cluster of accident characteristics which hang together over many accidents, and the factor loadings as a measure of the degree to which a particular characteristic hangs together with the cluster. A negative loading then measures the degree to which the absence of a characteristic is associated with the cluster. Factor loadings smaller than 0.05, and decimal points, have been omitted to make the table easier to read. Each factor is defined by the variables on which it has the highest loadings, either positive or negative.

The first factor characterizes features of the road where an accident took place--whether it was paved, whether traffic control devices such as signs or signals were present, whether it was a state or U. S. highway, and whether a road defect was reported. The smaller loadings on "vision obscured" is reasonable, since vision may be obscured by roadway features; likewise the small loading on speed. This factor differentiates modern high-type highways from secondary roads and streets and will be referred to as "good roads."

Factor II clearly refers to the weather in which an accident took place, with loadings on variables 9 and 11 which describe the weather. The smaller loadings on 13 (vision obscured), 20 (summer), and 7 (speed) are consistent with this interpretation. This factor will be referred to as "weather."

TABLE 3

FACTOR ANALYSIS OF TOTAL ACCIDENTS[a]

Characteristic	Factor[b]							
	I	II	III	IV	V	VI	VII	VIII
1. Female	09	07	-45	-	-18	21	-	-17
2. Age under 25	-06	-	14	09	05	73	-	-13
3. Alcohol	07	-13	55	-07	-	-24	26	-05
4. Intersection	08	-06	-11	68	-26	06	10	-16
5. More than 1 vehicle	19	-	-09	80	-	06	-	-10
6. Experience 1 yr	-	-	-11	-	-	73	-	-
7. Speed over 50	18	-21	-	-17	49	13	11	-19
8. Daylight	-	-10	-77	13	-	-05	-	13
9. Clear or cloudy	-	-85	-	-	-	-	-	-05
10. Road defect	55	-	-08	-	16	-	08	-
11. Dry pavement	-	-84	-	-	-	-	-	-
12. Paved road	73	-	-	-	-08	-	-	07
13. Vision obscured	-22	43	-07	14	09	-	10	-
14. Traffic control device	72	-	-	20	07	-	-	-
15. Open country	-	06	-	-26	67	-	-	-
16. Vehicle defect	-	-08	09	-	-	18	-	88
17. Fatality	-	-	12	-06	23	-	-30	-22
18. Out-of-state vehicle	-	-	-	28	49	-06	-08	12
19. Trucks, etc.	-10	-	07	-	55	20	-44	17
20. Summer	-11	-30	-20	10	23	-	40	10
21. Rush hour	-	-	-63	-	-	-15	-	06
22. Weekend	-	07	18	05	-	-	73	-
23. State or U. S. highway	58	09	-	16	42	-07	-05	-

[a]Decimal points and coefficients less than 0.05 omitted for ease of reading.
[b]Factors are I = roads, II = weather, III = night, IV = conflict, V = rural, VI = youth = inexperience, VII = weekend, and VIII = vehicle defect.

The interpretation of factor III is not so obvious. Accidents characterized by this factor are at night (or dusk or dawn), not during the rush hour, alcohol is likely to be involved, but not female drivers (who presumably do more of their driving during the day). The smaller loadings fit into the pattern—summer because of longer daylight hours, weekends because of more night traffic on weekends. In interpreting factors it is advisable to refer back to the correlation matrix and to compare the correlations between variables with loadings on the factor. When this is done it is seen that even the small loadings, such as those on age less than 25, and fatality, are consistent with the overall pattern. Although one might consider a designation such as "time of day" for this factor, it seems that the narrower designation of day vs night characterizes this pattern of characteristics more accurately. This factor will be referred to as "night."

Factor IV characterizes accidents which involve more than one vehicle, are at intersections and involve a vehicle other than a passenger car (in most cases, a truck). We find smaller loadings on variables 18 (out-of-state vehicle) perhaps partly because many out-of-state vehicles are trucks, 15 (not in open country), 14 (traffic control devices present), and 23 (state or U. S. highway). Reference to the correlation matrix verifies this pattern; we see, for example, that truck accidents are more likely to be at intersections, and particularly to involve more than one vehicle. (Of course, whether the cause is trucks per se or their traffic exposure is not answered by these correlations.) Clearly this factor implies something like traffic friction among vehicles, or interference in traffic movement, rather than just traffic congestion. This factor will be designated "traffic conflict."

Factor V yields a quite clear interpretation, characterizing accidents taking place in open country rather than urban or built-up areas, with high speeds and out-of-state vehicles more frequently involved. The smaller loadings, as well, point to a designation of this factor as "rural."

Factor VI has large loadings only on age under 25, and experience less than one year. The small negative loading on alcohol reflects the fact shown in Table 1, that alcohol is less likely to be associated with inexperienced drivers. The loading on female similarly reflects the greater likelihood of females being associated with experience less than one year. For want of a better term, this factor will be referred to as "youth-inexperience." It would seem that further data would be needed (or even analysis of male and female drivers separately) in order to make a clear interpretation of this factor.

Factor VII seems to characterize "weekend" accidents. The relation between weekend and summer, trucks, and even alcohol, are verified by the zero-order correlations in Table 1. However, that of variable 17, fatality, is not so verified although this loading is almost identical for the verimax solution, and holds up over different rotations. It may be that when other factors related to fatalities and weekends are adjusted fewer fatal accidents will be found on weekends than would be expected. Until verified by appropriate analysis, however, such relation appears doubtful. One might expect a loading on out-of-state vehicles as well, but this presumably does not occur because a large number of trucks are out-of-state vehicles, and few of these are on the road on Sundays. Perhaps Sundays need to be treated separately rather than treating the weekend as a whole. This factor should be interpreted with caution. It accounts for less variance than the previous ones, and was included in the rotation because the other factors emerged more clearly with it than without it.

Factor VIII, "vehicle defect," reflects the fact that vehicle defects do not seem to be strongly related to any of the other variables. Including it in the rotation allowed it to emerge by itself without its small relationships slightly disturbing the definition of the other factors. The amount of variance associated with this factor was quite small, and vehicle defects are reported in only a very small portion of accidents.

Additional Analyses

Since fatal accidents are of particular interest, a separate factor analysis was carried out on a random sample of 1,000 fatal accidents. (A sample of 1,000 non-fatal accidents was also analyzed. However, since about 94 percent of all accidents

TABLE 4

FACTOR ANALYSIS OF FATAL ACCIDENTS[a]

Characteristic	Factor[b]							
	I	II	III	IV	V	VI	VII	VIII
1. Female	-	-	-55	-	-	10	07	-
2. Age under 25	-	-09	23	12	-	61	-07	-41
3. Alcohol	05	-	24	-	08	-16	63	16
4. Intersection	-10	-14	-14	76	-18	-	10	-
5. More than 1 vehicle	21	05	-10	78	16	06	-08	-
6. Experience 1 yr	-08	-	-08	-	-	73	-	16
7. Speed + 50	19	-26	-05	-05	23	35	30	-06
8. Daylight	-11	-	-71	16	06	-	-18	06
9. Clear or cloudy	-	-85	-	-	-05	-	-	-
10. Road defect	-50	09	-10	08	20	09	07	-18
11. Dry pavement	-	-83	10	06	10	06	-	-
12. Paved road	70	-11	07	-08	-06	-	-08	-
13. Vision obscured	-16	51	11	15	08	23	-10	-
14. Traffic control device	75	-	-	11	-	-	10	-
15. Open country	06	-	-21	-25	64	15	-	-25
16. Vehicle defect	-	-	-09	-11	06	30	-	78
17. Fatality	-	-	-	-	-	-	-	-
18. Out-of-state	07	-06	05	27	57	-11	-12	10
19. Trucks, etc.	06	-	14	37	16	-	-54	32
20. Summer	-20	-20	15	12	48	-14	09	14
21. Rush hour	-	09	-66	15	-	-08	-	-
22. Weekend	-	08	09	13	-	17	62	-
23. State or U. S. highway	64	13	-	18	36	-09	-	-

[a]Decimal points and coefficients less than 0.05 omitted for ease of reading.
[b]Factors are I = Roads, II = weather, III = night, IV = conflict, V = rural, VI = youth = inexperience, VII = weekend, and VIII = vehicle defect.

were non-fatal, the results were essentially redundant with that of the total sample.) The results for the fatal accidents are reported in Table 4. It is obvious that the factorial structure is very similar to that of the total sample. The general description of the factors based on the total sample would apply almost equally well to the fatal sample. The pattern of loadings is very similar for factors I through VI, but not very close for factors VII and VIII. As the similarity of the factor analysis results implies, the correlation matrix for the fatal accidents was similar to that for the total sample given in Table 2; therefore, the matrix is not included for the fatals. Only a few of the correlations are sufficiently different to be of particular interest. The correlations of experience less than one year showed some suggestive changes from total sample to fatal—with speed, from -0.005 to 0.106; with alcohol, -0.100 to -0.027; with weekend, -0.007 to 0.072. Age less than 25 showed changes in the same direction, although to a lesser degree. The suggestion of a difference in the pattern of relationships between these variables for fatal vs non-fatal accidents points out the need for further analysis, taking account of the relations of these variables to others.

Since the mathematical model of factor analysis assumes linear relationships between continuous variables, its application to dichotomous variables introduces both theoretical and practical problems. Although it has proved useful in the analysis of such data (such as with test items which are answered right or wrong), the effect on the phi coefficient of differences in marginal proportions can lead to difficulties (10). One way that has been used to overcome this difficulty is to use ϕ/ϕ_{max} as a coefficient, where ϕ_{max} is the maximum ϕ possible for the given marginals. Samples of 1,000 fatal accidents and 1,000 non-fatal accidents were factored using this index. Again, the same factors were obtained, and in general the relative magnitudes of the loadings were similar. Since this index has undesirable mathematical properties that can lead to anomalous results in certain cases (11), the original analysis is preferred since the results are in general the same.

Another method of analysis, quite simple computationally and very different in mathematical model, was also applied. Elementary linkage analysis (12), although intended primarily to group individuals into types on the basis of agreement scores, can be used to group variables into types on the basis of their intercorrelations. This

method, applied to the matrix of the total sample, gave six types corresponding to factors I through VI. The variables in each type corresponded to the variables having the highest loading on the corresponding factor.

These secondary analyses, while adding relatively little to computer time, added considerably to the writer's confidence in the results. Other methods, more congruent with the dichotomous nature of the data and with other implicit hypotheses about its structure, are being tried out. To date, none has yielded a really satisfactory solution.

DISCUSSION

It seems clear that most of the common variance among the 23 variables can be accounted for by eight independent factors. Or, to put it informally, the 23 accident characteristics hang together in eight independent clusters.

Factor I, "good roads," is made up of characteristics in which modern high-type roads differ from secondary roads and streets. Although speed and multiple-vehicle accidents are related to this factor, it, to a great extent, stands by itself with a clear interpretation.

Factor II, "weather," although related to speed and time of year, is similarly clear in interpretation.

Factor III, "night," summarizes many characteristics on which the frequency of accidents is different at night than during the day. Most of the accident characteristics that are intrinsically of interest—age, sex, alcohol, speed, fatalities, etc.—are related to this factor. Although this factor may be viewed as a conglomerate—further research may characterize better the ways in which day and night accidents differ—it seems reasonable to think of this factor as a basic characteristic of accidents.

Factor IV, "traffic conflict," is characterized by intersections, more than one vehicle, and to a lesser extent, trucks. It is also related to variables of interest, and, more than the previous factor, might be viewed as a conglomerate that future research may clarify. But certainly this group of characteristics is important in the study of accidents. Some may prefer some other term like traffic interference or friction to conceptualize this factor.

Factor V, "rural," characterizes accidents that take place in rural areas rather than in urban or built-up areas. This seems clearly interpretable as a basic characteristic of accidents.

Factor VI, "youth-inexperience," should not be interpreted as a basic factor in the same sense as the previous ones. Except for sex, age under 25 and experience less than one year were the only purely human characteristics among the 23 included, so it is natural that they cluster together. This factor is of interest, however, and the suggestion of a different pattern for fatal and non-fatal accidents warrants further research.

Factor VII, "weekend," is of a very doubtful status. It was "underdetermined," i. e., it had too few variables with high loadings to determine it accurately, although its relation to alcohol at least is of importance. Lumping the whole weekend together may be erroneous—Sunday is certainly different for trucks, and probably for other characteristics.

Factor VIII, "vehicle defect," tells us little, except that vehicle defects are not strongly related to any other accident characteristic included in the study. Therefore, it came out pretty much by itself.

