HIGHWAY RESEARCH BOARD
Bulletin 161

Investigating and Forecasting Traffic Accidents

National Academy of Sciences—
National Research Council
publication 52

HIGHWAY RESEARCH BOARD

Officers and Members of the Executive Committee

1957

HIGHWAY RESEARCH BOARD
Bulletin 161

Investigating and Forecasting Traffic Accidents

PRESENTED AT THE
Thirty-Sixth Annual Meeting
January 7-11, 1957

1957
Washington, D. C.

Department of Traffic and Operations

Wilbur S. Smith, Chairman
Bureau of Highway Traffic, Yale University

COMMITTEE ON HIGHWAY SAFETY RESEARCH

J. H. Mathewson, Chairman
Assistant Director, Institute of Transportation and Traffic Engineering
University of California

Earl Allgaier, Research Engineer, Traffic Engineering and Safety Department, American Automobile Association
John E. Baerwald, Assistant Professor of Traffic Engineering, Civil Engineering Hall, University of Illinois, Urbana
J. Stannard, Baker, Director of Research and Development, Northwestern University, Traffic Institute, Evanston, Illinois
Dr. Joseph M. Bobbitt, Chief, Professional Services Branch, National Institute of Mental Health, Bethesda, Maryland
Dr. Leon Brody, Director of Research, Center for Safety Education, New York University
Basil R. Creighton, Executive Director, American Association of Motor Vehicle Administrators, Washington, D. C.
Professor John C. Kohl, Director, Transportation Institute, University of Michigan, Ann Arbor
C. F. McCormack, Deputy Chief Engineer, Highways Division, Automotive Safety Foundation, Washington, D. C.
J. P. Mills, Jr., Traffic and Planning Engineer, Virginia Department of Highways, Richmond
Charles W. Prisk, Supervising Highway Transport Research Engineer, Highway Transport Research Branch, Bureau of Public Roads
William F. Sherman, Manager, Engineering and Technical Department, Automobile Manufacturers' Association, Detroit, Michigan
G. D. Sontheimer, Director of Safety, American Trucking Associations, Inc., Washington, D. C.
Seymore S. Taylor, Assistant General Manager, Department of Traffic, City of Los Angeles, California
Wayne N. Volk, Traffic Engineer, State Highway Commission of Wisconsin, Madison

Department of Traffic and Operations

Wilbur S. Smith, Chairman
Bureau of Highway Traffic, Yale University

COMMITTEE ON ROAD USER CHARACTERISTICS

Dr. T.W. Forbes, Chairman
American Institute for Research, Pittsburgh

Dr. Terrence M. Allen, Highway Research Engineer, Council for Highway Investigation and Research, University of Virginia, Charlottesville
Earl Allgaier, Research Engineer, Traffic Engineering and Safety Department, American Automobile Association
Dr. Abram M. Barch, Department of Psychology and Highway Traffic Safety Center, Michigan State University
Dr. William G. Beadenkopf, Assistant Director, Bureau of Epidemiology and Communicable Disease Control, New York State Department of Health, Albany
Siegfried M. Breuning, Assistant Professor of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada
Dr. Leon Brody, Director of Research, Center for Safety Education, New York University
Dr. Harry W. Case, Department of Engineering, University of California
William G. Eliot, III, Highway Engineer, Bureau of Public Roads
H. A. Mike Flanakin, American Trucking Associations, Inc., Washington, D. C.
Gordon K. Gravelle, Deputy Commissioner, Department of Traffic, New York
Fred W. Hurd, Director, Bureau of Highway Traffic, Yale University,
Joseph Intorre, Administrative Assistant, Institute of Public Safety, Pennsylvania State University, University Park
Merwyn A. Kraft, Research Coordinator, Flight Safety Foundation, Inc. New York
Dr. A. R. Lauer, Professor of Psychology, Iowa State College
Alfred L. Moseley, Moseley and Associates, Boston, Massachusetts
Charles W. Prisk, Director, Highway Safety Study, Bureau of Public Roads
Dr. Robert V. Rainey, Driving Research Project, University of Colorado Medical Center, Denver
Dr. Julius E. Uhlaner, The Research Manager, Personnel Research Branch, TAGO, Department of the Army, Washington, D. C.
Wayne N. Volk, Engineer of Traffic Services, State Highway Commission of Wisconsin, Madison
George M. Webb, California Division of Highways, Sacramento
Houston F. Wynn, Wilbur Smith and Associates, New Haven, Connecticut

Contents

Indexes of Motor Vehicle Accident Likelihood

J. H. MATHEWSON and R. BRENNER
Institute of Transportation and Traffic Engineering
University of California, Los Angeles

Motor vehicle accident rates with the unit of risk expressed as mileage are useful for general safety promotional and educational purposes. Their usefulness for specific engineering and enforcement purposes is quite limited, however, as a result of the gross methods whereby mileage data are collected. Their meaningfulness also is reduced as the distance over which the rate is computed becomes smaller. In the limit, at a single point, the mileage-based statistics are completely meaningless. Another criticism of these statistics stems from the fact that the unit of risk is seldom identified with the site of the risk.

The single instance where site of risk is identified with unit of risk is in evaluations of the hazard of a particular stretch of road. It is demonstrated that even in a case as specific as this, a mileage-based index reduces in fact to volume-based indexes divided by a distance constant. This constant contributes nothing to the statistical behavior of the random risk factor, and, in fact, may obscure the true hazard of the road.

From these arguments it is concluded that motor vehicle accident rates should be expressed simply as volume-based indexes. These measures would relate the number of accidents occurring at a given point during some period of time to the volume of vehicles passing that point during the period. The point could be any stretch of road over which the volume of traffic is essentially constant. To increase the usefulness of the results, the points should be defined in operationally meaningful lengths.

●THE basic reason for maintaining and analyzing motor vehicle accident records is to quantify the hazard of motor vehicle operation and thereby provide direction to engineering, enforcement, and other personnel seeking to reduce the hazard. This hazard quantification is usually expressed as a rate relating the occurrence of an accidental event to some measure of risk. In general use today as the risk measure is vehicle mileage from which are derived well known indexes, such as fatalities per 100, 000, 000 vehicle-miles and collisions per 1, 000, 000 vehicle-miles. The messages implicit in such indexes are easily understood by the lay public, hence they are highly useful for the all-important public education and other promotional activities for obtaining public support for safety programs and improved facilities. However, fundamental difficulties arise when such indexes are utilized in more technical problems in engineering and enforcement, and the source of these difficulties essentially is the non-rigorous mileage measurement.

In this paper, the authors seek to analyze some of the factors which limit or possibly completely preclude the use of mileage as the risk measure in accident rates which are to provide bases for technical decisions. The analysis demonstrates that mileage, in its best form of measurement today for describing risk, is in effect a measurement of traffic volume. From this it follows that traffic volume itself can well be treated as the risk measure without any loss in rigor, and with the possibility of providing a much clearer quantification hazard.

MILEAGE AS THE UNIT OF RISK

The use of the vehicle-mile as the unit of risk in motor vehicle accident rates seemingly stems from the highly plausible concept that accident likelihood is measured by the ratio of the number of accidents and the amount of driving during the period in which those accidents occurred. It is well to note here that mileage is not the only measure of the amount of driving, nor is there any evidence, to the best knowledge of the authors, that it necessarily is the most meaningful basis for accident occurrence. For example, hours of driving without regard to distance covered also measures the amount of driving and could well correlate more closely with accidents than would mileage, particularly on long, open road trips, or nighttime versus daytime. The use of mileage, it would appear, further stems from the relative ease with which it can be plausibly estimated.[1] But in this paper, there is not so much concern with the validity of the rationale for the use of mileage as the risk measure as there is with the methods of measuring the mileage.

Perhaps the most general criticism of the mileage figure is that rarely, if ever, is it directly measured, but instead is usually estimated by indirect methods involving judicious manipulation of such variables as total gasoline consumption, car registrations, and average mileage per gallon. A reasonable estimate of total mileage can be obtained with these indirect methods if the region in question is sufficiently large, and the time period is sufficiently long. However, as the size of the exposure interval (whether expressed in distance or time) is increased in order to increase the precision of the mileage estimate, the value of the index for engineering and enforcement application is lessened. For example, an index over the entire United States is of little value for adequately identifying local problems, or, an annual index is of limited value for analyzing a seasonal problem. It can be stated almost axiomatically that mileage-based statistics do not usually identify the unit of risk with the site of the risk, and hence are of limited use for engineering and enforcement purposes, most of which require at least some degree of specificity.

Quite apart from the difficulties in measuring and localizing mileage so that the statistics will be useful for engineering and enforcement problems, there are other serious difficulties which relate to the distance over which the mileage is measured. If the distance is sufficiently long, there is no problem; as the distance decreases, however, the mileage-based statistics become less meaningful until in the limit, at a single point on the road, they are completely meaningless. Norden, Orlansky and Jacobs (2) recognize this and point out that mileage-based statistics would not be useful for study of accidents at toll gates. Other examples of the profession's recognition of this can be readily obtained.

AN ARGUMENT FOR TREATING VOLUME AS THE UNIT OF RISK

The argument for treating volume as the unit of risk in motor vehicle accident rates is developed in the following manner. First, it is postulated that the only application where mileage-based statistics come close to being rigorous is in highlighting the fact that a given stretch of road is unusually "safe" or "dangerous." It is then demonstrated that even for this, a relatively straightforward problem of mileage measurement, operational practice in making the measurement is such that the computed index is in effect a volume-based index divided by a constant. The constant, which turns out to be the length of the road in question, contributes nothing to the analysis of statistical fluctuation of the rate under the most ideal conditions, and in many cases can becloud the analysis. From this it is concluded that volume-based rates should be used.

Assume a thoroughfare, either rural or urban, that runs through two points, A and B. Parameters dealing with point A will be identified by the letter A; those dealing with B will carry the letter B; those dealing with the distance A to B will be identified by the

[1] Motor vehicle accident rates expressed on a mileage basis have been dropping consistently over the years (1). It is of interest to speculate on the behavior of the rate had it been expressed on the basis of hours of driving, assuming that this risk measure could have been estimated. If it is assumed that higher average speeds have been attained over the years, then the amount of driving time could not have increased as rapidly as the distance covered. The possibility therefore exists that the time-based rate might be increasing. If this should happen to be the case, it could be said that motorists have been driving increasingly greater accident-free distances but their accident-free driving time has not been increasing as rapidly, and possibly might even be decreasing. This certainly would not be the pleasant picture implicit in the continually decreasing mileage-based rate.

letters AB. Thus, if N represents the number of cars and t represents some time interval, N_{tA} represents the number of cars passing point A during interval t, and $N_{(t)}$ $_{(AB)}$ represents the number of cars that pass A and then pass B during period t.

Also adopted is the convention that vehicles entering thoroughfare section A-B at point A will carry the subscript A without a bar, whereas those leaving at A will carry a bar over the subscript (for example, $\bar{A}$). The distance between A and B in the direction of A to B is represented by D_{AB}, which equals D_{BA}, the distance from B to A. Point E, any place between A and B, is the only entrance or exit other than A and B for cars on A-B.

Finally, the number of accidents occurring during period of time t will be represented by X_{tA}, the number at B will be X_{tB}; the number that occur anywhere between A and B, including those that occur at A and B, will be $X_{t(AB)}$. The subscript t is dropped for the present purpose, as all discussions are based on a single period. The nomenclature is summarized in Figure 1.

To simplify the discussion, let it be assumed that all vehicles move from A to B; that is, the thoroughfare is one way. The total vehicle mileage, M_{AB}, driven over AB is given by

$$M_{AB} = (N_A - N_{\bar{E}})\, D_{AB} + N_{\bar{E}}\, D_{AE} + N_E\, D_{EB} \tag{1}$$

which may be simplified, by substituting $(D_{AE} + D_{EB})$ for D_{AB}, to

$$M_{AB} = (N_A - N_{\bar{E}})\ (D_{AE} + D_{EB})\ +\ N_{\bar{E}}\, D_{AE} + N_E D_{EB}$$

$$= N_A D_{AE} + N_A D_{EB} - N_{\bar{E}} D_{EB}\ - N_{\bar{E}}\, D_{EB}\ + N_{\bar{E}} D_{AE}\ + N_E\, D_{EB} \tag{2}$$

But the total number of vehicles, N_B, leaving at B, is

$$N_{\bar{B}} = N_A\ - N_{\bar{E}}\ + N_E \tag{3}$$

Therefore, substituting Eq. 3 in Eq. 2 gives

$$M_{AB} = N_A D_{AE} + N_{\bar{B}} D_{EB} \tag{4}$$

Thus, the accident rate on AB with vehicle mileage as the unit of risk becomes

$$R_{AB} = \frac{X_{AB}}{M_{AB}} = \frac{X_{AB}}{N_A D_{AE} + N_{\bar{B}}\, D_{EB}} \tag{5}$$

Eq. 5 facilitates demonstration of several points regarding an accident rate based on a distance unit of risk. First, and most obvious, the rate goes to infinity as the distance AB goes to zero. Thus, hazard analyses using such an index are meaningless at a single point such as an intersection or toll gate. Next, the probability structure underlying the rate R_{AB} as defined by Eq. 5 reduces to a volume-based rate divided by a constant, the distance over which the rate is computed. This will be demonstrated for two cases: first, where there are no entrances or exits between A and B; and, second, where there are entrances and exits.

CASE 1: No Intervening Entrances or Exits on the Road Section

Under the condition of no entrances or exits between A and B, all of the cars entering at A must leave at B,

$$N_A \equiv N_{AB} \equiv N_{\bar{B}} \tag{6}$$

Substituting this identity in Eq. 5 gives

$$R_{AB} = \frac{X_{AB}}{(N_A)\ (D_{AB})} \tag{7}$$

Considering the expected value, ξ, of R_{AB} in Eq.7, and noting that D_{AB} is a constant,

$$\xi\left[R_{AB}\right] = \frac{1}{D_{AB}} \; \xi \left[\frac{X_{AB}}{N_A}\right] \tag{8}$$

But the ratio of X_{AB} to N_A is simply the probability that a car on the road has an accident. Thus, the rate R_{AB} estimates the ratio of the pure risk, which is a statistical quantity, to the distance in question, which is simply a constant, or

$$\xi\left[R_{AB}\right] = \frac{\Pr\{\text{Acc on AB}\}}{D_{AB}} \tag{9}$$

CASE 2: Intermediate Entrances and Exits on Road Section

Consider the road section AB to have one entrance and exit at E between A and B, as shown in Figure 1. Because there are no entrances or exits between A and E, the separate analyses of sections AE and EB are both of the same form as that of section AB in Case 1. Thus,

$$R_{AE} = \frac{X_{AE}}{N_A D_{AE}} \quad \text{accidents per vehicle-mile} \tag{10}$$

$$R_{EB} = \frac{X_{EB}}{N_B D_{EB}} \quad \text{accidents per vehicle-mile} \tag{11}$$

$$\xi\left[R_{AE}\right] = \frac{\Pr\{\text{Acc on AE}\}}{D_{AE}} \tag{12}$$

$$\xi\left[R_{EB}\right] = \frac{\Pr\{\text{Acc on EB}\}}{D_{EB}} \tag{13}$$

The problem is to deal with the hazard over the section AB and not the individual hazards over the two sections AE and EB, these hazards being measured by Eqs. 12 and 13, respectively. It is plausible to consider that the hazard of the over-all section is some function of the individual hazards of the two sub-sections that comprise the whole. Inasmuch as the hazards are developed with vehicle-miles as the unit of risk, the over-all hazard may be considered as the weighted sum of the individual hazards, the weighting being according to the respective vehicle-mile totals for the two subsections.

$$\xi\left[R_{AB}\right] = \frac{(N_{AE}D_{AE})\;\xi\left[R_{AE}\right] + (N_{EB}\,D_{EB})\;\xi\left[R_{EB}\right]}{N_{AE}D_{AE} + N_{EB}D_{EB}} \tag{14}$$

or

$$\xi\left[R_{AB}\right] = \frac{(N_{AE})\Pr\{\text{Acc on AE}\} + N_{EB}\Pr\{\text{Acc on EB}\}}{N_{AE}D_{AE} + N_{EB}D_{EB}} \tag{15}$$

It can readily be seen that Eq. 14 is of the same form as Eq. 4, because $X_{AE} + X_{EB} = X_{AB}$. Therefore,

$$\frac{N_{AE}D_{AE}\left(\frac{X_{AE}}{N_{AE}D_{AE}}\right) + N_{EB}D_{EB}\left(\frac{X_{EB}}{N_{EB}D_{EB}}\right)}{N_{AE}D_{AE} + N_{EB}D_{EB}} = \frac{X_{AB}}{N_{AE}D_{AE} + N_{EB}D_{EB}} \tag{16}$$

Now interject into the argument the operational practice of either assuming that the volume over AE is the same as over EB, or obtaining ADT measurements on each of the two sections, averaging them, and applying the average to each section. Under these conditions Eq. 15 reduces to

$$\xi\left[R_{AB}\right] = \frac{Pr\ \{Acc\ on\ AE\} + Pr\ \{Acc\ on\ EB\}}{D_{AB}} \qquad (17)$$

Thus the hazard for the thoroughfare with the one exit reduces to the form with no exits; that is, Eq. 17 and Eq. 9 are similar, as

$$D_{AE} + D_{EB} = D_{AB}.$$

The argument can now be generalized to the case where there are n entrances or exits between A and B, with traffic volume assumed to be constant throughout. Thus, the section of road in question may be considered as being comprised of n + 1 sub-sections and

$$D_{AB} = \sum_{i=1}^{n+1} D_i \qquad (18)$$

where D_i is the length of the ith sub-section.

Let the risk associated with the ith sub-section be represented by Pr $\{i\}$. Then

$$Pr\ \{i\} = \frac{X_i}{N_i} \qquad (19)$$

and

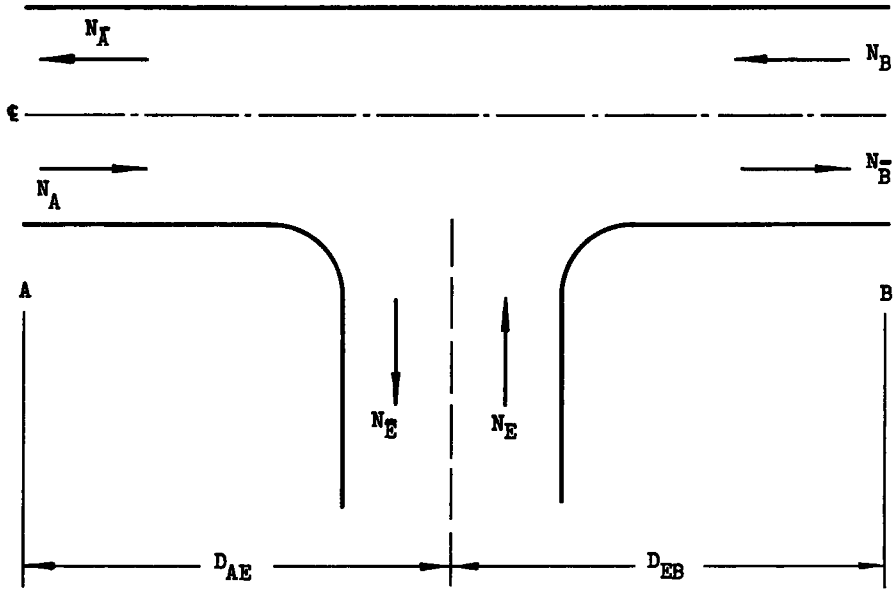
$$\xi\left[R_{AB}\right] = \frac{\sum_{i=1}^{n+1} Pr\ \{i\}}{D_{AB}} \qquad (20)$$

Because distance does not enter into the evaluation of the risk of the ith sub-section, the distance D_i can be defined as a single point on the section AB, or any continuous length on AB. The sole requirement in this argument is that volume be constant over section i, and that all D_i add up to D_{AB}.

The discussion to this point has established that present methods of obtaining mileage-based accident rates are such that these rates identically are volume-based rates divided by a constant which is the distance over which the rate is computed. Furthermore, the volume-based rate (or pure risk factor) for the whole road is the sum of the individual risks of the separate sub-sections which together comprise the road. The next step is to examine what is lost by using a mileage-based index, bearing in mind that implicit in this usage are (a) an average risk over the entire road and (b) the length of the road.

It can readily be seen that change in the risk of section AB can come only from change in any of the risks of the sub-sections that comprise AB. If Pr $\{i\}$ is the same for all i over AB, or if it is uniformly changing over all i from one period to the next, there will not be any deleterious effects from the averaging process. If, on the other hand, the Pr $\{i\}$ is changing for some sub-sections and remaining constant for others, a situation that the engineering or enforcement agencies wish to be able to recognize, any arithmetic process of averaging must necessarily obscure the changing Pr $\{i\}$. This represents a loss of information, which in turn reduces the usefulness of the rate.

