OBJECTIVE MEASUREMENTS OF DRIVER BEHAVIOR
(A JOINT PAPER)

THE OBJECTIVE EVALUATION OF TRAFFIC STREAM FLOW

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ABSTRACT
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This paper describes the evolution of equipment and techniques leading to the development of a "Quality Index of Traffic Flow". Four applications of the quality index were studied: The development of cost figures for different values of the index; an investigation of the relationship between density, volume and the quality indices; a test of the correlation between gasoline consumption and the quality of flow; and an attempt to discover if there is a correlation between the quality of flow and the frequency of highway accidents.

At the conclusion of these studies it became possible to modify the original equipment, as a result the "Drivometer and Traffic Events Recorder" was developed. Using this equipment, a mathematical interpretation of driver's responses to traffic events was developed and three additional studies were delineated. These included: the functional classification of streets and highways, effect of highway design and control devices on traffic flow, and testing vehicle proving grounds.

A recent study using the modified equipment was to determine the effective distance of urban highway travel for supermarket shopping trips.
THE OBJECTIVE EVALUATION OF TRAFFIC STREAM FLOW

BRUCE D. GREENSHIELDS

Many attributes of traffic flow, such as volume, speed and the nature of traffic accidents have received extensive study, but there have been few attempts to measure the quality of traffic flow. That such measurements have not been made is not due to a lack of need.

The justification for street and highway improvement, construction and installation of new traffic controls should be based on the kind of flow to be obtained by the betterments. The manner in which traffic moves over the street or highway is a measure of service to the road user. If traffic moves rapidly and freely the service is high, but if traffic moves slowly and erratically the service is costly, annoying and even dangerous.

That few studies of the quality of traffic flow have been attempted is understandable for it is a complex phenomenon. The driving patterns of individual drivers are extremely varied and it is the sum of these behavior profiles that compose the traffic stream. To record and analyze the varying time-space relationships is a difficult task. Also there has been no general agreement as to the desirable and undesirable attributes of traffic flow, hence no agreement as to what should be measured.

This is a chronological account of attempts to identify the desirable and undesirable attributes of traffic flow, to measure these and then combine them into a characterizing number or index of the quality of flow.

THE DEVELOPMENT OF A QUALITY INDEX OF TRAFFIC FLOW

The recognition of the need for a quality of flow index and a concept of its general nature preceded by several years its initial development. The first opportunity to develop such an index was at the Yale University Bureau of Highway Traffic in the fall of 1954. We will now consider in order, (1) the nature of the index, (2) the apparatus for collecting field data, and (3) the results obtained.

THE NATURE OF THE INDEX

In developing a theory and an index number for expressing the quality of traffic flow it was found helpful to consider traffic flow to be analogous to fluid flow despite the fact that traffic flow is much more complex.

1. For clarification we quote extracts from the 1955 report.

"But there is very little exact information on those aspects of traffic motion that not only disturb and annoy the driver, but add to the cost of driving."

"It was recognized that this new measure must have certain definite attributes. It must be dimensionless, free from arbitrary decision, easily understood and simple of application. It should be objective in yielding accurate and unbiased measurements, and at the same time it should reflect the driver's feelings."

"In presenting these results, it is realized that other methods of measuring the quality of traffic flow may be derived. In fact several have been considered..."

The term "quality of service" was used in this early report. The term now in use is "level of service".

In fluid dynamics there have been developed certain dimensionless numbers to characterize flow. These numbers are ratios of like quantities. Reynolds' Number, which is perhaps the best known, is obtained by equating the ratio of the inertia (resistance) forces in the model to the ratio of the viscous (accelerating) forces in the prototype.

Using the analogy of fluid flow it was reasoned that a quality of flow index number should be equal to the ratio of the desirable features of traffic flow to the undesirable features. In other words, the ratio of the way the collective driver likes to drive his car to the way he must drive it due to highway and traffic conditions.

The most obvious desirable and undesirable features of driving may be detected if drivers are questioned about what they like and dislike in driving. There was general agreement that the greater the speed within safe limits, the better is the quality of travel. There was also agreement that traffic interruptions making it necessary for the driver to change his speed are undesirable. Both the amount of change in speed and the number of times speed must be changed are undesirable. They are tiring and irritating to the driver. The optimum quality of travel might be thought of as that requiring no time and no effort. One would step into his car, press a button and be at his destination.

In formulating the basic concept it was proposed that the higher the speed the more desirable is the flow and the higher the expected index number. Conversely, the greater the amount of speed changes and their frequency, the less desirable is the flow, and the lower the expected index number.

Using these variables, there was derived the equation:

\[ Q = \frac{KS}{\Delta s \sqrt{t}} \]

\( Q \) = Quality Index; \( K \) = a constant inserted to keep the expression from becoming a small fraction; \( S \) = the speed of traffic; \( \Delta s \) = amount of change of speed; and \( \sqrt{t} \) = the square root of the number of changes.

This index met the major objective of the study which was to substitute measurement for opinion in determining the quality of traffic service. The measure was also found to be sensitive enough to reflect small variations in the quality of flow.