Interpretation of Factors

It is important to point out what these results may mean in practice, and what they do not mean. As in other applications of factor analysis, the results may help in conceptualizing the problem. The author, as a psychologist, is primarily interested in the human factors in accidents. However, the characteristics which might be regarded as human characteristics did not come out in factors by themselves, but clustered with non-human characteristics as well. It seems clear that study of human characteristics must take account of related non-human characteristics.

It was pointed out in the introduction to this paper that studies comparing accident rates or accident characteristics may lead to erroneous conclusions because of failure to control for extraneous variables. It is impossible to control for everything, and it can be quite confusing to decide what to control for and how control may be achieved. The factors obtained in this study are at least some important ones, and variables of interest may be related to some of the accident characteristics included in this study. By examination of the factor loadings (especially accompanied by examination of the correlation matrix), one may be able to identify some major variables and find some ways of control for them. For example, studies involving alcohol should control for at least the factors alcohol was found to be related to: night, youth, weekend, and perhaps weather. Similarly, if one were to compare summer accidents to those occurring the rest of the year, it is seen that this characteristic is related to seven out of the eight factors, making conclusions about summer accidents very likely to be influenced by extraneous variables.

Misinterpretation of Factors

It should be pointed out that these factors do not represent basic causes of accidents; they concern relationships among accident characteristics, and say nothing directly about causation. It cannot be concluded that these are the most important factors regarding accidents (as will be seen below, Factor I may be of minor importance); the factors represent merely clusters of characteristics commonly recorded in accident records. (If hair color, eye color, and skin color had been included in the analysis they would have clustered together as a factor, even though they are obviously not of importance.)

Also, these factors only summarize the data included in the analysis. The characteristics included in this study were judged to be the most important ones which could be obtained unambiguously from accident records in a form suitable for factor analysis. Including more characteristics would presumably result in additional factors in addition to better definition of the ones obtained.

Further Research Needed

It seems clear that this study should be regarded as a beginning. The need for the analysis of further variables, and further information on the variables studied, seem obvious. Also, factor analysis only takes account of the correlation between pairs of variables. It is reasonable to hypothesize that it is particular combinations of several variables that are important, over and above the effects of variables singly and in pairs. It is hoped that fruitful analysis methods, within the feasibility of computers, will be found to analyze accident data in ways consistent with this hypothesis and with other reasonable hypotheses.

Only one other study has been reported with which results can be compared. Versace (4) did a factor analysis pertinent to accidents. However, the units of analysis in his study were sections of highway and his variables were characteristics of the highway, one of which was an index of the number of accidents on each section. He found four factors which accounted for most of the common variance between highway characteristics: capacity, modern roads, traffic conflict and roadside structures. His factor, traffic conflict, which appears to correspond to the factor of the same name in this study, accounted for almost all the accidents variance. His factor, modern roads, which seems to correspond to the factor good roads in this study, was not related to accidents. Of course, it is only conjecture to equate the factors in the two studies. His modern roads factor was defined by high loadings on sight distance restriction (negative), calculated capacity, type of terrain, and number of curves (negative). His factor, traffic conflict, had its high loadings on accidents, average daily traffic, number of intersections, and number of commercial and residential driveways. Only one variable was common to the two studies--number of intersections per mile in one, and whether the accident took place at an intersection in the other study.

The need for variables common to the two types of study seems obvious. In studies of the accident characteristics of roadways, data on the proportion of truck traffic and

speeds, as well as certain accident characteristics such as were included in this study, would seem indicated. Similarly, it would be desirable to include on each accident card some code which would make it possible for a computer to make an estimate of the traffic volume, and the data necessary for calculated capacity, since these seem important with respect to where accidents occur. There is also need for related studies in which the unit of analysis is drivers, rather than accidents or sections of roadway. When we have a set of factors (or some other statistical model) which holds up over these three methods of analysis, we will have a basis on which a theory of accidents can be built.

ACKNOWLEDGMENTS

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Personality and Biographical Variables
In Relation to Driving Item Response

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Interest in this study was focused on the relations between driving item responses and selected personality and biographical variables. Survey data were obtained from 432 respondents interviewed in their homes on 24 driving items, 3 personality variables (authoritarianism, feeling of competence, and other-directedness), and 5 biographical variables (age, sex, education, occupational rating, and social area). A multiple regression equation was computed for each driving item, with the 3 personality and 5 biographical items as the independent variables. The proportion of variance accounted for by each independent variable was averaged over the 24 driving items.

The results indicated that the combined personality variables accounted for only about 1 percent of the variance in the average driving item, whereas the biographical variables contributed about 4 percent. The superior contribution of the biographical variables may have been due to their higher reliability. The relations which emerged between the personality-biographical variables and the driving item responses were essentially those which would have been expected from logical considerations.

•RESPONSES to driving items have been utilized in traffic safety research. This resort to the convenience of verbal response is justified on the grounds that driving item response is significantly correlated with more direct measures of driving behavior (1), although the correlations are seldom as high as one might wish. Nevertheless, to the extent that driving item response is related to traffic accidents, the ability to account for driving item variance is tantamount to the ability to predict accidents, which is a first step to their understanding.

There is a wide choice of variables which may be used in an attempt to account for driving item variance. For instance, driving variables (driving experience, driving exposure, accident rate, violation rate, etc.) would be expected to show correlations with driving items. While driving item response may be accounted for in part by driving variables, the use of such variables is restricted to subjects with previous driving experience. However, pre-drivers show no difficulty in answering driving items (1), suggesting the possibility of utilizing driving item response as one criterion in licensing. In this context it would be more appropriate to explore driving item response in relation to non-driving variables, and this orientation is taken in the current study.

The non-driving variables chosen for this study were personality variables and biographical variables. These two classes of variables were chosen because they have been shown to be related to traffic accidents (2, 3, 4, 5, 6, 7).

METHOD

The procedure involved the interviewing of drivers in their homes. The interview consisted of three types of items: driving, personality, and biographical. The driving items were analyzed in relation to the personality and biographical items.

Data Collection

Personal interviews were conducted by each student in an upper division university class in attitude and opinion measurement. Each interviewer was assigned to four neighborhoods throughout Los Angeles representing four levels of social area. The levels were based on the results of a social area analysis of Los Angeles (8), and the areas were chosen such that the respondents would be represented in proportion to the distribution of population in the Los Angeles area. The interviews were conducted during a one-month period.

The interviewer introduced himself as a public opinion reporter for the University of California Studies in Public Opinion, showed an authorization letter, and was granted an interview in practically all cases. The standardized interview lasted about $\frac{1}{2}$ hour. This study is based on the 432 drivers from whom complete data were obtained. About half the subjects reported having driven in California 10 years or more, and having driven 6,000 miles or more each year over the past few years.

Driving Items

In general, each of the 24 driving items represented a specific driving situation involving interaction with another driver, and the respondent was asked to indicate which of two alternatives most closely represented the action he would take in that driving situation. A few items pertained to the respondent's evaluation of the quality of his driving. A "no opinion" response was included with that alternative having fewer responses.

TABLE 1

DRIVING ITEMS

1. Would you say your driving is better than average, or about average? Better than (50%), About average (50%)
2. Do you feel that you are able to park a little better than, or about as well as most drivers? Better than (49%), As well as (51%)
3. Do you sometimes fear that you will lose control of your car when driving? No (86%), Yes (14%)
4. Suppose you are prepared to enter a parking space and another driver grabs the space. Do you sometimes tell him off? No (82%), Yes (18%)
5. Suppose a pedestrian were trying illegally to cross in front of you in the middle of the block. Would you usually stop for him? No (7%), Yes (93%)
6. Do you tend to use your horn less often than other drivers or more than they do? Less often (90%), More often (10%)
7. Suppose you are waiting in the front row at a stop signal. After a long time you begin to feel that the signals must be stuck, but see that other drivers are not moving. Would you cross the intersection against the signal? No (77%), Yes (23%)
8. Would you double-park to let a passenger out even though it meant that the driver behind you would have to wait? No (70%), Yes (30%)
9. Signals are set for 30 mph, and traffic is heavy. Even though you are traveling 30 mph, drivers behind honk their horns. Do you generally speed up somewhat, or do you ignore them? Speed up (25%), Ignore them (75%)
10. Do you think if you ever got in a serious accident it would more likely be your fault or the other person's fault? Respondent's fault (33%), Other's fault (67%)
11. Suppose you are stopped in bumper-to-bumper traffic, and the car ahead of you moves forward, but before you have a chance to move up yourself, the driver on your left cuts in front of you. Do you occasionally honk your horn at him? No (56%), Yes (44%)
12. An old car is stalled ahead on the highway. The driver is waving, but you are not sure what he wants. Do you usually drive by, or do you stop to see what he wants? Drive by (55%), Stop (45%)
13. When you reach an intersection at the same time as a car approaching from the side street, do you usually wait for it to cross first or do you try to cross first? Wait for it (76%), Cross first (24%)
14. When a green light changes to yellow as you approach an intersection, do you usually drive through when you're in a hurry? No (58%), Yes (42%)
15. Suppose you find yourself behind an old car stalled at a signal. The driver is indicating that he needs a shove. Would you push him or drive around him? Push (61%), Drive around (39%)
16. Two cars are waiting side-by-side at a signal. As you approach from behind, the signal changes to green. If only the curb lane is open, do you occasionally use it to pass the stopped cars? No (63%), Yes (37%)
17. Suppose you have stopped in the street waiting for a driver to pull out of a parking space so that you can enter. A car behind you honks to get by. Do you move on and try to find another space, or do you stay where you are? Move on (30%), Stay put (70%)
18. Suppose while you're waiting at a signal, the car ahead of you rolls back and hits your bumper. Would you get out to see if your car was damaged? No (49%), Yes (51%)
19. A pedestrian has stepped off the curb on your left and is in the crosswalk as you approach the intersection. Do you usually try to drive through before he reaches the middle of the crosswalk? No (88%), Yes (12%)
20. Suppose you are stopped behind another car at a signal, which changes to "go". The driver ahead doesn't start because he's talking to a friend on the curb. Do you usually honk until he starts? No (41%), Yes (59%)
21. Suppose a policeman is writing you a ticket which you think is unfair. Would you tell him so? No (50%), Yes (50%)
22. There's just enough curb space for you to park in front of the place you want to shop, but you see that half a block ahead is a larger parking space. Would you try to squeeze into the smaller space or go ahead to the larger one? Smaller (17%), Larger (83%)
23. Suppose you are approaching an intersection, and the driver of an oncoming car signals a left turn. Do you generally speed up so that he won't cut in front of you? No (82%), Yes (18%)
24. Do you feel that you can exceed most speed limits without endangering yourself or others? No (67%), Yes (33%)

The 24 driving items are given in Table 1, with the percentage of responses to each alternative given in parentheses.

Personality Variables

The 16 personality items comprised three personality scales. These three personality variables will be capitalized throughout this report when they are measured by the procedures described below. The three personality measures reflected authoritarianism, feeling of competence, and other-directedness. The three scales are given in Table 2, as are the positive responses to each item. The positive responses to a given item are associated with those alternatives offered to the respondent which reflect the positive end of the personality dimension; e.g., higher authoritarianism. The procedure used in determining these alternatives is described below. For each item in Table 2, the right-hand column lists the percentage of respondents giving a positive response.