The length of the road, of course, contributes nothing to the analysis except where the risk of a road is to be compared with that of some other road of different length. (The case of comparisons between different roads of the same length is of no interest here.) This is the most widely practiced operational usage of mileage-based indexes and is basically valid. Difficulties arise, however, in the user's failure to differentiate between what may be called "unit risk" and "over-all risk." The expression "unit risk" pertains to the risk associated with one unit of length, whereas "over-all risk"



N_A: Number of cars passing point A and entering thoroughfare section AB.

$N_{\bar{A}}$: Number of cars passing point A and leaving thoroughfare section AB.

D_{AE}: Distance, point A to point E in direction A to E.

D_{EB}: Distance, point E to point B in direction E to B.

X_A: Number of accidents at point A.

Figure 1. Nomenclature, Schematic Diagram.

describes the risk of the total length. The mileage-based index is a statement of unit risk. Two roads having the same (mileage-based) accident rate, have the same unit risk. But if the roads are of unequal lengths, their over-all risks must be different. However, common usage of such rates rarely distinguishes between unit and over-all risk with careful qualifications such as ".... trip CD and AB have the same unit risk, but trip CD is more dangerous because it is longer....." It can accordingly be seen how usage of mileage-based statistics can be misleading even in this relatively simple application where distance is differing while the unit risk is unchanging. The confusion is greatly increased if both the distance and unit risk differ for the two roads being compared.

A somewhat more subtle aspect of this criticism of mileage-based rates is seen in a hypothetical example in which a tortuous road 10 miles long between two cities is replaced by a straight, improved road 5 miles long. Assume that the volume of traffic using the new facility is the same as it had been for the old road. Assume, further, that travellers between the two cities were involved in a total of 20 accidents per year, on the averag on the old road whereas this figure was 10 for the improvement. Clearly with the new road there was a reduction in the trip hazard by a factor of 50 percent. Expressing the hazard for the two roads as mileage-based rates, for the old road

$$\text{M.B.R.} = \frac{X}{(V)\ (L)} = \frac{20}{(V)\ (10)} = \frac{2}{V}$$ and for the new road

$$\text{M.B.R} = \frac{X}{(V)\ (L)} = \frac{10}{(V)\ \ (5)} = \frac{2}{V}$$

in which: M.B.R. = Mileage-based rate; X = Number of accidents; V = Volume of traffic; and L = Length of road. Thus, even with the obviously different over-all hazard, the mileage-based rates would be the same. The arithmetic of the computation is such that any decrease in trip hazard accompanying a reduction in trip distance must be obscured by the very reduction in distance causing the decrease in the hazard. Thus, it can be seen that comparing these rates has little meaning.

It is meaningful at this point to deviate from discussions of operational utility of mileage-based indexes in order to consider some of the long-range implications in their use for support purposes. The fact that an improvement results in a reduction in accident likelihood is certainly a strong argument for similar improvements. But it is reasonable to state that highway improvements, particularly in rural areas, will generally involve reductions in trip distance, as in the hypothetical example just given. By continuing to express the hazard as a mileage-based rate, engineers will soon find that it is increasingly difficult to show a reduction in the rate, because as trip distance is decreased while traffic volume remains constant, the mileage-based rate must go up, as is shown in the example, irrespective of whatever change in risk might have been achieved with the improvement. On the other hand, if trip distance is increasing, as it might be in a suburban development around large cities, the mileage-based rate would tend to present an unduly rosy picture of hazard.

RECOMMENDATION

It has been demonstrated that incorporating mileage into rate computations is not a particularly useful practice, either for immediate operational uses or for long-range support uses. Accordingly, it is recommended that the practice should be discontinued. When mileage is dropped from the analysis, what is left is simply the number of accidents divided by the volume of traffic generating the accident experience. This ratio is a pure risk measure, that is, the probability that a car using that section will be involved in an accident. It will have the binomial

$$\text{Risk on section AB} = \frac{\text{Number of Accidents on AB}}{\text{Volume of Traffic on AB}} \qquad (21)$$

distribution and, being small, can be treated as having the Poisson distribution. Extensive tables of both the binomial and Poisson distributions have been published. Also, control chart techniques such as those reported by Norden et al, (2), and Mathewson et al, (3) are directly applicable to the proposed risk measure (Eq. 21). Thus, the statistical analysis of this measure presents no major difficulty.

To use this risk measure in practice, the network of roads and streets would be divided into operational sections. The sole mathematical requirement of the section definition is that the traffic volume be essentially constant over the defined section. Thus, the measure could have been used in the hypothetical example and would have demonstrated the 50 percent hazard reduction. The important practical requirement is that those lengths of roads or road features be designated as sections-of-interest that in fact are of interest to operating personnel who seek to use the index.[2] For example, an intersection might be considered as a section-of-interest in a typical urban network; or, in a typical rural system, a stretch of road between two towns might be a section. Another practical requirement is that a section be so defined that reasonably accurate measurements of section traffic volume can be made. Still another practical criterion is that the definition assist accident investigators in identifying the accident with the section. This is exemplified by a system used in various parts of Europe wherein road markers are placed at fixed intervals along a road to assist travelers as well as to identify specific sections of the road.

---

[2] The writers are indebted to Professor Harry Goode of the University of Michigan who first suggested to them that sections be so defined as to be of operational interest to persons who are to use the index in searching for and applying remedial measures to accident producing conditions on the streets and highways.

With the network somehow defined into operational sections, its risk pattern would simply be the frequency distribution of the risks of the defined sections. Then, by means of appropriate statistical tests on parameters of the distributions (such as the median, mean, interquartile range, etc.), it would be possible to compare the risk pattern of a network for one period with its pattern for another period. Similar comparisons could be made between patterns of different networks, provided the sections were defined the same way for the two networks.

One way of assuring the equivalence of sections is to define sections in standard lengths. An example of this system in practice is seen in California, where the Division of Highways considers its state-wide road system on the basis of coded quarter-mile sections. Another way of comparing two networks would be to compare operationally equivalent subsets of sections. Thus, the sub-set of sections comprised solely of intersections of one network might be compared with the sub-set of similar intersections from another network, or one sub-set of curves of a given superelevation could be compared with another set of similar curves. It is entirely possible that in time there would be developed risk standards of the form of Eq. 21 for all major operational or design features of a street and highway system. Risk analyses at specific locations would then only involve determining whether or not the deviation of its risk value from the standard was statistically and practically significant.

It should be noted that the recommended system is based solely on the two fundamental random variables, traffic volume and accident count, which are in fact the only data contributing anything to the statistical behavior of the mileage-based indexes. Thus the volume-based rate expresses all there is to be learned from the joint variation of these variables. Any attempt to reach additional inferences by interjecting normalizing constants or by performing arithmetic operations on these values can readily obscure whatever valid information might exist in the uncontaminated data.

SUMMARY

Motor vehicle accident rates with mileage as the risk measure are useful for general safety promotional and educational purposes. Their usefulness for specific engineering and enforcement purposes is quite limited, however, as a result of the gross methods whereby mileage data are collected. Their meaningfulness also is lessened as the distance over which the rate is computed becomes smaller, and in the limit (that is, at a single point) they are completely meaningless. Another weakness of these statistics stems from the fact that the unit of risk is seldom identified with the site of the risk.

The single instance where site of risk is identified with unit of risk is in evaluations of the hazard of a particular stretch of road. It is demonstrated that even in a case as specific as this, a mileage-based index reduces in fact to volume-based indexes divided by a distance constant. This constant contributes nothing to the statistical behavior of the random risk factor and, in fact, may obscure the true hazard of the road.

From these arguments, it is concluded that motor vehicle accident rates should be expressed simply as volume-based indexes that would relate the number of accidents occurring at a given "point" during some period of time to the volume of vehicles passing that "point" during the period. The "point" could be any stretch of road over which the volume of traffic is essentially constant. To increase the usefulness of the results, the "points" should be defined in operationally meaningful lengths.

References

1. Accident Facts, National Safety Council Chicago, Illinois.
2. Norden, M., Orlansky, J., Jacobs, H., "Applications of Statistical Quality Control Techniques to Analysis of Highway Accident Data," Highway Research Board Bulletin 117, National Research Council, Washington, D.C., January 1956.
3. Mathewson, J. H., Brenner, R., and Hulbert, S. F., "Analysis of Mass Air Force Motor Vehicle Accident Data," Report 54-69 Department of Engineering, University of California, Los Angeles, August 1954, 326 pp.

Driver Obedience to Stop and Slow Signs

WILLIAM T. JACKMAN, Traffic Engineer
Howard, Needles, Tammen and Bergendoff, Consulting Engineers
Cleveland, Ohio

The purpose of this study was to determine the effectiveness of standard manufactured "stop" and "slow" signs. Four of the stop signs used were of the new type (red and white, reflectorized); the remaining stop sign and the slow sign were of the old type (yellow and black enamel, non-reflectorized).

In addition to the slow sign itself, the slow sign study utilized a radar meter and a pneumatic tube speed meter.

The study showed that no combination of stop sign type or position was more effective than any other under the given conditions. However, an attempt was made to weigh the information gathered and assign definite obedience factors to the sign type-position combinations studied.

The study also showed that a slow sign placed at a location which obviously does not warrant it, is definitely ineffective. This seems to indicate that the average driver is influenced by the apparent factors involved rather than by the slow sign itself.

● IN recent years much attention has been directed to the matter of materials and color combinations of stop signs. Many years back, when the problem first came up, all evidence pointed to an enameled sign with the color combination of black legend on a yellow background. One reason for this was that paints commercially available at the time had inferior qualities compared to present-day products. It was felt that the yellow chosen would be the most effective as concerned attention getting value, fading of pigment, and distance seen.

Recently, however, progress has made possible reflectorization of signs in a multitude of colors. Also, paint pigments are now available which will withstand fading tendencies, at least during the average life of a sign (2) (7).

The present trend is to a red and white reflectorized stop sign. Red was chosen due to its association with danger by the average person.

This study was undertaken in an attempt to ascertain the effectiveness of reflectorized red and white stop signs, as compared to the standard enameled yellow and black stop sign (3). In other words, the study was made to test the truth of the hypothesis that the pattern of response is essentially the same as long as a stop sign is present.

It was understood at the beginning of the study that a stop sign alone would not be the only factor influencing the decision of a driver at a stop situation. Many other factors enter the picture; however, most of them are immeasurable. Some of these are habit, present disposition of the driver, the weather, familiarity with the intersection, presence of traffic on the cross road, alertness of the driver, individual judgment, newness of the sign, and a host of others. Each of these factors could be measured only by holding all other factors constant. This alternative, however, would be entirely out of the question unless some sort of controlled laboratory tests could be arranged.

The experiment was arranged, with the realization that many other influencing factors do exist, but with the stop sign and its position as the only controlled variable. It was assumed that the other factors would be present in an equal degree throughout the study.

It is also a generally accepted fact that motorists do not like to slow down frequently when driving on rural highways, which raises the question of just how effective a "slow" sign is. This study was initiated in an attempt to ascertain to what extent motorists obey a slow sign. The investigation was constructed so as to limit the reason for slowing down only to the slow sign. This was done by erecting a slow sign where none was needed and studying the results obtained. All data for both studies were obtained in close proximity to Purdue University, Lafayette, Indiana.

STOP SIGN STUDY

Purpose and Scope

The purpose of the stop sign study was to measure driver response to a stop sign, given certain specified conditions.

An attempt was made to select locations which were similar in roadside development and topographic features; however, this proved futile, because intersections with sufficient volumes to complete the study in the limited period of time available had some sort of signal control governing them. Another factor governing location selection was that each location had to have facilities for parking the observer's car near enough to the intersection to make observation practical without being conspicuous. Because of these factors, the locations chosen were considered fixed rather than random variables in the analysis.

The first location selected was the intersection of Tippecanoe County Farm Road with US 52 By-Pass. Due to the fact that topography is flat in this area and that the buildings had been set well back from the By-Pass, sight distance was more than adequate up to 100 ft back from the intersection.

The second location selected was the intersection of Ind. 28 with Ind. 43-US 231. This intersection was "wide open;" that is, the curves at the corners had large radii, thus giving a great amount of area within the intersection proper. A dip in the road several hundred feet back from the intersection causes oncoming drivers to lose sight of the main road for a short period. This, along with vegetation growth on the northwest and southwest sides of the intersection, materially cut down the available sight distance. Also, the main road crosses Ind. 28 on a slight curve at the intersection.

Observations were made both day and night at both locations. Location I was studied during the latter part of July and the beginning of August 1955; Location II was studied during most of October and the beginning of November 1955.

Both passenger cars and trucks were included in the study. The percentage of trucks at Location I was practically negligible, whereas at Location II this percentage was rather large. Passenger cars towing trailers or other passenger cars, and farming equipment (such as tractors or tractor-drawn wagons), were excluded from the study with the idea that the mere makeup of the vehicle would influence driver reaction much more than any of the conditions set.

Pavement width at both locations was 20 ft, and in both cases the riding surface was of bituminous material.

Weather conditions were similar during the time of study; that is, observations were made only at times when the pavement was dry and the visibility good.

At both locations a gasoline station was situated on the same corner of the intersection as the stop sign under observance. With the permission of the station operators concerned the observer's vehicle was parked on the station apron, thus allowing it to be inconspicuous, yet close enough for purposes of observation.

Two sign heights were investigated to ascertain their effectiveness. The two heights chosen were 3 ft and 5 ft, measured from the pavement crown to the bottom of the sign. The first height agrees with the present Indiana standard of 42 in. measured from the pavement crown to the middle of the sign. The second height (5 ft) agrees with the National standards (1) (3).

Equipment

At the beginning of the study, it was decided that five commercial types of stop signs would be investigated. This decision was influenced by the supply on hand and the different types of stop signs available commercially. The five sign types included in the group were as follows:

Sign 1 (S_1)—Black enameled message on yellow enameled background.

Sign 2 (S_2)—Entire sign covered with a reflective sheeting composed of microscopic spherical lenses; silver message and border on red background.

Sign 3 (S_3)—Entire sign covered with smooth-surfaced reflective sheeting composed of microscopic semispherical lenses; silver message and border on red background.

Sign 4 (S_4)—Entire sign covered with semi-plastic pigmented binder, into which are embedded microscopic glass spherical lenses of two sizes; white message and border on red background.

Sign 5 (S_5)—Consists of white enameled panel and border on red enameled background; message constructed of injection-molded plastic containing microscopic lenses ground in the surface; figures covered with transparent red-colored coating on which is sprayed aluminum flake paint.

All five of the signs used were standard 24-in. signs with 8-in. characters (3).

Procedure

The method of collecting the data entailed placement of one of the stop signs within 1 ft of the existing stop sign, which was removed with the permission of the proper authorities.

The individual driver's action at the intersection was recorded under one of three possible classifications: (a) unsatisfactory stop (lowest speed attained by the driver in observing the sign greater than 5 mph); (b) stopped by traffic (either traffic already at the stop sign or traffic on the cross road); and (c) satisfactory stop (lowest speed attained by the driver in observing the sign between 0 and 5 mph).

This division of response was selected after considering the fact that at 5 mph or less the driver has his vehicle under control and is capable of making a complete stop with little difficulty, if need be. Also, the advent of the automatic shift allows the driver to come to a "rolling stop" without the necessity of shifting gears. This should not be construed to mean that a "rolling stop" is legal, it only means that in the opinion of the observer, under the conditions investigated, such a stop is safe. It is also felt that an approach speed of more than 5 mph is unsafe and, as such, unsatisfactory.

A sample of 50 vehicles was observed for each combination of sign type, sign height, and time (daylight and darkness). As each group of 50 vehicles was observed, the conditions were changed and another group of 50 vehicles observed until a total of 1,000 observations was made at each of the two locations.

STATISTICAL ANALYSIS

General

Upon completion of the sampling the field data were tabulated into a form more easily adapted to analysis. This was accomplished by using frequency distributions of the drivers making either satisfactory or unsatisfactory stops. Those drivers who were in the category of having been stopped by traffic were disregarded, because their reaction to the stop sign could not be determined with the procedure used.

Study of Variance

To determine what effect the studied conditions had on driver obedience, an analysis of variance was carried out on the sample values. These were transformed to obtain homogeneity of variance by replacing each sample value by its arc sin value (4) (8).

The results of the analysis of variance indicate that the different sign types, their positions, the time of day or a combination of any two of these had no significant effect on driver behavior at either location. However, the interaction of all three factors proves to be highly significant at both locations.

Because, in a practical sense, it would be impossible to change the sign, its position, or both every 12 hr, the frequency polygons, mentioned earlier, were summed over day and night (Fig. 1 and 2). This was done in an effort to illustrate the extent of driver obedience to a particular combination of factors during both daylight and darkness. It can be seen from these figures that certain sign types apparently stand out above the others, however, it should be remembered that the analysis shows no significant difference between sign types. Any apparent difference, therefore, should be given much thought before being accepted.

It would not do to erect a certain sign expecting a high percentage of satisfactory stops if the percentage of unsatisfactory stops is also high. Therefore, an indicator of sign acceptability is used. This indicator is called R, or the recommendation criterion. This factor has the advantage of a higher rate of increase for decreasing values of unsatisfactory stops than for increasing values of satisfactory stops. This is a good feature in that the ratios do not vary proportionately, because there is always a certain number of drivers who fall into the classification of having to stop due to existing traffic conditions.

TABLE 1

NUMBER OF SATISFACTORY AND UNSATISFACTORY STOPS (BASED ON N = 100), AND R, THE RECOMMENDATION CRITERION

Sign	Stops[a]	Position 1		Position 2	
		Loc. I	Loc. II	Loc. I	Loc. II
	S	32	56	44	67
1	U	12	14	10	11
	R	2.67	4.00	4.40	6.09
	S	47	54	35	49
2	U	18	18	20	9
	R	2.61	3.00	1.75	5.44
	S	51	55	34	64
3	U	12	18	16	11
	R	4.25	3.06	2.12	5.82
	S	44	59	50	59
4	U	13	14	17	16
	R	3.38	4.21	2.94	3.69
	S	39	53	29	60
5	U	9	8	22	10
	R	4.33	6.62	1.32	6.00

[a] S = Satisfactory stops; U = Unsatisfactory stops; R = Recommendation criterion (S/U).

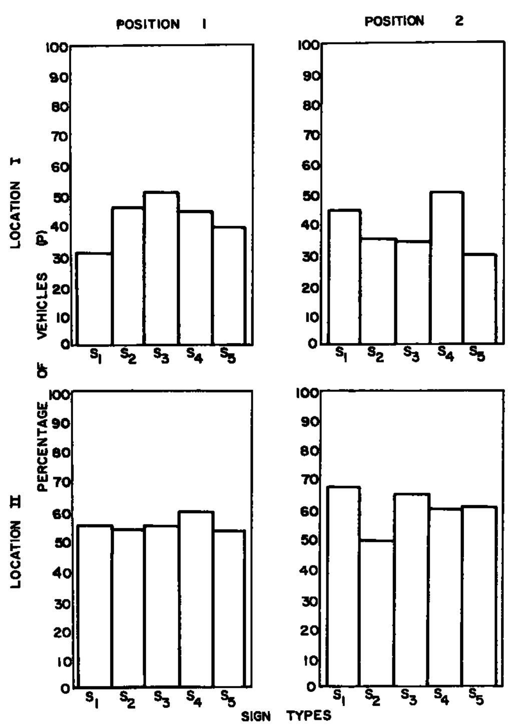


Figure 1. Frequency polygons of vehicles, summed over day and night, making satisfactory stops at each location.

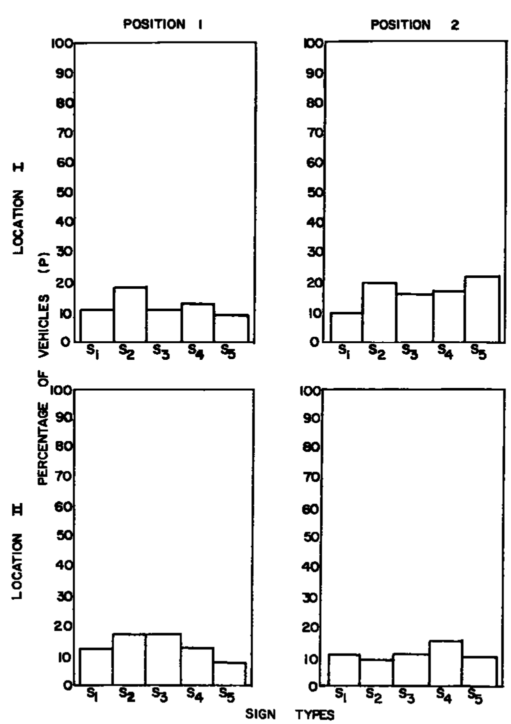


Figure 2. Frequency polygons of vehicles, summed over day and night, making satisfactory stops at each location.

Table 1 shows the number of satisfactory and unsatisfactory stops on the basis of 100 observations per sign, per position, per location. Figure 3 shows the use of the R factor for the different sign types by location and position.