APPARATUS FOR COLLECTING DATA

Having formed a preliminary hypothesis as to the type of data to be collected, methods of collecting them were needed. Two means were developed. One—the use of time-lapse photographs taken from the vantage point of an airplane. Two—the use of a "test" car, driven in
the traffic stream and equipped with a recording speedometer.

Although the two methods gave comparative results, the pictures proved very time-consuming because of the transcription of data from the films.

It was decided to use a "test" car equipped with a recording speedometer conceived prior to the beginning of the research. The device furnished us with a continuous speed graph, together with a time-distance record.

Using the test car method, it was found that the "average" car (judged by the driver to be traveling at the average speed of the stream) and the "floating" car (passing as many cars as pass it) gave the same degree of accuracy.

In very light traffic it is impossible to judge the speed of the traffic stream, and it was found that the data must be obtained by following or pacing individual vehicles. In any case, it is necessary to take into account varying traffic and weather conditions. The accuracy obtained depends upon the size of the sample.

Three applications of the quality index were included in this study:

1. The development of cost figures (based on estimated values of time and comfort) for different values of the index.
3. A test of the correlation between gasoline consumption and the quality of flow.

It was found that if accurate cost figures for time and comfort could be obtained that it would be possible to express the quality index in monetary values. Relative monetary values for time and comfort (or effort) have not yet been determined.

It was ascertained that the correlation between density and the quality of flow was reasonably good. On the other hand, no discernable correlation was found between quality of flow and volume.

In the third investigation, it was found that for runs of about 20 miles with the "Q" (quality) values ranging from about 10 to 100, the maximum variation was about one mile per gallon for any particular "Q" value.

It became apparent during the study that change of direction as well as change of speed should be included in the index. This could not be done with the recorder then in use. Also, due to the difficulty of interpreting graphical records in numbers for statistical analysis the desirability of digital records was made apparent.

**TRAFFIC ACCIDENTS AND THE QUALITY OF TRAFFIC FLOW**

The next use of the quality index was in a study of traffic accidents in 1957 at the University of Michigan Transportation Institute. This was an attempt to discover if there is a correlation between the quality of flow and the frequency of highway accidents.

The research was limited to:

1. The selection of three sections of highway with different accident frequencies.
2. The collection of data for the determination of the quality of traffic flow.
3. A comparison of the quality index with accident frequency.

The equipment developed at Yale, together with time-lapse photography, was used in this study.

The following table extracted from the research report is indicative of the results obtained.

<table>
<thead>
<tr>
<th>Road</th>
<th>Quality Index</th>
<th>Single Vehicel Accidents per Million Vehicle Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (two-lane)</td>
<td>618</td>
<td>1.28</td>
</tr>
<tr>
<td>B (two-lane)</td>
<td>1023</td>
<td>0.36</td>
</tr>
<tr>
<td>C (three-lane)</td>
<td>1930</td>
<td>0.25</td>
</tr>
</tbody>
</table>

This table shows that the higher the quality the lower the accident frequency. Thus, it is indicated that potentially dangerous traffic flow could be detected before accidents happen. It also suggests that any road that causes poor traffic flow is potentially dangerous.

**THE DEVELOPMENT OF THE DRIVOMETER AND TRAFFIC EVENTS RECORDER**

It was at about the end of this study (fall of 1957) that it became possible through a contract with Ford Motor

3. The "Q" equation resulting from the inclusion of change of direction is:

\[
Q = \left( \frac{KS}{\Delta s} \right) \left( \frac{1}{\Delta \phi} \right)
\]

wherein \(K\) = constant inserted to keep the expression from becoming a small fraction. \(S\) = speed; \(\Delta s\) = change of speed and \(\Delta \phi\) = change of direction. (The square root of frequency of changes of speed \(VT\) has been omitted as not being significant.) It may be noted that since speed is equal to distance divided by time and \(\Delta s\) and \(\Delta \phi\) may be assumed to be proportional to driver effort, that:

\[
Q = \frac{\text{Distance}}{(\text{Time} \times \text{Effort})}
\]

It could be argued that if either \(\Delta s\) or \(\Delta \phi\) equals zero, that the value of \(Q\) becomes infinity, an absurdity. To prevent this possibility the equation might be written:

\[
Q = \left( \frac{\Delta s}{\Delta \phi} \right) \left( \frac{1}{\Delta \phi} \right) + 1
\]

since the addition of one to the denominator would not change the value of \(Q\) significantly. But in practice the values of \(\Delta s\) and \(\Delta \phi\) have never been observed to be zero for any appreciable distance such as one-tenth mile or more.

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2. The recording device as conceived at the Bureau was developed by the Automatic Signal Division of Eastern Industries, Inc., Norwalk, Connecticut.
TRAFFIC EVENTS DENSITY

A mathematical interpretation of the relationship of driver's response to traffic events may be developed. This is a basic concept supporting the research conducted with the driverometer.

The two factors that are of prime importance in traffic operations are: (1) the time it takes a driver to respond to an event in his perceptual field, and (2) the number of events occurring in a unit of time. It is assumed that all events are continuous, that is, persist for a period of time.