1. Authoritarianism was based on seven items taken from the Short Authoritarian-Equalitarian Scale (9). These seven items, similar to those on the "F" scale, have been exposed to a validation study (10), and have been used in a previous interview survey (11). Each item presented the respondent with seven choices from "disagree very much" to "agree very much." Each of the seven items was dichotomized such

TABLE 2

PERSONALITY ITEMS

Item	Positive Responses	Percentage
Authoritarianism:		
1. A few strong leaders could make this country better than all the laws and talk.	No opinion, agree a little, pretty much, very much	52
2. Most people who don't get ahead just don't have enough will power.	Agree pretty much, very much	
3. Women should stay out of politics.	Disagree a little, no opinion, agree a little, pretty much, very much	48
4. People sometimes say that an insult to your honor should not be forgotten.	Disagree a little, no opinion, agree a little, pretty much, very much	41
5. People can be trusted.	Agree a little, no opinion, disagree a little, pretty much, very much	45
6. Human nature being what it is, there must always be war and conflict.	Agree pretty much, very much	54
7. The most important thing a child should learn is obedience to his parents.	Agree very much	69
Feeling of Competence:		
1. Some people feel that their lives have worked out just about the way they wanted. Others feel they've really had bad breaks. How do you feel about the way your life is turning out?	Satisfied	84
2. What do you think your chances are of living the kind of life you'd like to have? Do you think they are pretty good, or not so good?	Pretty good	84
3. Some people feel that they can make pretty definite plans for their lives for the next few years. Others feel they aren't in a position to plan ahead. How about you—do you feel able to plan ahead or not?	Can plan ahead	71
Other-directedness:		
1. With regard to parties, which do you prefer: a large group—"the more the merrier"—or a small group of close friends?	No opinion, large group	16
2. Which of these two kinds of books do you prefer: those about people like you and me, or famous people, adventurers, or great leaders?	People like you and me	50
3. Which kind of person do you respect more: the person who lives up to his own ideals and principles, or the person who is concerned that people will think well of him?	No opinion, others	17
4. As leisure-time activity, which do you prefer: activities like stamp collecting, photography, woodcarving, or painting, or card games such as bridge, discussion groups, or club meetings?	Games, etc.	51
5. Which do you think is more desirable: to be popular and well-liked by everybody, or to become famous and outstanding for success in some field of work or activity?	Be liked	71
6. Which of these would you prefer to belong to: political or social club or organization, or a club or organization interested mainly in scientific and educational subjects?	No opinion, political or social	38

that the dichotomy point split the ordered alternatives as close to the median as possible. The alternatives on one side of the dichotomy point were designated as positive, with the positive side being determined by that end of the item which, according to Sanford and Older (9), represented higher authoritarianism. Then, an authoritarianism score was computed for each subject by adding the number of his positive responses. Finally, these authoritarianism scores were dichotomized as close to the median as possible; a subject with a score of four or more was classified as higher in Authoritarianism.

2. Feeling of Competence was based on three presumably Guttman-type items previously utilized by Douvan and Walker (12) in an interview survey. In Table 2 the three items are given in the order suggested by Douvan and Walker. Each item was trichotomous, with the middle category being a "no opinion" category. Each of the three items was dichotomized by combining the "no opinion" category with the extreme category with the fewer responses. The alternatives on one side of the dichotomy point were designated as positive, with the positive side being determined by that end of the item which, according to Douvan and Walker (12), represented higher feeling of competence. Then, a feeling of competence score was computed for each subject by adding the number of his positive responses. Finally, these feeling of competence scores were dichotomized as close to the median as possible; a subject with a score of three (the highest possible) was classified as higher in Feeling of Competence.

3. Other-Directedness (one end of Riesman's inner- and other-directedness dimension) was based on six items developed by Kassarjian (13), and utilized in an interview survey by Centers (14), who reworded the items somewhat in order to make them more suited to survey applications. Each item was trichotomous, with the middle category being a "no opinion" category. Each of the six items was dichotomized by combining the "no opinion" category with the extreme category with the fewer responses. The alternatives on one side of the dichotomy point were designated as positive, with the positive side being determined by that end of the item which, according to Kassarjian (13), represented higher other-directedness. Then, an other-directedness score was computed for each subject by adding the number of his positive responses. Finally, these other-directedness scores were dichotomized as close to the median as possible; a subject with a score of three or more was classified as higher in Other-Directedness.

Biographical Variables

Each of the five biographical variables was measured by a single item. These five biographical variables will be capitalized throughout this report when they are measured by the procedures described below.

1. Age was based on the report of the respondent. These reported ages were dichotomized at a point as close to the median as possible; a subject who reported his age as 40 or more was classified as higher in Age.

2. Sex was based on the interviewer's observation.

3. Education was based on an item with seven ordered categories, ranging from "no schooling" to "completed college." These categories were dichotomized at a point as close to the median as possible; a subject who reported having completed high school, or a higher level, was classified as higher in Education.

4. Occupational Rating was based on the Warner, Meeker, and Eells scale (15), which involves seven ordered categories. These categories were dichotomized at a point as close to the median as possible; a subject who fell into one of the upper four categories was classified as higher in Occupational Rating.

5. Social Area was based on the interviewer's rating of the respondent's residential area according to one of four ordered categories, ranging from poor to wealthy. These categories were dichotomized at a point as close to the median as possible; a subject who fell into one of the upper two categories was classified as higher in Social Area.

Data Analysis[1]

Data analysis involved the determination of the contribution of three personality and five biographical measures to the variance in each driving item. Such a determination requires correlational analyses, and these are facilitated if all correlations involve only one type of correlation coefficient. Since the driving items were inherently dichotomous, it was decided to dichotomize the personality and biographical measures. The dichotomizing procedures have been described in the two previous sections.

In general, a determination of the proportion of variance in a dependent variable accounted for by n indedependent variables requires the solution of the equation $A_x = k$, where A is an n × n matrix whose elements represent the correlations between the independent variables, x is the unknown n-dimensional vector whose elements represent the correlations between the independent variables and the dependent variable. The n products of corresponding entries in the x and k vectors constitute the proportions of variance in the dependent variable accounted for by the n independent variables. The elements of the x vector are the beta weights, and the dot product of x and k is the coefficient of multiple determination, R^2.

The solution for x is often found by pre-multiplying k by the matrix inverse to A. However, in this study the x vector was found by the conjugate gradient method (16, 17), a method which does not require the computation of an inverse but which involves the application of an algorithm to yield a precise solution of the x vector in exactly n iterations.

RESULTS

Table 3 gives the percentage of subjects classified as higher on the three personality and five biographical variables. For sex, the percentage is for males.

Table 4 gives the variance in the driving items accounted for by the three personality and five biographical measures.

The last row shows the column average, which represents the variance, averaged over the driving items, accounted for by each personality and biographical variable.

The last column shows the row total, which represents the total variance in each driving item accounted for by the personality and biographical variables. This variance is also the coefficient of determination, the square of the multiple correlation of the driving item with the personality and biographical variables. A coefficient of determination of 0.0437 is significant at the 0.01 level. This level was achieved by 14 of the 24 driving items, and these 14 items are so indicated in Table 4. The test of significance is appropriate when all variables (dependent and independent) are normally distributed. Since the variables in this study were dichotomized (Sex was already dichotomous), some attention needs to be given to the applicability of the test employed.

Before dichotomization, most of the variables in this study were approximately normal. For instance, the distribution of the authoritarianism scores did not depart significantly from normality (chi-square = 9.51, df = 5), as was also the case for the other-directedness scores (chi-square = 7.39, df = 4). After dichotomization, none

TABLE 3

CLASSIFICATION OF SUBJECTS FOR PERSONALITY AND BIOGRAPHICAL VARIABLES

Variable	Classified as Higher (%)
Personality:	
Authoritarianism	54
Feeling of competence	58
Other-directedness	49
Biographical:	
Age	49
Sex (males)	51
Education	58
Occupational rating	36
Social area	34

[1] The computations were performed on an IBM 7090 and SWAC, both machines being operated by the UCLA Computing Facility.

TABLE 4

VARIANCE IN DRIVING ITEMS ACCOUNTED FOR BY PERSONALITY AND BIOGRAPHICAL VARIABLES

| Item | Personality Variable | | | | Biographical Variable | | | | | |
	Authori-tarianism	Feeling of Competence	Other-Directedness	Age	Sex	Education	Occupa-tional Rating	Social Area	Total Variance
1	0.0003	0.0001	0.0036	0.0064	0.0125	0.0056	0.0055	0.0052	0.0391
2	0.0213	0.0034	0.0016	0.0045	0.0328	-0.0001	0.0000	0.0047	0.0682[a]
3	0.0058	0.0096	0.0007	0.0007	0.0294	0.0032	-0.0002	0.0076	0.0567[a]
4	0.0004	0.0102	0.0012	0.0001	0.0056	0.0001	0.0051	0.0010	0.0238
5	0.0005	0.0012	0.0030	0.0040	0.0034	0.0045	0.0000	0.0143	0.0308
6	0.0035	0.0067	0.0075	0.0006	0.0032	-0.0001	0.0036	-0.0012	0.0238
7	0.0054	0.0036	0.0196	0.0104	0.0179	0.0136	0.0108	0.0012	0.0825[a]
8	-0.0009	0.0040	0.0060	0.0312	0.0002	0.0122	-0.0025	0.0190	0.0693[a]
9	0.0094	0.0000	0.0009	0.0178	0.0080	0.0112	0.0040	-0.0002	0.0511[a]
10	0.0070	0.0003	0.0102	0.0002	0.0080	0.0008	0.0011	0.0010	0.0283
11	0.0150	0.0110	0.0021	0.0047	0.0004	0.0002	0.0122	0.0002	0.0457[a]
12	-0.0005	0.0030	0.0011	0.0000	0.0376	0.0152	0.0017	0.0019	0.0600[a]
13	0.0063	0.0008	0.0039	0.0000	0.0008	0.0026	0.0151	0.0011	0.0306
14	0.0099	-0.0002	0.0043	0.0389	0.0152	0.0079	0.0176	0.0164	0.1101[a]
15	-0.0033	0.0004	0.0021	0.0024	0.0606	0.0045	0.0127	0.0012	0.0805[a]
16	0.0009	0.0001	0.0038	0.0361	0.0047	0.0053	-0.0001	0.0006	0.0515[a]
17	-0.0059	0.0024	0.0003	0.0087	0.0011	0.0254	0.0095	0.0074	0.0488[a]
18	0.0047	0.0006	0.0015	0.0029	0.0007	0.0104	-0.0005	0.0009	0.0213
19	0.0028	0.0013	0.0000	0.0035	0.0128	0.0082	0.0078	0.0001	0.0365
20	-0.0002	0.0001	0.0032	0.0035	0.0066	0.0006	0.0136	0.0084	0.0359
21	0.0000	-0.0002	0.0041	0.0031	0.0095	0.0002	0.0116	0.0000	0.0284
22	0.0039	0.0017	0.0115	0.0211	0.0155	0.0016	0.0007	0.0013	0.0574[a]
23	0.0033	0.0067	0.0021	0.0332	-0.0002	0.0033	0.0003	0.0004	0.0491[a]
24	0.0118	0.0090	0.0038	0.0454	0.0125	0.0005	-0.0002	0.0005	0.0832[a]
Avg. Variance	0.0042	0.0032	0.0041	0.0116	0.0124	0.0057	0.0054	0.0039	0.0505

[a]Significant at the 0.01 level.

of the personality or biographical variables departed significantly from a 50-50 split.

In general, a product-moment correlation based on two normal distributions will be larger than the phi correlation based on dichotomizations of the normal distributions. However, beta coefficients are relatively independent of which type of distribution is involved. If normal distributions are dichotomized, then the average element in the correlation matrix is reduced, resulting in an increase in the size of the average element of the inverse matrix. However, since this inverse matrix pre-multiplies a correlation vector whose average element is also reduced, the average resulting beta coefficient has a value which is essentially the same had it been based on the original normal distributions.

Since beta coefficients are relatively independent of which type of distribution was involved in their computation, the bias in the beta-r product is contributed primarily by r. Since a phi correlation based on dichotomizations of two normal distributions tends to be biased downward slightly, a slight Type II error is introduced in applying the test of significance to the entries in the last column of Table 4. Thus, in all probability, the correlations indicated by asterisks are indeed significant.

DISCUSSION

The last row of Table 4 reveals the major result emerging from this study: in comparison to the personality variables, the biographical variables account for more of the item variance. In fact, the average personality variable accounts for less than half as much variance as the average biographical variable. The personality variables as a group account for about 1 percent of the variance in the average driving item, the biographical variables about 4 percent. The predictive superiority of the biographical variables emerges more clearly when it is recalled that the personality variables involve 16 items, whereas the biographical variables involve only 5 items. The results suggest that a prediction of the response to the average driving item made on the basis

of all three personality variables combined would be about as accurate as a prediction made on the basis of age or sex alone.

The difference between the personality and biographical variables in predictive ability may be due to a difference in the reliabilities of these variables. Estimates of the reliabilities of the three personality scales were computed from the data of this study (18). The results yielded a Kuder-Richardson estimate of reliability of 0.38 for Authoritarianism, 0.48 for Feeling of Competence, and 0.21 for Other-Directedness. Since the Kuder-Richardson estimate of reliability is proportional to the inter-item covariance (19), one would expect the estimate of reliability to be related to the correlations between items within the same scale. This expectation is confirmed by the average correlation between items within the same personality scale: 0.08 for the Authoritarianism scale, 0.25 for the Feeling of Competence scale, and 0.04 for the Other-Directedness scale. Since each of the biographical variables involved a single item, estimates of consistency could not be computed. However, results from other survey studies indicate that the stability reliability for Age should be about 0.90, for Education about 0.80, for Occupational Rating and Social Area about 0.70 (20, 21). The reliability of Sex should approach 1.00. These results suggest that the proportion of driving item variance accounted for by each of the independent variables is related to its reliability.