CONCLUSION

It is important to remember that the stop sign analysis has been based on data collected at two particular intersections with only a few variables being controlled. Some of the ideas arrived at might have to be qualified by the results of analysis of additional intersections.

Under the conditions presented at the intersections studied, it has been concluded that, in general, no combination of stop sign and position is any more effective than another as far as driver obedience is concerned. However, it can be concluded that, using R as a criterion, sign type 1 (yellow and black nonreflective) at position 2 (5 ft high) for location I, and sign type 5 (red and white, reflectorized) at position 1 (3 ft high) for location II, exhibit the highest obedience factor for the particular location. The R value also indicates that sign type 5 is the best at position 1 for both locations, and sign type 1 is the best at position 2 for both locations.

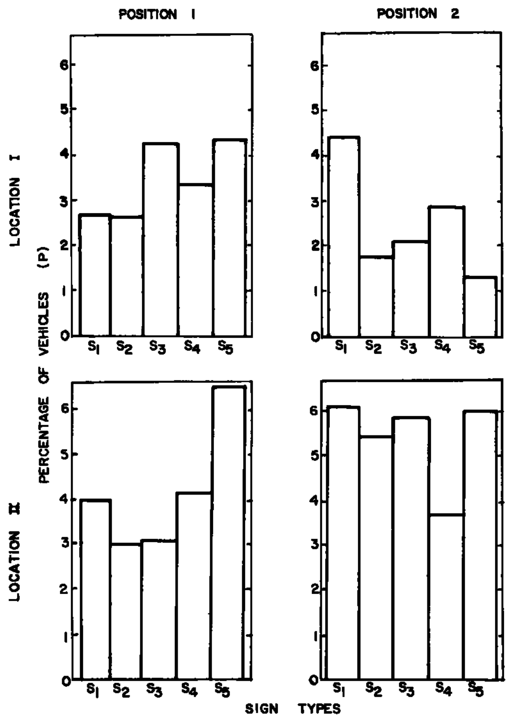


Figure 3. Recommendation criterion for sign types by position and location.

SLOW SIGN STUDY

It has been said that signs are primarily "crutches" to compensate for functional errors of design (5); however, until control of the vehicle can be taken completely away from the driver signs will be necessary. Still it is not a sound engineering or economic principle to erect signs which serve little if any value. This is not to say that no warning of danger should be given the driver, but that if the slow sign must be supplemented by a second sign stating the reason for caution, the slow sign could and should be dispensed with.

Purpose and Scope

The purpose of the slow sign study was to measure driver obedience to a standard slow sign (3).

Two locations were selected for this study. The first was approximately two miles west of the intersection of Ind. 25 and Ind. 43-US 231 on Ind. 25; the other, approximately one mile west of the intersection of Ind. 25-US 231 and US 52.

The locations selected were chosen because there was absolutely no reason for a slow sign. The topography was flat and the grade level; there were no crossings or entrances warranting lower speeds, and sight distance was much more than adequate.

It should be noted that location I was at a point where the vehicles checked had only traveled approximately 100 yards on a tangent after just having left a long sweeping curve. Location II was situated so that the vehicles checked had left a 30-mph speed zone approximately one-half mile back from the start of the check zone. It was noted in the data that a large majority of the cars checked increased their speed between the two check points at each location. This is probably due to the fact that the locations selected more or less lend themselves to be used as acceleration zones. This situation is not adverse, however, because one must realize that if the slow sign were effective, the vehicle operator would have slowed down regardless of the situation.

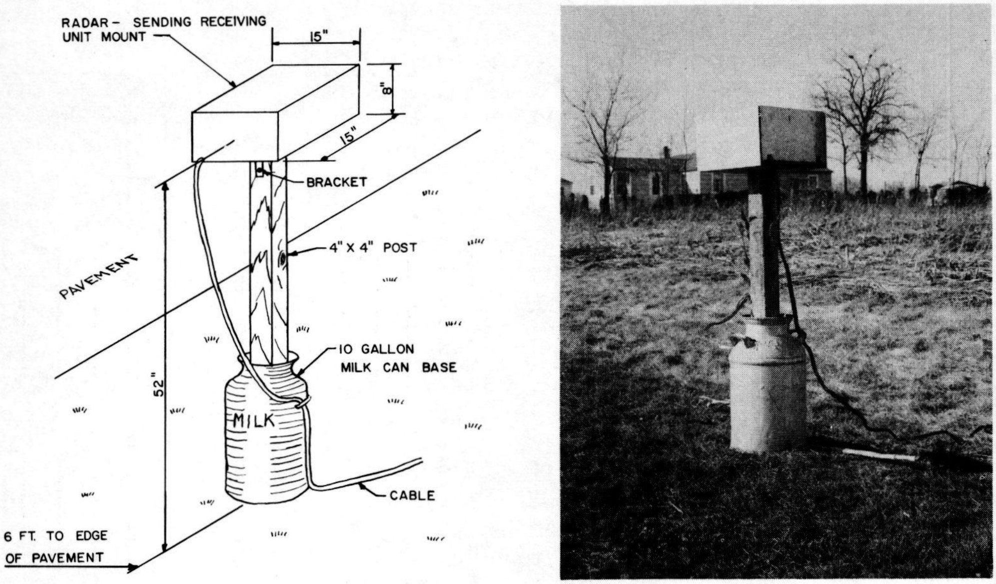


Figure 4. Radar unit in milk can mount.

Observations were made both day and night at both locations during the latter part of December 1955 and the beginning of January 1956.

Only passenger cars were included in the study; trucks, including panels, pickups, and farm vehicles, were excluded.

Weather conditions were similar during the time of study; that is, observations were made only at times when the pavement was dry, no snow was present, and visibility was good.

Speeds were taken, using a pneumatic tube speed meter, 700 ft in advance of the sign. Speeds were again taken of the same vehicles, using a commercially built radar meter, 300 ft beyond the sign.

Equipment

The equipment used in this study consisted of a standard 30-in. slow sign (black enameled message on yellow enameled background), a sign post with fasteners, a radar meter, a pneumatic tube speed meter, and a radar meter mount.

Speeds on both of the meters used can be read to the nearest 1 mph; $\pm$ 2 percent accuracy.

The radar meter mount (Fig. 4) was designed and constructed by the author. It consisted of a 10-gal. milk can, half filled with concrete to act as the base; a 4- by 4-in. wooden post, removable for easier handling, of such a length so as to bring the top of it to a distance of 4 ft above the ground; and a plywood box mounted on the top of the post by means of a heavy steel bracket. The box, made to simulate a rural mailbox, was left open at the front to allow interference-free operation of the radar unit and was equipped with a removable back for easier handling. A small opening was provided in the back to allow for the passage of the electrical cable of the radar unit.

Procedure

At the beginning of this study some concern was felt as to the effect the tubes of the pneumatic speed meter might have on the driver. To investigate this possibility, two samples of 50 passenger cars each were taken, both using the radar meter to measure the speeds. The first sample was taken without the tubes being on the road; the second was taken after the tubes had been positioned on the pavement in such a way that the speeds were taken when the driver was equidistant between the two tubes. It was found that the two average speeds thus obtained were practically identical in magnitude, thus it was decided that for purposes of this test no allowance need be made for the presence of the tubes.

After the position of the speed meter tubes was established, the slow sign was placed 700 ft from a point midway between the two tubes (Fig. 5). A distance of 700 ft was chosen because it was believed that at such a distance a driver would not be able to distinguish the slow sign and thus could not yet be influenced by it. The slow sign was placed at this point at a height of 5 ft from the middle of the sign to the ground.

The next question that had to be answered was where, in relation to the slow sign, should the radar meter be placed so as to record the lowest speeds attained by the drivers observed? Obviously this could not be at any one point; however, it was hoped that a point could be found at which the average speed of the sample would be at its lowest value.

Due to the fact that the "mailbox" mount was open at one end and the radar meter could be seen by the drivers, the meter was beamed down the road and speeds were obtained after the vehicle had passed the radar meter.

The range of the radar meter used varies between 0 and 150 ft, depending on the angle with the road at which the unit is placed. Therefore, the radar meter was placed successively at distances of 100, 200, and 300 ft beyond the slow sign, and positioned so that speeds were obtained as the vehicles passed a point 100 ft beyond the radar meter itself. In this way, the speeds of a sample of 50 passenger cars were obtained for each distance of 200, 300, and 400 ft beyond the slow sign. As the distance from the sign increased the average speed was found to increase; however, the total difference in average speed between a point 200 ft from the sign and one 400 ft from the sign was less than 2 mph. This difference in speed was not considered to be significant, but since the average speed was increasing, it was decided that speeds would be clocked at a distance of 300 ft beyond the slow sign. This placed the radar unit at a distance of 200 ft beyond the sign.

This investigation was conducted only at location I; however, the distance decided on was used at both locations.

STATISTICAL ANALYSIS

General

Upon completion of the field sampling, the collected data were tabulated in a form more conducive to analysis. This was done by subtracting the final speed from the initial speed. Therefore, a positive difference in speed indicates that the vehicle in question slowed down, whereas a negative difference indicates a speeding up.

A sample size of 50 passenger cars was used at each of the two locations for each sample taken. A t-test was then run on the collected data to ascertain whether or not this sample size was sufficient for the accuracy desired. It was found that, in each case, a sample size of 50 vehicles was more than adequate to obtain the desired results.

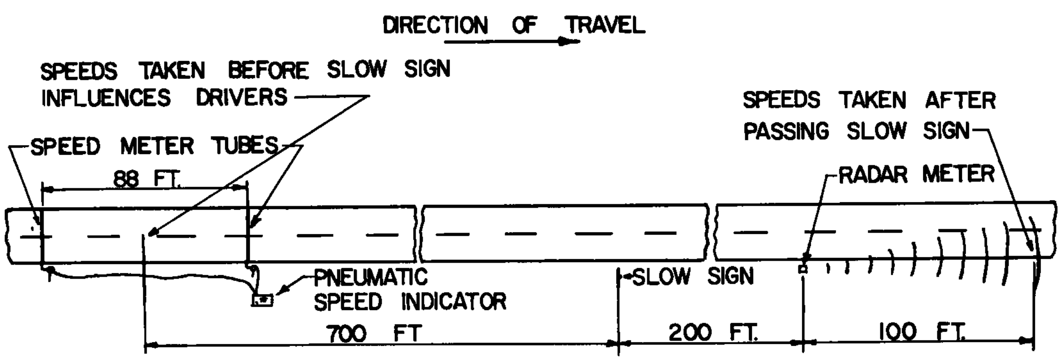


Figure 5. Diagram of slow sign set-up.

t-Test

It was decided that a one-sided t-test would be used to measure the effectiveness of the slow sign (6). It was hypothesized that a slow sign alone does influence a driver sufficiently to make him decrease his speed; that is, it is effective.

By effective, in the hypothesis, is meant that if the true mean of the speed difference (average difference for an extremely large number of drivers) was greater than zero, the slow sign would be defined as being effective. On the other hand, if the true mean of the speed difference was equal to or less than zero, the slow sign would be defined as not effective.

In this type of analysis, the error which is guarded against is the error of saying that the sign in question is not effective when in reality it is effective. With this idea in mind, the tests were designed so as to limit the probability of this error to 5 percent for each of the tests.

Table 2 gives the results of the six t-tests conducted on the collected data, plus the average speed observed for each sample. It can be seen that in four of the six cases the test indicates that the slow sign is not effective. If the slow signs were effective the probability of getting six samples, by chance, which gave four or more significances would be extremely small. Therefore, the conclusion drawn is that the slow signs are generally not effective and no further statistical work on these data is appropriate. The only conclusion which can be reached about the remaining two cases is that, even though it cannot be said, by this test, that the slow sign was not effective, the value of $\bar{d}$ is not of great enough magnitude to warrant any opposite conclusion.

This difference in significance might have come about because the drivers had a longer period of time in which to obtain their normal driving speed prior to arriving at the studied location.

Any further analysis of these data would only serve to point out how much less effective the slow sign was at one location and time of day than at another. This would be of no practical value and of little, if any, academic value.

TABLE 2

RESULTS OF t-TESTS AND AVERAGE SPEED FOR EACH SAMPLE

Sample	Sample Size	Average Speed, mph	Sample Mean	Standard Deviation	Sign Effectiveness[a]
		(a) Location I			
Day 1	50	44.3	-1.84	3.512	x
Day 2	50	46.5	-1.64	5.698	x
Night	50	47.0	-4.08	6.796	x
		Location II			
Day 1	50	44.5	+1.00	5.966	NS
Day 2	50	44.7	+0.92	5.581	NS
Night	50	45.7	-1.44	5.814	x

[a] x = Slow sign not effective; NS = Difference not significantly negative.

CONCLUSIONS

It should be noted that the slow sign analysis has been based on data collected at locations where the installation of slow signs is not warranted, and where the natural tendency of the driver is to accelerate. Therefore, with this fact in mind, the following conclusions and recommendations have been reached:

1. Slow signs are, in themselves, generally not effective.
2. Slow signs should not be used without additional signs stating the nature of the danger involved. Even then, slow signs are probably not warranted unless the need to decrease speed is extremely great.

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to the many persons who have aided in this study, particularly to Dr. Paul E. Irick and Professor L. J. Cote, of the Department of Mathematics, who devoted much time to the statistical design and analysis of the data and review of the manuscript; to Professor Harold L. Michael, Assistant Director, Joint Highway Research Project, for his helpful suggestions and review of the manuscript; to Professor N. C. Kephart, Department of Psychology, who shed some light on the psychology of driver obedience to traffic signs; and to the many others who have offered suggestions and assisted in the analysis and presentation of the data.

References

1. AASHO, "Location of Signs at Intersections," Policies on Geometric Highway Design, pp. 77-81 (1954).

2. Berry, D. S., and Davis, H. E., "A Summary of Developments and Research in Traffic Signs, Signals, and Markings." Paper presented at 1953 California Traffic Safety Conference, Inst. of Traffic and Trans. Engrs.

3. Bureau of Public Roads, "Manual on Uniform Traffic Control Devices." With revisions, pp. 1-72 (1954).

4. Eisenhart, C., Hastay, M. W., and Wallis, W. A., "Techniques of Statistical Analysis," pp. 395-416, McGraw-Hill, New York, N. Y. (1947).

5. Halsey, M., "Traffic Accidents and Congestion," p. 339, John Wiley and Sons, New York, N. Y. (1941).

6. Mode, E. B., "Elements of Statistics," 2nd Ed., pp. 198, 199, 365. Prentice-Hall, New York, N. Y. (1951).

7. "Symposium on Signs," The Highway Magazine, 45: 104-106 (May 1954).

8. Walker, H. M., and Lev, J., "Statistical Inference," p. 479, Henry Holt and Co., New York, N. Y. (1953).

9. Wilkie, L. G., "58,732 Motorists Checked at Stop Signs," Traffic Eng., p. 251 (Apr. 1954).

Driver Behavior and Highway Conditions As Causes of Winter Accidents

THEODORE W. FORBES and MILTON S. KATZ
American Institute for Research, Pittsburgh, Pennsylvania

A specialized segment is reported from research sponsored by the Pennsylvania Turnpike Commission on human and physical factors as causes of Turnpike accidents. State police accident reports are coded and analyzed continuously by IBM punchcard technique, thus furnishing indications of trends and clues and data for special studies.

Analysis by 3-month periods of the various physical and driver behavior factors showed "inadequate coping with road conditions" involved in a higher percentage of passenger-car-responsible than in truck-responsible accidents, especially in the fall and winter quarters. Further comparisons indicated that many of these accidents occurred on snowy and icy highway after the weather had cleared. These results indicated the importance of immediate cindering and the elimination of winter road conditions. The Pennsylvania Turnpike Commission instituted improved maintenance and enforcement procedures to accomplish reduction of the hazard.

A special study of driver behaviors and locations was undertaken to isolate possible combinations of driver behavior, weather, and road characteristics which contributed more than their share of winter road condition accidents. It was necessary to correct for traffic volume and exposure to winter weather conditions. Estimates of traffic volumes in each direction and of percentage of time exposed to winter road conditions were developed for each 10-mile strip of highway. Contingency analyses tested for greater-than-expected relationships between various factors, such as grade and curve combinations and accidents. Certain 10-mile segments showed a rate per million vehicle miles from five to ten times as high as other 10-mile segments. Eastbound and westbound accidents on the same segment often differed, and certain stretches in the mountain area showed the highest rates. On the basis of exposure to winter road conditions, such stretches showed higher than expected values under icy conditions but not necessarily under other conditions.

Use of the correction factors for exposure showed the hazards for the ordinary motorist to be much greater under the winter road conditions, even though the total number of accidents was often greatest for dry roadway on an over-all basis. Relationships of different driver behaviors and other factors in accidents under the different road conditions were analyzed. A further study is under way to investigate further underlying causes for the relationships indicated.

● IN research on accident causes for the Pennsylvania Turnpike Commission, analysis of state police reports on Turnpike accidents is carried out by IBM punchcard techniques. Comparisons by three-month periods furnish indications of trends and clues for further studies of special problems and factors in the causation of accidents. It also makes data available for the conduct of special studies. The accident reporting of the Turnpike Troop of the Pennsylvania State Police is of very good quality and includes both the usual type of standardized accident report and an additional statement from drivers and from the investigating officer summarizing any special features.

The uncorrected figures in analyses of fall and winter quarter accidents indicated that driver behavior coded as "inadequate coping with road conditions" was involved in a higher percentage of passenger-car-responsible than in truck-responsible accidents. Totals indicated that more accidents occurred on icy highway than under snowing and sleeting weather conditions; that is, many must have occurred after the storm had cleared. These results suggested the importance of immediate cindering, clearing snowy and icy road conditions, and warning of motorists. The Pennsylvania Turnpike Commission instituted maintenance and enforcement procedures to accomplish reduction of the hazard in February 1956.

In the meantime, a further study of relationships in these winter accidents was undertaken to investigate combinations of driver behavior, weather, and road conditions. This study, utilizing corrections for exposure in terms of motor vehicle miles and percentage of winter road conditions pointed to relationships between driver behaviors and physical factors and further indicated the importance of reducing winter hazards and improving driver behavior. It furnishes a basis for evaluating results by later comparisons.

Analyses using the corrections for exposure confirmed and strengthened the interpretation which had been made on the basis of raw percentages obtained quarter by quarter. A double sort of the passenger car accident punch cards for the 1954-55 winter[1] by dry, wet, and icy road conditions and then by clear, raining, and snowing weather conditions, showed interrelationships as follows:

A double breakdown of uncorrected figures gives the over-all number of accidents. Table 1 shows mainline passenger-car-responsible accidents and truck-responsible accidents in which two-fifths of the passenger car accidents in clear and cloudy weather occurred on icy highway, but only about one-fifth of truck accidents. The largest proportion of snowy, sleeting, and rainy-weather accidents were on icy highway, as would be expected. Clear-weather dry-highway accidents were more numerous than expected on a relative proportions basis without correction for exposure, a finding often reported in many analyses.

TABLE 1

WEATHER CONDITIONS

Comparison of Accidents Under Various Winter Road Conditions
(Expected Values in Parenthesis Based on Marginal Proportions)

Weather Conditions	Road Conditions at Time of Accident: Passenger Cars Dry	Passenger Cars Wet	Passenger Cars Icy	Passenger Cars Total	Trucks Dry	Trucks Wet	Trucks Icy	Trucks Total
Clear and cloudy	156 (83.4)	30 (49.5)	105 (158.0)	291	83 (56.5)	9 (19.9)	23 (38.6)	115
Raining	0 (22.1)	61 (13.1)	16 (41.8)	77	1 (11.8)	17 (4.2)	6 (8.0)	24
Snow, sleet, and freezing rain	4 (54.5)	4 (32.3)	182 (103.3)	190	1 (16.7)	4 (5.9)	29 (11.4)	34
Total	160	95	303	558	85	30	58	173
	Chi-Square = 433.37 df = 4 p < .01				Chi-Square = 116.63 df = 4 p < .01			

The clear-weather dry-road accidents, however, were actually fewer than expected when exposure in terms of motor vehicle mileage on each road condition was used. Table 2 shows resulting figures comparable to those of Table 1, but with expected accidents calculated on the basis of estimated exposure. The much greater hazard presented by icy highway and by wet highway during rain is shown by this table. Note that accidents on icy highway were two to nine times as numerous as expected, but on dry highway were less than expected.

[1] October through December 1954, and January through March 1955.

