Traffic and Highway Research and How It May Be Improved

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The solving of traffic and highway problems often eludes the present methods of research. There is no doubt that we have skills and techniques to build better highways and safer vehicles, but successful research depends on attitudes, concepts, and imagination, and these have not kept pace with the ever-increasing complexities of highway transportation.

Research is a "game," for its methods are largely those of statistics, which is one of the means of ascertaining the "laws of behavior" of things—be they animate or inanimate. Mathematical probability, which is the basis of all statistical theory, had its beginning in ancient times. Certain mathematical patterns developed as a pastime by the Greeks and other ancient peoples were first found to coincide with chance happenings such as occur in card games and later found to coincide with actual happenings (*1*).

In driving an automobile, the "odds" have steadily improved over the years, but more than 56,000 deaths per year, or one every 9.4 minutes, is no cause for complacency. More people have perished on our highways than in all the wars in which the United States has fought. If the "odds" are to be improved, the rules of the "game" must be carefully followed. Research, to be successful, must proceed through the successive steps of measurement, analysis, and interpretation. As measurement becomes difficult, the researcher is likely to slight or omit it altogether, with the result that his analysis becomes, as Gauss, the "Prince of Mathematicians," termed it, a "play upon symbols." Gauss was well aware of the need for measurements. The centimeter-gram-second unit of magnetic flux density is called a gauss. Our early ancestors proved arithmetic theorems by counting or by some other act of measurement (*2*). We should return to that method.

The highway transportation researcher is perhaps one of the worst offenders in omitting essential measurements. As traffic movements have become more dynamic and varied and as measurement has become more difficult, he has turned to simulation and to the computer for solutions. But simulation does not always copy reality, and the symbols the computer "plays upon" may be meaningless.

The problems of traffic and highway research in 1970 are quite different from the problems of 1920. Unlike the horse, the motor car is not a complete mechanism until the driver is behind the wheel. It is the driver's responsibility to control all the blind horsepower at his command. Long gone are the days when a faithful horse got his owner home safely after a night on the town. The horse didn't need a "breathalyzer" test.

The driver-automobile-highway combination is not a balanced system. Horsepower is not balanced by "horse sense," and the highway is often not constructed to fit the ability of the driver. It is unfortunate that the research being conducted to bring order and efficiency to the transportation system is as much in imbalance as the system itself. Measurement is tragically lacking, and something better is needed than visual observation, tickets for speeding, and citizens' complaints if we are to gauge the efficiency of an industry that operates at a yearly cost of over $100 billion. The traffic engineer has no reliable or adequate measurements to back his judgment. He measures speed and delay, but these give little indication of cost, safety, or the frustration and annoyance of the driver.

The lack of measurement is not the only block to progress in transportation research. A major deterrent is an "established" way of thinking. There are persistent myths that seemingly cannot be exorcised. One of these myths is that a dangerous driver will reveal dangerous tendencies only in a seemingly dangerous situation, and therefore the only place to test a driver is in a simulator. A driver actually reveals dangerous tendencies in ordinary driving. Another myth is that any competent driver can teach driving, and can judge a driver simply by taking a ride with him. A fallacy to which the traffic planner clings is that time of travel is the only important variable to be considered. A popular fable at present is that most lives and injuries can be saved through the use of "crash"-proof cars, and through better "packaging" of the driver. There is no gainsaying the need for safer cars, but some of us can remember that at one time it was the driver who was at fault. The burden of safety rests upon the highway, the vehicle, the driver, traffic regulations, enforcement, and other things.

That following the "rules" of research is an effective way of finding what is wrong (or right) with the operation of our highway system may be illustrated by some experiences in research. The first of these experiences had to do with the traffic stream; the second, with the individual driver; and the third, with the highway.

Evaluating Traffic Flow

The first of these evaluation studies began in 1954 at the Bureau of Highway Traffic (Yale University) and is still continuing. The most recently completed project was for the District of Columbia Traffic and Highway Department (*3*). The problem was to find a means of determining the efficiency and "quality" of traffic flow and to derive a mathematical expression for "quality."