The results do not necessarily mean that personality variables, in relation to biographical variables, are inherently less related to driving item response. The inherent relation between these two classes of variables and driving item response can be assessed only when the reliabilities of the two classes of variables are approximately equal. Nevertheless, if one were to want to predict driving item variance, one would want to use the predictive measures as they exist, with any limitations which they may have. Further, neither the personality nor biographical areas have been measured broadly, and the results, of course, apply only to those personality and biographical measures actually used in this study. For instance, when social area is measured not only by the interviewer's estimate of the neighborhood but also by his estimate of the respondent's home, social area accounts for twice the variance shown in Table 4.

While the results show clearly that the personality variables account for less of the driving item variance than do the biographical variables, even the combination of the two classes of variables does not account for much of the variance. In fact, only one of the 24 items has as much as 10 percent of its variance accounted for by all eight independent variables combined.

An examination of the results in Table 4, as well as of the correlations (not shown) between each driving item and the personality and biographical variables, suggests that (a) Authoritarianism is positively related to defensiveness about one's driving, (b) Feeling of Competence is positively related to acceptance of driving restrictions, (c) Other-Directedness is positively related to a dependency on other drivers to make initial moves, (d) Age is positively related to driving cautiousness, (e) Sex is related to driving confidence, with males tending to express a greater confidence, while (f) Education, Occupational Rating, and Social Area are all positively related to expediency and lack of social concern. All of these statistical results are those which might have been expected from logical considerations.

SUMMARY

Responses to driving items have been utilized in traffic safety research. This resort to the convenience of verbal response is justified on the grounds that driving item response is significantly correlated with more direct measures of driving behavior. To the extent that driving item response is related to accidents, the ability to account for driving item variance leads to the ability to predict accidents.

Pre-drivers show no difficulty in answering driving items, suggesting the possibility of utilizing driving item response as one criterion in licensing. In this context it is appropriate to explore driving item response in relation to non-driving variables, and this orientation is taken in the current study.

The non-driving variables chosen for this study were personality variables and biographical variables. These two classes of variables were chosen because they have been shown to be related to traffic accidents.

Survey data were obtained from 432 respondents interviewed in their homes. The interview included 24 driving items, three personality variables (Authoritarianism, Feeling of Competence, and Other-Directedness), and five biographical variables (Age, Sex, Education, Occupational Rating, and Social Area).

The results indicated that the personality variables combined accounted for only about 1 percent of the variance in the average driving item, whereas the biographical variables contributed about 4 percent. The superior contribution of the biographical variables may have been due to their higher reliability. The relations which emerged between the personality-biographical variables and the driving item responses were essentially those which would have been expected from logical considerations.

ACKNOWLEDGMENTS

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The Totally Deaf Driver in California

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●IN JULY 1963, the California Department of Motor Vehicles issued a report on the totally deaf driver in California (1). Basically a descriptive report, it concerned itself with a statistical portrayal of a large representative sample of California deaf drivers, and, in addition, presented comparisons between the deaf and non-deaf drivers based on a number of variables. The deaf drivers were found to differ from the non-deaf drivers in that (a) the deaf had more accidents and violations on their records; (b) the deaf drove a greater number of miles per year; (c) the distribution of deaf drivers among occupational categories differed from that of the non-deaf; and (d) the two groups differed with respect to the shape of their age distributions. Despite the fact that deaf drivers had poorer driving records, it could in no way be inferred that their increased accident and violation records were somehow caused by deafness or any ramifications of deafness because they differed on variables other than hearing (such as mileage and occupation) in a direction which previous empirical research has shown to be related to increased violation and accident frequency.

From this earlier report the following question evolved: if the deaf sample were matched with the non-deaf sample on all possible variables other than deafness, would the violation and accident frequencies of the deaf still be higher? It was to answer this basic question that the study presented herein was conceived. The present study also was designed to analyze the deaf sample with respect to other variables such as annual mileage, occupation, age, and types of violation. However, it was subsequently decided that this last aspect could best be handled as a separate report.

Before describing the methodology, we should define the term "deafness" as used in this study. The deaf in our sample may be considered totally deaf, in that their sense of hearing is either totally absent or so minimal as to be nonfunctional for the ordinary purposes of life; no distinction was made between the congenitally and adventitiously deaf. Because deafness may be correlated with other sensory anomalies and certain personality characteristics, the relationship between driving performance and the inability to hear could not be assessed apart from the influence of other correlated anomalies. Thus, it should be understood that when the authors make a statement regarding the apparent effects of deafness, they are referring to the entire syndrome in all of its manifestations and not just the inability to hear.

This study, then, is concerned exclusively with the problem of driving performance differentials between the deaf and non-deaf driving populations in an attempt to arrive at a definitive evaluation of the role of deafness in driving.

The basic problem confronting the researchers was the obtainment of matched samples of deaf and non-deaf drivers for the purpose of making driving record comparisons and statistical tests of significance. The specific purpose of such tests is to indicate the probability of a certain quantitative difference having occurred by random sampling fluctuation (chance). If the probability of such an occurrence is small, it is generally concluded that the difference is significant or real. An important fact to remember is that a significant difference does not necessarily indicate a serious discrepancy, as even small inconsequential differences can sometimes be "statistically" significant.

Before describing the matching procedure in detail, however, something more should be said about the exact nature of the samples involved. In the earlier study (1) two non-

deaf samples were involved in the comparisons between the deaf and non-deaf. The larger sample (95,000) was used for driver record comparisons, and the smaller one (7,000 to 8,000) was used for comparisons with regard to those variables not available in the larger sample. Since the four matching variables were available for only the smaller sample, it was necessary to use this as a basis for deriving the matched non-deaf group and making subsequent driver record comparisons.

The sample size of the deaf varied, depending on which variable was being considered, because information was available on certain variables (such as mileage and occupation) for only those who responded to the department's questionnaire. For other variables (such as driver record, age, and sex), information was available for both the respondents and non-respondents. As with the non-deaf, this restricted the pool of deaf subjects to those on whom information was available for all four matching variables. Thus, the initial pool of subjects to be matched consisted of 486 respondent deaf and approximately 8,000 non-deaf. (The fact that the deaf sample was restricted to respondents was not felt to be a serious limitation since the information on the non-deaf was also obtained through their voluntary cooperation.)

Four variables were involved in the matching—sex, age, annual mileage, and occupation. The initial matching was accomplished by a card collator and resulted in an exact card-for-card match for sex, age, and annual mileage. The matching of occupations was done by card-to-card sight matching of the machine-collated decks.

To counteract shrinkage in sample size, the matching restrictions were relaxed slightly by adding subjects who could not be exactly matched by the original machine collation. In all cases these inexact matches were very close, as deviations greater than four years on age and 4,000 miles on annual exposure were not allowed. The number of such inexact matches represented a minority of subjects in the final sample, and the direction of the deviations was allowed to operate randomly. No deviations were allowed with respect to occupation, and in all cases the machine and sight collating was done in such a way that all within-group frequencies were matched. In other words, the final samples were equated in terms not only of the four variables taken separately, but also of the frequency interrelationships between the four variables. In this way, the samples were equated with respect to interaction.

Tables 1, 2, and 3 show the results of the matching with respect to age, annual mileage and occupation, respectively. It can be seen that the matching was very close

TABLE 1

DISTRIBUTION OF MATCHED SAMPLES BY AGE

Age (yr)	Total		Male		Female	
	Deaf	Non-Deaf	Deaf	Non-Deaf	Deaf	Non-Deaf
21–25	32	32	20	20	12	12
26–30	40	40	27	27	13	13
31–35	61	59	33	31	28	28
36–40	69	69	49	49	20	20
41–45	73	75	50	52	23	23
46–50	62	62	43	43	19	19
51–55	37	37	30	30	7	7
56–60	36	36	24	24	12	12
61–65	24	24	20	20	4	4
≥65	19	19	17	17	2	2
Total	453	453	313	313	140	140
Mean age	43.04	43.08	44.13	44.19	40.60	40.60
Std. dev.	12.12	12.10	12.49	12.38	11.11	11.11

TABLE 2

DISTRIBUTION OF MATCHED SAMPLES BY NUMBER OF
MILES DRIVEN PER YEAR

No. Miles	Total		Male		Female	
	Deaf	Non-Deaf	Deaf	Non-Deaf	Deaf	Non-Deaf
<2,500	27	31	7	8	20	23
2,500- 7,400	99	107	39	45	60	62
7,500-12,400	184	177	136	132	48	45
12,500-17,400	80	80	72	73	8	7
17,500-22,400	42	38	38	35	4	3
≥22,500[a]	21	20	21	20	-	-
Total	453	453	313	313	140	140
Mean annual mileage	11,164	10,900	12,966	12,749	7,136	6,711
Std. dev.	6,873	6,967	7,061	7,190	4,245	4,112

[a]Means and standard deviations computed with the interval expanded to 50,000 miles at 5,000-mile intervals.

TABLE 3

OCCUPATION DISTRIBUTION OF MATCHED SAMPLES

Occupation	Total		Male		Female	
	Deaf	Non-Deaf	Deaf	Non-Deaf	Deaf	Non-Deaf
Professional	2	2	2	2	-	-
Laborer	85	86	72	73	13	13
Tradesman	184	184	170	170	14	14
Clerk	32	30	6	7	26	23
Exec. prof., semi., w,c drivers	45	48	29	29	16	19
Housewife, student	67	67	-	-	67	67
Other	38	36	34	32	4	4
Total sample	453	453	313	313	140	140

on all variables. Statistical tests of significance confirm that the resultant discrepancies can be attributed to chance.

Z (mileage): Males = 0.39, $P > 0.49$; Females = 0.74, $P > 0.45$.
F (mileage): Males = 1.04, $P > 0.25$; Females = 1.07, $P > 0.25$.
Z (age): Males = 0.06, $P > 0.94$; Females = 0.00, $P > \infty$.
F (age): Males = 1.00, $P = 0.50$; Females = 1.00, $P = 0.50$.
χ^2 (occupation): Males = 0.12 at 4 d.f., $P > 0.99$; Females = 0.44 at 5 d.f., $P > 0.99$.

Thus, we can safely conclude that the two samples represent similar underlying populations relative to all three matching variables.

Table 3 indicates that the occupational schema is some what atypical, and that in some cases rather dissimilar categories have been combined. This was necessary to achieve valid comparisons and was dictated by the occupation categories used for the non-deaf sample in 1958. The table also indicates that the matching on the fourth variable, sex, was exact—313 males and 140 females in each sample.

In addition to these matching variables, a fifth—area of residence—also had to be considered because the deaf sample was selected from all areas of the state, whereas the non-deaf sample represents only the Los Angeles and San Francisco areas. Since the probabilities of being convicted of traffic violations and being involved in accidents may differ throughout the state, the possible effects of area must be controlled or eliminated before any definitive conclusions can be reached.

To evaluate the effects of this area bias, all deaf subjects who did not reside in either San Francisco (S.F.) or Los Angeles (L.A.) were separated from those living in these areas. Respective accident and conviction counts were then derived for comparison (Tables 4 and 5).

Statistical tests of significance were subsequently performed on the area breakdowns and indicated that for both accidents and convictions, the L.A.-S.F. males had significantly poorer driving records than deaf males residing in other areas of the state.

$$Z'_c \text{ (conviction points)} = 3.24, \ P < 0.003; \ Z'_c \text{ (accidents)} = 3.47, \ P < 0.001$$

For the females, however, all differences could be attributed to chance.

$$Z'_c \text{ (conviction points)} = 0.59, \ P > 0.55; \ Z'_c \text{ (accidents)} = 0.82, \ P > 0.40$$

TABLE 4

DISTRIBUTION OF DEAF DRIVER SAMPLE BY NUMBER OF CONVICTION POINTS

No. of Conviction Points	Total				Male				Female			
	L.A.-S.F. Areas		Other Areas		L.A.-S.F. Areas		Other Areas		L.A.-S.F. Areas		Other Areas	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0	92	39.8	128	57.6	52	30.6	71	49.6	40	65.6	57	72.1
1	79	34.2	51	22.9	65	38.2	41	28.7	14	23.0	10	12.7
2	33	14.3	28	12.6	29	17.1	20	14.0	4	6.6	8	10.1
3	15	6.5	9	4.1	14	8.2	5	3.5	1	1.6	4	5.1
4	9	3.9	3	1.4	8	4.7	3	2.1	1	1.6	-	-
5	3	1.3	1	0.5	2	1.2	1	0.7	1	1.6	-	-
≥6	-	-	2	0.9	-	-	2	1.4	-	-	-	-
Total	231	100.0	222	100.0	170	100.0	143	100.0	61	100.0	79	100.0
Mean no. of points	1.04		0.74		1.24		0.88		0.56		0.48	

TABLE 5

DISTRIBUTION OF DEAF DRIVER SAMPLE BY NUMBER OF ACCIDENTS

No. of Accidents	Total				Male				Female			
	L.A.-S.F. Areas		Other Areas		L.A.-S.F. Areas		Other Areas		L.A.-S.F. Areas		Other Areas	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0	166	71.9	186	83.8	113	66.4	118	82.5	53	86.9	68	86.0
1	49	21.2	34	15.3	41	24.1	24	16.8	8	13.1	10	12.7
2	11	4.8	2	0.9	11	6.5	1	0.7	-	-	1	1.3
3	4	1.7	-	-	4	2.4	-	-	-	-	-	-
4	1	0.4	-	-	1	0.6	-	-	-	-	-	-
Total	231	100.0	222	100.0	170	100.0	143	100.0	61	100.0	79	100.0
Mean no. of accidents	0.377		0.171		0.465		0.182		0.131		0.152	

From here on, we must talk only of L.A.-S.F. subjects when comparing male deaf and non-deaf subjects. This same restriction does not apply to the females since the statistical tests indicate that the deaf females share a common underlying population with regard to accidents and conviction points.