TABLE 2

WEATHER CONDITIONS

Comparison of Accidents with Expected Accidents Under Various Winter Road Conditions (Expected Values Based on Percentage of Motor Vehicle Miles on Each Road condition)

Weather Conditions	Road Conditions at Time of Accident: Passenger Cars Dry	Passenger Cars Wet	Passenger Cars Icy	Passenger Cars Total	Trucks Dry	Trucks Wet	Trucks Icy	Trucks Total
Clear and cloudy	156 (203.6)	30 (57.8)	105 (29.6)	291 (291.0)	83 (80.2)	9 (23.2)	23 (11.5)	115 (114.9)
Raining	0 (53.9)	61 (15.3)	16 (7.8)	77 (77.0)	1 (16.7)	17 (4.8)	6 (2.4)	24 (23.9)
Snow, sleet and freezing rain	4 (132.9)	4 (37.7)	182 (19.4)	190 (190.0)	1 (23.7)	4 (6.9)	29 (3.4)	34 (34.0)
Total Expected	160 (390.4)	95 (110.8)	303 (56.8)	558 (558.0)	85 (120.6)	30 (34.9)	58 (17.3)	173 (172.8)
	Chi-Square = 1,933.4 df = 4 p < 0.001				Chi-Square = 287.2 df = 4 p < 0.001			

ANALYSIS BY 10-MILE SEGMENTS

Accident rates of mountain area segments were several times as high as those of eastern and western areas. Analysis of western, mountain and eastern sections of the Turnpike by 10-mile segments was made and an accident rate per million vehicle miles was calculated. The rate varied markedly between 10-mile segments as shown in Table

Much higher passenger car accident rates on icy highway were found in each area, however, as shown by Table 4. The higher rates for 10-mile segments in the mountain area in the previous table may have resulted from a larger proportion of exposure to winter road conditions in these areas. Therefore, from weather reports[2], estimates were made of the proportion of the time winter weather and roadway conditions were experienced on each segment. From these, expected numbers of accidents were calculated and compared with the actual number reported.

Segments with definitely higher-than-expected accident frequency were shown largely for icy highway in or near the mountain area. On this basis (which might not hold in other seasons) wet and dry conditions showed very few segments with higher than expected experience. Several 10-mile segments, however, in the foothill and mountainous area did show considerably greater than expected experience under icy conditions and wet conditions (Tables 5 and 6). The superscript numbers show the 10-mile segments where reported accidents were much greater than expected from vehicle mileage and winter road condition exposure.

Certain of these segments involved down-grade in one direction, and not in the other, which may account for the fact that the higher-than-expected segments were not in all cases the same for eastbound as for westbound initiating vehicle. Although the mileage of different road elements was not available for each 10-mile section, an over-all analysis was made based on total vehicle mileage and estimated proportion of the total highway represented by curve and grade combinations. This indicated that on icy highway, "straight-and-level" and "right-curve, down-grade" were higher than expected but not "left-curve, down-grade" taking the highway as a whole. Two other combinations of grade and curve showed somewhat higher than expected accidents. A more detailed

[2] Filed at Turnpike radio headquarters and made available through the courtesy of the Turnpike Commission staff.

TABLE 3

ACCIDENTS AND RATES BY 10-MILE HIGHWAY SEGMENTS
(Rates Per Million Vehicle Miles, Passenger Cars)

Total Vehicle Miles, 1,000's	Number	Rate
	(a) Western	
7,724	8	1.04
8,720	15	1.72
9,146	10	1.09
9,541	15	1.57
11,486	22	1.92
10,806	13	1.20
10,136	7	0.69
	(b) Mountain	
11,065	17	1.54
10,417	33	3.17
10,276	46	4.48
10,264	40	3.90
9,871	36	3.65
9,871	55	5.57
9,871	19	1.93
10,292	13	1.26
10,807	16	1.48
	(c) Eastern	
8,888	13	1.46
8,087	12	1.48
7,767	12	1.55
7,788	12	1.54
7,744	5	0.65
7,737	6	0.78
7,824	6	0.77
8,376	11	1.31
10,295	13	1.26
9,096	4	0.44
9,177	13	1.42
9,320	5	0.54
9,547	12	1.26
10,115	10	0.99
11,277	13	1.15
11,028	14	1.27
9,820	11	1.12
8,738	11	1.26
7,805	8	1.03
3,334	1	0.30

study is under way of relationships of grade and curve to get at underlying causes of apparently contradictory or unexpected relationships (Table 7).

ANALYSIS OF DRIVER BEHAVIORS

Analysis of driver behaviors showed that passenger car drivers got into trouble to a considerably greater extent under winter highway conditions than did truck drivers. This probably was the effect of greater driving "know-how" of the latter. Relationships to driver behaviors were as follows:

Ten major classifications of driving behavior with two to ten subclassifications each were used in coding the behavior judged to have been most related to the precipitation of the accident. The main categories, condensed into four, are shown in Table 8 and indicate somewhat more than expected "coping with road conditions" on icy highway and more "sleep" accidents and "other" accidents on dry highway. However, comparison with "expected" numbers of accidents based on exposure shows "sleep" and "other" accidents about as expected, whereas the "inadequate coping with road conditions" was much greater than expected.

In this category the number of passenger-car-responsible drivers involved was almost one-half the total, whereas drivers in truck-responsible accidents were only about one-third of the total (see Table 8). The former represented six times as many accidents as the latter, apparently showing the value of the greater training and experience of the professional drivers. It was known rather than unexpected winter road conditions which drivers misjudged. Further breakdown of precipitating behaviors in icy road accidents is shown in Table 9. Surprise winter road conditions (such as icy spots and indications that the driver had not anticipated the icy highway) comprised only about one-third of the accidents. For truck accidents this was an even more marked difference.

Four different driving behavior categories were frequent in winter accidents, both as a first and a second "precipitating behavior." In addition to "inadequate coping with road conditions" in Table 8, "inadequate driving skills," "misperception" and "unsafe action" accidents also were higher than expected on icy road conditions. Second precipitating behaviors in "coping with road conditions" accidents included these factors, also, in some cases on the part of the same driver or another one (Table 10). In accidents not classified as due to "inadequate coping with road conditions," a second driving behavior fell in this category

TABLE 4

ACCIDENTS AND RATES BY GEOGRAPHICAL AREAS

(Rates Per Million Vehicle Miles, Passenger Cars)

Direction	Dry		Wet		Icy	
	Number	Rate	Number	Rate	Number	Rate
(a) Western						
Eastbound	15	.67	4	.54	18	4.48
Westbound	21	.94	9	1.22	23	5.74
(b) Mountain						
Eastbound	24	.83	25	2.51	79	9.69
Westbound	27	.96	18	1.86	102	12.88
(c) Eastern						
Eastbound	43	.66	14	.90	36	7.51
Westbound	33	.51	21	1.34	44	9.15

TABLE 5

WESTBOUND ACCIDENTS, BY GEOGRAPHICAL AREAS

(Expected Computed for Each Area from Vehicle Miles Corrected for Percent Time for Each Road Condition)

Number of Accidents					
Dry		Wet		Icy	
Observed	Expected	Observed	Expected	Observed	Expected
(a) Western					
2	2.5	1	1.0	2	2.7
3	2.8	2	1.1	1	3.0
1	2.9	0	1.2	3	3.1
5	2.9	0	1.3	6[1]	3.2
6	3.5	1	1.6	7[1]	3.9
2	3.3	4	1.5	1	3.7
2	3.1	1	1.3	3	3.5
(b) Mountain					
4	3.1	3	2.3	2	12.1
2	2.6	5	2.3	7	14.6
2	2.6	2	2.2	20[1]	14.5
3	2.7	0	1.8	11	16.6
2	2.6	1	1.7	29[1]	16.0
5	2.9	2	1.9	19[1]	10.4
4	3.1	3	1.9	5	8.1
2	3.4	1	1.9	5	6.0
3	3.9	1	1.9	4	3.8
(c) Eastern					
2	1.7	1	1.1	6[1]	2.2
2	1.5	1	1.0	1	2.2
2	1.5	0	1.0	5[1]	2.1
0	1.5	2	1.0	5[1]	2.1
1	1.5	1	1.0	1	2.0
1	1.5	1	1.0	3	2.0
1	1.5	1	1.0	1	2.0
1	1.6	0	1.0	2	1.9
2	2.1	1	1.3	1	2.4
1	1.8	1	1.1	0	2.2
3	1.8	4	1.1	2	2.3
1	1.8	1	1.1	2	2.7
5[1]	1.9	2	1.1	1	3.0
3	2.0	4	1.2	1	3.2
2	2.2	0	1.4	5	2.8
1	2.2	0	1.4	2	2.7
2	1.9	0	1.2	1	2.3
2	1.7	1	1.0	3	1.9
1	1.5	0	0.9	2	2.1

[1] 10-mile segments where reported accidents were much greater than were expected from vehicle mileage and winter road condition exposure.

TABLE 6

EASTBOUND ACCIDENTS, BY GEOGRAPHICAL AREAS

(Expected Computed for Each Area from Vehicle Miles Corrected for Percent Time for Each Road Condition)

Number of Accidents					
Dry		Wet		Icy	
Observed	Expected	Observed	Expected	Observed	Expected
(a) Western					
1	1.7	0	0.4	2	2.0
3	2.0	1	0.5	5	2.3
3	2.0	0	0.5	3	2.4
2	2.1	1	0.6	1	2.5
2	2.5	1	0.7	5	3.0
3	2.4	1	0.7	2	2.9
1	2.2	0	0.6	0	2.7
(b) Mountain					
2	2.8	2	3.2	4	9.3
4	2.4	0	3.2	15	11.5
4	2.3	5	3.1	13	11.2
2	2.4	2	2.5	22[1]	12.8
0	2.3	1	2.4	3	12.3
4	2.6	10[1]	2.6	15[1]	8.1
2	2.7	3	2.6	2	6.2
1	3.1	1	2.6	3	4.6
5	3.4	1	2.6	2	2.9
(c) Eastern					
2	2.2	2	0.8	0	1.9
3	2.0	0	0.7	5[1]	1.8
1	1.9	1	0.8	3	1.7
3	1.9	0	0.7	2	1.7
0	1.9	0	0.7	2	1.7
0	1.9	0	0.7	1	1.7
1	1.9	1	0.7	1	1.7
2	2.1	1	0.7	5[1]	1.5
3	2.6	3	0.9	3	1.9
1	2.3	0	0.7	1	1.8
2	2.3	1	0.7	1	1.9
1	2.3	0	0.7	0	2.2
3	2.4	1	0.7	0	2.4
0	2.5	0	0.8	2	2.6
3	2.8	0	0.9	3	2.2
6[1]	2.8	3	0.9	2	2.2
8[1]	2.5	0	0.8	0	1.9
2	2.3	1	0.7	2	1.6
2	2.0	0	0.6	3	1.7

[1] 10-mile segments where reported accidents were much greater than expected from vehicle mileage and winter road condition exposure.

TABLE 7

ROAD ELEMENT AND DIRECTION

Comparison of Actual and Expected Winter Accidents (Expected Values in Parenthesis Based on Total Vehicle Mileage and Estimated Proportion of Highway)

Road Element	Dry		Wet		Icy	
	East	West	East	West	East	West
Straight, level	17 (14)	22[a] (13)	6 (8)	14 (7)	29 (25)	52[a] (25)
Straight, down	25 (22)	13 (22)	8 (12)	14 (12)	37 (42)	34 (41)
Straight, up	20 (22)	18 (22)	5 (12)	3 (12)	20 (42)	37 (41)
Right, level	2 (2)	3 (2)	2 (1)	3 (1)	2 (4)	4 (4)
Left, level	2 (2)	2 (2)	1 (1)	2 (1)	3 (4)	3 (4)
Right, down	7 (5)	5 (5)	12[a] (3)	4 (3)	22[a] (9)	14[a] (9)
Left, down	3 (5)	6 (5)	6 (3)	5 (3)	8 (9)	7 (9)
Right, up	4 (5)	4 (5)	1 (3)	1 (3)	9 (9)	11 (9)
Left, up	2 (5)	8 (5)	2 (3)	2 (3)	3 (9)	8 (9)
Total Expected	82 (82)	81 (81)	43 (46)	48 (45)	133 (153)	170 (151)

[a] For estimated proportion see:
Eckhardt, Paul K., Flanagan, John C., and Forbes, T. W., "Road Elements and Precipitating Behaviors in Turnpike Accidents." Proc. 37th Ann. Tennessee Highway Conf., Univ. Tenn. Record, 58: 4, 53-58 (July 1955).

in 44 out of 58 accidents (not shown in table).

Fixed-object collisions, rear-end-and-sideswipes, "other" and crossover accidents were most frequent in that order under icy road conditions; all were higher than expected taking account of exposure factors (Table 11). "Inadequate coping with road condition" accidents on icy road most frequently involved collisions with guardrail on the right for passenger car accidents, with rear-end accidents second. Both were equally frequent for truck-responsible accidents (Table 12).

SPEEDS AT TIME OF ACCIDENT

Maximum safe speed as judged by the investigating officer and estimates of initial speed in the accident indicate that drivers had slowed under winter road conditions but still misjudged or reacted in such a way as to get into trouble.

Although estimates by the police officer of maximum safe speed and of initial speed are difficult to make with reliability, they gave some important information. The former have shown some relation to weather and road conditions and the latter probably reflect indirect indications, such as skid marks, the officer's experience with damage and other indications of effects of speed, and his evaluation of drivers' reports. Under icy road conditions speed estimates were, in the lower ranges, more frequently-than-expected (statistically); but for wet and dry highway greater-than-expected estimates tended toward the higher speeds (Tables 13 and 14).

TABLE 8a

GENERAL PRECIPITATING BEHAVIOR

Relative Share of Accidents Under Winter Road Conditions (Expected Values in Parenthesis Based on Marginal Proportions)

General Precipitating Behavior	Road Conditions at Time of Accident: Passenger Cars Dry	Wet	Icy	Total	Trucks Dry	Wet	Icy	Total
Coping with road conditions	3 (82.6)	33 (47.6)	247[a] (152.8)	283	0 (24.0)	6 (8.4)	42[a] (15.6)	48
Sleep, fatigued attention	60[a] (23.4)	13 (13.4)	7 (43.2)	80	33[a] (21.0)	7 (7.3)	2 (13.7)	42
Inadequate driving and perception	24 (24.5)	30 (14.1)	30 (45.3)	84	12 (9.5)	2 (3.3)	5 (6.2)	19
Unsafe action	34[a] (17.8)	7 (10.2)	20 (32.9)	61	17 (16.5)	8 (5.7)	8 (10.8)	33
Other (vehicular failure, object on road, etc.)	44[a] (16.6)	12 (9.6)	1 (30.8)	57	27[a] (18.0)	8 (6.3)	1 (11.7)	36
Total	165	95	305	565	89	31	58	178

Passenger cars: Chi-square = 345.43, df = 8, $p < 0.01$

Trucks: Chi-square = 104.03, df = 8, $p < 0.01$

TABLE 8b

GENERAL PRECIPITATING BEHAVIOR

Relative Share of Accidents Under Winter Road Conditions (Expected Values Based on Percent of Motor Vehicle Miles on Each Road Condition)

General Precipitating Behavior	Road Conditions at Time of Accident: Passenger Cars Dry	Wet	Icy	Total	Trucks Dry	Wet	Icy	Total
Coping with road conditions	3 (198.0)	33 (56.2)	247[a] (28.8)	283 (283.0)	0 (33.5)	6 (9.7)	42 (4.8)	48 (48.0)
Sleep, fatigued attention	60 (56.0)	13 (15.9)	7 (8.2)	80 (80.1)	33 (29.3)	7 (8.5)	2 (4.2)	42 (42.0)
Inadequate driving and perception	24 (58.8)	30[a] (16.7)	30[a] (8.6)	84 (84.1)	12 (13.3)	2 (3.8)	5 (1.9)	19 (19.0)
Unsafe action	34 (42.7)	7 (12.1)	20[a] (6.2)	61 (61.0)	17 (23.0)	8 (6.7)	8 (3.3)	33 (33.0)
Other (vehicular failure, object on road, etc.)	44 (39.9)	12 (11.3)	1 (5.8)	57 (57.0)	27 (25.1)	8 (7.3)	1 (3.6)	36 (36.0)
Total Expected	165 (395.4)	95 (112.2)	305[a] (57.6)	565 (565.2)	89 (124.2)	31 (36.0)	58 (17.8)	178 (178.0)

Passenger cars: Chi-square = 192.0, df = 8, $p < 0.001$

Trucks: Chi-square = 33.5, df = 8, $p < 0.001$

TABLE 9

SUBCLASS PRECIPITATING BEHAVIOR OF "ICY" ACCIDENTS

(Expected Road Condition, Collision, and Other Characteristics of Accidents in Table 8a, Icy)

Subclass Precipitating Behavior	Road Conditions at Time of Accident: Passenger Cars			Trucks		
	Icy	Wet	Total	Icy	Wet	Total
Coping with road conditions						
Expected road condition, off roadway	9	2	11	7	0	7
Expected road condition, collision	124	7	131	21	0	21
Unexpected road condition, off roadway	8	4	12	1	1	2
Unexpected road condition, collision	80	16	96	2	2	4
Roadway blocked, collision	20	0	20	2	1	3
Roadway blocked, off roadway	1	0	1	0	0	0
Trailer weaving	2	0	2	3	0	3
Other	2	1	3	5	0	5
Total	246	30	276	41	4	45

SUMMARY

In the winter of 1954-5, the accident rate per million vehicle miles for icy highway was many times higher than for wet and for dry road conditions, although the uncorrected accident total was highest for clear weather, as has been so often reported. More frequent-than-expected accident experience (on the basis of vehicle miles and exposure to winter road conditions) was shown for some 10-mile segments in and near the mountain area.

Passenger car drivers had more difficulty than did truck drivers, indicating the effect of better training, experience, and "know-how" of the latter. More occurrence of driver behaviors classed as "inadequate coping with roadway conditions," "inadequate driving skills," "mis-perception," and "unsafe actions" were involved. The majority of the accidents were under winter road conditions known to the driver rather than under surprise conditions. Drivers had apparently reduced speeds considerably as compared with wet and dry road condition accidents, but they had still misjudged or used inadequate driving behavior to cause accidents.

