A Comparative Study of Two Vehicle Operating Characteristics Instruments

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The purpose of this project was to compare methods and equipment available for measuring passenger car operating characteristics in a wide variety of traffic studies. The equipment included the Highway Research Board statistical instrument, a modified speed and delay recorder, and a travel time recorder. The operating characteristics recorded were elapsed time, distance traveled, speed profile and distribution, acceleration and deceleration rates, brake utilization, and fuel consumption.

The equipment was used in four selected types of traffic studies: the measurement of acceleration and deceleration characteristics, the comparison of 1-mi sections of expressways and city streets, the comparison of bypass and business routes, and the evaluation of interstate highways.

This paper discusses equipment cost, operation, and analysis; procedure and manpower needed for operation and analysis; anticipated results and presentation of data; and the advantages and disadvantages of the equipment.

• THE MEASUREMENT of operating characteristics of vehicles on streets and highways is becoming increasingly important. The concept that the adequacy of a route can be evaluated by measuring the operating characteristics of its traffic further focuses attention to this area of endeavor. The measurement of these characteristics is necessary if highway and traffic engineers are to evaluate the economic and convenient movement of traffic.

Three sets of equipment have been developed during the past ten years to measure operating characteristics. During 1957 Michigan State University in cooperation with the Michigan State Highway Department and the Bureau of Public Roads embarked on a research study, Quality of Traffic Flow, in which a modified speed and delay meter and the statistical instrument were used. Because both instruments had not previously been used simultaneously, it was suggested by the Vehicle Characteristics Committee of the Highway Research Board that this comparative study be made, and reported at the annual meeting. Later in the study, the travel time and distance recorder was included.

The purpose of this paper is to compare the three methods and accompanying equipment by utilizing each in three types of traffic studies: 1. Acceleration and deceleration tests; 2. Comparison of travel on a bypass and business route; and 3. Evaluation of two interstate highways.

DESCRIPTION OF EQUIPMENT

The test vehicle was a moderately-priced 4-door, 8-cylinder station wagon with automatic transmission. The statistical instrument and speed and delay meter were installed on the test-vehicle in December 1956 at the General Motors Proving Grounds at Milford, Michigan. The speed and delay meter was modified in the early spring of 1957 and the travel time and distance recorder was installed in the fall of 1957.

Statistical Instrument

The Committee on Vehicle Characteristics has provided the leadership and coordination in the development of ideas and equipment for measuring operating characteristics. The main concern of this committee is the evaluation of the operating characteristics of the motor vehicle and how these characteristics are used by the driving public. The committee selected velocity, acceleration, deceleration, and fuel consumption as the basic characteristics for study. It was decided that an instrument should be designed and built to measure quantitatively these characteristics with a minimum amount of analysis.

With the assistance of the Bureau of Public Roads, Chrysler Corporation, General Motors Corporation and the Automobile Manufacturers Association, a statistical instrument was built and a study utilizing this equipment was conducted in 1950. The results of this study were reported by Carmichael and Haley (*1*). Since 1950 additional studies have been conducted utilizing the statistical instrument (*2,3,4,5,6*).

The recording portion of the statistical instrument consists of 51 counters which automatically record the basic characteristics: speed, fuel, deceleration and acceleration (acceleration rate and engine torque). There are 5 horizontal rows of 10 counters each and a single master counter. The units of measurement for all counters except fuel are seconds while for fuel the units are 0.00132 gal of fuel consumed. Each counter on the horizontal row records the time or fuel consumed for a particular range of values (that is, the first counter on the speed row records the number of seconds the vehicle traveled between 0 and 8 mph). The master counter records the total time in seconds for a particular trip. The statistical instrument is shown in Figure 1, and a typical data sheet is shown in Figure 2. A complete description of the installation