In the forthcoming sections, all driver record comparisons between deaf and non-deaf males involve only subjects residing in the L.A.-S.F. areas, thereby reducing the deaf male sample from 313 to 170. This reduction did not significantly alter the previous matching by age, occupation and mileage because the male deaf did not differ significantly by area with respect to the matching variables. The female deaf sample, of course, remains the same—140 subjects.

RESULTS AND FINDINGS

This study covers the three-year period, 1959 to 1962. In the formula for determining number of convictions, certain equipment and technical violations have been excluded from the count. Also, an additional count was given to the more serious major violations. Conviction points were used instead of total convictions to make the deaf driver data completely conparable to that of the non-deaf sample.

Conviction Points

In the earlier study (1), it was found that the deaf had significantly more total traffic convictions on their driving records than the non-deaf. This was true for each sex separately and combined. The same was true when the comparisons were limited to "countable" convictions. However, since this previous study did not match the two samples by certain relevant variables, the differences in conviction rates could not be attributed to deafness.

The present problem, then, is to ascertain whether or not any conviction differentials exist now that the two groups have been adequately matched. Comparisons of mean conviction points of the matched groups are presented in Figure 1 and Table 6.

Statistical tests for the significance of the difference between rank sums[1] indicate that any differences can be attributed to chance.
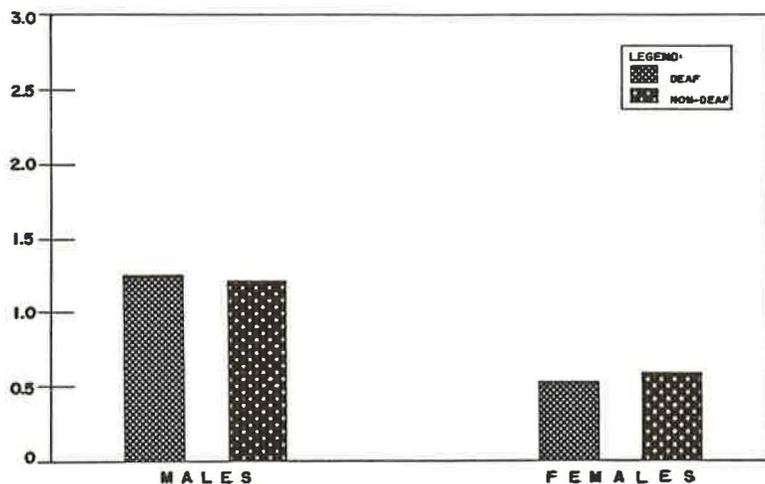

Figure 1. Mean number of conviction points of deaf and non-deaf drivers, three-year record.

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[1] The Mann-Whitney test has been used throughout the report to test driving record differentials. Since the matching procedure introduced some correlation between samples, the probability levels derived from the tests are slight underestimates of the actual significance. In most cases, incidentally, parametric tests for mean differences produced Z ratios similar to those produced by the Mann-Whitney. The only exception concerned Table 6, where the parametric test on the male means yielded a critical ratio much further from significance than that produced by the Mann-Whitney test.

TABLE 6

DISTRIBUTION OF MATCHED SAMPLES BY NUMBER OF CONVICTION POINTS

No. of Conviction Points	Deaf Drivers				Non-Deaf Drivers			
	Male		Female		Male		Female	
	No.	%	No.	%	No.	%	No.	%
0	52	30.6	97	69.3	134	42.9	93	66.5
1	65	38.2	24	17.1	78	24.9	30	21.4
2	29	17.1	12	8.6	58	18.5	7	5.0
3	14	8.2	5	3.6	19	6.1	7	5.0
4	8	4.7	1	0.7	12	3.8	2	1.4
5	2	1.2	1	0.7	6	1.9	-	-
≥6	-	-	-	-	6	1.9	1	0.7
Total	170	100.0	140	100.0	313	100.0	140	100.0
Mean no. of points	1.24		0.51		1.21		0.57	

Z'_c (males) = 1.42, P > 0.16; Z'_c (females) = 0.42, P > 0.67

Therefore, it is certain that deaf and non-deaf drivers do not differ with respect to the number of conviction points on their driving records—at least in those areas from which the samples were drawn. Since all areas of the state could not be represented in the sampling, we cannot legitimately generalize these conclusions to all areas of the state and all types of driving situations. It is not inconceiveable that a different relationship might exist in those areas where the types of exposure differ from the L.A.-S.F. areas.

We have at least provided a partial answer to the question concerning the relation between deafness and violation frequency: there is no evidence from driving record histories that deafness results in an increase or decrease in traffic violation frequency.

Accidents

The most important variable in any study of this nature is accident frequency. In the previous study (1) the deaf were found to have 1.78 times the accident rate of the non-deaf sample. Statistical tests indicated that the differences for each sex, singly and combined, significantly favored the non-deaf driver. The question remained, however, as to whether the differences were directly related to the deafness syndrome or merely the indirect manifestations of other coincidental factors such as mileage, occupation, and area of residence. As was seen from the preceding discussion on conviction points, the role played by coincidental factors was indeed a dramatic one, for when these factors were held constant through matching, the deaf male and deaf female were no longer significantly worse than the non-deaf in terms of conviction points. Could the same also be true of accidents? The mean number and distribution of accidents by sex for the matched samples of deaf and non-deaf drivers are presented in Figure 2 and Table 7.

We again remind the reader that we are comparing only L.A.-S.F. area males and cannot evaluate deaf males in other areas of California. With this in mind one notices that the difference between males is rather dramatically in favor of the non-deaf driver and is highly significant.

$$Z'_c = 3.01, \ P < 0.003$$

On the other hand, the small difference for females could easily have resulted by chance.

$$Z'_c = 0.48, \ P > 0.63$$
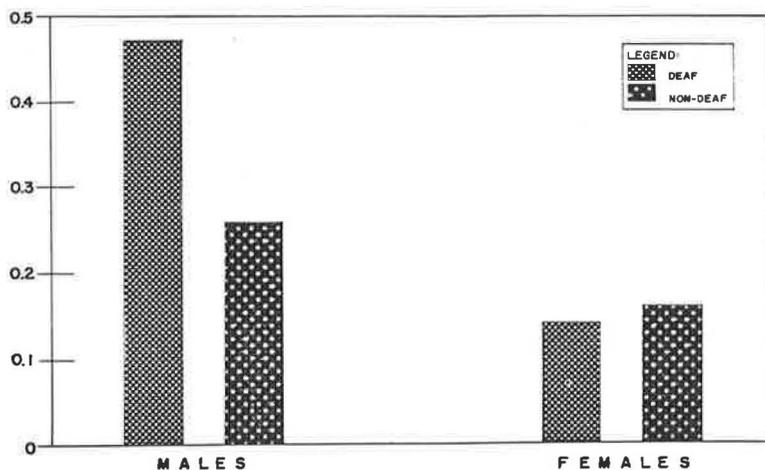
Figure 2.   Mean number of accidents of deaf and non-deaf drivers, three-year-record.

TABLE 7

DISTRIBUTION OF MATCHED SAMPLES BY NUMBER OF ACCIDENTS

| No. of Accidents | Deaf Drivers | | | | Non-Deaf Drivers | | | |
| | Male | | Female | | Male | | Female | |
	No.	%	No.	%	No.	%	No.	%
0	113	66.4	121	86.4	244	78.0	118	84.3
1	41	24.1	18	12.9	60	19.2	22	15.7
2	11	6.5	1	0.7	7	2.2	-	-
3	4	2.4	-	-	2	0.6	-	-
4	1	0.6	-	-	-	-	-	-
Total	170	100.0	140	100.0	313	100.0	140	100.0
Mean no. of accidents	0.465		0.143		0.256		0.157	

Our conclusion, then, is that in the type of driving typified by our samples, deaf males have a disproportionately high number of accidents, whereas deaf females do not differ in this respect from their non-deaf counterparts. Some possible explanations for this rather interesting finding are offered in the next section.

DISCUSSION

Theoretical Interpretation

The finding in regard to accident frequency raises some rather interesting theoretical questions. At first glance the existence of a sex by deafness by accident interaction may seem paradoxical. In other words, why should deafness affect the driving performance of males but not females. One possible explanation—admittedly a very speculative one—is that male drivers, by nature of their driving habits, patterns, and needs, are more often subjected to driving situations in which auditory cues play a relatively more important role than is the case with females. If a greater proportion of male driving occurs in situations where sound stimuli serve as important cues, then we might expect the deaf males to do poorly relative to their sex, but not necessarily to the females. In other words, males may drive more in situations where traffic is heavy and where hearing may be a comparatively relevant factor; for example, effective hearing may be more essential in driving to and from work on crowded city streets and freeways than in other locals.

This physiological-environmental explanation of the sex interaction is, of course, highly speculative and the possibility of psychological determinants certainly cannot be excluded. For example, it could be hypothesized that males react differently to their deafness than do females and the resulting male personality configuration, in turn, articulates with driving in such a way as to produce a predisposition to accidents for deaf males. In the opinion of these authors, such an hypothesis is not supported by the finding with regard to violation frequency. If the accident frequency of deaf males were largely a function of attitudinal and personality variables, one would expect the deaf male to be a more frequent violator of traffic laws. However, as we have shown, such is not the case. Despite this, personality variables cannot be entirely dismissed on the basis of these findings, since it is not inconceivable that personality factors could affect accident frequency without increasing violation rate. A final answer to this question must await rigorously controlled experimentation.

Methodological Qualifications

Before summarizing the findings and presenting recommendations, it seems appropriate that the methodological limitations of the study be made explicit, for these contingencies may have a bearing on the interpretation and evaluation of the findings. In so doing we will, whenever possible, indicate the possible influence which these qualifications have in regard to the empirical results.

Nonrandomness of Sample Selection.—Strictly speaking, neither sample represents a random sample of California drivers. The deaf sample was selected from members of the California Association of the Deaf (CAD), on a voluntary basis. None of the non-respondents could be included in this study. The non-deaf sample was also composed of volunteers and, in addition, was selected from two areas of the state.

In the earlier study (1), the implications of the membership factor were discussed in detail, and it was felt that its effects were negligible. It was reasoned that the deaf, by nature of their anomaly, are a relatively homogeneous group and that there are no stringent economic requirements which would preclude their joining such a deaf organization. Support of this assumption can be found in the fact that the great majority of all deaf people belong to one or more organizations, and the CAD is the only statewide organization in California. At most, the membership factor might slightly limit the generality of any findings.

Although the non-deaf sample does not represent all areas of the state, this factor was controlled by matching. In addition, the non-deaf, like the deaf, represent volunteers and, therefore, both samples actually represent populations of volunteers. The authors do not feel this nonrandomness necessarily invalidates any findings emanating from the study, although one must be cautious in describing the nature of the population about which he is generalizing. The fact that the deaf were selected from an organization would, if anything, seem to favor the deaf in any comparison with the non-deaf. If this were true and if we wish to generalize about all deaf drivers, the findings regarding males are all the more significant.