Many of the accidents on icy road during snowy, sleeting, and freezing rain storms apparently involved misjudgments and driving behavior inadequate for winter road conditions during storms, but others may have included misjudgment of winter road conditions when the weather had cleared. Both suggest the importance of immediate cindering, clearing of ice and snow from the highway, and of warnings to unwary

TABLE 10

SECOND AND THIRD PRECIPITATING BEHAVIORS

Coping with Road Conditions in Accidents (General Precipitating Behavior)

Second and Third Precipitating Behaviors	Road Conditions at Time of Accident							
	Passenger Cars				Trucks			
	Icy		Wet		Icy		Wet	
	2nd	3rd	2nd	3rd	2nd	3rd	2nd	3rd
Vehicular failures	1	2	9	0	1	0	0	0
Objects on road	1	0	0	0	0	0	0	0
Road condition	16	2	0	0	5	1	0	0
Sleep	3	0	1	0	0	0	0	0
Attending other tasks	4	0	1	0	0	0	0	0
Inadequate driving skills	33	2	3	5	5	0	1	0
Unsafe action	22	7	1	0	3	2	1	0
Preception errors	15	5	1	2	2	0	0	0
Chemical agents and intoxicants	0	0	0	0	0	0	0	0
No additional driver behavior	151	228	14	23	25	38	2	4
Total	246	246	30	30	41	41	4	4

TABLE 11

HOW VEHICLE WAS INVOLVED

Comparison with Expected Accidents Under Each Road Condition (Expected Values in Parenthesis Based on Percent of Motor Vehicle Miles on Each Road Condition)

How Vehicle Was Involved	Road Conditions at Time of Accident							
	Passenger Cars				Trucks			
	Dry	Wet	Icy	Total	Dry	Wet	Icy	Total
Rear end, sideswipe	58 (102.1)	10 (29.0)	78 (14.9)	146 (146.0)	43 (50.2)	9 (14.6)	20 (7.2)	72 (72.0)
Crossover	6 (39.2)	11 (11.1)	39 (5.7)	56 (56.0)	2 (4.9)	1 (1.4)	4 (0.7)	7 (7.0)
Fixed object	35 (126.6)	31 (35.9)	115 (18.4)	181 (180.9)	12 (26.5)	10 (7.7)	16 (3.8)	38 (38.0)
Other	66 (127.3)	43 (36.1)	73 (18.5)	182 (181.9)	32 (42.6)	11 (12.3)	18 (6.1)	61 (61.0)
Total Expected	165 (395.2)	95 (112.1)	305[a] (57.5)	565 (564.8)	89 (124.2)	31 (36.0)	58[a] (17.8)	178 (178.0)
	Chi-Square = 31.4 df = 6 p < 0.001				Chi-Square = 25.9 df = 6 p < 0.001			

TABLE 12

HOW VEHICLE WAS INVOLVED IN "ICY" ACCIDENTS

General Precipitating Behavior - "Coping With Road Conditions" Accidents (Table 8a - Icy) Further Analysis by How Vehicle Was Involved

How Involved	Road Conditions at Time of Accident: Passenger Cars Icy	Wet	Total	Trucks Icy	Wet	Total
Collision·						
Rear end	53	1	54	10	0	10
Sideswipe	2	0	2	0	0	0
Vehicle, crossed median	30	3	33	3	0	3
Fixed object, or off road, crossed median	22	1	23	3	0	3
Fixed object, right shoulder (guard-rail)	91	17	108	8	2	10
Guardrail in median	7	1	8	2	0	2
Other object	2	0	2	0	0	0
Overturning	9	3	12	4	2	6
Stopping or parked	3	0	3	0	0	0
Other	27	4	31	11	0	11
Total	246	30	276	41	4	45

TABLE 13

MAXIMUM SAFE SPEED

Relative Share of Accidents Under Winter Road Conditions (Expected Values in Parenthesis Based on Marginal Totals)

Maximum Safe Speed, mph	Road Conditions at Time of Accident: Passenger Cars Dry	Wet	Icy	Total	Trucks Dry	Wet	Icy	Total
Stopped	7 (2.6)	1 (1.5)	1 (4.9)	9	7 (3 5)	0 (1.2)	0 (2.3)	7
1 - 9	0 (0.9)	0 (0.5)	3 (1.6)	3	1 (1.5)	1 (0.5)	1 (1.0)	3
10 - 19	1 (5.8)	1 (3.4)	18 (10.8)	20	1 (6.4)	0 (2.3)	12[a] (4.3)	13
20 - 29	9 (22.9)	0 (13.4)	70[a] (42.7)	79	0 (9.4)	1 (3.3)	18 (6.3)	19
30 - 39	7 (37.4)	10 (21.8)	112[a] (69.8)	129	8 (16.3)	6 (5.8)	19[a] (10.9)	33
40 - 49	9 (28.4)	20 (16.6)	69[a] (53.0)	98	16 (18.3)	16[a] (6.5)	5 (12.2)	37
50 - 59	16 (20.9)	34[a] (12.2)	22 (38.9)	72	54[a] (31.6)	7 (11.3)	3 (21.1)	64
60 - 69	70[a] (29.3)	22 (17.1)	9 (54.6)	101	-	-	-	-
70 - 79	44[a] (14.8)	7 (8.6)	0 (27.6)	51	-	-	-	-
Total	163	95	304	562	87	31	58	176
	Chi-square = 367.44 df = 16 p < 0.01				Chi-square = 122.76 df = 12 p < 0.01			

TABLE 14

INITIAL SPEED

Relative Share of Accidents Under Winter Road Conditions (Expected Values in Parenthesis Based on Marginal Totals)

Initial speed, mph	Road Conditions at Time of Accident							
	Passenger Cars				Trucks			
	Dry	Wet	Icy	Total	Dry	Wet	Icy	Total
Stopped, Parked	9 (4.6)	2 (2.8)	5 (8.6)	16	7 (4.9)	1 (1.7)	2 (3.4)	10
1 - 9	2 (1.1)	1 (0.7)	1 (2.2)	4	0 (0.5)	0 (0.2)	1 (0.3)	1
10 - 19	0 (2.0)	1 (1.2)	6 (3.8)	7	7 (5.9)	1 (2.0)	4 (4.1)	12
20 - 29	2 (6.6)	0 (4.0)	21[a] (12.4)	23	4 (9.3)	2 (3.2)	13[a] (6.4)	19
30 - 39	8 (20.4)	4 (12.2)	59[a] (38.4)	71	9 (15.2)	4 (5.2)	18[a] (10.5)	31
40 - 49	16 (39.0)	12 (23.4)	108[a] (73.6)	136	31 (29.0)	13 (10.0)	15 (20.0)	59
50 - 59	55 (46.7)	41[a] (28.1)	67 (88.2)	163	21[a] (15.7)	6 (5.4)	5 (10.8)	32
60 - 69	52[a] (31.2)	30[a] (18.8)	27 (59.0)	109	4 (2.9)	2 (1.0)	0 (2.0)	6
70 - 79	12[a] (5.7)	4 (3.4)	4 (10.8)	20	1 (0.5)	0 (0.2)	0 (0.3)	1
80 - 89	2 (0.6)	0 (0.3)	0 (1.1)	2	-	-	-	-
Total	158	95	298	551	84	29	58	171
	Chi-square = 149.64 df = 18 p < 0.01				Chi-square = 34.92 df = 16 p < 0.01			

motorists during and after the storm while roadway conditions are still slippery. Such procedures have been introduced by the Pennsylvania Turnpike Commission and a follow-up study of their effectiveness is under way.

Accident figures corrected by estimates of exposure in vehicle miles on each type of road condition (derived from Turnpike records) indicated that combinations of road condition, curvature, and grade were more misjudged by drivers than statistically expected. A more specialized study of these factors is under way.

Thus, research using corrections for both mileage and other types of exposure can point out specific principles and combinations of human and physical factors causing hazards. Such specific information and resulting specific remedial action and driver training will increase effectiveness of safety activities in enforcement, engineering, and education. Such research is, therefore, of great importance.

A Method of Investigating Highway Traffic Accidents

THOMAS G. BRITTENHAM, Research Assistant,
DAVID M. GLANCY, Research Assistant, and
EMMETT H. KARRER, Professor of Highway Engineering
Ohio State University, Columbus

● THE PURPOSE of this study is the development of a methodology for determining the causes of highway traffic accidents. The study is being conducted through the Engineering Experiment Station of The Ohio State University under sponsorship of the Ohio Department of Highway Safety. This study is only part of a more comprehensive study of highway traffic accidents which is under way, and the report which follows must be considered as an interim report. Time has not permitted a complete evaluation of many of the observations and findings from the field work.

It is generally agreed that the three major factors contributing to highway traffic accidents are the driver, the road, and the motor vehicle. The premise on which this study was undertaken is that the driver is responsible for keeping his vehicle under control at all times. All other factors can then only contribute to, or detract from, the driver's ability to properly handle his vehicle.

To eliminate or control some of the many variables present in any traffic accident, such as blaming other drivers or pedestrians, this study was limited to those accidents which are classified as one-car. A one-car accident is defined as one which involves one passenger car and no other moving object, either animate or inanimate. Only passenger car accidents occurring on a county or state rural highway involving a non-commercial auto, and which were reported and investigated by the Ohio State Highway Patrol, were included.

Based on a comprehensive statistical examination of the record of all one-car accidents occurring in Ohio in 1955, the state was divided into three areas so that each area had approximately the same number of probable rural one-car accidents. During the summer of 1956 all of the rural one-car accidents occurring in each of these areas within a four-week period were investigated. Each time period was consecutive, but none of the three time periods overlapped.

The research project was divided into two phases. A team of engineers examined all of the roadway and traffic control devices which were thought to have possibly contributed to each accident, and a team of sociologists interviewed the drivers involved. An advisory board of faculty members in sociology, psychology, mechanical engineering, civil engineering, and medicine served as consultants in the development of the technique of accident investigation.

The samples used in the engineering phase, and those used in the social research phase, are not entirely the same, because all of the accident scenes were investigated, but not all of the drivers were interviewed. The highway engineering phase of the study includes a sample of 375 one-car accidents; the driver phase, as handled by the social research team, includes only 201 male drivers who were involved in one-car accidents.

The highway phase of this study is reported in a separate section of this paper, as is also that phase which concerns the driver. Another section contains the joint tentative conclusions of the authors.

HIGHWAY FIELD MEASUREMENTS

At the site of each one-car accident the following were determined:

1. Exact location of the accident and the path followed by the accident car.
2. Pavement cross-section, number and width of lanes (hereafter referred to as road type and lane width.)
3. Shoulder cross-section.
4. Safe speed.
5. Sight distance available for passing.

6. Dry pavement coefficient of friction.
7. Pavement ridability.
8. Presence of advisory speed signs and pavement marking.

Field measurements were made in approximately 375 cases by an engineering research assistant, who drove a specially-equipped new 1956 passenger car rented from the Ohio Department of Highway Equipment. Each car was equipped with an airplane ball-bank indicator (Figure 1), a calibrated Stewart Warner survey speedometer (Figure 2), and an American Automobile Association braking reaction-time device (Figure 3). In addition, each assistant had an Abney clinometer, a 50-ft tape, a small ruler, and a camera.

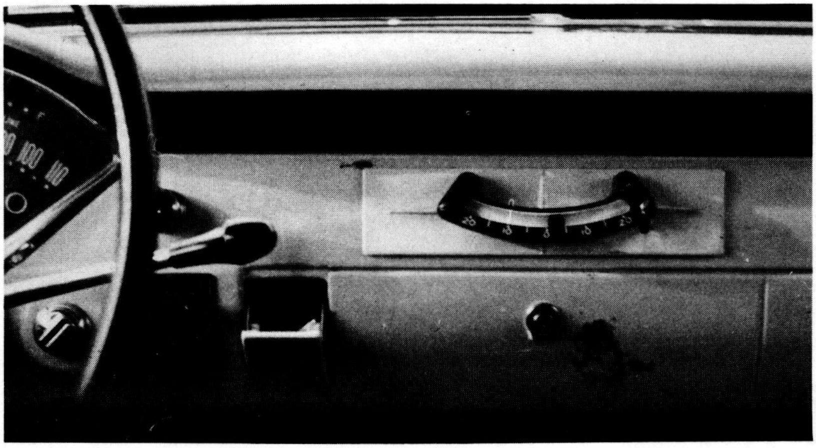


Figure 1. Airplane ball-bank indicator.

All measurements were recorded and later punched into I. B. M. cards. Photographs were obtained at each location where measurements were taken and these photographs were used as an aid to insure correct data being punched on the I. B. M. cards.

Accident Location and Road Conditions

The exact location of each accident was determined using the State Highway Patrol Report (HP-3), the survey speedometer, and, on occasion, by observance of property damage reported by the Patrol. The approach to each location (the path the accident car followed prior to the accident) was determined in the same manner. The length of approach studied was approximately one mile.

At each location the pavement cross-section and the number and width of lanes were determined by observation and measurement. This information was recorded as road type and lane width. The shoulder cross-section in each case was determined by measurement.

Determination of Safe Speed

The safe speed at each location and on the approach to each location was determined using the ball-bank indicator and the survey speedometer. The safe speed was that speed at which a reading of 10 degrees on the ball-bank indicator was observed. A reading of no more than 10 degrees is generally considered as the limiting value for safety. The average safe speed observed on three runs was recorded to the nearest 5 mph. This method is similar to the standard method of determining ball-bank safe speed (1).

Sight Distance Available for Passing

The sight distance available for passing at each two-lane road accident location was determined by measuring the most distant point on the pavement which the observer

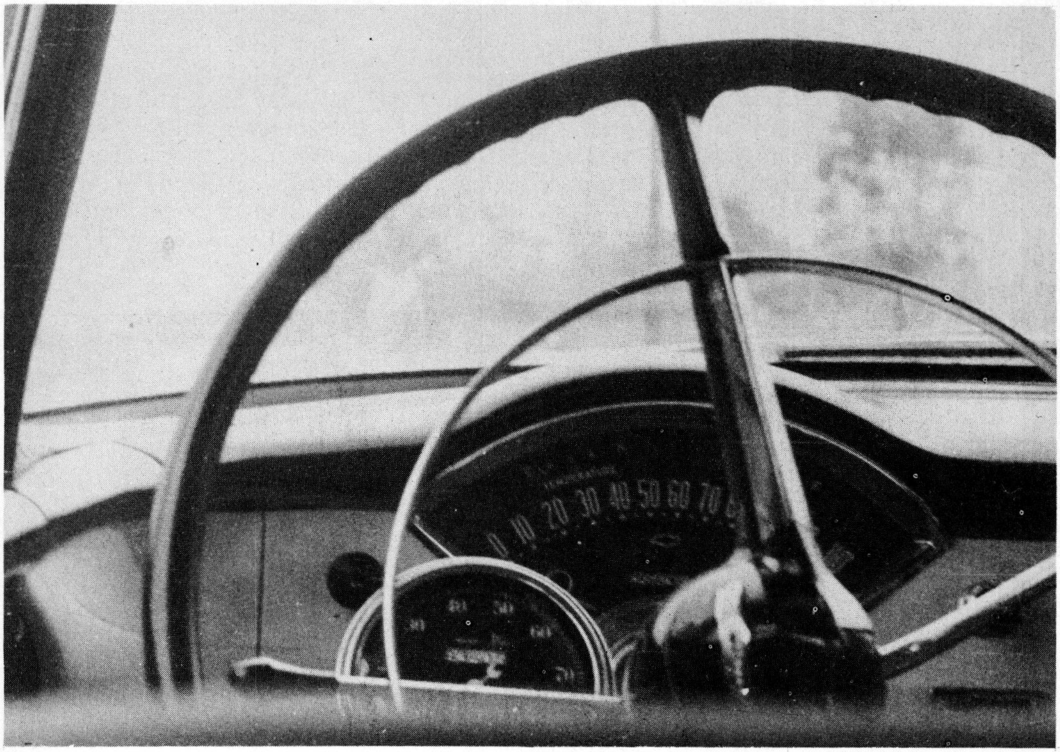


Figure 2. Stewart Warner survey speedometer.

could see clearly. The standard method of determining sight distance for passing on two-lane roads is to measure the distance an object 4.5 ft high can be seen (2). Because each observer operated independently, the method described, rather than the standard method, was used. The measured distances are approximately the same in most cases as those which would have been obtained in the standard manner. At hill crests, however, the distances are somewhat shorter than would have been obtained using the standard method (see Figure 4).

Dry Pavement Coefficient of Friction

To determine the dry pavement coefficient of friction the dry pavement braking distance at 20 mph was measured at each location. The braking distance was measured from the point where the brakes were applied, while the test car was traveling 20 mph, to the point where the car came to rest. The point where the brakes were applied was marked on the pavement by the AAA braking reaction-time device, which, mounted on the front bumper of the test car, was electrically connected to the brake pedal. It fired a blank cartridge containing dye marker the instant the brake pedal was touched. The distance from the dye spot on the pavement to the rear bumper of the test car after it had come to rest was measured and to this distance was added the length of the test car. This method is similar to one used by Whitehurst (3). Distances were roughly

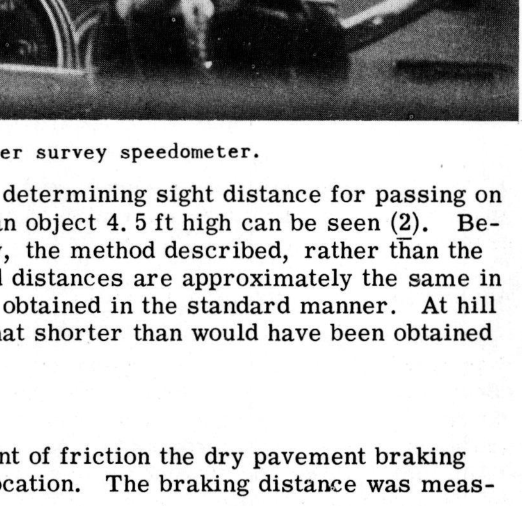


Figure 3. AAA braking reaction-time device.

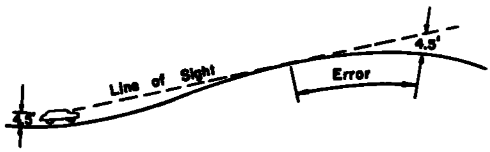


Figure 4. Error in sight distance available for passing at hill crest.

corrected for grade, which was measured with the clinometer (4). Distance corrections used for grade are as follows:

Grade, Percent	Up	Down
0 to 1½	0	0
1½ to 5	+ 1 ft	- 1 ft
more than 5	+ 2 ft	- 3 ft

Pavement Ridability

At accident locations and on the approaches to these locations the adequacy of pavement ridability was determined by observation. Pavements were considered to be inadequate when there were pot-holes, ruts, and other poor conditions present in sufficient quantity to affect the driver's control of the car.

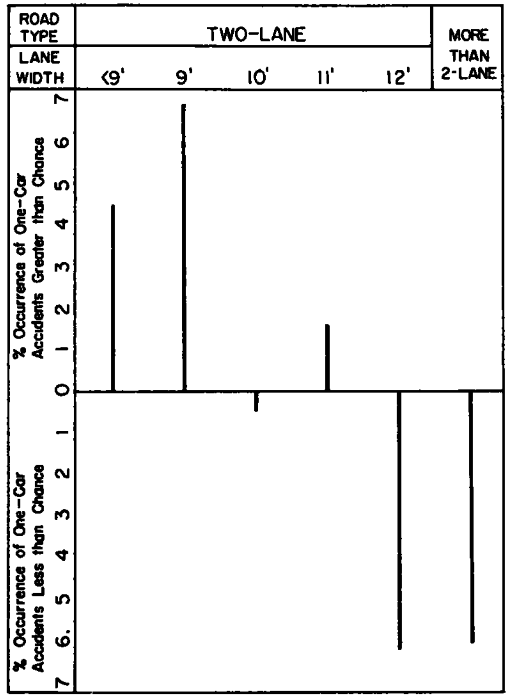


Figure 5. Occurrence of one-car accidents other than chance by number and width of traffic lanes.

Presence of Pavement Marking and Advisory Speed Signs

The presence of pavement marking and advisory speed signs was determined by observation.

Summary of Findings

The road features evaluated in the study are by no means all the features of the road which could contribute to the driver-errors causing accidents. However, because of budgetary, personnel, and time limitations, the study was restricted to the previously listed features, which were considered most important and about which reliable data were easiest to obtain.

Tables 1 and 2 contain a summary of the findings of the engineering phase of the study. In Table 2 the percentages of occurrence of rural one-car accidents on two-lane state highways and the percentages of travel on these roads are tabulated according to the shoulder widths present at the accident sites. The other features studied are tabulated in Table 1 by the number and width of traffic lanes present at the accident sites.

Table 2 shows, for example, that on two-lane roads 15.7 percent of the one-car accidents occurred on roads having 1-ft shoulders, whereas only 1.1 percent of the travel on two-lane roads occurred on these roads. Table 1 shows that 9.9 percent of the accidents occurred on two-lane roads having lane widths of less than 9 ft, whereas while only 5.4 percent of the travel occurred on these roads.

If the percentages of travel by number and width of lanes are considered the percentages of one-car accident occurrence by chance on these roads, then the actual percentages can be plotted against chance, as in Figure 5, which indicates that lane widths of less than 12 ft on two-lane roads appear to contribute to driver errors causing the accidents.

TABLE 1

SUMMARY OF FINDINGS OF ROAD FEATURES

No. of Lanes	Lane Width, ft	Percentage of Travel[a]	Occurrence of Accidents[c]	Shoulder Height at Edge of Pavement[c]		Geometrics[c]		Pavement Coef. of Friction[c,f]	Pavement Ridability[c,g]	Pavement Marking[c]		Advisory Speed Signs[c,h]
			Percent	Uneven	Lower	Safe Speed[d]	Sight Distance[e]			Not Vis	Total Missing	
2	<9	5.4	9.9	70.3	56.8	62.2	78.5	48 3	70.3	78.5	56.8	
2	9	16.9	23 8	74.2	69.6	46.1	86.5	37.7	40.5	46.1	24.7	
2	10	34.2	33.7	72.2	70.7	41.3	65.0	30.5	22 2	26 2	10.3	
2	11	8.0	9 6	66.7	30.6	47.2	55.6	45.5	16.7	19 4	8.3	
2	12	21.8	15.6	70.7	15 5	41.4	72.5	53.1	8.6	32.8	15 5	
>2	Var.	13 6	7.5	86.6	10 3	17.8	0.0	12.5	0 0	3 3	3.3	
Total	—	—	100.0	72.9	52 0	43.3	66.9	38 1	26.9	34.6	18.4	17.1

[a] Based on 1952 traffic volumes / 1956 mileage, from Ohio Dept. of Highways Bureau of Planning Survey
[b] Rural one-car accidents on state highways
[c] Percentages of those in fourth column.
[d] Compared with 50-mph speed limit.
[e] For two lanes, compared with AASHO standard for 50-mph design speed.
[f] Braking distance at 20 mph compared with AASHO standard extrapolated to 20 mph
[g] Deteriorated or inadequate pavement ridability.
[h] Absent where safe speed is at least 5 mph less than safe speed on the approach. Assumed not required when safe speed at location is greater than 45 mph.

If the percentages of travel by shoulder width on two-lane roads are considered the percentages of one-car accident occurrence by chance on these roads, then the actual percentages of accident occurrence can be plotted against chance, as in Figure 6, which indicates that shoulder widths of less than the standard partial 4-ft shoulder appear to contribute to the driver errors causing these accidents.

The standards for shoulder cross-section require that the shoulder be even with the edge of the pavement (5). Sub-standard shoulder heights were present at nearly three-fourths of all the accident locations studied. The fact that nearly seven-eights of the accident locations, on roads having more than two lanes, had shoulders which were other than even with the edge of the pavement is somewhat surprising.