It was postulated that highway travel is improved as the time and effort needed to drive are reduced to a minimum. Almost everyone agrees that if he could step into a car, press a button, and immediately be at his destination he would be experiencing the ultimate in transportation—no time required, and no effort needed to change direction or speed.

Two methods were tried as a means of recording the driving variables. One was that of taking aerial time-lapse pic-

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tures. This method made it possible to record the movements of a large group of vehicles at one time, but the transferring of the data from the pictures was tedious. In the other and more practical method, instruments are placed in what the traffic engineer calls an "average" or "floating" car that travels with the traffic. The movements of this average vehicle are those of the traffic stream.

There was little question about what variables should be selected for evaluating traffic flow. But when a "quality of traffic flow" index (a "traffic number") was derived by multiplying time of travel, amount of change of speed, and amount of change of direction per unit distance, and the result was said to be a dimensionless number, confusion arose. What is a dimensionless number?

Perhaps it is easier to understand what a dimensionless number is if we understand what is meant by a number that has dimension. Undoubtedly our early ancestors thought of numbers always in connection with counting or measuring things—so many foot lengths or arm lengths, so many warriors, so many days. A number that has dimension is one that is wedded to a single dimension such as a foot, a second, a pound, and so on. A dimensionless number, while wedded to no single dimension, may be associated with several. The ability to represent several variables by a single number greatly simplifies analysis.

A well-known dimensionless measurement is that of angular measure. Angular measure is dimensionless, for it is always expressed as a proportional part or multiple of the angle generated by a line making one revolution about a point—2π radians or 360 degrees.

By definition, the traffic number N_t equals

(Time) × (amount of change of speed) ×
(amount of change of direction)/
(unit distance)

(The unit distance is 1 mile, or 1.6 kilometers.)

When we express this relationship mathematically we use symbols as follows: $t =$ time, $s =$ change of speed, $\theta =$ change of direction, and $l =$ unit of length or distance. Remembering that θ is dimensionless and that speed change has the same dimension as speed (distance relative to time, or l/t), we may write the dimension equation of N_t as

$$N_t = \frac{t}{l} \times \frac{l}{t}$$

Note that the dimensions cancel out.

Use of the Traffic Number

The most obvious use of the traffic number is its use in comparing highway routes of travel. The route requiring the least time and effort to travel (the route having the lowest traffic number) is clearly the best. Inclusion of the factor of effort as well as the factor of time also makes it possible to compare different modes of travel. Getting to the airport not only requires time, it requires the effort of walking; riding in a car, bus, or taxi; getting a ticket; carrying and checking baggage; and so on. The traffic number furnishes a means of evaluating the work involved in driving, but at present there is no measure of the work involved in transferring from car to plane. Such a measure must be developed. It is suggested that heart rate plus blood pressure could be used as a gauge of effort. Studies of a sample of people wearing simple gauges, of a type now available, making, say, the trip from New York City to Washington, D.C., by plane, by train, and by private car would give the total work and time involved for each mode of travel.

It is believed that effort is more of a deterrent to the use of public transportation than time. An experiment with "Maxi-Taxi" buses is now being conducted in Flint, Michigan. A short-wave communication system warns the rider that the bus is coming, and he meets it at his door with no waiting. He is delivered to the door of his place of work. The trip may take longer than it would by private car, but the work involved is certainly less. The venture is quite successful, despite the cost, which is greater than that of travel by private car.

To be of use to the traffic engineer, the traffic planner, and the safety engineer, the relationship of the traffic number to the variables of traffic flow should be known. Research is needed to determine this relationship. Once correlations and standards have been determined there will exist a measure of the effectiveness of steps taken to improve traffic flow, reduce travel costs, and increase comfort and safety. From field measurements which, with suitable equipment, are more easily obtained than the speed measurements now used, the traffic engineer will know whether his new settings of traffic signals have improved flow, whether the cost of travel over a given section of road has been reduced, whether travel on the road is more comfortable, and whether safety has been increased.

The traffic number, alone, may be of limited use, but when used as a research tool it can become a criterion for evaluating all traffic operations. Without such a single summarizing number, accurate evaluation of the efficiency of traffic operations is an almost impossible task.

