Driving Behavior and Related Problems

BRUCE D. GREENSHIELDS, Assistant Director, Transportation Institute, University of Michigan, Ann Arbor

This research report is based on the concept that differences in driving patterns may be determined by accurate measurements integrated over a route of sufficient length to reveal differences in driving behavior.

The measuring device used in collecting data, records: (a) driver actions, (b) vehicle motions and (c) traffic and/or highway events. All readings are in digits, and the device may be mounted in a car within a short time.

It was found that different classes of drivers tend to exhibit different driving patterns. Based on this fact, the paper points out related fields in which the "drivometer" may be used. These include driver training, traffic-stream flow, evaluation of highway design from the standpoint of driving, and the measurement of the "drivability" of vehicles.

•TWO RELATED studies of driving behavior have been conducted at the University of Michigan Transportation Institute during the past three years.[1] One study, devoted mainly to determining the relationship between driving behavior and accident experience, has been sponsored by the National Institutes of Health (Project AC-53). The other study, which made an operations analysis of the driving task, has been sponsored by the Ford Motor Company Fund. Fletcher N. Platt, manager of Ford's traffic safety and highway improvement, served as a consultant.

The research has been based on the hypothesis that different classes of drivers such as the accident prone and the accident free, the beginning driver, and the experienced driver exhibit different driving patterns which may be measured and related to the driving environment.

It was also hypothesized that differences in driving profiles may be determined only by accurate measurements integrated over a route of appreciable length such as 10 to 15 miles. The skill of the driver, like that of the golfer, is shown by his score for the entire course.

PREVIOUS WORK

Research related to the present study includes that of Lauer, Suhr and Allgaier, who performed research to develop a criterion for driving performance (1). They state that the ordinary road test has been found to have a low reliability as a criterion of driving performance.

In their investigation, each subject was given a simulated driving test in the laboratory under controlled conditions. The second test consisted of driving an instrumented car over an 8-mi standard route. A tachograph record was obtained for each subject while the trip was being made. The tachograph record included: trip time, model speed, maximum speed, and number of fluctuations. The driving performance was rated by means of the Roger-Lauer scale, which was reported to have a reliability of

---

Paper sponsored by Committee on Road-User Characteristics.

[1] A preliminary report on these studies "Driving Behavior and Traffic Accidents," Bruce D. Greenshields, was presented at the 1962 International Road Safety Congress, Salzburg, Austria, September 1962. The material herein reviews the previously published material and presents additional information.

the order of 0.90. They concluded that the better driver turns the wheel less, uses less gasoline, works the accelerator less, and is less severe on the brake than the poorer driver. The conclusions reached by Lauer, Suhr and Allgaier agree at least in part with the results of the present study.

Another study was made by Billion (2). The part of his study particularly significant to this project is that devoted to the observation and analysis of the behavior of drivers. A scale recording actions of the observed drivers was developed (2, Fig. 3). Drivers were followed and observed for 1 to 2 mi.

The present research is different in that the drivers were observed for a longer period and their actions were recorded mechanically.

In 1933, time-lapse pictures were used to measure vehicle speed and spacing. In 1954, the Yale Bureau of Highway Traffic measured traffic stream flow by means of a special recording speedometer that gave a continuous graphic chart of the varying speeds together with a time-and-distance record (3). From these data a "characterizing number" to describe the quality of traffic flow was derived, combining speed, change of speed, and number of changes of speed. It was evident that change of direction should be included, but, equipment then in use was inadequate.

Because it was possible to measure and characterize the flow of a traffic stream, it was deduced that it should be possible to measure and characterize the behavior of the individual driver. This deduction was supported by a study conducted by the University of Michigan Transportation Institute in 1957 (4) which found that there is a correlation between the way traffic moves and the frequency of traffic accidents in the stream, and that it is possible to pace a driver and closely imitate his driving profile.

The theories and findings of Platt (5) provided an important background for the present research. Platt developed a method of relating traffic situations to the major parameters that occur to a driver and his vehicle. He related in sequence highway and traffic events—driver observations, decisions, actions, errors—near collisions, injuries and fatalities.

These traffic situations were classified and defined in detail, and empirical formulas and equations were developed for estimating the number and kind of situations that might occur to a single driver under particular conditions. This development was followed by a discussion of operations analysis and the scientific method. Fundamental goals and research needs were discussed.

PRELIMINARY INVESTIGATION

The initial part of this investigation demonstrated that the measurement of traffic stream flow and the determination of driving patterns of the individual driver are distinctly different problems.

In the first part of the National Institutes of Health study, it was decided that it should be possible to select drivers at random, pace them over the selected section of roadway, obtain their accident experiences, and then compare their driving performances with accident experiences and determine the relation, if any, between accidents and driving behavior.

The driving-behavior patterns of more than 950 drivers were observed over the selected route of about 5½ mi in length. The behavior indices, based on speed change and direction change, ranged from 0.5 to 20.

Serious defects were found in that procedure, and it was abandoned. Too many drivers failed to remain on the selected route, even though it was chosen because of its few turnoffs. Also, it was found that there are apparently so few high-accident drivers in the average traffic stream, that thousands of observations would have to be taken to obtain a sufficiently large sample of "poor" drivers. Furthermore, the route did not have a large variety of highway and traffic conditions. It did have a high accident record. Trial runs over a more varied and partly urban route yielded driving indices varying from 0.5 to over 900. In addition, the "following car" method cannot be as exact as having the subject-driver in a car equipped with the "drivometer."

The selection of a new route with more and varying amounts of traffic meant that the recording apparatus should include means of recording the changing traffic conditions. It could no longer be assumed that all drivers observed would be traveling in essentially the same traffic environment.

DESCRIPTION AND USE OF EQUIPMENT

In 1960, the Ford sponsored study was initiated. This study was an opportunity to test Platt's theories. The measuring equipment which evolved from past experience, furnishes digital recordings integrated over any selected time or distance. The basic design for recording a series of like events consists of enumerating the events on an electric counter and then taking a picture of the accumulated count at desired intervals. Total counts for a trip may be read directly. For example, an electric counter in circuit with the brake-light switch will be actuated every time the brake is applied.

A photocell actuating a switch records speed change numerically, rather than graphically. A speedometer dial with alternate transparent and opaque divisions is arranged to pass between a light source and a photocell. As the dial moves in either direction with change in speed, the counter is actuated every time the light ray is interrupted. Thus, the count shows the total speed change.