All drivers are aware of the fact that it takes time to respond to an event. The traffic engineer calls this PIEV time, the letter standing for perception, intellect, emotion, and volition.

To begin our explanation, let us center our attention on any one event in the perceptual field, which we will call the ith event. This event may be any happening, such as a vehicle that is being overtaken. The driver perceives the vehicle and decides to pass or not to pass. This acting or not acting take an interval of time which we designate as $t_i$—the time associated with the ith event. We may express this relationship as

$$D_E = \frac{\sum (e^i)}{t_i}$$

which simply means that the events density $D_E$ is the sum of events and associated PIEV times. The sum of the response times must always be less than the actual time, for the driver can perceive and respond to only so many events in a given time.

The driver limits the number of responses he must make by lowering his speed, for the greater the density and the higher the speed, the less time the driver has to respond. That this fact is universally recognized is shown by speed laws which require the driver to reduce his speed in congested urban areas.

This explanation also shows that dividing the number of events by the running time gives an average events density index number that may be used in comparing the traffic conditions on the same route at different times.

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5. The terms (PIEV) as defined as follows:

**Perception**—Sensations received through the eyes, ears, and body that are strong enough to be recognized as perceptions. Experience, habit, and other factors cause some sensations to result in "reflex responses" before they are perceived. It is believed that most, if not all, driver responses are more complex than simple reflex actions.

**Intelection**—Intelection is the exercise of the intellect. The time required for registering, regrouping, and comparing new sensations, the forming of "messages" to be sent to the muscles, is intelection time.

**Emotion**—Emotion is defined as "an agitation; strong feeling; any disturbance". Emotions may influence or affect the final message sent to the muscles to be carried out.

**Volition**—Volition is the "act of willing or choosing; act of the will". The act of the will results in definite action.

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4. The switches are coded largely by their positions. A symbol near the center of the keyboard indicates the position of the test car. The switch above this symbol represents a vehicle in front of the test car. When the observer sees that there is a vehicle ahead, he pushes this switch to the "on" position and leaves it there until the vehicle is no longer in front. During the time any switch is on, the connected counter, operated through a timer is recording time in seconds. Other switches, are coded for other traffic situations such as "car passing on right", "parking on right", etc.
or on different routes.

I would now like to describe three additional areas we may examine using the drivometer and traffic events recorder. These include: the functional classification of streets and highways, the effect of highway design and control devices on traffic flow and the comparison of test tracks. In addition, I would like to briefly describe an origin and destination study in which the equipment was employed.

THE FUNCTIONAL CLASSIFICATION OF STREETS AND HIGHWAYS

One of the most critical problems facing the traffic engineer today is that of determining the quality of traffic transmission service furnished by a street or highway. Perhaps the most difficult part of the problem is determining what is meant by quality of service.

The principal difficulty seems to be the diversity of drivers' likes and dislikes. Some like a faster route, some a more comfortable one, and others perhaps regard cost of travel as important. But these factors are not entirely independent of each other. The higher the quality of flow the less costly it is in time and operating cost per mile. Perhaps the better service furnished by one of two routes of equal length is that which can be traveled most quickly and with the least effort.

If two terminals are connected by several routes, then we would expect to find that some drivers prefer the shortest, some the quickest and others the most comfortable (least effort).

One way of determining the percentages of drivers that prefer one attribute of travel to another such as time or effort would be to count those making definite choices. It is well known, for example, that people living in the same area and working at the same place take different routes to work.

Another way would be to ask a fairly large group of drivers, say one or two hundred selected at random, to drive several routes with different traffic and highway conditions and then rate the routes in order of preference.

Objective measurements of the differences in the "quality of flow" would then be obtained for the separate routes by use of the drivometer. The "drivometer and traffic events recorder" is believed to be the only instrument that furnishes all of the required data and presents it in a digital form for ease in analysis.

Once the group preferences are known it should be possible to weigh the factors involved and derive an expression for "quality of flow" that would more correctly reflect actuality, than the original expression. This could be a modification of the quality of flow index shown earlier in this report which, it will be recalled, is a ratio of what are believed to be desirable factors of driving to what are believed to be undesirable factors. The drivometer offers a more accurate and precise method of measuring the quality of traffic flow than has been possible in the past. This should lead to a more exact mathematical expression for defining traffic flow.

EFFECT OF HIGHWAY DESIGN AND CONTROL DEVICES ON TRAFFIC FLOW

The measure of the quality of traffic flow may also serve as a measure of effectiveness of highway design and traffic control devices. High quality traffic flow depends on good highway design and traffic control. In fact, it would seem to be the only objective direct measure of whether a highway has good "driveability" or not. Any design or traffic control that produces high quality flow is serving its purpose. Highway or traffic control improvement is measured by the extent to which traffic flow is improved.

This method of "checking" may be applied to any phase of street or highway improvement. The traffic control on a certain street is to be improved. What is the quality of flow index before the improvement? What is the quality after the improvement?

Is the entrance ramp to an expressway of good design? It is, if the quality of flow on the ramp and on the expressway is not materially reduced. It is known that some ramps are operating safely and efficiently and that others are not. There needs to be built up a greater knowledge of what constitutes good construction. Accurate measurements of the operating characteristics are pre-requisites to improved design. A study of several streets in Washington, D.C. is currently being made to test out the techniques developed.