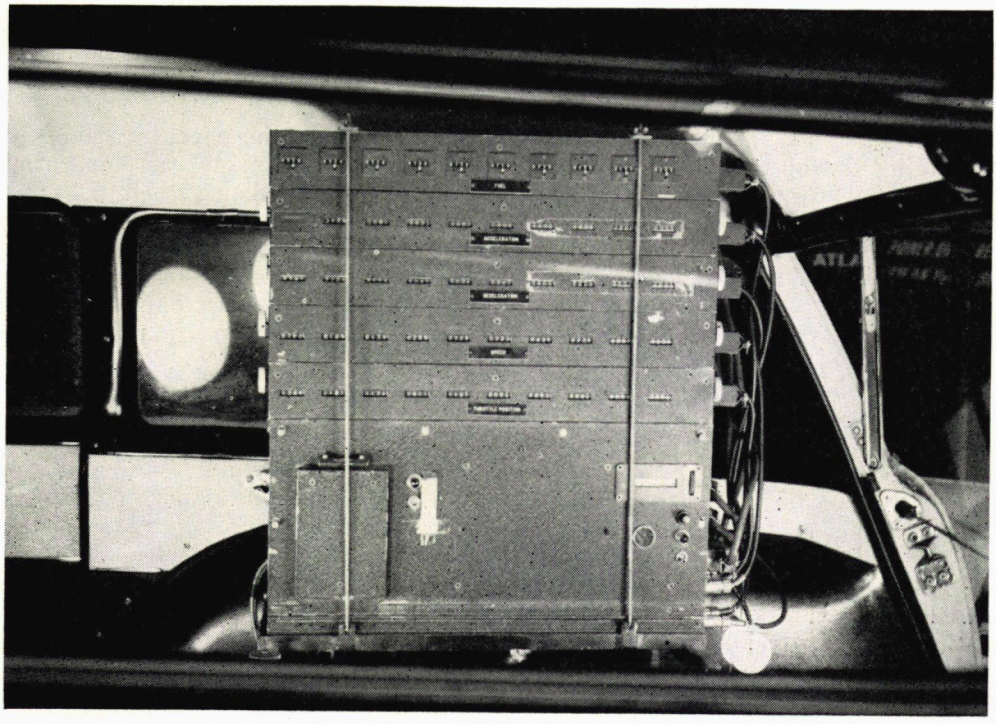


Figure 1. Highway Research Board statistical instrument.

Group No.- B.R. Jackson Test Run 3 Route US 12 Direction East

Time 1:00 PM Day of Week Sat Date 11-30-57

Driver Benson Weather Warm Temperature 40°+

FUEL

COUNTER NO.	1	2	3	4	5	6	7	8	9	10	TOTAL
SPEED, MPH	0- 8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-74	75-UP	COUNT
FINISH	28	21	51	85	101	47	85	44			
% TOTAL	6.1	4.5	11.0	18.4	21.9	10.2	18.4	9.5			

ACCELERATION

COUNTER NO.	1	2	3	4	5	6	7	8	9	10	TOTAL
ACCELERATION	0-1	2-3	4-5	6-7	8-9	10-11					COUNT
FINISH	841	33	19								
% TOTAL	94.2	3.7	2.1								

DECELERATION

COUNTER NO.	1	2	3	4	5	6	7	8	9	10	TOTAL
DECELERATION	0-1	2-3	4-5	6-7	8-9	10-11					COUNT
FINISH	841	219	48	7	1						
% TOTAL	75.4	14.6	4.3	0.6	0.1						

SPEED

COUNTER NO.	1	2	3	4	5	6	7	8	9	10	TOTAL
SPEED, MPH	0-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-74	75-UP	COUNT
FINISH	154	67	153	247	203	107	136	63			
% TOTAL	13.6	5.9	13.5	21.9	18	9.5	12	5.6			

THROTTLE POSITION

COUNTER NO.	1	2	3	4	5	6	7	8	9	10	TOTAL
% OPENING	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100	COUNT
FINISH	580	259	154	22							
% TOTAL	57.1	25.5	15.2	2.2							

ODOMETER

FINISH	8.2
START	0
TRIP MILEAGE	8.2

MASTER COUNTER

FINISH	1147
START	0
TOTAL COUNT	1147

TRIP AVERAGE SPEED 25.71 MPH

TRIP GAS CONSUMPTION 13.44 MPG

Figure 2. Data sheet for statistical instrument.

and connections for the original statistical instrument was presented previously (*1*), and only the modifications incorporated since then will be discussed.

In 1953 a second statistical instrument was built and during the summer of 1957 some modifications were made. The second model included a manual counter reset dial which permitted the resetting to zero of all the counters before each run. Another modification was the redesign of the instrument so that power could be

obtained from a 12-volt car battery. Before this an auxiliary 6-volt battery had been used; however, when the voltage dropped below 5 to 5.5 volts the statistical instrument did not function properly. The third modification was to increase the sensitivity of the acceleration and deceleration counters by calibration so that the individual counters recorded for smaller ranges of acceleration and deceleration.

Modified Speed and Delay Meter

A speed and delay meter was developed by the Automatic Signal Division of Eastern Industries for the Bureau of Highway Traffic at Yale University (*7*). The original speed and delay meter required only a connection to the speedometer cable and an electric source from the car through the cigarette lighter; it graphically recorded elapsed time, distance traveled and a continuous plot of vehicle speed. Modifications were made by providing connections to the fuel meter portion of the statistical instrument and the tail light electric circuit to record graphically fuel consumed, number of brake applications, and length of time of brake application. The speed and delay meter is shown in Figure 3, a speed and delay chart in Figure 4, and a typical data sheet in Figure 5.