This system (adding counters and actuators) may be extended to any number of events. The drivometer and traffic events recorder used in the investigation records driver actions, vehicle motions, and traffic and/or highway events.

The driver actions recorded include: (a) number of reversals of the steering wheel, (b) number of times the accelerator is depressed and (c) the number of times the brake is applied. The accumulated amount of steering wheel turning is also shown.

The recorded vehicle motions are change of speed and change of direction. Both are recorded by means of a gyrocompass with a photocell relay that records accumulated direction change.

Traffic events are recorded by a group of counters wired to a panel of switches on a small board held in the hand. The switches are coded for various traffic events. (They may be recoded and used to record highway events.)

Events are recorded by an observer sitting in the front seat and operating the keyboard by pushing the proper switches on and off as the traffic situations change. The switches are coded largely by their positions. A symbol near the center of the keyboard indicates the position of the test car. The F switch above this symbol represents a vehicle in front of the test car. When the observer sees a vehicle ahead, he pushes this switch on and leaves it there until the vehicle is no longer in front. When any switch is on the connected counter, operated through a timer, is recording time in seconds. If there are two cars ahead, another switch (C) is pushed on. Switches A to N are coded for other traffic situations, such as "car passing on right," and "parking on right."

The number of switches in the "on" position shows the observer's estimate of the number of events in the visual field at any instant.

A 16-mm recording camera is focused on the counters which are mounted on a dis-

Figure 1. Test car with drivometer mounted on rear seat.

play panel. The camera is set to take a picture every $\frac{1}{10}$ mi, at a definite time interval such as 1 sec or 1 min, or if desired, by manually closing a switch. The panel includes a watch and counter to record time in seconds. Another counter, operating only when the car is moving, records the running time.

Figures 1 and 2 show the drivometer and traffic events recorder. In the present arrangement, the drivometer contains only the camera, timer and counters. The auxiliary speedometer is mounted under the cowl and the gyrocompass under the hood.

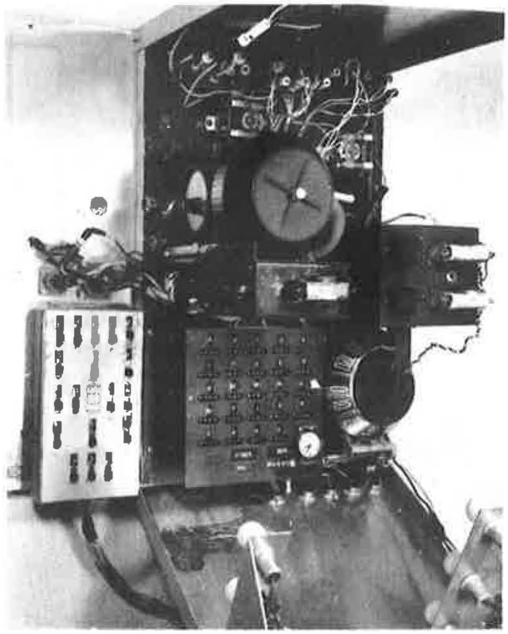

Figure 2. Drivometer with cover removed; recording camera (not shown) attaches to cover.

PHOTOGRAPHIC METHOD OF RECORDING EVENTS

The use of a camera to record events was indicated by experience with time-lapse pictures that furnish a record which may be examined in detail and at leisure. But transcribing data from the pictures is time-consuming, and for this reason, the observer-keyboard method was devised. It remained to be demonstrated, however, that the keyboard method would give as complete and accurate results.

The camera is mounted back of the rear seat to give both front and back views by means of a mirror mounted on the back of the front seat (Figs. 3 and 4).

If the pictures are taken at sufficiently short intervals of time, a continuous average space or perceptual density (number) of events is obtained, regardless of the speed at which the vehicle is moving. Statistical sampling methods have been used to determine the proper interval between pictures. A 2-sec interval has been found to be a short enough time.

The results obtained from scanning the pictures, and those obtained by the events tabulator have been found to be practically equal. In 18 test runs involving the scanning of over 15,000 pictures, the average densities obtained from pictures differed from the densities obtained by the observer tabulation by 0.004. Table 1 compares the camera and observer results.

Using the t-test ($t = 0.177$) and the F-test ($F = 0.16$) it was found that there are no grounds to reject the hypothesis that the observer method is as good as the picture method. Because transcribing the data from pictures is very time consuming, the observer-recorder method is deemed the better. The digital recording of motions or events makes the data immediately ready for statistical analysis; it would be possible to feed the data directly into an electronic computer.

A camera may be used for cataloging fixed highway events such as signs, intersections, and curbs. The camera is mounted to take pictures through the windshield at 0.01-mi intervals. Figure 5 shows a sequence of four such pictures. They are on 35-mm film with approximately 1,600 frames per 100-ft roll.

CLASSIFICATION OF HIGHWAY EVENTS

In the tabulation of the traffic and highway events, it was recognized that it would be impossible to record everything that the driver sees. Several schemes of classification or selection of events were considered.

All events may be divided into two classes: those related to the driving task, and those unrelated. An unrelated event is defined as one that has no potential for requiring