Two requests for an opinion as to the best types of highway signs have come to my desk recently. This illustrates the fact that the design of highway signs is still largely a matter of opinion. There is a lack of factual information on what type of sign best accomplishes its purpose of getting better traffic behavior. This again can only be ascertained by observing and recording the behavior.

VEHICLE PROVING GROUNDS

From a comparison of highways let us briefly turn our attention to proving grounds. These vehicle test tracks are actually highway simulators. Automotive engineers have built into them features designed to test the "driveability" and the "roadability" of vehicles.

The characteristics of a proving ground and test course to actual roads and highways could be accurately compared by a vehicle equipped with the drivometer. Also, a practical means for comparing one proving ground course to another is provided.

EFFECTIVE DISTANCE OF URBAN HIGHWAY TRAVEL FOR SUPERMARKET SHOPPING TRIPS

A study in which this "drivometer and traffic events recorder" has been used is that of determining the effective distance of urban highway travel for supermarket shopping trips. This study was conducted by Dr. Clinton L. Heimbach, Associate Professor of Civil Engineering, University of Michigan. The author states:
"Given a demand for shopping at a particular supermarket, the investigation made measurements of the driver responses to the highway route that the shopper chose when driving to the supermarket, and determined the effective distance, expressed in units of driver actions and vehicle motion, which spatially separated the supermarket from the shopper's home."

"Using units of effective distance, the study shows that an increase in effective distance from the store results in a decrease in customer contacts at the supermarket, and that this relationship is mathematically functional. The investigation also indicates that sections of urban arterial streets can be characterized in units of effective distance."

Dr. Heimbach further states that:

"Any comprehensive planning solution to urban transportation problems will require a more fundamental knowledge of individual travel behavior in relation to land use problems and the highway network than is now available."

Dr. Heimbach found that the sum of driver actions is a more meaningful expression for effective distance than either time or distance.

The respective coefficients of correlation were as follows:

**Driver Actions**

\[ R \text{ (Coefficient of correlation)} = -0.891 \]

**Time and Vehicle Motions**

\[ R \text{ (Coefficient of correlation)} = -0.842 \]

**Distance Traveled**

\[ R \text{ (Coefficient of correlation)} = -0.855 \]

These findings of Professor Heimbach, the earlier findings in the Yale Bureau of Highway Traffic study and the findings we expect to be confirmed in a present study being conducted at the University of Michigan Transportation Institute, indicate that it should be possible to make a functional classification of streets and highways.

**THE INDIVIDUAL DRIVER**

These studies of the traffic stream have led into studies of the individual driver who collectively makes up the traffic stream. It is easily comprehended that characterizing the traffic stream is a much simpler task than evaluating the behavior of the individual driver. (Figure 2)

But despite the anticipated difficulty of evaluating individual driving behavior success in measuring the quality of the traffic stream, led to the conclusion that it might be possible to measure the "quality" of individual driving.

The improvement of traffic stream flow and safety on the highway depends on the individual driver. The opportunity to study driver behavior with the object of improving it offered a challenge that could not be ignored.

The theoretical operations analysis by Fletcher N. Platt provided a firm base for the study of individual driving behavior.

Mr. Platt's paper will reveal new findings on the various aspects of driving behavior.
REFERENCES


3. HEIMBACH, CLINTON LOUIS, Effective Distance of Urban Travel for Supermarket Shopping Trips, a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan, June, 1963.
Figure 1
Counter Board for Events Recorder
and Drivometer

Figure 2  The Drivometer
ABSTRACT

OBJECTIVE MEASUREMENTS OF INDIVIDUAL DRIVER BEHAVIOR

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Research studies to date have indicated that objective measurements of driver behavior, vehicle motion and highway environment obtained by the use of the drivometer, are far more revealing than those obtained by subjective evaluations.

Five areas have undergone initial study using the drivometer: driver education on-the-road teaching techniques; single driver performance; effects of fatigue; driver performance rating, and driver classification studies. The results of this research have suggested other areas which may be able to benefit from the objective driver measurements afforded by the drivometer.

These areas include: driver licensing; driver motivation; driving simulators; engineering test driver, and further investigation into driver education teaching techniques.

The ultimate capabilities of the drivometer, not yet ascertained, will be brought to light by future studies in the areas of driver behavior, vehicle characteristics and highway environment.
OBJECTIVE MEASUREMENTS OF INDIVIDUAL DRIVER BEHAVIOR

FLETCHER N. PLATT

Early studies of driver behavior tried unsuccessfully to relate accidents to reaction time, to certain vision characteristics and to general social characteristics of the driver. The lack of success of these studies was undoubtedly due to the fact that a number of factors, but relatively few of the total possibilities, are related to any particular accident. The driver-vehicle-highway complex has so many variables, any one of which may be dominant at a given instant, that the probability of obtaining a high correlation with any single factor or any small group of factors is remote. Also the probability of accident occurrence is rare when compared to many commonplace experiences of everyday life. The fact that this is a problem of many variables and at the same time a rare event requires it to be studied in a manner not generally understood by laymen.