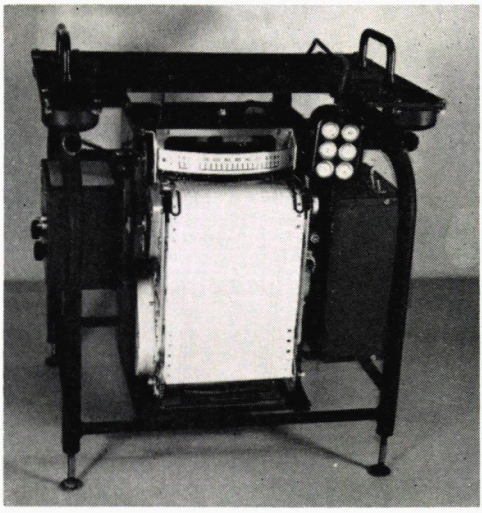


Figure 3. Speed and delay meter.

Seven pens are available for recording various operating characteristics. Each impulse on lines A and B represents 6 sec and 1 min elapsed time, respectively. Each impulse on line C indicates an elapsed distance of either 200 or 400 ft, while manual impulses may be placed on line D for predetermined codes. Pen E impulses denote the number of brake ap-

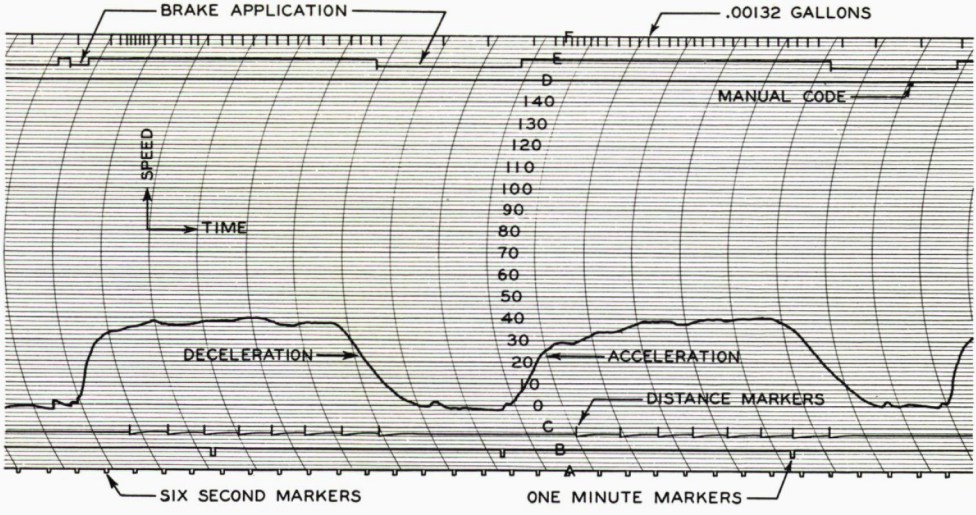


Figure 4. Speed and delay chart.

LOCATION B.R. JACKSON (U.S.-12) DISTANCE 8.22 MI.

DRIVER BENSON WEATHER WARM RUN No. 2

DATE 11-30-57 DAY OF WEEK SATURDAY TIME 1:00 P.M.

DIRECTION EASTBOUND

TOTAL TIME 17.85 MIN. STOPPED TIME 1.56 MIN. No. BRAKES 21

BRAKE TIME 3.85 MIN. DISTANCE TRAVELED per BRAKE 0.39 MI./BRAKE

MAX. SPEED 54 MPH MIN. SPEED 0 MPH SPEED RANGE 54.0 MPH

RUNNING SPEED 30.44 MPH AVG. SPEED 28.35 MPH

GAS COUNT 422 GAS MILEAGE 12.57 MPG

SPEED DISTRIBUTION

0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
148	122	286	302	133	80	-	-	-
14%	11%	27%	28%	12%	8%	-%	-%	-%

CALCULATIONS BY R. BENSON

DATE 12-21-57

Figure 5. Data sheet for speed and delay meter.

plications and the length of time or distance the brakes are applied, while each impulse on pen F indicates that 0.00132 gal of fuel has been consumed. The middle pen provides for a continuous plot of speed (vertical scale) against either distance or time (horizontal scale) indicating the number of delays, length of delays, unevenness of flow, maximum and minimum speeds, acceleration and deceleration rates, and speed distribution. If time is selected as the horizontal scale, a downward slope indicates deceleration rate and an upward slope indicates acceleration rate expressed in units of miles per hour per second. The speed of the graph can vary in increments from 12 in. per min. to ¾ in. per hr. Either a 6-volt or 12-volt D.C. power source may be used.