A study conducted in 1958 by the Transportation Institute of the University of Michigan showed the following relationship: the better the quality of traffic flow, the fewer the accidents (*4*). This 1958 study at least suggests that it is possible to detect potentially dangerous traffic flow by measurement of traffic behavior rather than by counting the dead and maimed after the accidents have happened.

Scoring the Driver

When we focus our attention on the individual driver who, in the aggregate, makes up the traffic stream we again find that effective research is stymied by "established" concepts and hindered by lack of measurement.

A study of driver behavior, begun in 1956 at the University of Michigan, has revealed that far too little is known about driving and what to do about poor driving (*5, 6*). The "good" driver, according to accepted thinking, is one who has been able to avoid accidents and violations for several years; conversely, the "bad" driver is one on the verge of having his license revoked or his insurance canceled. If he is too "bad," of course, he isn't driving.

Driver attitudes—disrespect for the law, carelessness, and aggressiveness—and just plain bad luck are assumed to be the causes of poor driving. A recent scientific article (*7*) contains the statement: "Accidents appear more and more to be the result of random and chance events having little correlation with any particular human characteristic or set of characteristics." If all accidents were due to chance, striving to be a "safe" driver would be useless. But indeed, there are "good" drivers and "poor" drivers.

It is an amazing fact that we know how to score golf and other games but we do not know how to test driving ability. The young driver is arbitrarily charged a higher insurance rate, while the beginning golfer is given a handicap based on his average score, not on his age. The young golfer's handicap is lowered as he learns to play better, not just as he gets older.

And why should we not score the driver as we score the golfer? There is a similarity between the two "games." The golfer, judging the course, tries to avoid hazards; the driver, judging the highway and the proximity and movements of other vehicles, tries to avoid possible collisions or other hazards.

The analogy between golf and driving is obviously not exact. Setting par for golf depends on the distance from tee to green. The standard golf course is 18 holes long, and it takes about 3½ hours to play one round. In driving, there is no standard-length test course, and the hazards are more varied than those in golf. Despite the dissimilarity, however, a comparison is meaningful.

Scoring in golf is easy, and the golfer keeps his own score. He simply counts his strokes. It is impossible for the driver to score himself. How many times is the accelerator depressed in a mile of travel? How many times is the steering wheel turned in a minute? What is the amount of speed change the driver makes in going through an intersection? Neither the driver nor an observer without mechanical aid is able to record all driving variables, yet they constitute the driving task. Driving studies at the University of Michigan were based on the hypothesis that measuring the driving task would disclose many of the unknowns of the driving "game." The first project was sponsored by the National Institutes of Health; the second, by the Ford Fund. The results of the second study corroborated those of the first. But "established" concepts persist, and, with one exception, I know of no study of on-the-road driver tests being conducted at present. The exception is the research being conducted with the Ford Motor Company's highway systems research car under the direction of Fletcher N. Platt of the Ford Motor Company (*6*).

Results of On-the-Road Driving Tests

In the studies of driving behavior it was found that drivers with different driving histories (the high-accident driver, the low-accident driver, the high violator, and the beginner) exhibited measurably different characteristics when tested on the same route. This route presented no unusual hazards. All tests were conducted in good weather when traffic was very light. The results of the two studies were essentially the same. Here I explain only the second study.

The test procedures included (i) the use of test equipment to record, in digits, driver control actions, vehicle motions, and traffic events; (ii) selection of a test route; and (iii) selection of drivers as test subjects.

The items recorded consisted of the following.

1) Traffic events such as a vehicle in front of the test car, a vehicle passing on the left, a vehicle passing on the right, and pedestrians crossing.

2) Total trip time.

3) Running time (time during which the vehicle is in motion).

4) Delay time (total time minus running time).

5) Amount of change in speed.

6) Amount of change in direction.

7) Accelerator reversals [upward or downward changes in position of ⅛ inch (0.3 centimeter) or more].

8) Applications of the brake.

9) "Gross" steering wheel reversals (reversals in direction of about 1½ inches at rim of wheel).

10) "Micro" steering-wheel reversals (reversals of about ½ inch at rim of wheel).