A NEW APPROACH

Rather than continuing to tackle the difficult problems of studying driver behavior during the critical period preceding an accident, which has been unrewarding, the author proceeded to study driver's actions under normal driving conditions. A probability theory of traffic situations was developed: utilizing the driving task in relatively simple terms. On the basis of this theory, which defines the relationship of driver-vehicle-highway complex, a method of measuring each of the fundamental characteristics on the highway was sought. A digital recording device for measuring traffic flow was being tested by Dr. Greenshields. The device, after a number of modifications, is now called the Drivometer and Traffic Events Recorder. This instrument has been described by the first author.

It seemed reasonable that if the theory of traffic flow developed by Dr. Greenshields was sound, the principles should also apply to the individual driver. If the equipment to measure the parameters was sensitive to variations in traffic flow it would follow that individual driver characteristics might also be differentiated. Finally, if this hypothesis proved true, then research conducted in both the traffic and driver behavior fields could be inter-related by use of the same measuring equipment. This has proven to be the case. The drivometer is a fundamental instrument for studying, comparing and evaluating each of the basic parameters of the highway transportation system.

A number of exploratory research projects have been conducted over the last five years, using this instrument, relating to driver behavior and the driving task. Based on the experience of these studies the author has reviewed earlier descriptions of the driving task in context with the parameters measured by the drivometer. The following is a new, and hopefully, a better presentation of the driving task, based on synthesis rather than analysis. It also describes the reasoning which led to the final design characteristics of the drivometer.

THE DRIVING TASK AND DRIVOMETER DEVELOPMENT

The question of how to obtain objective measurements of a driver's behavior has plagued researchers for many years. What specifically determines the driver's decision to transport himself from one point to another via his automobile? What motivates him to drive in a particular manner on a particular trip?

For many years, researchers studying driver motivation considered distance a primary factor, not only in the decision to drive, but also in the difficulty of the driving task. Many of the conditions which once lent credence to theories on distance and driver behavior have changed, and time of travel has become the basic criterion for origin-destination studies.

Not the least reason for this change has been the vast improvement in our system of roads and expressways. A fast, efficient, all-weather road system has physically shortened driving distance and has made time more important than distance. Recent research, however, has shown that not time alone but effort combined with time, is a fundamental factor to the driver.

Time rather than distance is more closely related to the driver's effort involved in the driving task. For instance, it is possible for a driver to be involved in a driving situation requiring more observations of traffic and highway events, decisions and actions over a 15-mile stretch of city streets than in a 50-mile trip over a lightly traveled freeway. A minute-by-minute breakdown of a 30-minute ... 15-mile trip might show great peaks and valleys in each time period, depending upon each driving situation encountered. It is obvious that the actual observations, decisions and actions a driver makes are limited by the time period involved, not the distance traveled.

SOLUTION OF THE PROBLEM

The task then becomes one of developing a means of objectively measuring the environment (number of events) and the driving operation and relating them to accepted subjective scales. From then on basic measurements can be quantitatively measured and related.

A closer scrutiny of time also allows us an insight into driver motivation. On a pre-set route, drivers with aggressive tendencies exhibit lower periods of running time . . . that is, periods of time when the car is actually in motion . . . than the normal time for the route, established by pre-tests at various traffic densities. On the other hand, cautious
drivers usually take longer to drive the same route. Thus, it is possible to establish a driver’s motivation scale, from cautious to normal to aggressive, using time as an objective measurement. It has been found that delay time, time the vehicle is stopped, is also a sensitive measurement relating to a driver’s motivation. Here it is plain to see that with distance held constant, on a pre-set route, time becomes a variable and determining factor . . . one which is adaptable to scientific techniques in the study of driver behavior.

In addition to time measurements, certain aspects of the driver’s control of the vehicle assume importance. Obviously, one of the fundamental driver functions is to maintain control of the vehicle speed.

As the driver moves along the highway, his speed reflects the differences in changing traffic conditions, traffic signs and signals, weather and road conditions, light conditions and the driver’s motivation on a given trip. All of these factors are important inputs or feedbacks to the driver and are reflected in his movement of the accelerator, application of the brake and the resultant speed of the vehicle under any specific situation. As we are usually more interested in a driver’s overall characteristics, the duration of the test run is an important factor, as this is directly related to average speed of the trip.

The brake is generally considered to be the primary device in controlling the speed of the vehicle. However, in terms of the number of applications, the brake is actually secondary compared to the accelerator. In a recent experiment by Dr. Greenshields, in which drivers traveled an identical route, driving the same vehicle, accelerator movements exceeded brake applications by several times.

Actually, the great majority of speed changes, in response to traffic flow and road geometry situations, require accelerator movements, up or down, rather than brake applications. Braking action of the engine is used far more frequently in normal driving to decelerate the vehicle than the brake. It has been found that when the brake is applied, it is used more often just to decelerate the vehicle than to bring the vehicle to a complete stop. It is for these reasons that the number of accelerator reversals are a far more sensitive measurement of a driver’s ability to control speed than the number of brake applications.