Differential Response Bias.—As indicated, both samples were composed of volunteer subjects. This would present no serious difficulty, had the response media not differed for each group—the deaf having been contacted by a mailed questionnaire, whereas the non-deaf were selected in person at the time of drivers' license renewal. It is known that a considerably greater proportion of the deaf failed to respond to the questionnaire than did non-deaf to the department's verbal request for their participation. It is also known that the respondent deaf had significantly superior violation records than did the non-respondent deaf. Because of this, the possibility exists that the samples were unequally biased, at least in terms of violations. To a certain extent, this factor was undoubtedly mitigated by the matching process. If, after matching, a differential bias still remained, it would seem likely that the deaf would again be favored.

Unlike violations, the accident frequencies of the respondent and non-respondent deaf studied previously did not differ significantly. Therefore, we have no grounds for suspecting that an unequal bias may presently exist between the deaf and non-deaf with

respect to accidents and our conclusions in this study regarding accidents require no additional qualifications.

Limitation of Accident and Violation Frequency Data to Departmental Records.— Although implicit throughout the study, it should be emphasized that the driving performance criteria are those events contained on departmental records. It is known that many accidents and some violations are not reported to the Department of Motor Vehicles. To generalize from departmental records to actual driving behavior, one must assume the events to be linearly correlated; that is, that those who have the most violations or accidents on their records also violate most frequently or are involved in the greatest number of total accidents. This assumption, of course, is inherent in all such studies.

Although we have no evidence in this regard, it is not impossible that the proportion of deaf driver accidents reported to the Department differs from the non-deaf proportion. Such a difference could emanate from a variety of sources. For example, it could be that the deaf are more likely to suppress an accident from fear of being discriminated against because of their handicap. On the other hand, it could also be that the deaf are more conscientious and, therefore, more likely to report an accident. Another possibility would be that traffic officers are more likely to report an accident involving a deaf driver. Such occurrences could result in a distorted picture since departmental accident records would not be proportionally representative of the overall incidence. We should emphasize that there is no evidence to support the existence of these distortions and in the absence of such, we must assume that the Department's records present a representative picture.

Conclusions and Recommendations

In the earlier study (1, p. 28), it was stated that it "does not appear that the California deaf driver, as a group, constitutes a special problem from the standpoint of traffic safety. Subsequent analysis, however, may indicate possible areas in which the deaf driver is in need of further training." Whether the matched analysis indicates the existence of a "serious" problem cannot be determined from the present research. A great deal, of course, depends on how one defines or quantifies seriousness and on the values of society. It appears to these authors that some type of problem is at least suggested. One possibility is that there are certain types of driving circumstances in which hearing may be an important sensory modality, and the lack of hearing a definite handicap. This is contrary to the generally held belief that sound is a neutral or negative stimulus in relation to driving and suggests that under certain circumstances auditory cues may play a more relevant role in driving than was formerly anticipated.

If subsequent research confirms the findings of this study, then further or specialized training of at least some deaf drivers might be indicated. As pointed out in the previous study, only one in eight of the drivers comprising the deaf sample had received any formal driver training. Whether an increase in the formal training of deaf drivers is indicated and would prove beneficial is, of course, at this point speculative. However, to the extent (if any) that formal driver training is or can be an effective means of reducing accident frequency, an extension of such training to a greater number of deaf drivers should prove beneficial.

Despite some rather definitive findings, the authors wish to emphasize that a number of questions have been left unresolved by the present study, and that additional research is necessary before the practical and theoretical significance of deafness as a factor in driving can be completely assessed. Further deaf driver research should involve a consideration of the specific types of accidents and their precipitating circumstances. Another fruitful avenue of research would be the testing of a sample of deaf drivers on driver simulators evoking appropriate sound cues to determine experimentally whether their responses to various traffic situations differ from non-deaf drivers. A survey of comparative accident frequencies in all areas of the state might also prove illuminating. Finally, future research in this area should involve an analysis of driving performance by type of deafness (age at onset, precipitating trauma, associated defects, etc.).

SUMMARY

1. Two large samples of deaf and non-deaf drivers were matched on five variables—age, annual mileage, occupation, sex, and area of residence. A total of 313 males and 140 females remained in the sample after matching by four of the variables. A subsidiary analysis was undertaken with the samples matched by the fifth variable—area of residence. Satisfactory matches were obtained on all variables, as differences were not statistically significant.

2. The matched samples were compared and statistical tests of significance performed on two driver record variables: conviction points and reported accidents.

3. Deaf females did not differ significantly from a matched sample of non-deaf females on any of the driver record variables, regardless of whether the samples were matched by area. All differences were slight and could be attributed to chance.

4. When matched on area, deaf males had a significantly greater number of accidents on their driving records than a matched sample of non-deaf males. In the case of accidents, the deaf male frequency was 1.8 times higher than the non-deaf accident frequency. With regard to total conviction points, the males did not significantly differ from each other.

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Program for Determination of
High-Accident Locations

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ABRIDGMENT

•FOR TWENTY YEARS, the Oregon State Highway Department has compiled motor
vehicle traffic accident data, coded on machine cards, in the form of individual detail
records containing pertinent information taken from official accident reports. Because
Oregon law requires all accidents involving any property damage, personal injury, or
death to be reported, these reports represent a high percentage of all accidents occur-
ring in the state.

Before the advent of the high-speed computer, use of these accident data was limited
by simple data processing equipment and manual decoding techniques. Various types
of accident summaries had been developed, most importantly: (a) tabulation of the
number of accidents, personal injuries, and fatalities for selected intersections; and
(b) tabulation of the number of accidents and the accident rate per million vehicle-miles
by section of highway for the state highway system. The usefulness of these analyses
was limited because the intersectional accident summaries did not include a measure-
ment of exposure and most sections used for the accident-rate summary were too long
to pinpoint high-accident locations closely enough that corrective measures could be
determined.

In 1962, a series of IBM 1401 computer programs was developed to summarize ac-
cidents and compute accident rates by highway sections. The following criteria were
set:

1. The analysis would be developed using basic data in the format already available.
2. An accident-rate calculation would be included so that the accident experience
could be evaluated in terms of an exposure factor as well as total number of accidents.
3. The data must be available for sections sufficiently short to permit pinpointing
of hazardous locations so that probable causes of high-accident rates could be located
with reasonable certainty.
4. The tabulation produced could be used directly by the engineering staffs in the
district offices without need of additional decoding or interpretive analysis.

Form of Basic Data

To facilitate machine operation and reduce storage requirements, the accident rec-
ords for each calendar year are placed on tapes, with the urban and rural accident
cards (Figs. 1 and 2) sorted separately. Mileage control data for the state highway
system including vehicle-miles of travel have also been recorded on cards (Fig. 3) and
put on tape. Finally, intersection control cards were devised containing the identifica-
tion for each intersection on the state highway system, the highway index number, mile
point, route number, and name of the intersecting road or street. Because of differ-
ences in the coding procedure used on the accident records and in the format desired
for the final listings, separate programs had to be developed for the urban and rural
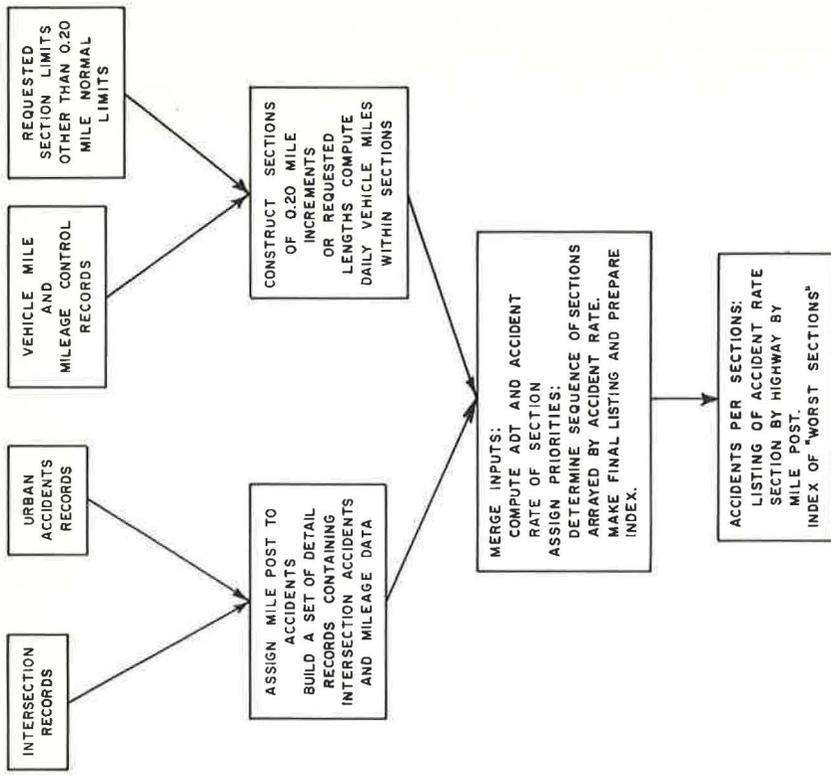analysis (Figs. 4 and 5).

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Figure 1.

Figure 2.

Figure 3.

Figure 5. Schematic diagram of urban accident per section program.
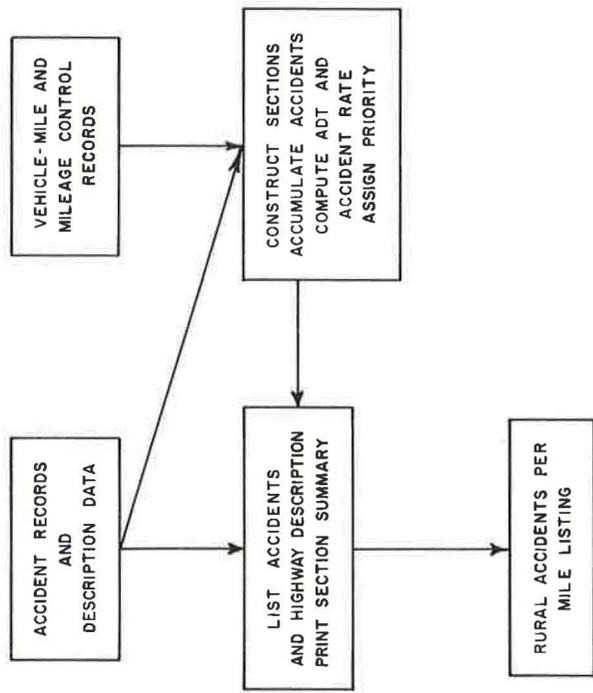

Figure 4. Schematic diagram of rural accident per mile program.

PACIFIC HIGHWAY

INTERSECTION MILEPOST ACC.	NON-INTERSECT MILEPOST ACC.	TOTAL BY MILE ACC. KIL. INJ.	PRIOR YEAR INT. OTH	ACC
	7.35	2		RE-- 1 BCK- 1
	7.36	1		SSO- 1
	7.40	2		FO-- 2
	7.49	2		SSO- 1 NC-- 1
	7.50	2		RE-- 1 NC-- 1
	7.59* HWY W 1W UXING PACIFIC			
	7.77	1		NC-- 1
	7.80	1		FO-- 1
	7.84	1		FO-- 1
	7.85	1		FO-- 1
	7.86	1		RE-- 1
	7.89	1		SSO- 1
	7.90	2		RE-- 1 FO-- 1
	7.91	1		SSO- 1
	7.94	1		SSO- 1
	7.97	1		FO-- 1
	7.98	1		RE-- 1
	7.99* MULT WASH CO L			
TOTAL M.P. 7		37 2 22	4 12	RATE 4.91 ADT 20573 PRIORITY 781
	8.03	1		FO-- 1
	8.07	1		SSO- 1
	8.10	3		RE-- 2 FO-- 1
	9.43	1		FO-- 1
	8.50	1		FO-- 1
	8.69	1		RE-- 1
	8.77	1		FO-- 1
TOTAL M.P. 8		9	6 9	RATE 1.42 ADI 17266 PRIGRITY 1806
	9.11	1		FO-- 1
	9.23	1		NC-- 1
	9.31	1		FO-- 2
	9.34* WASH CLACKAMAS CO LINE			
TOTAL M.P. 9		5 2	1 7	SSO- 1 RATE .80 ADT 16907 PRIORITY 186
10.03 1	10.00	1		MIS- 1 SSO- 1
	10.08* CLACK WASH CO LINE			
	10.34	1		RE-- 1
	10.64	1		RE-- 1
TOTAL M.P. 10		4	2 6	RATE .68 ADT 15854 PRIORITY 188
11.03 2				RE-- 1 TRN-
11.09 1				TRN- 1
11.25 1				ANG- 1
	11.27	1		FO-- 1
	11.35	1		FO-- 1

Figure 6. Output format of rural accident per mile program.