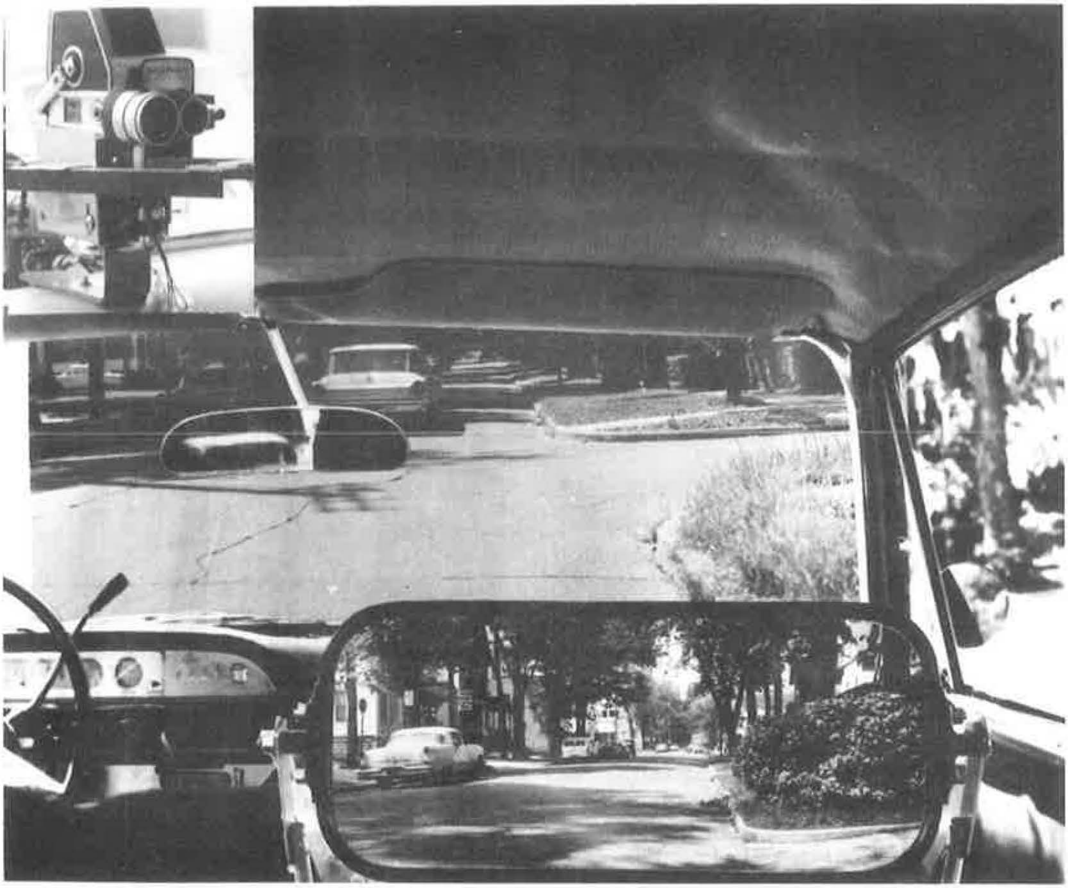

Figure 3. Front and rear view of street; insert shows camera mounting.

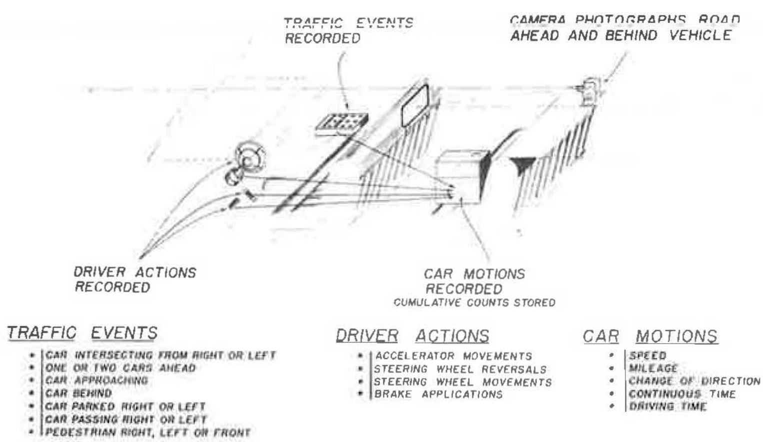

Figure 4. Arrangement of drivometer and traffic events recorder and front and rear view camera.

TABLE 1

PICTURE AND OBSERVER RESULTS[1]

Recording	Avg. No. of Events	Standard Deviation
Camera	$X_C = 0.203$	$\sigma_C = \pm\ 0.240$
Observer	$X_O = 0.199$	$\sigma_O = \pm\ 0.213$

[1] Difference of means: $X_C - X_O = 0.004$.

the driver to change the motions of his car. An airplane in the sky may distract the driver, but there is no possibility that he will swerve to avoid it. A moving vehicle or an obstacle close to the roadway can cause the driver to change the speed or direction of his car.

No attempt was made to classify events as hazardous or non-hazardous. An event not directly related to the driving task may distract the driver and cause an accident. Sometimes, the lack of events can be dangerous by blunting the driver's alertness through monotony.

All traffic and highway events, whether related or unrelated to the driving task, fall into two general classifications: fixed and variable. The fixed events include all stationary features such as curbs, signs, stop lights, trees and buildings. The variable events include all vehicles and pedestrians whether moving, standing, or parked. A parked car may suddenly become a moving car. All events, both fixed and variable, are dynamic with respect to a driver in a moving vehicle. In the one case, the relative velocity depends on the speed of both vehicles; in the other case, the relative velocity is only that of the driver's vehicle.

In the enumeration of events, it is reasoned that the driver pays more attention to objects near him than those farther away. A vehicle directly in front is noted along with a second; but more than that may simply be observed as a string of vehicles. One or several cars parked on the right or left side of the street are perceived simply as parked cars. Perhaps one or several pedestrians in the same area have the same observed effect.

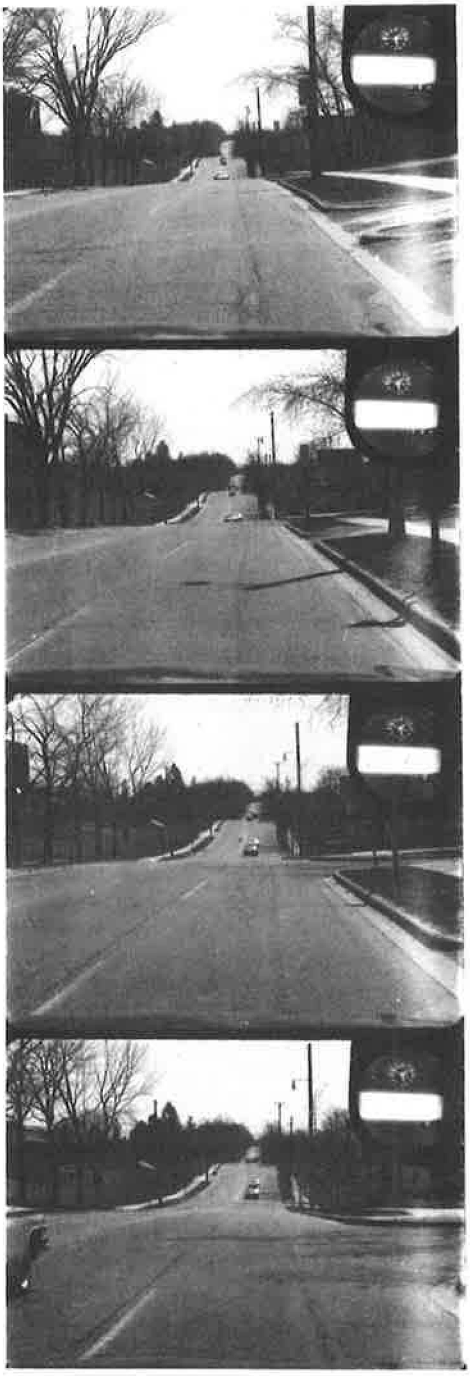

Figure 5. Sequence of pictures for tabulating highway events.