It is apparent that speed control is one of the two basic variables in an objective study of driver behavior. If the driver’s vehicle ran on railroad tracks, only speed control would be required of the operator. However, since highways permit freedom of direction as well as speed, steering of the vehicle is the second basic variable in the driving task. The resultant of these two variables—speed and direction—is position of the vehicle in respect to time and space. Position then, is a dependent variable of speed and direction control.

NO EFFECT ON SPEED

It is important to recognize the fact that steering motions have no direction relation to the speed of the vehicle. On the other hand, the steering control is very sensitive to vehicle speed because vehicle tracking becomes more critical as the vehicle speed increases. Thus, it follows that this one parameter, steering, related to both direction and speed, is the primary action of the driving task. For example, a competent driver can keep a vehicle in lane at high speeds, but a beginning driver has difficulty steering a vehicle even at low speeds.

There are many parameters of steering control that can be measured. Among these are total turns of the wheel, the force applied to the wheel, the time the wheel is in contact with the road, and the total radians of turning. Several years of detailed study have shown steering wheel reversals to be a most sensitive measure of the driver’s response to conditions of environment, traffic and vehicle. It also has proven to be extremely sensitive to the driver’s emotions, skill and attention.

It is possible to measure steering wheel reversals to any degree of sensitivity, from a complete turn of the wheel, to a fraction of a degree. Gross measurement may indicate only when turning a corner, or parking, a very fine measurement will be inaccurate because of tolerances in the steering system.

The desirable measurement of steering wheel reversal has been determined to be just sensitive enough to respond to driver decisions required to maintain the vehicle centered in the lane at the maximum speed limit.

The rate at which drivers make steering wheel reversals has special significance. Each driver tends to have a steering reversal rate which is characteristic of his normal driving habit. That is—an attentive driver is subconsciously compensating, by changing speed, to attempt to maintain a constant steering reversal rate. When the driver is in a hurry he travels at a higher vehicle speed. This act tends to increase his attention to the driving task, tracking more accurately, resulting in an increase in steering reversal rate. The opposite holds true when the vehicle moves at slower speeds under the same conditions.

SIGNIFICANCE OF REVERSAL RATES

Although rates based on one-half and two-minute intervals have been studied, a one-minute interval is best. Rates computed at half-minute intervals proved too sensitive to environment and traffic, while two-minute averages damped out the effect of driver emotions. The effect of driver tension, depressions and inattentions seem to fluctuate over two-minute intervals or less, while the effects of individual traffic and highway situations generally pass at intervals of less than 30 seconds.

It has been found that one-minute steering wheel reversal rates are about equally sensitive to physical and psy-
chological characteristics of the driver, when compared to the effect of the environment and traffic conditions. On the other hand, speed change and accelerator reversal rates are most sensitive to different traffic and environmental conditions, and to a lesser degree, reflect the sensitivity of the driver.

It is easily recognized that individual drivers may act differently from one day to the next or even minute-to-minute. One of the most interesting aspects of the research conducted to date involves the study of a number of individual drivers supposedly at their attentive best and in various stages of degraded performance. These exploratory studies have been made comparing driver’s characteristics measured with the drivometer, not only under ideal conditions, but exposed to distractions (windshield wipers, radio on loud or general discussion), at various stages of fatigue, with temporary change of physical condition (one eye covered), in inclement weather and distracting traffic conditions.

Other experiments of interest have included:

—The training and rating of five beginning drivers.
—Repetitive runs made during a six-month period by the same driver.
—A fatigue study made by a team of two drivers.
—Selecting a winner from five finalists in a driving contest.
—Tests of a large number of drivers over a fixed course under similar environmental conditions.

Many time studies have been reported and several are in the process of completion at the present time. From these studies have come a better understanding of the driving task, the inter-relationship of man and machine, and some new insights into the driver’s psychological characteristics.

DRIVOMETER RESEARCH STUDIES

The following represents a brief summary of the testing conditions and the results of this research in five diverse areas.

Driver Education Evaluation Study—Five beginning driver education students at Ann Arbor High School in Ann Arbor, Michigan received behind-the-wheel instruction using the drivometer. For the first time, an instructor has been able to numerically record a student’s performance and plot this information on a graph. Results showed a definite learning curve can be plotted; the instructor can determine when the task is too difficult for the student; when the student has become adept in a particular maneuver; that it is possible to objectively compare the student’s performance on a day-to-day basis with other students in the class, and ascertain when a student exhibits unsteady and erratic behavior patterns.

Single Driver Performance—For more than a six-month period, a drivometer equipped car was used by a single driver going to and from work. A 20-mile section of interstate highway I-94 was used as the test run. Data was taken each morning and evening when test requirements were fulfilled. Distinct differences in the morning and evening runs could be determined, including variations in speed, steering reversals, accelerator reversals, speed changes, predictability of the driver’s behavior and motivational characteristics.

Fatigue Study—A two-man team drove a drivometer equipped car on a 1,200-mile trip from Ann Arbor, Michigan to Philadelphia, Pennsylvania and return. The drivometer made it possible to objectively record the various stages of degraded driving performance resulting from the effects of fatigue. Evaluation of steering reversal rates, speed change rates and the average speed of the vehicle revealed a widening tolerance of both vehicle tracking and speed control, less reluctance to risk taking and greater irritability as fatigue increased.