The rate of occurrence of accidents at locations having shoulders lower than the pavement edge, as might be expected, varied from least on roads having more than two lanes to most on the narrower

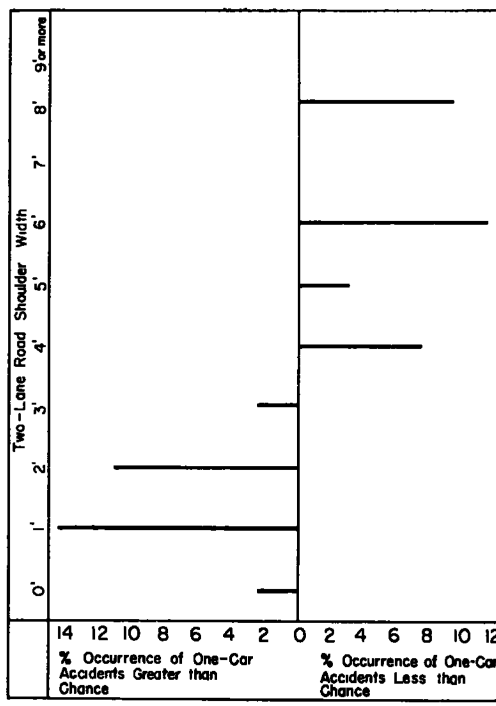


Figure 6. Occurrence of one-car accidents other than chance by shoulder width on two-lane roads.

TABLE 2

SHOULDER WIDTH FINDINGS

Shoulder Width	Travel on 2-Lane Roads,	Occurrence of Rural One-Car Accidents on 2-Lane Roads
ft	Percent	Percent
0	2.4	4.9
1	1.1	15.7
2	5.5	16.8
3	17.1	19.7
4	19.3	11.9
5	10.2	7.2
6	20.9	9.6
7	2.4	2.3
8	11.6	2.3
9+	9.4	9.6

TABLE 3

1952 OHIO AVERAGE DAILY TRAVEL, IN VEHICLE-MILES, BY SHOULDER WIDTH VS ROAD TYPE AND NUMBER OF LANES

No of Lanes	Lane Width ft	Shoulder Width 0	1	2	3	4	5	6	7	8	9 or more	Total
2	9[a]	5,098	39,348	248,981	519,116	365,892	91,734	78,524	16,237	5,171	4,850	1,374,951
2	9	3,881	51,527	527,606	1,303,390	1,187,065	556,462	480,618	75,946	67,193	33,812	4,287,500
2	10	23,957	33,770	254,754	1,510,476	1,786,866	1,061,678	2,146,097	215,469	1,064,051	555,275	8,652,393
2	11	38,613	29,983	49,306	225,337	360,899	199,278	497,913	45,396	333,030	253,852	2,033,607
2	12+[b]	453,417	92,616	111,516	188,847	529,737	317,555	1,371,078	161,675	1,067,676	1,209,663	5,503,780
> 2		-	-	-	-	-	-	-	-	-	-	3,454,978
Total		524,966	247,244	1,192,163	3,747,166	4,230,459	2,226,707	4,574,230	514,723	2,537,121	2,057,452	25,307,209[c]

[a] 7- to 17-ft total pavement surface

[b] 24- to 60-ft total pavement surface marked as two-lane.

[c] Two-lane total = 21,852,231.

TABLE 4

1956 OHIO RURAL STATE HIGHWAY MILEAGE BY SHOULDER WIDTH VS ROAD TYPE AND NUMBER OF LANES

No of Lanes	Lane Width ft	Shoulder Width 0	1	2	3	4	5	6	7	8	9	Total
2	9[a]	21 81	136 62	852 90	967 01	530 00	142 71	171 74	18 68	15 48	21 67	2,878.62
2	9	9 87	153 07	955.68	1,727 27	1,257 13	576 93	509 99	63 22	85 51	61 97	5 400 64
2	10	27 18	34 48	282 99	1,043 88	1,059 59	533.59	1,063 86	99 64	566 68	240 93	4,952 82
2	11	17 10	10 42	21 56	89 32	132 57	72 44	180 84	13 71	169 91	114 96	822 83
2	12+[b]	86 65	21 34	29 99	43 35	124 35	76 35	315 63	30 53	294 33	345 14	1,367 66
> 2		-	-	-	-	-	-	-	-	-	-	498 09
Total		162 61	355 93	2,143 12	3,870 83	3,103 64	1,402 02	2,242 06	225 78	1,131 91	784 67	15,920 66[c]

[a] 7- to 17-ft total pavement surface.
[b] 24- to 60-ft total pavement surface marked as two-lane
[c] Two-lane total = 15,422.57.

two-lane roads. The percentages of occurrence at locations having shoulders higher than the pavement edge can be obtained by subtraction. The shoulder height data are given in Table 5.

Two standards of comparison for minimum geometrics were used. First, the ball-bank safe speed at the accident locations was compared with the 50-mph speed limit in effect when the accidents occurred. All locations having a safe speed at least 5 mph less than the 50 mph speed limit were assumed to be sub-standard. On this basis, sub-standard geometrics were present in more than 40 percent of the locations studied. The breakdown by road type and lane width appears in Tables 1 and 6.

Finally, the passing sight distance was compared with the AASHO standards for 50-mph design speed (6). Sub-standard geometrics, on this basis, were present in approximately two-thirds of the cases. Tables 1 and 7 contain the rates of occurrence by road type and lane width.

In Table 8 the braking distances observed at the accident locations are listed by braking distance, road type, and lane width. These distances were observed at 20 mph on dry pavement and are corrected for grade as previously discussed. The AASHO coefficients of friction for design (6) were used for a standard of comparison. The design values of coefficient of friction are plotted and extrapolated to 20 mph in Figure 7. From these curves the minimum coefficient of friction for a speed of 20 mph on dry pavement was determined to be 0.64 and the corresponding maximum braking distance was calculated to be 20.8 ft (9, 10).

Sub-standard pavement coefficients of friction were present at nearly 40 percent of the accident locations studied. The percentages of occurrence of this feature are tabulated by number and width of lanes in Table 1. It should be noted that the rate is markedly lower on roads having more than two lanes. The data indicate that nearly three-fifths of the accident locations which had sub-standard pavement coefficients of friction had pavements which were otherwise adequate.

As has been previously stated, pavement ridability at accident locations was considered inadequate (or sub-standard) when the pavement surface was deteriorated.

Slightly more than one-quarter of the accident locations had sub-standard ridability characteristics. Table 1 shows the breakdown by road type and lane width. The IBM tabulation of the data appears in Table 10.

Comparisons of the ridability at the accident locations with the ridability on the

TABLE 5

SHOULDER HEIGHT AT PAVEMENT EDGE AT ACCIDENT LOCATION VS ROAD TYPE AND LANE WIDTH

No. of Lanes	Lane Width, ft	Shoulder Height at Pavement Edge, in.									No Curb or Shoulder	Total
		Higher					Lower					
		6	4-6	2-4	0-2	Even	0-2	2-4	4-6	6		
2	<9	2	-	2	1	11	15	5	-	-	1	37
2	9	-	-	1	3	23	48	10	-	-	4	89
2	10	-	1	-	1	35	66	13	4	4	2	126
2	11	-	-	-	1	12	20	3	-	-	-	36
2	12+	4	-	1	3	17	24	7	-	1	1	58
>2	-	8	1	-	-	4	13	2	1	-	-	29
Total		14	2	4	9	102	186	40	5	5	8	375

TABLE 6

BALL-BANK SAFE SPEED AT ACCIDENT LOCATIONS VS ROAD TYPE AND LANE WIDTH

No. of Lanes	Lane Width, ft	Ball-Bank Safe Speed, mph												Total
		0	10	15	20	25	30	35	40	45	50	55	60+	
2	<9	-	2	-	1	7	4	4	4	1	2		12	37
2	9	2	1	3	3	5	6	8	10	5	7		39	89
2	10	1	2	3	3	10	13	9	8	4	2	5	66	126
2	11	-	-	-	-	4	7	1	4	1	1		18	36
2	12+	4	-	1	2	4	6	3	5	3	1	2	27	58
>2	-	-	-	-	-	-	2	2	1	-	2		21	28
Total		7	5	7	9	30	38	27	32	14	15	7	183	374

TABLE 7

PASSING SIGHT DISTANCE AT ACCIDENT LOCATION VS ROAD TYPE AND LANE WIDTH

No. of Lanes	Lane Width ft	0.07 or less	0.70-0.08	0.09-0.12	0.13-0.24	0.25-0.31	0.32-0.37	0.38-0 43	0 44-0.54	0.54 or more	Total
2	<9	4	4	7	10	4	1	3	-	4	37
2	9	10	9	20	29	9	3	3	2	4	89
2	10	4	14	15	37	12	14	8	6	16	126
2	11	2	1	3	8	6	2	2	4	8	36
2	12+	2	2	8	22	8	1	1	1	13	58
>2	-	-	-	-	-	-	-	-	-	28[a]	28
Total[b]		22	30	53	106	39	21	17	13	73	374

[a] 2-lane passing sight distance not applicable.
[b] Sample not large enough for further breakdown.

TABLE 8

BRAKING DISTANCE AT ACCIDENT LOCATION

No of Lanes	Lane Width ft	20-mph Braking Distance, ft.									Total
		<18	18	19	20	21	22	23	24	>24	
2	<9	5	2	2	6	1	3	3	5	2	29
2	9	3	12	15	8	8	6	2	6	1	61
2	10	9	24	17	14	8	7	3	5	5	92
2	11	4	3	2	3	1	4		4	1	22
2	12+	2	8	2	3	8	3	4	1	1	32
>2	-	1	1	2	3	-	-	1	-	-	8
Total	-	24	50	40	37	26	23	13	21	10	244

TABLE 9

BRAKING DISTANCE AT ACCIDENT LOCATION VS PAVEMENT RIDABILITY AT ACCIDENT LOCATION

Pavement Ridability	20-mph Braking Distance, ft									
	<18	18	19	20	21	22	23	24	>24	Total
Adequate	18	46	32	24	20	14	6	10	6	176
Inadequate	6	4	8	13	6	9	7	11	4	68
Total	24	50	40	37	26	23	13	21	10	244

approaches and the visibility at the times of the accidents were also made. These comparisons tend to support the theory that change in conditions rather than the conditions themselves, affect drivers. From Table 11 it appears that nearly one-fifth of the accident locations having sub-standard ridability characteristics probably could not have been anticipated by the drivers involved, because the ridability was satisfactory until a short distance before the accident locations. Somewhat more significant is the fact that nearly two-thirds of the accidents occurring at locations having sub-standard ridability characteristics occurred at times of reduced visibility (night, rain, or fog) as reported by the Patrol (see Table 12.)

TABLE 10

PAVEMENT RIDABILITY VS ROAD TYPE AND LANE WIDTH AT ACCIDENT LOCATION

No. of Lanes	Lane Width ft	Pavement Ridability		
		Adequate	Inadequate	Total
2	<9	11	26	37
2	9	53	36	89
2	10	98	28	126
2	11	30	6	36
2	12+	53	5	58
>2	-	30	0	30
Total		275	101	376

TABLE 11

PAVEMENT RIDABILITY ON APPROACH VS AT ACCIDENT LOCATION

Pavement Ridability at Accident Location	Pavement Ridability on Approach		
	Adequate	Inadequate	Total
Adequate	262	13	275
Inadequate	20[a]	81	101
Total	282	94	376

[a] 19.8 percent of accident locations having inadequate pavement ridability probably could not have been anticipated by the drivers involved.

TABLE 12

VISIBILITY VS PAVEMENT RIDABILITY AT ACCIDENT LOCATION

Pavement Ridability at Accident Location	Visibility		
	Normal Daytime	Reduced	Total
Adequate	84	191	275
Inadequate	35	66[a]	101
Total	119	257	376

[a] 65.4 percent of accident locations having inadequate pavement ridability probably could not be seen by the driver due to reduced visibility.

TABLE 13

PAVEMENT MARKING AT ACCIDENT LOCATION VS ROAD TYPE AND LANE WIDTH

No. of Lanes	Lane Width ft	Marking: Clear	Partially Worn-off	Totally Worn-off	None	Total
2	<9	8	8	5	16	37
2	9	48	19	7	15	89
2	10	93	20	3	10	126
2	11	29	4	2	1	36
2	12+	39	10	3	6	58
>2	-	27	2	0	1	30
Total	-	244	63	20	49	376

Lack of pavement marking at accident locations was assumed to be a contributive feature of the road in one-car accident causation. Table 13 shows that pavement markings were not clear at more than one-third of the accident locations. Markings were totally missing at nearly 20 percent of the locations. The breakdown by road type and lane width appears in Table 1.

Advisory speed signs were assumed to be required at all locations having a safe speed at least 5 mph less than the safe speed on their approaches. No advisory was assumed to be required where the safe speed at an accident location exceeded 45 mph.

More than one-sixth of the locations requiring advisory speed signs did not have them (Table 14). However, Table 15 indicates that nearly one-eighth of the locations not requiring advisory speed signs nevertheless had them.

THE DRIVER

As previously mentioned, the objective in this study was to attempt to develop an adequate method of research into the causes of one-car accidents. Because it was assumed for the purposes of this study that the driver was primarily responsible for all automobile accidents, the sample was chosen as those one-car accidents in which there were no animals, pedestrians, or other factors involved, to even a secondary degree, other than the road and the auto. In this way it was felt that it would be easier to control to some extent the driver's putting the responsibility on these other factors.

From the standpoint of the social researcher the main concern was getting background material on the driver, along with his stoty of the accident. The emphasis was upon his opinions, ideas, evaluations, and reactions so that the accident might be seen as he saw it and an understanding obtained as to how he felt about it, as well as determining his over-all concept of himself as a driver.

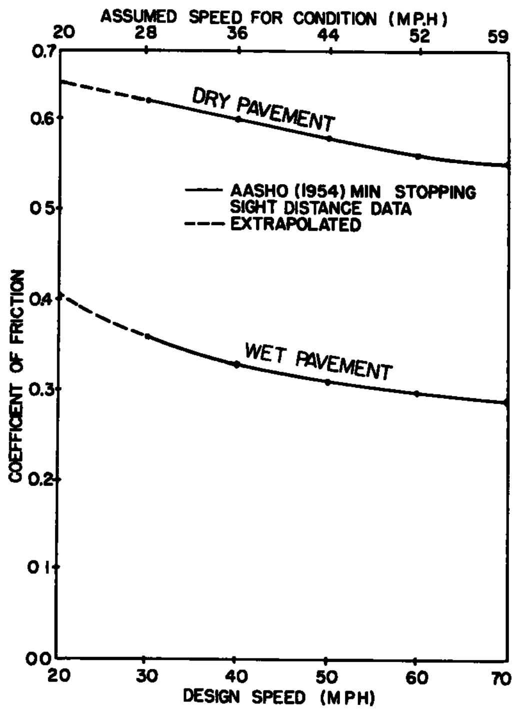


Figure 7. Pavement coefficient of friction vs design and assumed speed.

TABLE 14

SAFE SPEED ON APPROACH VS AT ACCIDENT LOCATION
(No Advisory Speed Sign Posted)

Safe Speed[a] at Accident Location, mph	Safe Speed,[a] mph											
	10	15	20	25	30	35	40	45	50	55	60	Total
10	-	-	-	-	-	-	-	-	-	-	5	5
15	-	-	-	-	1	-	-	-	-	-	1	2
20	1	1	-	1	-	-	-	-	1	-	3	7
25	1	1	1	3	3	1	1	1	-	-	4	16
30	-	1	-	2	3	3	3	1	2	1	4	20
35	-	-	2	3	5	-	3	1	-	-	2	16
40	-	-	2	-	-	2	5	8	3	1	6	27
45	-	-	-	1	-	-	4	1	1	-	4	11
50	-	-	-	1	-	2	-	3	-	-	7	13
55	-	-	-	-	-	1	-	-	-	-	5	6
60	1	1	3	6	-	6	5	3	3	2	134	164
Total	3	4	8	17	12	15	21	18	10	4	175	287

[a] By ball-bank indicator.

TABLE 15

SAFE SPEED ON APPROACH VS AT ACCIDENT LOCATION
(Advisory Speed Sign Posted)

Safe Speed[a] at Accident Location, mph	Safe Speed,[a] mph											
	10	15	20	25	30	35	40	45	50	55	60	Total
0	-	-	-	-	-	2	-	-	-	-	5	7
10	-	-	-	-	-	-	-	-	-	-	-	0
15	-	-	-	-	-	-	-	-	-	-	5	5
20	-	-	-	-	-	-	-	-	-	-	2	2
25	-	-	1	1	4	1	2	1	-	1	2	13
30	-	-	-	-	-	4	4	1	-	1	8	18
35	-	-	-	-	2	2	2	1	1	-	3	11
40	-	-	-	1	-	-	1	-	-	1	2	5
45	-	-	-	-	-	-	-	-	1	-	2	3
50	-	-	-	-	-	-	1	-	-	-	1	2
55	-	-	-	-	-	-	-	-	-	-	1	1
60	-	-	-	-	-	2	3	2	1	-	12	20
Total	0	0	1	2	6	11	13	5	3	3	43	87

[a] By ball-bank indicator.

Since the interest was in getting the driver to tell his story of the accident, considerable time was spent in developing a method of contacting and interviewing the driver that would be confidential and reassuring, yet informative. The four interviewers were carefully trained in terms of their interpretation of the study to the driver, and particularly their approach to, and administering of, the schedule itself. The concern throughout the study was to make as certain as possible that the driver understood

TABLE 16

RESULTS OF RESPONSES TO DRIVER CONCEPT QUESTIONS ACCORDING TO FOUR AGE GROUPINGS OF 201 MALE ONE-CAR ACCIDENT DRIVERS

Driver Concept Questions	Age Groupings									
Dr. opinion of driving ability as indic. scale	16-19 No.	16-19 %	20-29 No.	20-29 %	30-39 No.	30-39 %	40+ No.	40+ %	Total No.	Total %
Better than average	29	46.8	43	70.5	22	68.7	36	78.3	130	64.7
Average or less	32	51.6	18	29.5	10	31.3	10	21.7	70	34.8
No response	1	1.6							1	.5
Total	62		61		32		46		201	
Dr. opinion of chance of same accident again										
Maybe	19	30.6	17	27.9	12	37.5	21	45.7	69	34.3
Don't know	7	11.3	8	13.1	4	12.5	4	8.6	23	11.4
No	35	56.5	36	59.0	14	43.8	21	45.7	106	52.7
Other	1	1.6			2	6.3			3	1.6
Total	62		61		32		46		201	
Dr. estimate of amount alcohol can drink and drive										
None	52	83.8	37	60.7	8	25.0	28	60.9	125	62.2
2 ounces or less	5	8.1	9	14.8	6	18.8	5	10.9	25	12.4
Over 2 ounces	5	8.1	12	19.7	18	56.2	11	23.9	46	22.9
No response			3	4.9			2	4.4	5	2.9
Total	62		61		32		46		201	
Dr. insight as to need to improve dr. habits										
Needs impr. and know how	46	74.2	39	63.9	19	59.4	18	39.1	122	60.7
Needs impr. but doesn't know how can achieve	14	22.6	20	32.8	11	34.4	21	45.7	66	32.8
Other	2	3.2	2	3.3	2	6.2	7	15.2	13	6.5
Total	62		61		32		46		201	
Dr. determination of cause of the accident										
Self	42	67.7	31	50.8	16	50.0	16	34.8	105	52.2
Road	9	14.5	12	19.7	8	25.0	11	23.9	40	19.9
Auto or other driver	9	14.5	16	26.2	6	18.8	16	34.8	47	23.4
Don't know	2	3.2	2	3.3	2	6.2	3	6.5	9	4.5
Total	62		61		32		46		201	

the objective of the study, and that he felt in no way under duress or pressure, but that he was responding of his own volition and desire. In this way it was hoped to get a true and fairly accurate picture of the accident and, at the same time, the opinions and reactions of the driver.

Rating Scale

Throughout the schedule there were questions in which the driver was requested to give his own evaluation or opinion on a scale designed to lend more objectivity to the response. Twice the driver was asked to rate his driving ability as compared to other drivers; once as he himself would rate it, and then again later, as he thought others would rate him. In each case he was asked to give his verbal opinion first before using the scale, so that we could in some way measure the difference, if any.