HIGHWAY I-E, ROUTE US99E,   SALEM   - CONTINUED

MILE-POINT	HIGHWAY-STREET NAME	CROSS-STREET NAME	ACCIDENTS TOTAL	INT-SCTN	NON-SCTN	CASUALTIES I	F	TYPE OF COLLISION
S 50.80	COMMERCIAL ST	BEGIN SECTION						
S 50.81	COMMERCIAL ST	LESLIE ST						
S 50.86	COMMERCIAL ST		2		2			RE-- 1 SSC- 1
S 50.87	COMMERCIAL ST		1		1			SSO- 1
S 50.88	COMMERCIAL ST	MISSION ST	6	6		4		ANG- 2 RE-- 2 TRN- 3
S 50.89	COMMERCIAL ST		2		2	2		RE-- 1 PRK- 1
S 50.90	COMMERCIAL ST		1		1			RC-- 1
S 50.93	COMMERCIAL ST		1		1			RE-- 1
S 50.95	COMMERCIAL ST	KEARNEY ST	2		2			RE-- 1 PRK- 1
		TOTALS	15	6	9	6		RATE 33.72 ADT 12220 PRIORITY 4
S 51.00	COMMERCIAL ST	BEGIN SECTION						
S 51.02	COMMERCIAL ST	RUSH ST						
S 51.03	COMMERCIAL ST		1		1			PRK- 1
S 51.08	COMMERCIAL ST	OWENS ST	6	4	2			RE-- 3 TRN- 3
S 51.15	COMMERCIAL ST	MILLER ST						
		TOTALS	7	4	3			RATE 17.16 ADT 11210 PRIORITY 17
S 51.20	COMMERCIAL ST	BEGIN SECTION						
S 51.22	COMMERCIAL ST	WILSON ST	1	1				RE-- 1
S 51.29	COMMERCIAL ST	MYERS ST	2	2				ANG- 2
S 51.36	COMMERCIAL ST	LEFELLE ST						
		TOTALS	3		3			RATE 8.09 ADT 10185 PRIORITY 22
S 51.40	COMMERCIAL ST	BEGIN SECTION						
S 51.43	COMMERCIAL ST	LINCOLN ST	1	1				TRN- 1
S 51.50	COMMERCIAL ST	WASHINGTON ST						
S 51.57	COMMERCIAL ST	SUPERIOR ST						
		TOTALS	1	1				RATE 2.77 ADT 9905
S 51.60	COMMERCIAL ST	BEGIN SECTION						
S 51.62	COMMERCIAL ST	LIBERTY ST CONN						
S 51.63	COMMERCIAL ST	OXFORD ST						
S 51.68	COMMERCIAL ST							BCK- 1
S 51.70	COMMERCIAL ST	RURAL ST	10	7	3	3		ANG- 7 RE-- 5 SSO- 3
S 51.74	COMMERCIAL ST		1	1		1		NC-- 1
S 51.75	COMMERCIAL ST	JERRIS ST	1	1		1		RE-- 1

Figure 7. Output format of urban accident per section program.

Rural Accident Program Series

Since the highway number and mile point are coded on each rural accident card, a straightforward operation was possible involving the matching of accident and vehicle-mile cards with a subsequent calculation. As accidents and vehicle-miles are accumulated by one-mile sections, composite accident rates are calculated from the two sets of data. Finally, the sections are arrayed in sequence by accident rates and assigned a priority rating, with the number one priority being that section with the highest accident rate. To provide convenient geographic references for persons using the final listing, a separate set of cards was created which identified selected mile points with a brief locational description. These are merged into the final tape after the calculations are completed and before the print-out of the final listing (Fig. 6).

Urban Accident Program Series

Accidents in urban areas (within the corporate limits of cities) are coded as occurring either at an intersection or in terms of distance and direction from an intersection. For precise location, distances are coded in feet. This coding procedure made the analysis and programming steps for urban accidents much more complicated than for rural accidents.

Work on intersection control records had been started previously because the information was required for other accident summaries, but only selected intersections were included. For this program, however, it was imperative that the intersection reference be as complete as possible. Otherwise, both intersections and the accidents occurring at them would not appear in the listing.

To make the listing as useful as possible, the procedure for delineating the accident-rate sections had to be carefully defined. A standard distance of 0.20 mile was used for each section. Specifications for the beginning and ending termini were as follows: (a) municipal boundaries, (b) beginning or ending of a highway, (c) the beginning or ending of a break or discontinuity in the mile-point sequence of a highway, such as would be caused by mile-point equations, (d) the beginning or ending of a mileage control change such as occurs at the beginning or end of a couplet, and (e) any particular mile point specified by a set of control cards.

The first step in the program sequence matches the accident records with the intersection control records, thus locating the accident by highway mile point. A set of detail records is then made containing accident data and a mile-point reference for each intersection. At the same time, the sections are defined, vehicle-miles are computed, and the two sets of data are compatible for merging into the subsequent operation. At this stage, the accident rates are computed for each section and the sections are arrayed by these rates. Priority numbers are then assigned by position in the array. An example of the final listing is shown in Figure 7.

Application of Analysis

To make maximum use of this accident analysis procedure in the identification and correction of high-accident locations, listings are prepared semiannually. Besides a complete listing of the state highway system containing priority sequence on a statewide basis, listings are also prepared for each geographic division of the highway department. These listings contain only the sections in the respective divisions with the priority numbers assigned accordingly.

Approximately 100 locations have been investigated to date and appropriate measures have been taken to correct deficiencies. Corrective measures taken include the installation of signs and pavement markings, installation of traffic signals, correction of superelevation, and in one case complete redesign of an intersection. Since the program has been in effect only a short time, the effectiveness of corrective measures taken so far cannot be fully evaluated. However, in one example involving minor improvement, sign installation, the accident rate was reduced 54 percent; in another, involving extensive reconstruction, accidents have been reduced 89 percent. A secondary use of the listings is to provide before-and-after accident comparisons to determine the effectiveness of corrective measures taken as a result of this program.

Programming Hazard-Reducing Improvements

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ABRIDGMENT

●GUIDELINES developed for programming highway safety improvements represent a synthesis of existing practices: accident reporting and hazard identification, accident analyses, spot improvement programs, safety values in regular improvement programs, and management and research. The guidelines are not conceived as a list of requirements that a highway department must meet completely for an effective accident-reduction program. However, individual states perhaps will find portions helpful in upgrading their efforts to define hazards and program safety improvements.

Considerable attention is being given in some states to the problem. Efforts are being made to improve accident reporting, by getting both more complete coverage and more precise definition of the locations at which accidents occur. Some examples of what are and can be done are as follows:

1. Cooperation of investigating officers may be encouraged by having highway department field personnel establish and maintain personal contact with officers in their area, and by having the chief highway administrator direct communications to officers soliciting their cooperation.

2. The highway department can evaluate ratios of total reported accidents to fatal accidents, make correlations between department-employee reports, news reports and operator reports, and use the results to inaugurate campaigns to inform officers and the public of apparent inadequacies of accident coverage.

3. Highway departments can see that report forms and instructions specify needed location-defining data. These should include the unit and accuracy of measurement to reference points, preferably miles to hundredths or feet to nearest 50 feet. Reference points, such as mileposts, structure markings and utility pole numbers, can be suggested.

4. Mileposts or other log-mile markers can be placed at regular intervals and at bridges, culverts and other structures to provide accurate and easily identifiable reference points. Their use can be encouraged by informing investigators that data provided on reports will be valuable in making engineering assessments for the correction of hazardous situations.

5. Furnishing mileage logs to investigating officers facilitates consistent referencing of accident locations and eliminates subsequent matching of accident locations with log points.

Uses of electronic data processing (EDP) showing real promise for much wider application in the establishment of hazardous locations include the following:

1. EDP can provide a list of accidents by location as defined by log miles and/or road section. Listings can be run for different accident-experience time periods. Short interval, current listings may be helpful in pinpointing critical, newly developed hazards. Longer periods of time generally will be necessary to establish accident concentrations with statistical reliability.

2. EDP can compute and print accident rates for road sections based on accident report data. The rates can be computed in 0.01-mile increments of route mileage if reports are made to this accuracy, or in accumulations of 0.01-mile increments if

desired to obtain greater statistical reliability. If accident data are reported less accurately than to a 0.01 mile or simply to road sections, rates can be computed and print-outs made to fit.

3. EDP can relate current accident data with previous time periods by having comparative data included in the print-out or by side-by-side comparison of current and past experience listings.

4. EDP can provide analyses which show the numbers and percentage of accidents of different types and develop incidence and rate values by location for different types of accidents.

5. EDP analyses of accident data can be correlated with data processing records for highway information developed as part of other statistical and inventory processes. This permits analyses of accidents in relation to highway geometrics and other record information.

6. Establishing critical rates and confidence limits, using statistical quality control techniques, will enhance the use of accident rate data developed in computer programs. The critical rates may be set up as an overall rate for a route or section or on a state-wide rate. The computer program then will indicate by symbol in the print-out the rates which exceed the critical rate by a statistically valid amount.

Spot safety improvement programs are being given special attention through legislative or administrative provisions:

1. A specific amount may be provided in the budget—by legislative action in states where the budget is subject to legislative approval or appropriation of funds, or by administrative action where the highway department has authority to program its funds—for spot improvements by contract construction and state-force maintenance and betterments.

2. A highway department policy may be established to define the character and magnitude of spot improvement programs. A specific amount of funds may be set aside by policy to be programmed for spot improvements and for defining the types of improvements to be undertaken.

3. A department policy may be established that no specific amount of money will be earmarked for hazard-reducing spot improvements but specific safety improvements when defined and justified will be given priority consideration for inclusion in the programs for construction and maintenance.

4. A department policy may be established to define the responsibility within the department and to indicate criteria for developing spot improvement programs.

5. A routine within operating units, such as traffic engineering and maintenance, may be established to report potentially hazardous situations and initiate investigation for corrective action. This may result in programming an improvement project or performing corrective actions as a maintenance function.

These efforts by state highway departments are encouraging but, viewed in total, leave much to be desired. In many states, there is an urgent need for department policy in this area. There is need for specific assignment of responsibility to an organizational unit, the setting of objectives for that unit, and the provision of personnel and facilities to carry on research and program development.

Teaming Up for Safe Design and Operation

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ABRIDGMENT

•HIGHWAY TRANSPORTATION is obviously a team operation. Planning, design, construction, maintenance and operations all figure in the quality of service and, therefore, in the safety on a highway system[1]. With the systematic kind of surveillance now in use, and with the obligation of funds to carry out improvement programs, everyone in the organization can do what is necessary to reduce accidents.

Planning

Proper planning can make a system of streets inherently safer. For example, residential areas with conventional gridiron street patterns have accident rates twice those of subdivisions with limited-access design; therefore, four-way intersections should be used only where noncontinuous streets intersect. At moderate to high traffic volumes, the accident rates at four-way intersections run from 3 or 4 to 14 or 15 times those at three-way. Multi-legged, jogged, acute angle, and Y-type intersections should also be avoided. Collector streets should exit into one major street only and should not run completely through the subdivision. Through traffic should be carried on major streets with access no more frequent than $\frac{1}{4}$-mile intervals. Along these streets, cul-de-sac, back-up or side-on treatment is preferable to a continuous service road, although service roads are safer than direct driveway connections (1, 2).

Design

Generosity and consistency are necessary in design. Substandard design features are consistently associated with higher than average accident rates. A substandard feature appearing in otherwise good alignment is doubly hazardous. The features characterizing freeways with lower than average accident rates are (a) generous width of lanes, shoulders and medians; (b) paved flush shoulders; (c) no curbs either right or left; (d) uniform cross-sections (number of lanes is constant over fairly long distances); (e) generous ramps, all on the right side; (f) good alignment, practically straight and level. Freeways in California with rates lower than the average have these features in common. Those with higher than average accident rates lack one or more of these characteristics (3).

Short acceleration and deceleration ramps are consistently the scene of high accident rates. Left-hand ramps are 3 or 4 times as accident prone as right-hand ramps. Accident rates increase at about 0.15 per degree of curve on conventional roads and about 0.3 to 0.4 per degree of curve on divided expressways. That is, curves over 5° have rates 4 times as great as tangents, and when they are combined with grades over 5 percent the rate is about 20 times that for straight and level alignment.

Construction

Construction specifications relating to mineral aggregates and pavement mixtures can keep accidents down if they are drawn so that the end result is a pavement with good skid-resisting and light-reflecting qualities. Skidding may be involved in as much as 40 percent of all accidents. In one state, skidding occurred before the brakes were applied in 10 to 15 percent of all accidents. On the Pennsylvania Turnpike, the accident rate is twice as high when the pavement is wet as when it is dry.