It is thought that the overall effect of like environmental areas (such as residential or shopping) is somewhat the same. The main difference would be in such things as number of intersections, driveways, traffic islands and highway signs.

It is deemed impossible to obtain an absolute measure of the density of events. All that can be obtained is a relative measure of density--perhaps, that is all that is necessary.

RELATING EVENTS TO TIME

In determining the significance of the density of events, they must be related to time, for the driver's ability to respond to events is limited by this factor.

The amount of time a driver has to respond to changing traffic and highway situations clearly depends on the space density of events and the speed at which he is traveling. The greater the density and the higher the speed, the less time the driver has to respond. That this fact is universally recognized is evidenced by speed laws which require the driver to reduce his speed in urban areas.

An events density index expressing this relationship could equal the product of speed and the density of events. The principal objection to this index is that it does not take into account the changing extent of the perceptual field.

A measurement of the extent of this field is that of the distance from the driver to the point on which he focuses his attention as his speed increases. One reference (6) states that the average distance of the focal point increases in a straight-line relationship with the speed, being about 500 ft at 20 mph and 1,800 ft at 60 mph. In time, these distances amount to about 17 sec and 20 sec.

A simple method of estimating the focal depth or length of perceptual field while riding is to note the point ahead on which the eyes are focused and then measure the distance to that point by reading the odometer. An odometer reading to 0.01 mi is needed. An observer reads the odometer and speedometer and records them. Several trips over a route should give a close estimate of the average depth of focus. A trial series of runs gave results similar to those obtained by Hamilton and Thurstone: 510 ft at 20 mph and 1,600 ft at 60 mph.

From these results and the experience of driving on congested city streets, it may be judged that the time-distance at which events begin to influence the driver may vary from 20 sec or more on the open highway to as little as 2 or 3 sec on a busy street.

TRAFFIC DENSITY INDEX

Having determined the extent of the perceptual field, the density index may be expressed as

$$E = \frac{N \times S}{L} \tag{1}$$

in which

E = events index;
N = perceptual density or number of events in visual field;
S = speed; and
L = length of perceptual field.

The dimensions in this equation show that the index is equal to the number of events per unit time.

Because the speed S = L/T, Eq. 1 becomes

$$E = \frac{N}{L} \times \frac{L}{T} = \frac{N}{T} \tag{2}$$

This shows simply that the amount of time that a driver has to respond to events increases with travel time and decreases with number of events, and that the events index may be expressed as E = N/T, wherein T is equal to the running time. It is assumed that the driver is making no positive response to his environment when the vehicle is not moving. The depth of perceptual field which varies directly with speed has disappeared from the equation.

In comparing the driving behavior of different drivers over the same route only, the traffic events have to be taken into account for the highway events remain constant.

The density of events was not used in the analysis, but to obtain information about the effect of traffic conditions on driver actions a small group of drivers drove the test route under different traffic densities. Figure 6 shows one of the relationships between events and driver actions. For this relationship

$$X = 6.34 + 1.26 \, (TC) \tag{3}$$

in which

X = average number of steering wheel reversals per minute; and
TC = average number of traffic events in perceptual field at any instant.

For example, at an average traffic density of 3 events the average number of steering wheel reversals per minute is equal to 10.1 (Fig. 6). The number of steering wheel reversals should be adjusted if traffic conditions vary appreciably. Thus, a driver experiencing a traffic density of 3.0, in comparison with a driver experiencing a count of 1.0, would be expected to make 2.5 (10.1 - 7.6) or more reversals per min due to traffic conditions.

SELECTION OF TEST ROUTE AND DRIVERS

The test route was to have a fairly wide range of traffic and roadway conditions. It was also to be of sufficient length to reveal differences in driving behavior. The driver is not to be judged by the individual mistakes he made, but by his overall score or driving pattern.

The 15-mi route selected for the project consisted of approximately 4.9 mi of downtown streets, 4.0 mi of residential, 2.9 mi of 4-lane divided expressway and 3.2 mi of 2-lane rural road (Figs. 7, 8, 9 and 10).

The data were recorded so that the behavior patterns on different sections of the route could be analyzed separately.

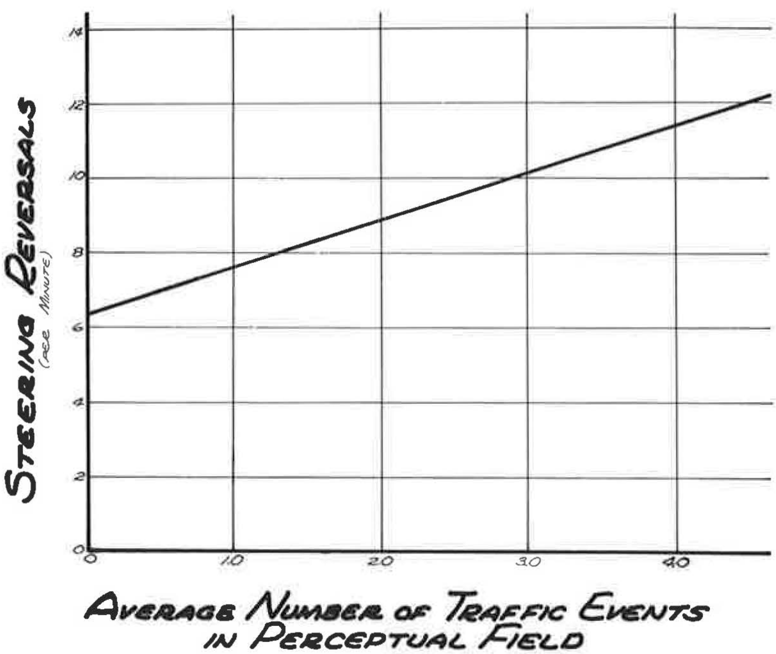

Figure 6. Relationship of steering wheel reversals to traffic events.

Figure 7. Downtown.

Figure 8. Residential.

Figure 9. Expressway.

Figure 10. Rural.

Selection of Test Drivers

The selection of test drivers proved a more difficult task than the selection of the test route. Because a major purpose of the project was to compare the driving behavior of the safe with the unsafe driver, a main task was to find drivers in these two categories.