TABLE 17

RESULTS OF RESPONSES TO DRIVER CONCEPT QUESTIONS ACCORDING TO MARITAL STATUS OF 201 MALE ONE-CAR ACCIDENT DRIVERS

Driver Concept Questions	Marital Status of the Drivers							
Dr opinion of driving	Married		Single		Other		Total	
ability as indic. scale	No.	%	No.	%	No.	%	No.	%
Better than average	70	77.7	53	53.5	7	58.3	130	64.7
Average or less	20	22.3	45	45.5	5	41.7	70	34.8
No response			1	1.0			1	.5
Total	90		99		12		201	
Dr. determination of the cause of accident								
Self	38	43.2	58	58.6	9	75.0	105	52.2
Road	19	21.1	20	20.2	1	8.3	40	19.9
Auto or other driver	28	31.1	17	17.2	2	16.7	47	23.4
Don't know	5	3.6	4	4.0			9	4.5
Total	90		99		12		201	

TABLE 18

RESULTS OF RESPONSE TO DRIVER CONCEPT QUESTIONS ACCORDING TO ARRESTS FOR TRAFFIC VIOLATIONS FOR 201 MALE ONE-CAR ACCIDENT DRIVERS

Driver Concept Question	Amount of Traffic Arrests of Drivers					
Dr estimate of amount of	None		Some		Total	
alcohol can drink and drive	No.	%	No.	%	No.	%
None	65	69.9	60	55.6	125	62.2
2 ounces or less	10	10.8	15	13.9	25	12.4
Over 2 ounces	14	15.0	32	29.6	46	22.9
No response	4	4.3	1	0.9	5	2.9
Total	93		108		201	

TABLE 19

RESULTS OF RESPONSE TO DRIVER CONCEPT QUESTIONS ACCORDING TO PERSONALITY TYPE OF 201 MALE ONE-CAR ACCIDENT DRIVERS AS EVALUATED BY INTERVIEWERS

Driver Concept Questions	Personality-type of driver					
Dr. opinion of chance of	Normal		Other than Normal		Total	
same accident again	No.	%	No.	%	No.	%
Maybe	61	40.4	8	19.0	69	34.3
Don't know	16	10.1	7	16.7	23	11.4
No	81	50.9	25	59.5	106	52.7
Other	1	0.6	2	4.8	3	1.6
Total	159		42		201	
Dr. opinion of driving ability as indic. scale						
Better than average	109	68.6	21	50.0	130	64.7
Average or less	50	31.4	20	47.7	70	34.8
No response			1	2.3	1	0.5
Total	159		42		201	

The scale was made of clear plastic and had no markings on it other than two words at opposite ends: "WORST" on the left and "BEST" at the right. The driver was instructed to place the marker at the point on the scale which would come closest to his own opinion or evaluation. Other than that, no further instructions were given. There was purposely no midpoint or "average" on the scale, as it was felt that most persons tend to place themselves in this category verbally, and they might do the same if the scale was designed that way.

This, in a sense, gave the driver an opportunity to put down his true or honest opinion without being concerned about language, which might be more subjective. It was felt that semantics must be considered and quite possibly the same words mean different things to different people. Also, it is possible for the tone of voice or the inflection of a word or phrase to carry an entirely different meaning than is found in the dictionary. The scale was a means of being more objective and at the same time providing an easy and fairly uniform way of expressing opinions.

By having the driver give his opinion, and that of others, it was hoped to provide him with an opportunity to do some projecting. That is, he could safely and comfortably say what he really wanted to say by claiming it was someone else's opinion and not necessarily his. This, it was felt, was important in this study, because all of these drivers could be expected to be a bit on the defensive about their accidents.

The scale was designed so that an overlay scale with the numbers one through seven could be placed along side of it and the number tabulated after the driver had moved the indicator to the desired spot. The driver was not able to observe this operation, and this gave the interviewer an opportunity to tabulate the number which later was interpreted as follows, reading from left to right: 7, worst; 6, poor; 5, fair; 4, average; 3, good; 2, very good; and 1, best.

Definitions and Delimitations

Amount of alcohol driver estimated he could consume. The driver was asked "How much beer, whickey, wine, etc., do you think you can drink before it would affect your driving?" The amount then was converted into ounces of alcohol using the volume and the percentage of alcohol contained in the particular beverage. This was done on a rather general basis. For instance, all whiskeys were considered to be 100 proof, therefore 50 percent alcohol, so one shot would be comparable to a ½ ounce of alcohol. This is not considered completely accurate, but as an estimate only. Therefore, 2 ounces, or less, was comparable to four beers or shots.

Responsibility for the one-car accident. Here the driver was not asked directly who or what he thought caused the accident. Rather, the question was phrased as follows: "How do you think that this accident might have been prevented?" If he indicated that he made some definite error which actively contributed to the accident, or if it came out that some aspect of the variables which were under the driver's control were not handled in such a way as to prevent the collision, he was considered responsible. This means that, either by contributing positively or by failing to prevent the accident, the driver was responsible. This delineation was based on the one used by Ross A. McFarland in his report, "The Development of Procedures for Detecting Accident Repeaters." If the driver indicated that the highway design, construction, signing, etc., was at fault this was classified as "road" in terms of responsibility. When the weather, the other driver, or the auto was deemed by the driver to be the cause of the accident the responsibility was placed in the "other" category.

Although 243 complete and valid interviews were obtained, only 201 were used for this phase of the study. The 42 that were not used were all women drivers who were involved in one-car accidents. The remaining 201 were all men drivers. Women were not included because they may not have been representative numberwise yet due to the sex factor they would have influenced the results. Findings on women drivers will be included in the final phase of this study as a comparative group.

Because the entire interviewing situation was aimed towards getting the true feeling and evaluation of the driver, there was no attempt to interview anyone who resisted or refused. In other words, the entire sample of drivers represents only those drivers here would probably be due to chance only 5 percent of the times. The chi squares were, in each case, greater than the necessary value for the various degrees of freedom needed in each of the tables. For the sake of consistency and to facilitate ease in reading the tables, the general sample of the 201 drivers has been used. However, when the chi square check was made each of the net samples was used.

Results of Driver Concept Compared to Background Factors

There was found to be no relationship between the following background factors and driver concept: community size, number of jobs in past five years, job tenure, and method of learning to drive. The most significant findings were, as might be expected, in the comparison with age. In each case there was indication that how a driver views himself and the accident might be influenced by his age.

Driver concept and age. It was found that for opinions as to their general driving ability the younger drivers (that is, those in their teens) tend to rate themselves as average or worse, whereas older drivers think of themselves as better than average. Those 40 years of age and older appear to think of themselves as better than any of the others, with the 20-year-olds following close behind.

When asked about the possibility of having another accident, the younger drivers are more certain that they will not have another one. The 20-year-olds were a little more certain than the teenagers; the 30-year-old group was next; and those the least certain were those over 40, who felt that they had about a 50 percent chance for another such accident.

When asked to estimate the amount of alcohol they can drink before it will affect their driving ability, the teenagers said that they should not and/or could not drink anything and drive safely, whereas the 30-year-olds strongly believe they could imbibe more than four beers or shots of whiskey (approximately more than 2 ounces) and still manage to drive safely. The 20-year-old group and those over 40 agreed that about 60 percent of the time they cannot drink and drive.

The teenagers strongly believe that their driving habits can be improved. Conversely, the older drivers (those over 40) are satisfied with their driving as it is or maintain that they do not know how they can better their driving ways. This could be a matter of insight or self-evaluation on the part of the driver and might indicate a lack of knowledge of their own driving habits and/or what good driving habits are.

Again, the indications are that the younger driver, particularly the teenager, differs considerably from the older driver. The driver over 40 believes that his accident was not due to any error or lack of proper preventive action on his part, despite the fact that 95 percent of these accidents were considered to be the driver's fault primarily. Those drivers between 16 and 19 years of age took the responsibility for the accident in nearly three cases out of four. The other age groups responded as did the general sample.

Driver concept and marital status. When asked to show how they rate themselves on the scale as to their driving ability, it was noted that the single man believes less often than the married man that he is about average as a driver. The married men must feel fairly confident of their driving skills, as they said that for the most part (77.7 percent) they are better than average.

In the matter of determining responsibility for his one-car accident, the married driver places the blame on the road and other factors (the auto and other drivers) in more than one-half the cases. The bachelor accepts the responsibility in most of the cases.

It should be noted that 34 percent of the married men are under 30 years of age, whereas 90 percent of the single men are in this age category. It may be that age is a factor causing the variation in the results, rather than the marital status.

Driver concept and amount of alcohol consumed before accident. Of the five driver concept questions, only two appeared to have any relationship when compared with the amount of alcohol consumed on the trip. Those who drank on the trip were considerably more uncertain about their chances for having a similar accident, because 22 percent of them said they did not know about this compared to only 7 percent of the nonwho were willing to talk about their accident experiences and other matters concerned with their driving history and such. It was possible to get response from approximately 40 percent of those who were involved in one-car accidents during the time of the study. A remaining 10 percent were responsive to questionnaires sent to them, which made a total of 50 percent response of all those involved. Therefore, this sample of 201 drivers is not necessarily representative of one-car accident drivers, but only those who were willing and able to talk to the investigators. Those who were injured were seen at home, often in a convalescent stage; but no attempt was made to get data on those who were killed.

Method of Determining Driver Concept of Self

Means of contacting and interviewing. A letter of interpretation was sent to each driver within ten days after the accident, requesting an appointment for an interview. The interviewer spent as much time with each driver as was necessary to establish a good friendly relationship. The purpose of this was to develop a feeling of confidence and relaxation on the part of the driver so that a more accurate picture of his real feelings, opinion, and attitudes about the accident, his driving ability, habits, and behavior could be obtained. The investigators were encouraged by the results, because in many cases the drivers confided to the interviewers a great deal more meaningful material about themselves and the accident than the accident report indicated.

Preliminary study: Two separate pilot studies were conducted prior to the actual study to develop the schedule, revise it and to learn the best method of operating in the field. Even before the schedule was pilot tested it was revised three times with the aid of an advisory group of engineers, sociologists, and psychologists. The schedule that finally evolved consisted of a total of 82 statements covering the driver's information on the accident and background material on himself, and contained the five driver concept questions.

Concept Questions and Selected Background Material

The five questions excerpted from the general One-Car Accident Study schedule covered the following information:

1. Driver's opinion of his ability as a driver compared to other drivers, as shown by him on the scale.
2. Driver's opinion of the probability of the recurrence of a similar accident.
3. Driver's estimate of the amount of alcohol he can consume before it affects his driving ability.
4. Driver's insight as to the need of improving his driving habits and how this might be done.
5. Driver's determination of cause of the accident.

In an effort to determine if there was any relationship between how a driver sees himself and the data collected on him, a comparison was made of responses to the concept questions and some general and specific data on his background material. The material used for this included the following:

1. Age of the driver.
2. Marital status.
3. Education.
4. Size of community in which he resided.
5. Traffic arrest history.
6. Personality type of the driver as evaluated by the interviewer.
7. Number of full-time jobs in the past five years.
8. Job tenure on present job.
9. Method of learning to drive.
10. Amount of alcohol consumed within 6 hr prior to accident.

The chi square test of association was run on each of these combinations to determine if there was any statistically significant relationship between the concept questions and the background factors. Fourteen of these combinations were found to be statistically significant at the 5 percent level, which means that any differences shown drinking drivers who disclaimed any knowledge. Yet more of the non-drinking drivers than those who drank said that it is possible that they might have an accident. About 7 percent more of the non-drinkers than of the drinking drivers were sure that they would not have another similar mishap.

On the question about their estimation of amount of alcohol they can consume before it affects their driving, the non-drinkers were overwhelmingly convinced that they should not or could not imbibe and drive without it bothering them in the operation of the vehicle. Almost the reverse is true of those who drank on the trip. These men are quite sure they can hold their drinks and drive, in fact well more than one-half of them stated that they can take more than four shots of whiskey or four bottles of beer without effect on their driving ability.

Driver concept and traffic arrest history. Of those drivers who had no arrest history for traffic violations it was found that they are generally of the opinion that they shouldn't, or possibly couldn't, drive and drink without the drinking negatively affecting the performance of their driving. Considerably fewer of them (15 percent) believe they can take more than four beers or shots without adverse effect, whereas twice as many (30 percent) of those with some traffic arrests think that they can.

Driver concept and education of the driver. It is interesting, and possibly significant, to note that there is a direct correlation between the amount of education a driver has and his recognition of how he can improve his driving habits. Those with an elementary education (44 percent) for the most part do not know how they can improve, but do believe they need improvement in more than 85 percent of the cases. Ninety percent of the drivers who had post-high-school education believe they need improvement, and in three cases out of four they made suggestions as to how this might be done—that is by driving slower, using hand signals, etc.

In terms of placing responsibility for the accident, it appears as though the drivers with the elementary education are less likely to accept it for the accident than those who attended high school. However, the sample is so spread out in the post-high-school-educated group that the results are not considered meaningful.

Driver concept and personality type of driver as evaluated by interviewer. Of the 201 male drivers, 42 were considered as either withdrawn, conforming, or aggressive by the interviewers. When compared against the "normal" group the results on the driver opinion scale are quite interesting. Those in the "normal" group are inclined to place themselves in the better category considerably more often than those who were described as other-than-normal. Only one-half of the other-than-normal group considered themselves as better, as compared to the normal who rated their driving ability above average in 68.6 percent of the cases.

In the matter of the possibility of having another similar accident, the other-than-normal drivers think the chances not too good that they would do so. They were certain in 60 percent of the cases that they would never get into such a mishap again, but only one-half of the "normal" group said that they wouldn't be involved again in a one-car accident.

Summary of Findings and Conclusions

It would seem that the teenagers view themselves as only mediocre drivers who could improve their driving habits, but they don't think they can drink and drive safely. In regard to their one-car accidents the younger drivers blame themselves, but don't think they are likely to make the same mistake again. The driver who is over 40 feels that the responsibility for the accident is due the road and, primarily, the auto and other drivers, even though nearly all of these accidents were selected because they were at least 95 percent driver caused. Apparently, since the older driver puts the blame on others, he is of the opinion that such a mishap may occur again because it is more or less "out of his hands." This is, perhaps, a fatalistic type of thinking. In line with this type of defensive thinking, the older drivers see themselves as better drivers, in most cases, than other drivers on the road. Also, they seem to realize that they could improve their driving habits, but they don't know how in most cases. Those over 40 are rather conservative, compared with the 30- to 39-year-olds, when it comes to drinking and driving. Here the 30-year-olds show a definite opinion that they can consume considerably more alcohol than other drivers before it affects their safe operation of the auto.

From the findings to date there appears to be some possible connection between the driver's marital status and two concept questions. The married men are more inclined to have a higher opinion of their ability to drive and are more likely to believe that the road, auto, or other driver was responsible for their one-car mishaps. But this may be due more to age than marital status.

Those drivers who did drink within 6 hr before the accident seem to be a bit more uncertain about the possibility of this type of accident occurring to them again than do the non-drinking drivers. As might be expected, the trip drinking drivers believe they can safely drive and drink more often than those who didn't imbibe on the trip.

The more education a driver has the more inclined he is to be aware of how to improve his driving habits. Those drivers who had only elementary schooling took less personal responsibility for the accident than did the driver with the 9th to 12th grade education.

Personalities of the drivers, as seen by the interviewer, seemed to have some effect on the driver's concept of himself regarding his driving ability and his opinion of the chance of having a similar accident in the future. The "normal" personality said that his chances are about fifty-fifty, and he thinks of himself as a better driver more often than does the driver who appeared to be "other than normal."

The driver who was arrested on traffic violations thinks that he can drink and drive, more so than the non-arrested driver.

It would seem that from the standpoint of the general study dealing with the driver, there have been some fairly encouraging results as far as being able to develop a confidential approach and personal interviewing technique. The drivers who were contacted and interviewed were, for the most part, apprehensive, and in some cases fearful of the consequences of participating in the study. Therefore, it was rather surprising that they were willing to confide as much material to the interviewers as they did. It would appear that by giving the driver a chance to tell his own story, assisted by a trained and skillful interviewer, much valuable information may be obtained concerning causes of particular accidents, as well as being able to find a yardstick for measuring the driver's emotional, intellectual, and sociological make-up and the possible relationship between these factors and the accident.

It may well be, if this sort of approach were used to get a better picture of the general driving public, it might give some interesting and hopefully significant data about the man behind the wheel. If an effective program of accident prevention based on the education of the driver is ever to be attained more must be known about what sort of individual he is. This, it is believed, can be done if the driver is approached properly and if the interviewing situation is one in which the driver is "sold" on the idea that he is an important person who has something important to tell.

As for the concept question phase of this study, it is not yet feasible to draw any definite conclusion because of the many obvious unknowns. It appears that the interviewers were able to get some rather interesting responses from the drivers on the questions asked, but in view of the limited and somewhat selective nature of the sample it would not be practical to do anything other than suggest that such a technique may have merit. It might be utilized as a sort of test to measure driver insight or awareness of self of the general driving public.

CONCLUSIONS

If any reduction is to be made in the terrible price which the citizens of the United States are paying in terms of lives and property damage due to highway traffic accidents, a vigorous and continuous program of research into traffic accidents is vital. Regardless of how the highway engineer looks at the cause of highway traffic accidents, it is still the driver who is going to cause or avoid the accident. Therefore much more research is needed in the behavior of the driver as he operates the automobile on the road.

The method employed in this study, that of interviewing the drivers who have survived one-car accidents, seems to produce factual and reliable results. Studies of many more cases with evaluation of variables, and with correlation of the conditions of the roadway as evaluated by the engineer, are needed before conclusions can be drawn as to the cause of one-car accidents. The only conclusion which can be drawn at this time is that the methodology described here gives promise of producing desired information.

References

1. Henry K. Evans, et al., Traffic Engineering Handbook (New Haven, Connecticut: Institute of Traffic Engineers, 1950), pp. 388-9.
2. Ibid., p. 365.
3. E. A. Whitehurst and W. A. Goodwin, Pavement Slipperiness in Tennessee (Knoxville: University of Tennessee, 1956), pp. 205-9.
4. A. E. Johnson, et al., A Policy on Geometric Design of Rural Highways (Washington, D. C.: American Association of State Highway Officials, 1954), p. 116.
5. A. E. Johnson, et al., A Policy on Geometric Design of Rural Highways (Washington, D. C.: American Association of State Highway Officials, 1954), p. 223.
6. Ibid., pp. 460-4.
7. Henry K. Evans, et al., Traffic Engineering Handbook (New Haven, Connecticut: Institute of Traffic Engineers, 1950), pp. 388-9.
8. Johnson, op. cit., p. 121.
9. E. A. Whitehurst and W. A. Goodwin, Pavement Slipperiness in Tennessee (Knoxville: University of Tennessee, 1956), pp. 205-9.
10. Johnson, op. cit., pp. 113-6.

Predicting Accident Trends and Traffic Improvement

CLIFFORD O. SWANSON and A. R. LAUER,
Iowa State College, Ames

The traffic death rates per 100 million miles vehicular travel as used in this study are those published by the National Safety Council for 1935 to 1954, inclusive. A wide range in rates prevails yearly, as well as from year to year, for the individual states during this time.

By taking account of such trends for individual states, for groups of states, or for the country as a whole, it should be possible to evaluate the results of different types of road building programs, of enforcement policies, of educational efforts and other variables. This paper is presented as a pilot study in the area of accident-trend analysis.

Iowa and the total U. S. rates were chosen as those to be extrapolated for ten years hence. Linear, logarithmic and reciprocal time series trends were calculated for each of the two areas of study.

In the calculations of the linear regression trend extrapolations, a zero value is reached during 1978 for Iowa. Because the linear regression trend for the total U. S. rate is much steeper, a zero value is reached in 1968. This seems untenable; therefore, other assumptions were used.

The equation of a straight line admits of no irreducible minimum. To avoid such an assumption a logarithmic curvilinear relationship was considered whereby an irreducible minimum was determined. The method of arriving at this value was by using one-half of the average traffic death rate for the last ten years recorded. The value for Iowa was 3.2. This rate value was then held constant for the calculation of a logarithmic trend for the full period under study. The irreducible minimum calculated by this method for the total U. S. gave a much higher figure, 4.1.

The prediction of traffic death rates should not exceed a period of more than 10 years for practical purposes. If at that time, or at an intervening year, unforseen events (such as a war or economic recession) cause drastic fluctuations, a recalculation should be made prior to the end of the original decade. It is possible that calculations on the basis of 5-year intervals would be more satisfactory, but that remains to be determined upon further evaluation and experimentation.

A reciprocal trend line was developed by the method of least squares for the same two groups. It was not necessary in this type of trend to assume any irreducible minimum, but it was necessary to use the reciprocal of some year as a basis of calculation. Therefore the rate for 1920 was arbitrarily used as the base. A decade of extrapolation was calculated by the two previous methods. Again it is possible that a shorter period of extrapolation may prove to be of greater value.

The use of one or more of these or similar techniques of evaluating traffic death rate trends might be used by enforcement agencies, transportation or insurance companies, and highway engineers in further appraising phases of their respective programs.

● TRAFFIC ACCIDENTS were responsible for 40 percent of all accident fatalities and 14 percent of all accident injuries in the U.S. during 1954 (3), and ranked first as the cause of death. An accident on the highway can generally be considered as an actual failure on the part of the road user, the vehicle, or the facilities concerned, in properly discharging their allotted functions in traffic movement (2). A study of the facts surrounding traffic accidents is of a vital concern to all those whose explicit purpose is reducing the resulting fatalities and injuries to a minimum. Only limited use has been made of the accumulated data on accidents to evaluate the various aspects of traffic control. The authors intend to suggest certain procedures whereby accident files may become more useful in this respect. Swanson (9) has made some explorations in this field.