In Virginia, skidding rates for a certain region were twice those for the rest of the state. This difference was traced to the native mineral aggregates, used for paving in that region, which polished rapidly under traffic.

Skidding is more likely to occur at naturally hazardous places. An easy curve is twice as likely to be a skidding accident site as a straight stretch of road. Even easy to moderate grades can be 4 times as likely skidding accident sites as straight and level roads. When curves and grades come together, the risk of a skidding accident increases to something like 8 times that for straight and level roads.

Pavements good when they are laid will polish under traffic. Under light traffic or on straight and level roads, the polish is almost negligible, but it increases rapidly with the volume of traffic on curving stretches where skidding is most likely to be a problem. Elimination of this polish is one of the functions of maintenance.

Maintenance

Maintenance can keep accidents down by keeping sight distance unimpaired. When sight distance is less than 1,500 feet on 2-lane roads, the accident rate is twice that where it exceeds 2,500 feet. Even stretches of road with sight distances of 1,500 to 2,500 feet have about 1.5 times the accidents of those with unlimited sight distance. Where the obstructions occur infrequently, the accident rate is doubled.

Operation

The full and proper use of signs and markings at curves has reduced night and day accident rates as much as 50 and 55 percent, respectively. Setting up through streets and keeping through traffic off local streets by using stop signs to define through streets has reduced the accident rate on the through and the two parallel streets. In three such cases in San Francisco, the reductions ranged from 17 to 37 percent (based on studies by Shoaf in San Francisco).

A signalized intersection with both a left turn lane and a special turning phase will generally have only one-third as many accidents as one with the left turn lane only. Mast arms to get the signal indications out where they can be seen more readily will also bring the accidents down. In one urban area this resulted in reductions of 78 percent in angle collisions and 33 percent in pedestrian accidents. On a rural high-speed divided highway, the use of mast arms for additional indications decreased accidents about 45 percent (based on studies by Webb in California).

Recently, on approaching a major freeway-to-freeway interchange I noticed a driver making a U-turn, then proceeding back to the interchange and taking one of the ramps. On the next trip I saw a driver do exactly the same thing. On a third trip I saw a driver backing up one of the ramps and on a fourth trip I saw another driver making a U-turn across the median. I decided to look further into this and began to study the signs at this interchange. It seemed to me that almost without exception the signs tell people how to get to places they don't want to go. In the same general vein, I have noticed that about 5 percent of all fatalities on freeways involve vehicles driving on the wrong side of the median. Better signing and designs could reduce these occurrences.

On another occasion, a traffic engineer asked me how I would sign an interchange of two freeways which was $\frac{1}{2}$ mile from an interchange of their common stem with an arterial street. We began to work something out, and then he said: "In the next fiscal year we plan to build another interchange 2,000 feet from the one serving the two freeways. How would you suggest we sign it?" Now, there are some things signing can do and there are others signing can't, and I submit that good teamwork takes into account

the limitations as well as the capabilities of each team member with no one being asked to perform beyond his capacity.

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Adapting the Highway to the Human Element

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ABRIDGMENT

●ONE MAIN direction of recent research on the driving task has been the examination of the characteristics of the environment relative to the visual requirements essential to accurate and reliable vehicle control. This work has provided an insight into certain of the basic mechanisms employed by drivers to locate themselves in time and space, and the results indicate that the driver is faced less with the problem of simple detection than with the scaling of speed and projection of position, his own and others. Research has also indicated that immediate control is determined by conditions existing with a driver's visual field whose longitudinal extent is fairly short, varies as a function of speed, and laterally extends beyond the road borders. However, elements outside these limits are important because they provide coherence and structure to the visual world. This orientation is essential for accurate interpretation of what enters the driver's field. Further, they serve as advanced cues by which the driver may sort and order events or changes with which he must deal in the near future. Finally, there are indications that because of his limited information-processing capabilities, the driver must do considerable time sharing among the many sources in the environment. This appears to degrade accuracy and reliability of any one operation.

Results of this research indicate that visual velocity information is the most significant perceptual dimension for the safe performance of the functions of driving. This information must be available relative to the roadway itself and other objects, fixed or moving, with which the driver must deal. Thus, the basic conditions for safety are that the roadway environment be structured to provide this visual velocity information without discontinuities or distortion. Further, the environment must be adapted to these requirements and organized to be within the driver's information processing limitations.

Some examples may clarify these principles. A driver's speed and lateral position on a roadway will be adjusted to the availability of visual velocity information and to its magnitude. The driver will adapt his control to insure having the needed information in appropriate time and space sequence. This is a significant reason for having not only geometric design criteria, but also high contrast demarcation of the roadway. Fixed objects entering the drivers visual field will cause a lateral displacement whenever they enter without a detectable component of lateral velocity. If a driver cannot displace, he will reduce speed to minimize the probability or magnitude of displacement. Other vehicles are picked up as they enter the driver's visual field and are scaled on the basis of relative visual velocity. Thus, when and where they become of active concern to a driver depends on the extent of his visual field. Only in the case of car following, however, does there appear to be a direct way to translate the perceived motion into control responses. Gap acceptance and passing appear to reduce to a go, no-go decision process.

It is evident that there is a range of conditions in which a driver uses a common perceptual process for controlling his speed and position. Implicit is the principle that whenever and for whatever reason the accuracy or reliability of these perceptual and judgmental processes are reduced, safety is compromised. This human factors principle can be applied in safety engineering. Although it does not define what should be done, it does provide criteria for specifying conditions which compromise safety and when changes should be instituted to improve safety.

At present, a location is specified as unsafe when it has an excessive accident record. Ironically, a significant number of accidents must accumulate before safety measures

aimed at preventing them are initiated. There is something very wrong, and I think unnecessary, with such a logic, because from what is now known about the driving task we can begin to see an alternative. What we are looking for are the locations or situations in which the environment is so complex or so ambiguous that the driver is forced to compensate in speed or position to maintain or minimize loss of accuracy of his control. We are in a position to specify some of the most significant environmental conditions which cause degrading of safety. They may be stated as follows:

1. Where the geometrics of the highway restrict a driver's view ahead so that there is insufficient visual information for him to control reliably for changes in gradient or curvature;

2. Where the continuity or differentiation of referents within the driver's field of view are so inadequate that there occurs high variability in lateral placement or high frequency of speed reduction;

3. Where there occur constraints within the driver's visual field that cause significant lateral displacements or speed reductions to avoid displacement;

4. Where the frequency of large speed differences occur from any cause;

5. Where the accurate judgment and/or frequency of occurrence of adequate gaps for turning, crossing, or passing is compromised regardless of cause; and

6. Where the number, complexity, and uncertainty of information sources with which the driver must deal becomes so great that speed reductions are frequent.

Each of these restrictions may be determined by direct measurement, which, including volume, becomes the real criterion for instituting any physical changes. The crux of that program is the appropriate measurement of changes in speed or placement. Further, the detection of many potentially unsafe locations may be determined by subjective driving experiences. All that is required is a sensitivity to the ease or difficulty experienced in driving.

This approach to safety engineering is predicated on the assumption that highway safety is a problem of adapting a machine-environment system to the requirements of human control. Using our growing understanding of driving behavior in this fashion can provide an objective basis for establishing priorities for safety improvements, and thereby avoid the dilemma of the accident criterion.

A Future for Highway Safety Research

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ABRIDGMENT

●THE MAGNITUDE of losses from highway accidents demands systematic, carefully planned research studies. Fortunately, the scope and numbers of such efforts are reaching unprecedented levels. Major thrusts in highway safety research have developed in a number of programs, and more widely diversified disciplines and skills are now being directed toward accident research than ever before:

1. Pharmacologists and pathologists are beginning to study complex blood-alcohol-drug effects on driving;
2. Social psychologists are tracing demographic and other sociological relationships to accidents;
3. Experimental psychologists are studying signs, markings and other visual displays in highly sophisticated laboratories;
4. High-speed computers are enabling statisticians to apply the most complex factorial models to mass accident data analyses;

In the engineering disciplines, broad-scale studies are in progress on such aspects as the mechanism of vehicle failure in crashes, dynamic stability of truck-trailer combinations, and relationships of geometric design alternatives to accident likelihood.

Likelihood of Research Payoff

Along with the result-producing projects, others undoubtedly will come up empty-handed or provide only partial answers or hints of new avenues for study. It is unrealistic to expect any single major breakthrough in highway safety. Instead, individual projects and observations will produce facts and partial facts that gradually will come to be related to each other over a period of time. Early findings may be proved or disproved, and working theories will evolve out of diverse contributions. This almost piecemeal process of accumulating real facts and discarding false ones characterizes virtually all scientific progress. To expect otherwise of safety research would be unrealistic, if not completely naive.

Need for On-Going Programs

The need for on-going programs characterizes virtually all research, and is almost self-evident for a number of reasons: personnel have to be hired on a sustained basis with job security, not on a project-to-project basis; laboratory facilities must be obtained, maintained, and replaced as new tools evolve; investigators cannot do the research itself if they are spending substantial amounts of time writing proposals, progress reports, interim reports, financial reports, and final reports. There are many other reasons as well.

In safety research, an additional, unique aspect demands a programmatic approach. The criterion measure can only be accidents. And no matter how great the accident losses are on a national basis, they are very rare events within the framework of any single, closely controlled study. A certain amount of manipulation of data with modern statistical methods helps to overcome this difficulty, but the only substantial recourse is to have the study continue over a sufficiently long period of time to give the accidents

that normally would happen a chance to happen, or, stated positively, to assure the researcher that accidents are no longer occurring at the same rate. When we ask for the study to continue for an extended period of time, literally to wait for accidents, we are asking for safety research programs—not projects.

Involvement of Operational Personnel

The second dominant need in highway safety research is a greater involvement of operational personnel in programmatic research. This refers not only to the need for sustained activity but also to the nature of the problem under study. Most operational personnel in highway safety research seem to be concerned with what may be called "putting out fires" types of problems. This is understandable. Somebody must do this and lives are undoubtedly saved as a result.

Typically, the broad gaged problems, those problems not likely to produce immediate results, are thought of as being in the province of universities and non-operational research centers. But the experience and skills of operational personnel are also badly needed for these problems. Here I am not referring to support assistance, such as in making field measurements, and I am not deprecating the importance of such support. Any university researcher who has ever attempted to instrument an 8-lane freeway can corroborate my comfort in having the support of California Division of Highways engineers during these phases of a recent joint research effort. Nor am I referring to the equally important supportive role of helping to identify the significant basic problems for programmatic type of support; nothing will discredit research more quickly than spending large sums of money on small problems.

My reference is to more involvement by operational personnel in their own broad gaged highway safety research programs, such as the comparatively recent build-up of the U. S. Bureau of Public Roads Office of Highway Safety and the recently initiated continuing five-year Highway Safety Research Program of the California Highway Transportation Agency. As a part of the latter program, the Agency recently sponsored a two-day seminar attended by engineers of the California Division of Highways, the Department of Motor Vehicles, the Highway Patrol, and the ITTE staff. All participants had charge of one or more safety research projects in California's five-year program. The purpose was simply to communicate to one another the plans and problems in conducting the separate research projects. The men from the operating agencies found that our work was not completely impractical, and we, in turn, gained a better appreciation for the kinds of answers urgently needed by the operating agencies.

Conclusion

At the 1964 meeting of the Highway Research Board Committee on Highway Safety, Ed Ricker described a very simple finding that undoubtedly could save many lives on the highways—a 5-cent washer inserted behind the head of bolts and nuts used to hold guardrails in place. He used this example to highlight the need for systematic procedures for implementing such findings.

I am unfamiliar with the facts leading up to the discovery of this simple design improvement. Possibly it was the culmination of a systematic research program of some sort. Possibly some bright mathematician generated a series of simultaneous equations, solved them on a high-speed digital computer, and found the answer—use the 5-cent washer. More likely, however, the discovery had large elements of luck in it. This is not a derogatory statement; to the contrary, such discoveries—radioactivity, penicillin, and others of equal importance to mankind—also were largely lucky. But these discoveries were made by people who had the skill and experience to understand a problem and recognize a solution, even when it appeared by chance.

Such discoveries will continue; everything should be done to encourage more, to create a climate of understanding of the accident, and hence, the capability of recognizing remedial measures when they occur, both with regard to prevention of accidents and mitigation of injuries, and then implementing the findings. The future of highway safety research rests with diverting at least a part of the skill, experience and judgment implicit in making such discoveries to full-time programmatic research problems.