11) Rate at which "micro" steering-wheel reversals occur.

Since traffic conditions cannot be rigidly controlled, it is usually assumed that any on-the-road driving test is biased. To meet this objection it was decided to record the density of traffic events (item 1 in the list given above). To do this, two methods were used: (i) picture-taking at 2-second intervals with a mirror arrangement to give both front and back views, and (ii) an observer-keyboard method. In this method the hand-held and hand-operated keyboard, about 4 by 6 inches, had button switches coded by location to represent traffic events. A symbol in the center of the board represented the test car. Events were recorded in seconds of duration. If a car took 15 seconds to pass, then it was a 15-second event. If five keys on the keyboard were depressed at one time, then five events were occurring simultaneously. The density of traffic events was treated as one of the driving variables.

The results obtained from scanning the pictures and those obtained from the "events" tabulator were found to be practically the same. In 18 tests involving the scanning of over 15,000 pictures, the average traffic-event densities obtained from the pictures differed from the densities obtained by the observer's tabulation by a factor of 0.004. With the observer-keyboard method the densities were immediately available at the end of the test run. The "observer" was the person giving the test. "Par" for the course differed for different densities. Light traffic had little or no effect, particularly on the "good" driver.

The test route selected for the second study (item 2 above) was 17.0 miles (27.2 kilometers) long. It consisted of different types of roadway, as follows: rural, approximately 6.4 miles; expressway, 5.1 miles; commercial (downtown), 2.0 miles; industrial, 2.0 miles; and high-density residential, 1.5 miles. The average running time was approximately 28 minutes, about equally divided among the various types of roadway.

Drivers for testing were selected with care to avoid representation of overlapping groups, such as individuals having both high-violation and high-accident records. For the control group chosen to establish a standard measurement (par for the course), drivers with excellent records were selected from lists supplied by an insurance agent. In addition, a group of driver training instructors was screened, and those with the best driving records were selected. The high-accident group was chosen from those in danger of losing their insurance because of too many accidents. This high-accident group, on the average, had had 48 times as many accidents as the control group. This is beyond the expected variation attributable to chance.

The high-violation group was made up of drivers with over 12 Michigan "moving violation points" (3 for improper passing, 6 for drunken driving, and so on) acquired in 2 years (sufficient for revocation of a driver's permit). Their accident records, however, showed fewer than the average number of accidents. The beginning student drivers selected were those who had passed their high school driver education course and had had drivers' licenses for not more than 3 months. Information on their age, sex, driving experience, and other factors was also obtained, in order to have generally representative samples.

The objective of the analysis of data was to find some function of a set of the driving variables that would discriminate between drivers of the different classes. The particular multivariate analysis method used is known as "discriminatory analysis."

In analyzing the data, since the variables were not entirely independent of each other (for example, changes in pressure on the accelerator cause changes in speed), it was reasonable to suspect that use of some of them in combination could be as effective as use of all of them. For this reason, different combinations were tried. The method followed was that of using all the variables for a first trial and then omitting one variable at a time. In several cases fewer variables gave a separation of groups as good as, or better than, the separation given by a larger number. For example, in discriminating between the accident group and the control group, six variables (traffic density, running time, accelerator reversals, gross steering-wheel reversals, and micro steering-wheel reversals) were found to give an assurance level of 97.5 percent (level of significance, 2.5 percent) that the groups were different, whereas omission of the variable of micro steering-wheel reversals gave an assurance level of 99.0 percent.

The "discriminatory analysis" method was used in preference to other statistical methods because it permits ranking or grading of individuals. By ranking it was found that there was about a 25-percent overlap. If there were no overlap, all of the "good" drivers would be those above a certain rank, and all "poor" drivers would be those with a lower ranking.

Ranking permits the testing of drivers on an individual basis. Having established "par" for the course by having the "expert" drivers drive the course, one can determine whether a driver fits into a predetermined class.

It was found, on selecting a group of young drivers and comparing them, by test, with the control group, that only 67 percent of them drove like young drivers. The fact that not all of the young drivers were correctly placed does not necessarily mean that the test is a poor one, for it could be that some young drivers are "good" drivers. In any case, it can be assumed that the more they drive like "good" drivers the better they become. The correct placements for the high-violation and high-accident individuals were 100 and 67 percent, respectively, and for the low-violators, 75 percent.