The unsafe driver, it seemed, would be among those with a high number of traffic violations. With the cooperation of the Michigan Secretary of State's office, drivers on the point of having their licenses revoked because of too many violations were tested. But the accident records of these high violators were discovered to be no higher than the average driver. Some had experienced no accidents. Of course there was interest in the high violators for they are among the problem drivers, and hence they were included in the study.

It also appeared that the high-accident driver would be among those on the point of having their insurance policies canceled. Insurance companies, of course, do not make these names public, but with assurance that the names would not be revealed in any way, they willingly cooperated.

Inasmuch as the overall objective of the studies was to determine whether drivers in several categories have characteristic driving patterns, other groups, such as beginning drivers, were selected for study. They were obtained through driver education teachers.

Collection of Data

In collecting data the usual experimental precautions were taken. For example, the drivers in each group were selected in random order and not informed as to why they were selected beyond telling them the purpose of the investigation was to study drivers of various driving experiences and ages, and that there was no interest in their driving experiences except as data for the experiment.

At the beginning of the test each driver filled out a questionnaire giving miles driven, age, type of car driven, accident experiences and other information. The accident experiences reported were checked against State and insurance records.

All driver tests were made in good weather under practically equal traffic conditions. The same vehicle, an automatic shift 1960 Ford, was used throughout the tests. The sensitivity of the measurements was kept constant even though it became apparent during the study that greater sensitivity would be more meaningful.

ANALYSIS OF DATA

The data were first transferred to IBM cards. Many of the 53 variables recorded have not been used in the analysis because they are believed to be unnecessary for the main purpose of the research. Such items included kind of car normally driven, observers evaluation of driver, number of accidents experienced during past year, and answers to questions such as "Did the equipment disturb you?" and "Were you nervous?".

Another variable that has not been taken into account is the effect of the density of traffic events. As mentioned, the tests were made under essentially the same traffic conditions.

The first data to be analyzed were those taken in connection with the Ford Fund project to obtain some indication of the reliability of the measuring equipment. The data proved to be more meager than anticipated. This was due mostly to failures of the recording device. It is still not known how to completely eliminate the equipment failures, although the equipment has been improved.

The analyses of the data (Tables 2 and 3) gave encouraging results; the analysis of additional data is shown in Table 4.

Table 2 gives a comparison of the driving behavior of driver trainers and high-accident drivers. The speed change as read from the dial is equal approximately to one-fourth of the actual change. Thus the reading of 635, represents actual speed change of 2, 540.0 mph.

Based on averages, the high-accident groups have higher counts than the driver trainers on all eight variables. In general, the driver trainers travel slightly faster and make fewer motions than the high-accident group. The driver trainers seem to be more efficient.

The t values and corresponding P values, however, show that singly with the exception of accelerator actions, the variables for the two groups are not significantly different.

Table 3 gives six categories of drivers: (1) high school drivers who have completed a driver training course (HS); (2) driver education teachers (DT); (3) professional drivers such as truck drivers, highway patrolmen, and taxi drivers (PD); (4) high-violation drivers (HV); (5) high-accident drivers (HA); and (6) average drivers (AD). The samples are small and only indicate trends, without statistical verification. Apparently, the two most similar groups in behavior are the high school or beginning drivers and the high-accident drivers.

TABLE 2

COMPARISON OF DRIVER TRAINERS WITH HIGH-ACCIDENT DRIVERS

Classification	Driver Trainers	High-Accident Drivers	t Values	P Values
Number of tests	17	14		
Test run mileage	12.4	12.4		
Total time (min)	24.1	28.1	0.984	0.40 - 0.30
Running time (min)	20.6	24.1	1.27	0.30 - 0.20
Stopped time (min)	3.5	4.0	0.26	0.90 - 0.80
Accelerator actions	138.0	262.0	2.46	0.02 - 0.01
Steering reversals	200.0	384.0	1.53	0.20 - 0.10
Brake applications	39.0	61.0	1.28	0.30 - 0.20
Speed change (mph)	635.0	1,010.0	1.01	0.40 - 0.30
Direction change (dial readings, 0.1 rad.)	171.0	213.0	1.30	0.30 - 0.20

TABLE 3

DRIVER BEHAVIOR PATTERNS

Classification	HS	DT	PD	HV	HA	AD	Avg.
No. of tests	6	17	23	9	14	53	-
Length of run	12.36	12.36	12.36	12.36	12.36	12.36	12.36
Total time	26.30	24.10	26.50	25.00	28.10	25.70	25.50
Running time	23.60	20.60	22.10	23.10	24.10	21.20	21.50
Stopped time	2.70	3.50	4.40	3.50	4.00	4.50	4.00
Acc. actions	240	138	178	132	262	158	160
Steering reversals	322	200	226	250	384	242	248
Brake applications	51	39	39	36	61	38	41
Speed change (mph)	837	635	815	785	1,010	759	762
Dir. change (rad.)	171	217	222	244	213	234	217
Tot. driv. act.	613	377	443	418	707	438	449

TABLE 4

HIGH ACCIDENT VS CONTROL GROUP[1]

Classification	HA	CG	DFC
Number of tests	50	31	10^{-5}
Running time (sec)	1,670	1,540	1.720
Stopped time (sec)	226	229	0.446
Accelerator reversals	118	88	17.473
Steering reversals	134	117	3.221
Speed change (mph)	724	926	3.174
Direction change	394	351	3.663
Brake applications	51	37	36.141
Turning of steering wheel	824	675	2.944
Mean rating	+ 0.0878	+ 0.0634	
Variance	+ 0.00036	+ 0.00022	
Standard deviation	± 0.0190	± 0.0148	

[1]F = 4.20.

The high-violation drivers in general are very similar to average drivers, but they are more agressive as indicated by their comparatively small amount of stopped time, especially in unknown areas. In total actions they are more efficient than either the high school or the high accident groups.

The sensitivity of the measures in detecting the effect of distractions or other influences on driving are, in order: (a) the steering wheel reversals, (b) the speed change, and (c) the accelerator actions. The most sensitive measure has been found to be the steering wheel actions, provided the measurements are precise. For best results, all turnings of about $^3/_8$ in. or larger (measured at rim of steering wheel) should be counted. In contrast, the sensitivity of the recordings given in Table 3 are of about $1\frac{1}{2}$ in. or larger.

As has been indicated, judged by the differences in the means of the sample population characteristics, drivers generally regarded as good are not significantly different in behavior from those regarded as inferior. However, the question of whether the differences in the means of the separate parameters is significant or not is not really vital to the goal sought. The decisive question is whether some function of a set of characteristics can be found that will discriminate between drivers of different classes.