Any safety program must be based on accurate reports and records that may be used for analysis in the prevention of traffic failures in the future. Such data if properly analyzed and used, would serve as a guide in a program of accident prevention for the many phases of traffic control improvement. No clear-cut methodology has so far been developed.

In the period of study ending in 1954, nearly 672,000 deaths and 23,500,000 nonfatal injuries have occurred in the nation as the result of motor vehicle accidents (4). Although the traffic death rates per 100 million vehicle miles of travel are decreasing, the absolute number of deaths and nonfatal injuries are on the increase, as is indicated from the number of licensed drivers, the number of vehicles registered, and the average annual mileage driven by individual drivers. These combine to give more vehicular miles being driven in greater traffic densities and at higher speeds.

During 1954, 36,000 fatalities and 1,250,000 nonfatal injuries with property damage of $1.6 billion were recorded for the U.S. Considering rates only, 1935 was the peak year for the two decades, with 15.9 fatalities per 100 million miles of vehicular travel. For the remaining period, deaths per unit of travel have been steadily decreasing, and a low traffic death rate of 6.4 fatalities per 100 million miles was reached in 1954. However, the absolute number of persons killed had reached a high of almost 40,000 with 1.4 million nonfatal injuries in 1941 (5). These data should be useful in evaluating the effectiveness of controls.

By determining trends, establishing the equations for best fitting curves, and extrapolating the curves, the expected number of fatalities can be predicted. If this method fails to show the expected results, a need for a change in the approach to the problem might be indicated.

Various factors should be taken into consideration. With a growing population and an increase in vehicle registration (as well as usage), trends can be better evaluated by comparison, when all factors are considered. The relationship of traffic deaths to vehicular miles during a given year seems to be the most widely accepted method of comparison. This acceptance is largely due to the greater validity of this index. The usage takes into consideration vehicle registrations and the mileage driven. Traffic density, population density, types of surfacing, enforcement policies, educational development, and other factors must be considered.

Trends and their extrapolations are based on deaths per 100 million vehicular miles of travel. However, the same techniques could be employed using the several other statistical data available.

Method of Procedure

The method used was that of collecting available accident and traffic data throughout the United States, organizing them into a systematic relationship, selecting the best fitting mathematical parameters and curves, and extrapolating these.

The trend curves were developed on traffic death rates for the 20-yr period 1935—1954. Extrapolations were made to the year 1970. The calendar year has been used in these calculations; thus, the study includes data from January 1, 1935, to December 31, 1954, with extrapolation to December 31, 1965. The rationale assumes a gradual evolutionary process of accident prevention development as well as the introduction of added hazards during the next 10 years.

Data on annual fatality rates per 100 million vehicle miles were obtained from several states, along with the U.S. rate, for the period. A great range in traffic death rates was found in various geographical areas.

Source of Data

The statistical data on the traffic death rate per 100 million miles vehicular travel were secured from the National Safety Council (6). The data as published listed individually the total number of traffic fatalities and the vehicular mileage traffic death rate for the U. S., for each state, and for the District of Columbia. A special study of data for Iowa in comparison with the U. S. only will be presented as an example of extension of the method to smaller geographical areas. The methods of trend extrapolations could be applied to any of the various states with the data presently available. Patrol districts or subdivisions of a state could be similarily studied to ascertain their relative standing and progress. Too often accident files are kept, and no practical use of the collected data is made.

TABLE 1

FATALITY TRENDS OF TYPICAL STATES

Year	Deaths per 100 Million Motor Vehicle Miles						
	U. S. Average	Conn.	Iowa	Mich.	Nevada	R. I.	Wash.
1935	15.9	14.1	11.5	16.7	26.0	6.6	17.7
1936	15.1	10.8	9.1	15.5	16.6	7.0	15.4
1937	14.7	9.7	9.5	15.9	13.9	7.0	12.5
1938	12.0	7.8	7.8	11.3	13.9	4.5	11.0
1939	11.3	7.6	8.1	11.2	14.5	3.8	9.9
1940	11.4	6.7	8.0	11.4	14.5	4.4	10.4
1941	12.0	7.5	8.2	12.5	16.9	4.6	12.0
1942	10.6	7.1	6.6	9.5	19.0	4.8	9.3
1943	11.5	8.0	6.4	9.4	16.0	5.9	9.8
1944	11.5	7.4	6.6	9.7	9.4	5.9	10.3
1945	11.3	7.1	6.5	9.7	15.0	6.6	12.6
1946	9.8	5.0	7.2	9.1	13.5	4.8	9.2
1947	8.8	4.4	7.3	8.2	11.9	4.8	7.6
1948	8.1	4.6	6.9	7.9	11.9	2.9	6.9
1949	7.5	3.4	6.4	7.2	9.8	3.0	5.8
1950	7.6	4.1	6.2	7.5	12.0	3.9	6.3
1951	7.5	4.0	6.2	7.2	12.1	3.0	6.3
1952	7.4	3.3	5.3	7.5	12.0	3.1	6.4
1953	7.1	3.7	5.8	7.5	10.6	2.9	5.2
1954	6.4	3.1	5.9	6.9	10.2	2.4	4.4

The purpose of this study is to suggest ways in which the extrapolation of such trends may be used to determine the effectiveness of any given program or programs designed to reduce traffic accidents. Sample best fitting trend curves are presented for the nation as a whole, and an index is suggested for use in evaluating trends of accidents in any state or geographical subdivision where data are available. The basic data are given in Table 1.

Analysis of Trends

The usual methods of trend analysis have been employed. Trend extrapolations have been determined by the method of least squares. The first attempt was made by assuming a linear trend. This leads to a fallacy of complete elimination of accidents about 1978. The assumption of a logarithmic curvilinear type of regression relationship was also tried since extrapolations were desired. From logical considerations, the trend cannot be less than some irreducible minimum. This was arbitrarily assumed to be ½ of the average death rate for the past 10 years. A reciprocal trend curve was calculated whereby it was unnecessary to assume such a minimum. The three types of time series trends were computed for the U. S. and Iowa.

Description of Trends in Fatality Rates

The fatality rates for Iowa, Connecticut, Rhode Island, Nevada, Washington and the

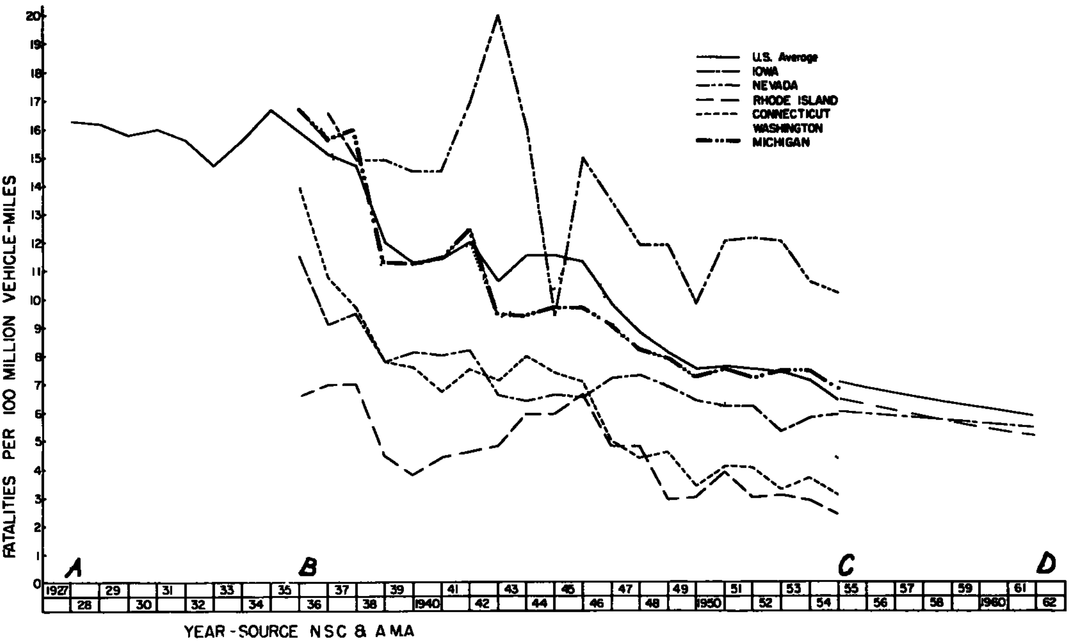


Figure 1. Deaths per 100 million motor-vehicle miles (compare with Table 2).

U. S. are given in Table 1, and Figure 1 was constructed from the data (7). Although the fatality rates per 100 million miles vehicular travel are included for the five states, trend analyses were computed only for Iowa and for the U. S. rates.

Linear trends. Any number of possible functions could be explored with respect to over-all trends in traffic death rates per 100 million miles vehicular travel. The first to be suggested is that any rate changes that take place constitute a linear function of time:

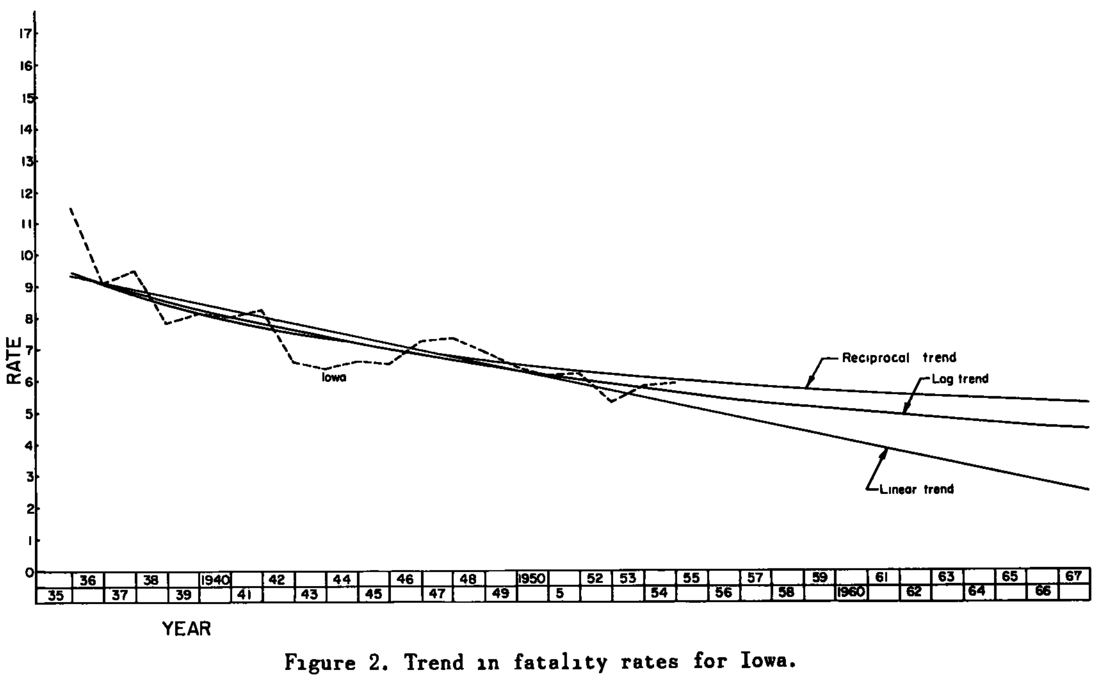


Figure 2. Trend in fatality rates for Iowa.

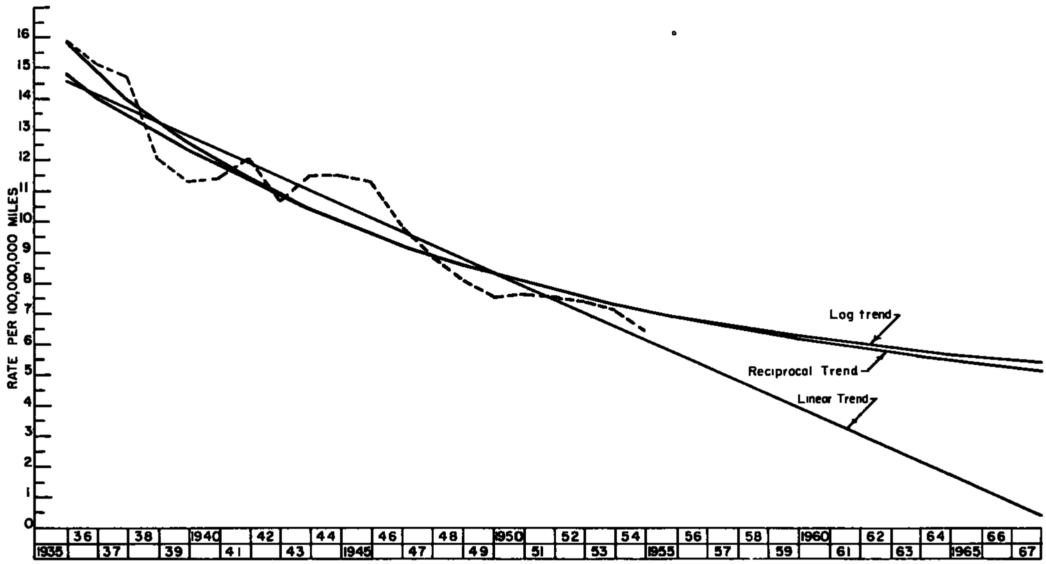


Figure 3. Trend in fatality rates for U.S.

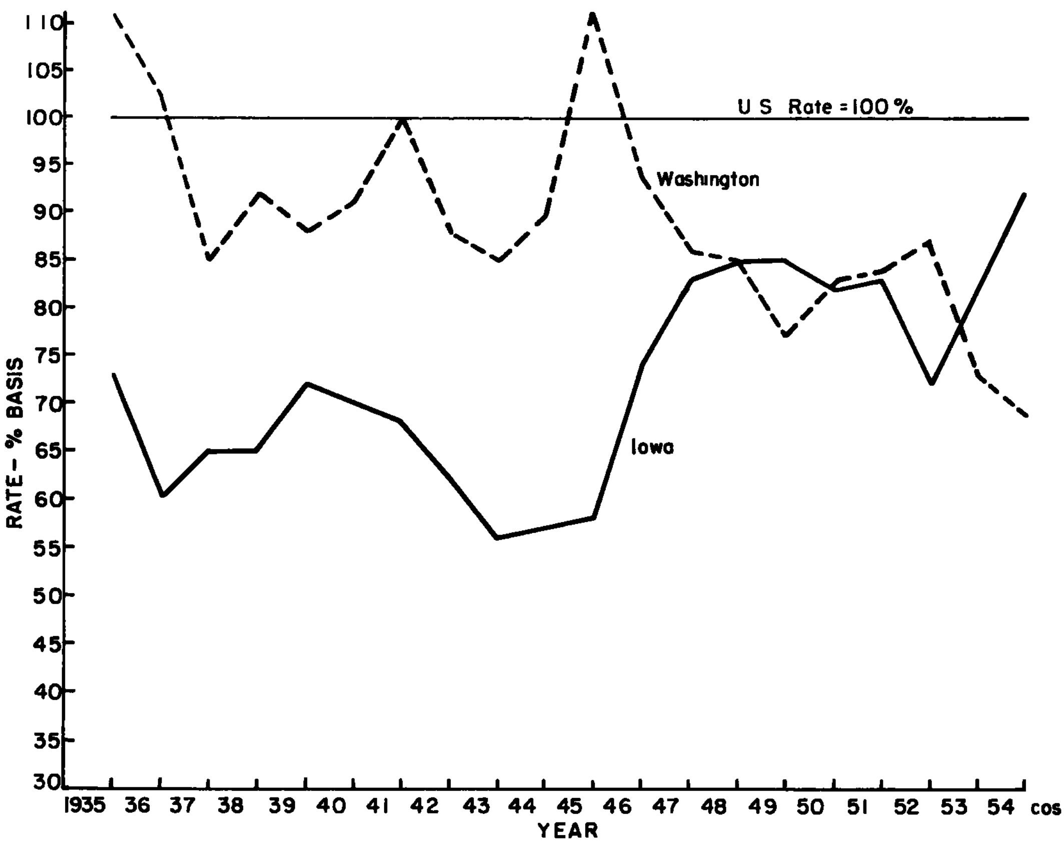


Figure 4. Fatality rates as a percentage of U.S. rate.

$$y = ax + k \qquad (1)$$

in which y = traffic death rate per 100 million vehicle miles travel;
x = twice the years removed from series middle 1944-45; and
a and k = constants.

A linear trend would reach zero about 1978 in Iowa and about 1968 for the U. S. From a rational point of view it was thought advisable to try some kind of curvilinear relationship which takes into consideration some irreducible minimum.

The determination of such an irreducible minimum must necessarily be somewhat arbitrary. For purposes of this study, one-half of the 10-yr average traffic death rate on a 100 million mile vehicular travel basis (1945-1954) was selected. For Iowa this value was 3.2 and for the U. S., 4.1. Thus, a trend equation asymtotic to 3.2 was used in computations concerned with Iowa:

$$\log (x - 3.2) = ax + k \qquad (2)$$

in which y = rate;
x = twice the years removed from series middle 1944-45; and
a and k = constants.

When the traffic death rate data for Iowa was substituted in the equations, values of a and k produced the logarithmic trend curves shown in Figures 2 and 3.

TABLE 2

ABSOLUTE NUMBER OF TRAFFIC DEATHS BASED ON EXTRAPOLATION TRENDS OF NUMBER OF VEHICLES, AVERAGE MILES PER VEHICLE, AND THE RECIPROCAL RATE

Year	No. of Vehicles (millions)	Av. Miles per Vehicle (thousands)	Reciprocal Trend Rate per 100 Million Vehicle Miles Travel	Absolute No. of Fatalities
1956	64	10	6.68	41,416
1957	66	10	6.49	42,834
1958	68	10	6.32	42,976
1959	70	10	6.16	43,120
1960	72	10	6.02	43,344
1961	74	10	5.89	43,438
1962	76	10	5.73	43,548
1963	78	10	5.61	43,758
1964	80	10	5.47	43,760
1965	82	10	5.37	43,870

Reciprocal trends. Reciprocal regression is a special form of the type of analysis indicated. If the exponent equals one, changes in y_1 are related reciprocally to changes in y_2. The normal equation by the reciprocal method of least squares has been selected:

$$y = \frac{a}{x} + k \qquad (3)$$

in which y_1 = year within the series;
y_2 = traffic death rate per 100 million miles vehicular travel;
x = twice the years removed from the series middle 1944-45; and
a and k = constants.

The resulting curves are shown in Figures 2 and 3. Table 2 has been prepared taking into consideration the number of vehicles and the average mileage estimated (1).

Other possibilities. Because each of these possibilities seems inadequate, the equation of a best-fitting curve might be used. The explorations made here are only suggestive of methods which could be used for evaluation of traffic control measures and policies.

By extrapolating the resultant curve for a 5- to 10-year period, a reasonable goal could be established against which to compare actual trends with a given speed law, enforcement policy, set of road conditions, or educational policy. For example, Michigan is just putting into effect a state-wide driver education program. The basic trend curve for Michigan is shown in Figure 1, with extrapolations from C to D. What might the fatality index be expected to be about five years hence? To single out systematic influences, as was done for Iowa and Washington, (Figure 4) for the next five years it should be possible to determine whether this program is substantially effective. Statistical methods are available for testing the significance of differences found at any given period of time. The same type of evaluation could be applied to sectional changes due to any type of treatment imposed and desired to be evaluated.

SUMMARY AND CONCLUSIONS

A method is proposed whereby accumulated accident data may be assembled to be of value in evaluating any set of conditions or program designed to reduce traffic accidents. The present paper is to be considered as exploratory in this field and many improvement and refinements will be made.

ACKNOWLEDGMENT

This study was made possible by a grant from the Allstate Insurance Company to Iowa State College for driving research.

References

1. Automobile Manufacturing Association. Automobile Facts and Figures. 1956, p. 36.
2. Matson, T. M., Smith, W. S. and Hurd, F. W. Traffic Engineering. New York, McGraw-Hill Book Co., 1955, p. 176.
3. National Safety Council. Accident Facts. Statistics and Research Div., N. S. C., Chicago, Ill., 1955, p. 3.
4. National Safety Council. Accident Facts. op. cit., p. 58.
5. National Safety Council. Accident Facts. op. cit., p. 58.
6. National Safety Council. Motor vehicle deaths and death rates from 1935 to 1954 for each state and the total U. S. op. cit.
7. National Safety Council. Motor vehicle deaths and death rates from 1935 to 1954 for each state and the total U. S. op. cit.
8. Swanson, C. O. Factors associated with traffic death rates (masters thesis), 1956, Iowa State College, p. 68.
9. Swanson, C. O. Consideration of motor vehicle traffic death rate trends in Iowa, Washington and the U. S. Proc. Iowa Academy of Science, 1956, 63, 600-604.

HRB:OR-92

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.