Performance Rating Study—A drivometer equipped car was used in the final judging of the 1963 Detroit “Good Driver of the Year” contest. Five drivers, selected from an initial field of 50, drove the drivometer car over an 11-mile course which included city, suburban and expressway driving. The winner was determined objectively by comparing his drivometer scores to those of the other contestants. The numerical scores, provided by the drivometer, allowed the participants to be graded down to one-tenth of a percentage point. Such a tolerance was not possible with subjective scoring methods used in previous contests.

Classification Studies—Drivers were chosen at random from pre-selected groups having driving backgrounds which included: high accident records, high violation records, beginners just receiving their license after driver training, professionals with excellent records, driver training instructors and average drivers. These drivers drove a drivometer equipped car on a pre-set route and their numerical records were subjected to a computer analysis. It was found that drivers can be classified by this statistical method and that a one-half hour test is sufficient to detect the basic characteristics of a driver for classification.

Here are the highlights of these findings:

1. Traffic density, from light to moderately heavy has relatively little effect on the competent driver.

2. Even very light traffic is of measurable concern to the beginner or incompetent driver.

3. The high-accident driver is the least efficient driver, making many more control corrections than others.

4. Drivers with good records are more consistent in their control habits and are less seriously affected by distractions and other disturbances.

5. All drivers reflect, to some degree, their emotional state in their control motions.

6. Steering reversal rate is the primary subconscious “flywheel” used by drivers to control speed.

7. Variations in visibility, sight distance (including
spacing to vehicle ahead) and eye optics cause measurable differences in the number of steering reversals of the driver.

8. Small variations of speed from a norm, for a given driver, cause major variations in the steering reversal (tracking) rate. This is probably due to the desire to track more accurately as speed is increased and to accept a wider track below normal speeds.

9. Coordination of vehicle tracking and speed control can be detected in the beginning driver and a learning curve of a student driver can be obtained.

10. Fatigue causes major fluctuations of driver control motions and resulting vehicle movement probably caused by cycles of tension and relaxation of the nervous system.

11. Certain individual characteristics, such as aggressiveness of a driver, can be recognized by accurately measuring time delay and running time on a fixed course and comparing them to results of a large sample of drivers.

12. Drivers in the high-accident classification, on the average, have significantly different characteristics than drivers with high violations. The high-accident driver tends to be overly cautious, and erratic in nature, while the high violator is more competent but aggressive. The high-accident driver, because of his accident experience, tries to compensate by driving more slowly. The high violator, on the other hand, will probably have the more serious accident if one occurs, but has a lower probability of having an accident than anticipated.

The research which has been completed thus far has opened the door to other areas in which the drivometer may serve as an efficient and practical driver evaluation device.

PROPOSED USES FOR THE DRIVOmeter

Driver Education—As mentioned previously the drivometer has been used as a training and testing instrument in behind-the-wheel driver education. A manual has been written by the teacher evaluating these experiences. It is anticipated that other teachers, having the same opportunity, will base their methods on the original manual but will suggest changes and improvements in technique as a result of their work. After several generations of teacher usage, a controlled experiment might be set up to statistically relate the drivometer trained student to those using standard methods. Not only will this lead an understanding of the value of the drivometer but it will also establish a means of rating other teaching methods as well.

Licensing—Experience has shown that most people want some impartial scoring system rather than a subjective rating by another person. Driving is no exception. Few people like to be criticized about their driving, even by the driver license examiner. The drivometer can become the impartial, unbiased, repeatable "black box" to rate drivers and impersonally score a driver's capability to control a vehicle. The drivometer could be placed in the trunk of a test car. The applicant would then be given the route to follow and 20 minutes later, when he returned unattended, the drivometer would provide the score. Under some circumstances it might be advisable to have a subjective evaluation as well, but in most cases the drivometer would be more accurate and objective than an examiner's opinion.

Driver Motivation—There is much that is not known about driver motivation, the range of driver desires and their effect on driving characteristics. Certainly the effects of health, drugs, alcohol and environmental conditions have an effect on driver motivation, which, up to the present have only been explored superficially. Psychological tests have been developed for selecting those who are qualified to drive. However, the only way to relate these studies and tests to safe driving has been to compare them to past driving records or take three to five years to obtain future accident and violation records. Now, for the first time, the drivometer will enable one to determine immediately, on a sound probability basis, a driver's characteristics as they relate to the driving task and, in turn, to accidents.

Driving Simulators—Over the last ten years, there has been much work done in the development and refinement of driving simulators. Those used for driving training, such as the Aetna Drivotrainer, have become most popular in schools. Research has demonstrated their value. Other simulators are in the design, development or refinement stage for performing research that cannot safely, economically or conveniently be performed on the highway or test tracks.

It is visualized that the drivometer can be used most effectively to compare these simulators to real life conditions and to help establish standards of reliability for each type of laboratory device. It will also be useful in determining the most effective areas of investigation for simulator research, particularly the areas that cannot be performed by the drivometer in "real life" situations.