The significance of the tests is far-reaching. Driver training could be placed on a sound basis. Availability of means of checking driving performance would be very advantageous from the standpoint of training. Albert E. Gallup, director of driver education at Ann Arbor High School, Ann Arbor, Michigan, used the instrumented car for a short time in driver training. The following are some of the advantages he found (*8*).

1) The student is given immediate confirmation at the end of each driving period of the improvement he has made for that day. This support gives him encouragement above and beyond that that can be given by words alone.
2) Students who do not relate well to adults find the impartial mechanical record a challenge and it is difficult for them to rationalize their way out of the objective performance record.
3) The machine record provides a standard of individual performance that he can compete against—a similar incentive to that provided in the game of golf.
4) The teacher is provided with numerical support for his interpretations and his own personal judgments of the student's skills, reactions and attitudes.
5) The fact that data are being collected and recorded all the time in the driver education car adds importance to this phase of the program and promotes efficient use of the driving time allotted each student.

There are many formidable obstacles to the use of the mechanical test. As stated above, practically all drivers (99 percent) consider themselves good drivers, and they have no desire to jeopardize that opinion. Who wants or needs a driver's test? Few driver trainers want a little black box with a bright and flashing face constantly supplying information that has to be properly interpreted to be useful.

But it is to be hoped that the generally negative attitude toward an objective test will change. Too many lives and too much economic loss is at stake to permit the "state-of-the-art" of driving to continue to flounder in a mass of misconceptions.

There were some surprising sidelight findings in the study. The micro steering-wheel reversals were found to constitute an emotional barometer. Each person tends to have his own rhythm, ranging from about 15 to 30 such movements per minute. The driver tends to keep this rate constant and slows his speed in city traffic to maintain it. This count fluctuates over a wide range. An attempt to read outdoor advertising signs caused one individual's count to jump from 25 to 45 per minute. The recording device has been called a lie detector. It is perhaps possible to be trained to beat part of the test. One man's micro steering-wheel reversal count was not disturbed by conversation, by turning on the radio, and so on. How come? He had been driving a school bus for 10 years! One former highway patrolman could tailgate and keep his count normal. The count could be a safety device warning the driver, by bell or magnetic speaker, of anger, inattention, fatigue, sleepiness, intoxication, and so on.

In contrast to many reactions to the studies, J. J. Adams of NASA's Langley Research Center, in a 1966 report (*9*), commented that the study "suggested potential applications for the automatic determination of human transfer function techniques of NASA research." He also commented that, "in the area of automobile design many automobile manufacturers have neglected for too long the characteristics and limitations of the adaptability of human transfer functions. This neglect will become more evident as demands upon the human transfer function continue to increase" (*9*).

Evaluating the Highway

Our multilane highways with their long straightaways, smooth gleaming surfaces, and gentle sweeping curves dwarf any other engineering task ever undertaken. They are marvels of perfection produced by precise engineering skill. It would seem foolhardy to question their perfection.

But a short time ago I took an investigative ride on some of the expressways near Ann Arbor, Michigan, in a specially instrumented car (*10*). This car has sensors that detect driving skills and emotional, mental, and physical stress. One of these, heart rate, is a well-known indicator; another and perhaps more sensitive, but not well-known, indicator is the rate of micro steering-wheel reversals.

As we approached and entered some of the curves at the design speeds of 65 or 70 miles per hour, the driver's heart rate increased from 80 to 125 beats per minute and the steering-wheel reversal rate jumped from 20 to over 50. On other curves, just as sharp but apparently better designed, the heart rate and steering-wheel reversal rates remained constant. The variation in rates was not entirely unexpected, for Michigan does not build true easement or "transition" curves into its highways. In a "transition" curve, the curvature increases gradually while the outer edge of the pavement is raised to counteract the centrifugal force on the car rounding the curve. Railroads have been constructing transition curves since about 1900. In Michigan, the outer edge of the pavement is raised about 200 feet before the road curves, and this creates a reverse action when the car enters the curve.