Multivariate Analysis

The task of extending tests of significance from single population characteristics (such as accelerator actions) to sets of population characteristics is generally referred to as multivariate analysis. The particular multivariate analysis method employed, discriminatory analysis, was suggested by Leo Razgunas, and confirmed as a correct one by Frank Westervelt.

To indicate the purpose of the method, Bennett and Franklin (7) have written:

> The problem which we shall consider is: Suppose that we have n_1 individuals known to be from one population and n_2 individuals known to be from another population. For each of the n_1 and n_2 individuals we observe a number of characteristics x_1, x_2, ... x_k. Then what linear combination of these k characteristics ($X = a_1 x_1 + a_2 x_2 + \ldots + a_k x_k$) will be best in assigning an unknown individual to one of the two populations; i.e., what single derived value X will in some sense best reflect the difference between the two populations? We shall assume that for each population the k characteristics have a multivariate normal distribution, with different means, but common variances and co-variances. X is commonly called a discriminant function.

Using the discriminant analysis method (Computer Program Bimed. No. 005 UCLA), Table 4 compares 50 high-accident drivers (HA) with 31 good drivers or control groups (CG). The good drivers were driver trainers and professional drivers with good accident records. The last column shows the discriminant function coefficients (DFC).

The mean rating for the 50 HA drivers obtained by multiplying the variable for each individual driver by the corresponding DFC values is equal to + 0.0878; that for the CG drivers is equal to + 0.0634. From the F value of 4.2, the two samples are different at a significance level of less than 0.5 percent.

If the X values are arranged in order of rank, the range is from 0.1426 to 0.0360. Forty-one of the HA group fall within a range of 0.1426 to 0.0719, while 25 of the good-driver group fall within the range 0.0716 to 0.0360. Thus, of the 50 expected to fall within the range of 0.1426 to 0.0719, 9 fall without and of the 31 that should fall within the range 0.0716 to 0.0360, 6 fall without. A general comparison of these two groups of drivers as to age, sex, driving experience, and accident experience, is given in Table 5.

The discriminate function gives the best possible separation between the two groups that can be achieved ignoring sampling errors that may exist. If two additional independent groups are taken, this discriminate function cannot be expected to separate them as well.

TABLE 5

GENERAL COMPARISON OF TWO GROUPS OF DRIVERS

Group	Age		% Male	Driving Exper. (yr)	Mi. Driven Last Year	Total Accidents	Last 5 Years
	Avg.	Range					
Low accident	29.2	20-58	74	12.4	17,700	1.04	0.46
High accident	35.8	16-79	76	18.5	15,200	4.2	2.6

TABLE 6

ADDITIONAL GROUP OF DRIVERS

Group	Age		% Male	Driving Exper. (yr)	Mi. Driven Last Year	Total Acci-dents	Last 5 Years
	Avg.	Range					
High accident	42.6	23-76	81	18.2	13,750	3.25	2.19

As a partial check on the validity of the discriminant function in detecting the high-accident driver, it was applied to 17 new subjects listed in the high-accident category. It should be noted that there is no accurate way of preselecting drivers as being "accident prone" or not, due to the high incidence of chance. Drivers can be "lucky" or "unlucky." The general characteristics of this group of drivers are given in Table 6.

The X values ranged from 0.12072 to 0.04564. Of the 17 drivers, four fell into the low-accident group. The fact that 14 of the 17 drivers tested fell into the preselected grouping gives some indication of the reliability obtained. But it must be kept in mind that the groups tested were small and the preselections could have been inaccurate. All that is indicated at present is that it should be possible to develop a more reliable road test than is now available. Many more tests must be made before the true reliability of the test will be known.

A comparison of beginning drivers (or high school drivers) and control group drivers is given in Table 7. A statistical comparison of the two groups shows that of the 46 individuals that should fall in the first group, as arranged in rank according to X values, four fall into the control group. Of the 31 that should fall in group two, 7 fall into group one.

Table 8 gives a general comparison of these two groups. Using an independent group of 15 drivers to test the ability of the test to differentiate between beginning drivers and the control group, the X ratings for the HS group range from 0.17054 to 0.32749 and that 7 of the 15 fall into the control group, instead of in the HS group where they should fall.

At present, due to the small size of the sample, it is not known whether the actual discriminatory value of the test is greater or less than just indicated. It is largely for this reason that further research on the testing of drivers with the aid of the drivometer is being undertaken. More rigid controls will be exercised in conducting the new tests.

The fact that there is evidence that drivers in different categories of driving experience have different driving patterns, indicates that the potential uses of the equipment and technique evolved are broader than those covered in this present study.

TABLE 7

HIGH SCHOOL VS CONTROL GROUP[1]

Classification	HS	CG	DFC
Number of tests	46	31	10^{-5}
Running time (sec)	1,726	1,540	10.974
Stopped time (sec)	254	227	5.804
Accelerator reversals	98	88	9.274
Steering reversals	180	117	23.735
Speed change (mph)	952	926	0.899
Direction change	333	351	14.586
Brake applications	52	37	156.339
Turning of steering wheel	872	675	54.834
Mean rating	+0.2807	+0.2106	
Variance	+0.00118	+0.00056	
Standard deviation	±0.03437	±0.02373	

[1]F = 11.03; level of significance less than 0.5%.

TABLE 8

GENERAL COMPARISON OF HIGH SCHOOL AND CONTROL GROUPS OF DRIVERS

Group	Age		% Male	Driving Exper. (yr)	Mi. Driven Last Year	Total Acci- dents	Last 5 Years
	Avg.	Range					
Low acci- dent	29.2	20-58	74	12.4 yr.	17,700	1.04	0.46
High school	16.1	15-18	42	3½ mo.			

POTENTIAL USE OF EQUIPMENT AND TECHNIQUES

Finding that the driving habits of beginning drivers differ from those of more experienced drivers suggests the use of the behavior-measuring equipment in driver training.

In driver training, it is judged that recording traffic events will not be necessary provided the test runs are made under similar traffic and weather conditions.

With this in mind, a driver training unit that is much simpler than the complete drivometer has been constructed. The present model furnishes a visual digital recording of (1) change of speed, (2) number of reversals of the steering wheel, (3) number of times accelerator is depressed, (4) number of brake applications, (5) total time for run, and (6) running time. The readings are shown on ten counters. The recording box with ten counters fits into the glove compartment (Fig. 11).