Engineering Test Drivers—Most control handling and comfort characteristics of cars and trucks are evaluated subjectively by experienced test drivers. Their ratings are related to or supplemented by instrumentation. However, as no two drivers perform exactly alike, or the same driver from one day to the next, it is often difficult to get repeatable results that are satisfactory for engineering interpretation. Also, it is difficult to inter-relate one type of test to another, or to safe and unsafe driving characteristics. Not having had any efficient means of objectively measuring
good or poor drivers, the engineer has difficulty evaluating test driver characteristics to customer characteristics.

The drivometer can become the common instrument to relate all types of tests and drivers so that results can be more meaningful. If drivometers are used as supplementary equipment in all basic experiments, then information can be related to other studies not only of driver characteristics, but highway and environment as well.

CONCLUSION

The two papers presented have described new ways of making objective measures of the way traffic moves over the highway and the way individual drivers behave.

It has been found that objective measurements of driver behavior, vehicle motion and highway environment with a single instrument, the drivometer, are far more revealing than subjective observations. Methods and techniques are being improved through further research.

Behavioral scientists have studied man in all his complexities of attitudes, emotions, mental and physical abilities, and limitations. Research has assisted in the development of better vehicles and highways. What has been lacking is an operation analysis of how well man, vehicle and the highway perform together. Man himself is the key to the operation for it is he who perceives and interprets the highway environment and then controls his vehicle not only to get him to his destination, but to maintain safe time and space relationships with other vehicles, pedestrians and his surroundings.

But granting that man is the key element in the man-machine-highway combination does not mean that his is the sole responsibility for optimum operation. The highway builder, the traffic engineer, the automobile designer are all responsible for better, safer highway transportation and the proof of the excellence or failure of their work can only be found in measuring and analyzing both the highway environment, the individual and the collective behavior of traffic.

New means of obtaining objective measurements are providing answers from research not obtainable before. It is believed that the drivometer and its successors will be the key to unfolding whole new areas of traffic operations, studies and safety research.

The findings to date indicate that such measurements and analyses can be made and that when they are made new knowledge comes to light. With increased knowledge will surely come better vehicles, better highways, better drivers, and of ultimate importance, a safer, more efficient highway system.
REPORTS RELATING TO RESEARCH WITH
THE "DRIVOMETER"

TRAFFIC CHARACTERISTICS REPORTS


GENERAL REPORTS


1958 PLATT, FLETCHER N., "Operations Analysis of Traffic Safety"


BASIC DRIVER BEHAVIOR AND CLASSIFICATION REPORTS

1960 PLATT, FLETCHER N., "Operations Analysis of Traffic Safety"


DRIVER FATIGUE


DRIVER EDUCATION REPORT


DRIVER PERFORMANCE RATING REPORT

SCHEMATIC DIAGRAM OF HIGHWAY TRAFFIC SITUATIONS
**INTERPRETATION OF THE VARIABLES**

**High Steering Reversal Rate**  
(same as high rate of vehicle tracking cycles)

<table>
<thead>
<tr>
<th>Causes</th>
<th>Minimum Results</th>
<th>Possible Serious Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tracking more accurately than necessary for conditions</td>
<td>Inefficient, fatiguing</td>
<td>None (directly)</td>
</tr>
<tr>
<td>2. Driving faster than conditions permit</td>
<td>Reckless driving citation</td>
<td>Loss of control—accident</td>
</tr>
<tr>
<td>3. Nervousness</td>
<td>Fatiguing</td>
<td>None (directly)</td>
</tr>
<tr>
<td>4. Vision limited and speed too high</td>
<td>Reckless driving citation</td>
<td>Accident</td>
</tr>
<tr>
<td>5. Not looking correctly for proper tracking</td>
<td>None</td>
<td>Loss of control</td>
</tr>
<tr>
<td>6. Driving too close to vehicle ahead</td>
<td>Discomfort to passengers. Sudden brake application required</td>
<td>Front-rear end collision</td>
</tr>
<tr>
<td>7. Inattention to task</td>
<td>Temporary loss of control. Less attention for emergencies</td>
<td>Accident</td>
</tr>
<tr>
<td>8. Uneven road surface</td>
<td>None</td>
<td>Loss of control</td>
</tr>
<tr>
<td>9. Unstable hold on steering wheel</td>
<td>None</td>
<td>Loss of control</td>
</tr>
<tr>
<td>10. Passing another vehicle</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>11. Heavy traffic</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Driving Record of New Driver - for Six Sessions

<table>
<thead>
<tr>
<th>Time in Minutes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Straight Road</td>
</tr>
<tr>
<td>2</td>
<td>Straight Road</td>
</tr>
<tr>
<td>3</td>
<td>Turns (off street)</td>
</tr>
<tr>
<td>4</td>
<td>Turns (off street)</td>
</tr>
<tr>
<td>5</td>
<td>Residential Street</td>
</tr>
<tr>
<td>6</td>
<td>Residential Street</td>
</tr>
</tbody>
</table>

Mean Values (Composite) Horizontal not to scale

Graph X—Typical Learning Pattern