Curves are not the only examples of poor design. Almost all drivers complain of poor pavement markings and traffic signs. The function of these signs and markings is to properly control vehicle and pedestrian traffic. Pavement markings are easily obliterated by snow and ice and are not clearly visible under certain weather conditions, and they are obscured by traffic. Signs deteriorate and are often obscured by trees and shrubs. The "glance" legibility of signs is often not adequate at the prevailing high speeds. The geometric appearance of a highway may be deceptive and invite excessive speeds. Highway design must be in balance. The surfaces of rough and curving roads have been improved and still accidents have increased.

It seems obvious that roads should be built to fit the ability of the driver, who is not all-seeing and not infallible in his judgments. It was apparent 40 years ago that fitting the highway to the driver would require skills and concepts not then associated with engineering. It is discouraging to reflect that we still strive to build better highways without knowing the faults of those we now have.

The story of the development of a device to measure the ease, comfort, and safety with which one may drive upon a given highway began in February 1957 with a series of conferences between members of the University of Michigan's Transportation Institute and members of the Traffic Division of the Michigan State Highway Department. The objective of the conferences was to "develop new concepts and bring new associations of various disciplines to bear on the broad problems of traffic behavior and its highway environment." The program was not carried out, but from these conferences came the concept of a "highway characteristics recorder."

The instrumentation was designed to fit into a passenger car or station wagon and record the three characteristics that determine a highway's service worth and "drivability": (i) its appearance, (ii) its geometry, and (iii) the condition of its surface. The complete data would all be recorded on a series of photographs taken on 16- or 35-millimeter film.

A view of the road is the most important element in driving. One who cannot see the road cannot drive. The appearance of the road could be shown in color. Since the pictures would be taken at intervals of 50 feet, or 1/100 mile, the view of the road could, in effect, be continuous. The pictures would show the highway as the driver sees it: the signs, the curbs, the scenery, the traffic lights, the grade, and the curvature.

As the engineer will recognize, the record would not only be complete for any point on the highway but would be very easy to interpret and use, since the readings would be given in numbers.

At the time the need for a recorder of highway characteristics was conceived, a description of the concept was sent to the state highway departments for comment. Most of these comments were favorable. The reply from the Ohio state highway department was as follows.

> We have received comments from several bureaus in the Divisions of Operation, and Planning and Programming with reference to the merits of such a device. Summarizing these comments we concluded the following:
>
> This device would be worthwhile in:
>
> (a) Perpetuating a road and bridge inventory
>
> (b) Determining sufficiency ratings for structural adequacy
>
> (c) Perpetuating needs study
>
> (d) Determining adequacy of maintenance
>
> (e) Effective control maintenance operations
>
> (f) The study of correcting accident-prone locations.

Comment

A recorder of highway characteristics would make it possible to bring the highway "into the office" for quick and complete analysis at a cost of a few dollars per mile. Problems that now escape solution could be analyzed with assurance. Let me give an example. Several years ago it was found on the New York Throughway that there was an excellent correlation between the number of accidents and the number of outdoor advertising signs. It was falsely concluded that the signs caused the accidents. But when some 13 other road variables were included in the study, it was found that the signs had no measurable effect on the number of accidents.

The ability to measure leads to new ideas for highway research methods. Millions of dollars have been spent on simulators to test driving. Why not reverse the process and test the highway in a simulator. Suppose it is desired to test the effectiveness of highway signs or pavement markings. Motion pictures or perhaps time-lapse pictures taken from a car traveling over the highway and projected on the simulator screen would make it possible to measure and record drivers' response to existing signs. New signs could be designed and projected onto the screen in place of the old ones, and drivers' responses noted. The final test, of course, would be of the new signs in actual road use, tested by driver response.

With present methods of making "improvements" without before-and-after checks, poor designs may persist for generations of highway construction. It seems that there is no highway design so permanent as one that cannot be tested. It is said that a test is worth a thousand expert opinions. When we start testing driving ability, determining the "quality" of traffic flow, and really knowing our highways, we will have safer, more efficient highway transportation.

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