In addition to the total counts for the trip, the number of steering wheel reversals and the amount of speed change at 1-min or ½-min intervals are shown. This minute-by-minute integration indicates the smoothness of the driving performance.

Albert Gallup, Supervisor of Driver Education in the Ann Arbor High School, had an opportunity to use the drivometer for a short time last summer in making some field studies on driving students and teachers.

Gallup gives part of his findings in the following words:

> From the teacher's point of view the device demonstrated its value by providing a tool to support subjective judgments; by giving immediate evidence of a student's relative progress; by showing when a student had been put in a situation that he could not handle; by indicating when the student reached a point of stress where he was not accepting instruction normally.

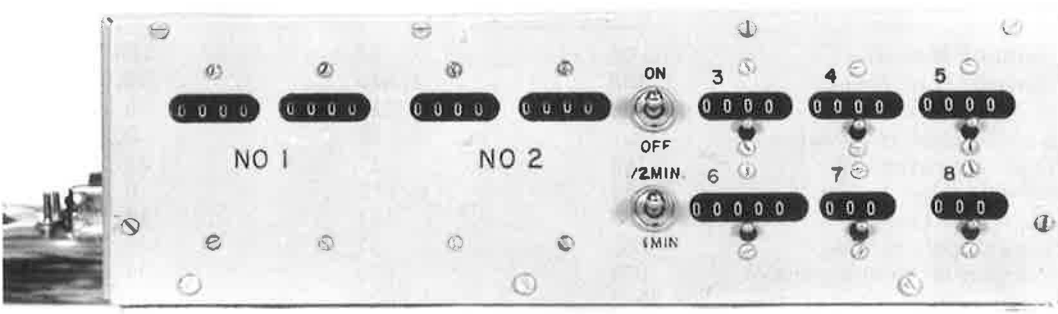

Figure 11. Driver training unit.

> The Drivometer was available for my exclusive use for only a limited period. There is much more to be learned about the device as a teaching aid. But I no longer have doubts now about the potential value of this device as a teaching aid. I have gone back to teaching in my regular dual control car, without the instrument installed, and I keep catching myself wishing that my electronic friend was back to help the student and me to do a better job.

A Driving Simulator

The fact that the drivometer furnishes an integrated measure of driving performance over a course of any desired length suggests a new approach to the driving simulation problem. The problem of driving simulation is simplified if limited to the task of simulating driver actions rather than reproducing driving environment. The simulation of driver environment to the point of seeming reality is very difficult and costly.

Construction of a device which would cause the driver to go through the same sequence of driving operations he would cover in driving over a highway should be much less difficult than simulating the highway environment. The idea of simple driving simulators goes back over thirty years. Several such devices have been developed and are in use.

One may ask why it is necessary to develop a new one if simplified simulators are already available. The answer lies in the manner in which the driving simulator is to be used. It would be used to furnish a sequence of stimuli to obtain a desired driving profile rather than single responses.

Suppose one wishes to make a laboratory check of the driving performance of a beginning driver against the performance of a skilled driver. First, the driving pattern of the skilled driver would be measured and recorded over a selected section of highway. The next step would be to obtain the same patterns in the laboratory by varying the stimuli until the field pattern was obtained.

Responding to the same stimuli, the beginning driver's record would be compared with that of the skilled driver. The drivometer furnishes an integrated record in numbers; the driving simulator would obviously be designed to furnish a similar record. Using this procedure, a file of driver training stimuli and response records could be built up.

The discovery that is is not necessary to have absolute duplication of highway events in studying the differences in individual driving patterns and that even minor physical or emotional disturbances cause measurable variations in driver actions, leads to the conclusion that most, if not all, driving behavior tests may be performed as well on the road as in a simulator. For safety in conducting such tests as the effect of fatigue or alcohol, a dual control vehicle should be used, and the observer should be alert.

The sensitivity of the steering wheel movements is shown in Figure 12 by means of the variation in the number of reversals of the steering wheel per 50-sec interval in a drive from Dearborn to Ann Arbor.

During the past year, experiments have been made with a safety warning device actuated by movements of the steering wheel. Having determined the driver's norm of movements per unit of time, a dial is set for both a high and a low level of actions. Whenever the actions reach a critical level, a buzzer warns the driver.

Evaluating Traffic Stream Flow

The sum of the skills of the drivers in a traffic stream largely determines the safety and efficiency of the stream flow. The other major factor affecting stream flow is the highway environment. Despite high speeds, the limited-access expressway is about three times safer per mile of travel than the average road.

The quality of traffic transmission is a fundamental factor in transportation (3). A successful method of evaluating traffic stream flow should make it possible to detect flows that are potentially dangerous.

Limited experience in measuring the quality of stream flow by an instrumented vehicle moving with the stream indicates that it is far easier to measure the significant differences between two streams of traffic than between the performances of two drivers. Further experiments in measuring and evaluating traffic stream flow are now being conducted.

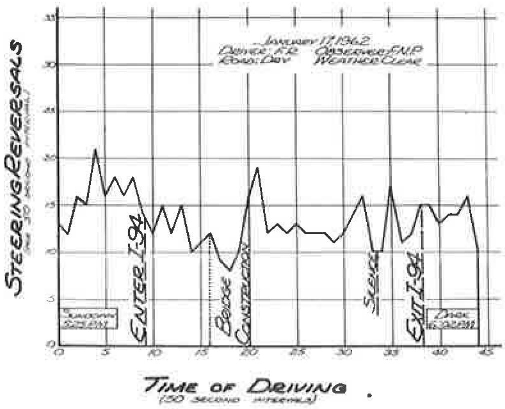

Figure 12. Steering reversals vs time.

Effect of Highway Design and Control Devices on Traffic Flow

Along with a study of the way traffic flows, there should be a study of the highway features and traffic-control devices that cause a traffic stream to flow smoothly and safely, or erratically and dangerously. In other words, both cause and effect should be studied.

The highway features that determine "drivability" are appearance, geometry, and surface condition. A highway characteristics recorder has been designed to operate in a station wagon driven at 35-45 mph. Using 35-mm film, it will record the surface condition, the geometry of the road, and provide pictures of the roadway at 50-ft intervals.

From experiments to date, it is apparent that more can be learned about the interrelationships of the quality of traffic stream flow, the characteristics of the highway, and the frequency of traffic accidents. When knowledge is increased, safer and more efficient highways can be built.

Vehicle Design and Driving Performance

Along with better highways, perhaps it is possible to build safer vehicles. It is logical to suspect that the types of driving controls, such as standard and power, along with other features of the vehicle have a lot to do with driving behavior. Does the stick control enable the skilled driver to give a better, safer performance? Is ease of handling important? The drivometer should make it possible to test the drivability of the vehicle as well as the skill of the driver.

SIGNIFICANCE OF RESULTS

The methods and techniques described are being improved through further research. It is believed they could have broad significance in improving the safety and efficiency of highway transportation. They should lead to a better understanding of the driving task and its relation to the traffic and highway environments, furnish information on the effect of different kinds of vehicles and vehicle equipment on driver actions and safety of operation, and provide new driver training aids and equipment.

Further tests of the driver's behavior under normal and some abnormal conditions should provide information that could be useful in developing mathematical models of the driving task, and methods for evaluating drivers, vehicles, and highways.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Fletcher N. Platt and Miss Jacqueline DeCamp, who worked for the duration of the project. Donald N. Cortright acted as assistant director of the project during the summer of 1960 and later served on a part-time basis. Clinton L. Heimbach was research assistant during the summer of 1960.

Appreciation is also due the following: Leo Razgunas; Frank Westervelt; William Grimes; Cassimere Samborski; and Robert P. Rapley.

REFERENCES

1. Lauer, A.R., Suhr, V.W., and Allgaier, Earl, "Development of a Criterion for Driving Performance." HRB Bull. 172, 1-8 (1958).
2. Billion, C.E., "Community Study of the Characteristics of Drivers and Driver Behavior Related to Accident Experience." HRB Bull. 172, 36-94 (1958).
3. Greenshields, B.D., "Quality of Traffic Transmission." HRB Proc. 34:508-522 (1955); and "The Quality of Traffic Flow." In Quality and Theory of Traffic Flow, Bureau of Highway Traffic, Yale Univ. (1961).
4. Greenshields, B.D., "Traffic Accidents and the Quality of Traffic Flow." HRB Bull. 208, 1-15 (1959).
5. Platt, F.N., "Operations Analysis of Traffic Safety: Part I, A Classification of Traffic Situations; Part II, A Mathematical Approach to Traffic Situations; Part III, Methods of Evaluating Traffic Situations; Part IV, Proposed Fundamental Research on Driver Behavior." International Road Safety and Traffic Review, VI:2 (1958); VI:4 (1958); VII:3 (1959); VIII:4 (1960).
6. Matson, Smith, and Hurd, "Traffic Engineering." McGraw-Hill (1955); referring to Hamilton, J.R., and Thurstone, L.L., "Safe Driving." Doubleday (1930).
7. Bennett, C.A., and Franklin, N.L., "Statistical Analysis in Chemistry and the Chemical Industry." Wiley (1954).

Discussion

PAUL L. OLSON, General Motors Research Laboratories--These comments relate to a procedure employed in Dr. Greenshields' paper and are common to research efforts in which an attempt is made to separate "good" and "poor" drivers.

Table 5 is a comparison between the low- and high-accident groups used in the test. High-accident drivers were defined, apparently, as individuals who were on the verge of having their insurance canceled. A low-accident driver is defined as one who has about one accident in 12 years. Since the bulk of the accidents of the high-accident group occurs in the last five years it is apparent that, at 12 years' driving experience, many of the members of the high-accident group would not have been so classified. Or, to look at it another way, had the study been conducted five years earlier, a good many of the members of the high-accident group would not have been so classified.

Why has the recent driving experience of the high-accident group been relatively poor? The assumption which seems inherent in this study is that, for many of the group at least, after performing acceptably for a number of years, they rather suddenly became poorer accident risks. It is not impossible, if unlikely, that the driving skill of many of the members of this group did deteriorate significantly in the last five years. Some other reasons are suggested, for instance: Do these people drive more miles than formerly? Are they exposed to more congested traffic? Has the traffic situation over their usual routes changed in some significant way? These are certainly possibilities; it could be that they were just unlucky. It is known that truly random, low-probability events have a way of distributing themselves so that some few individuals end up with far more than "their share." It has been demonstrated that drivers who have many accidents in one period will probably not have many in subsequent periods. If corrections are made for such factors as exposure, the number of true repeaters drops still further. It is questionable procedure to take drivers who are on the tail of a Poisson distribution at time t_1 and call them high-accident drivers when there is a low probability of their being so classified at time t_2 or any other time. The point under discussion, of course, is criterion reliability.

Based on the data in Table 5, there is good reason to believe that the criterion on the basis of which the high-accident group was selected was not reliable. In all probability this simply reduced the sensitivity of the statistical tests. On the other hand, one might consider the intriguing possibility that the investigator was really measuring differences between drivers characteristically exposed to different driving conditions. He might even have been measuring the effect of several recent accidents. However, any rigorous investigation in which an attempt is made to dichotomize good and poor drivers must demonstrate that the criterion on the basis of which the split was made had sufficient reliability so that the reader can be reasonably sure that the investigator is dealing with some sort of individual accident potential.

In all fairness, this point is not of critical importance to the inferences drawn in Dr. Greenshields' paper. What is important, is the damage caused by reinforcing the notion that there is a group of accident-prone drivers who can be readily identified on a basis of a quick look at accident records or some other performance index.

Those, who peruse the literature dealing with traffic and traffic safety encounter many investigations which seek to develop instruments to predict or select poor accident risks. Almost universally the researchers in this area pay little or no attention to the problem of criterion reliability. It inclines one to think that this is the mandatory starting point for research of this type. Admittedly, it is not very glamorous, and one is faced with the distressing possibility that there may not be a significant group of accident repeaters, but it would be refreshing to see someone start researching this problem at its beginning—not at a point where it is necessary to make some rather dubious assumptions.

BRUCE D. GREENSHIELDS, Closure—Mr. Olson's comments are much to the point. He stresses what is, perhaps, the most difficult problem in the study of driving behavior: Who is the good driver? Who is the poor driver? Is the good driver always "good"? The author doubts that he is.

The point raised by Mr. Olson is at least partly recognized in the report, which says: "It should be noted that there is no accurate way of preselecting drivers as being 'accident prone' or not, due to the high incidence of chance. Drivers can be 'lucky' or 'unlucky'." As indicated (by quotes) it is doubted that 'accident prone' is the correct term to use. All that is known is that one group of drivers experienced more accidents than the other.

How to solve the problem of classifying drivers without a much more extensive and longer-range investigation than the present one, is unknown. When a method is found to score a driver, perhaps his faults can be corrected.