Travel Time and Distance Recorder

A travel time and distance recorder was developed by the Streeter-Amet Company in cooperation with the Institute of Transportation and Traffic Engineering at the University of California (*7*). The total elapsed or incremental time and distance is printed on a tape when the circuit is manually actuated. The travel time and distance recorder is shown in Figure 6, the travel time and distance tape in Figure 7, and an analysis sheet for the travel time recorder in Figure 8. One of 12 code numbers can also be printed with each distance and time recording. The first vertical column on the tape is the code, the next column is the elapsed time expressed in one-hundredths of a minute, and the last vertical column is elapsed distance expressed in one-hundredths of a mile. The recorder is powered by a 12-volt battery, and a connection is made to the speedometer cable.

DESCRIPTION OF FIELD PROCEDURE

The three methods and accompanying equipment were used in three types of traffic studies: (a) acceleration and deceleration tests; (b) comparison of travel on a bypass and business route; and (c) evaluation of two interstate highways. A map of the study area is shown in Figure 9. These three types were selected because they were considered to be typical and they permitted comparison of equipment on relatively short, medium, and long distance tests.

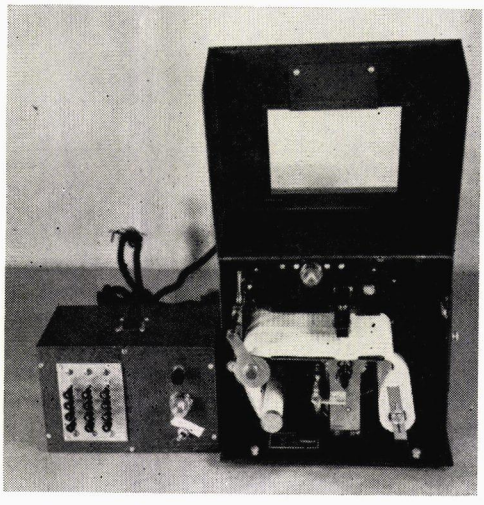


Figure 6. Travel time and distance recorder.

CODE	ELAPSED TIME	ELAPSED DISTANCE
1	0 0 8 2 8	0 2 5 8
6	0 0 7 9 6	0 2 4 4
5	0 0 7 5 6	0 2 4 4
1	0 0 7 2 9	0 2 3 5
1	0 0 6 9 0	0 2 1 6
6	0 0 6 4 7	0 1 9 7
5	0 0 5 9 6	0 1 9 7
1	0 0 5 5 3	0 1 7 7
1	0 0 5 1 4	0 1 5 8
1	0 0 4 7 9	0 1 ˘ 1
1	0 0 4 3 9	0 1 1 2
1	0 0 4 0 3	0 0 9 ˘
1	0 0 3 6 4	0 0 7 7
6	0 0 3 3 2	0 0 6 5
5	0 0 3 2 6	0 0 6 5
1	0 0 3 ˘ 3	0 0 5 6
1	0 0 2 8 3	0 0 4 6
5	0 0 2 3 7	0 0 3 2
5	0 0 1 9 6	0 0 3 1
6	0 0 1 7 3	0 0 2 5
5	0 0 1 2 7	0 0 2 5
6	0 0 0 7 6	0 0 1 2
5	0 0 0 4 5	0 0 1 2
1	0 0 0 2 6	0 0 0 7
4	0 0 0 0 0	0 0 0 0

Figure 7. Travel time and distance tape.

It was not possible to operate all three instruments simultaneously on a particular test since each required a connection to the speedometer cable. However, each instrument was operated in each test under similar conditions.

Acceleration and Deceleration Tests

Acceleration and deceleration tests were conducted on the campus of Michigan State University on a flat, straight, bituminous roadway which was closed to traffic while tests were being conducted. The driver was instructed to accelerate from a standing position to 60

LOCATION B.R. Jackson (U.S. 12) DIRECTION EAST

DRIVER Benson WEATHER Warm RUN No. 3

DATE 11-30-57 DAY OF WEEK Saturday TIME 1:30 PM

DISTANCE 9.27 Miles TOTAL TIME 18.19 min. AVG. SPEED 30.6 mph

No. OF STOPS 11 TOTAL STOP TIME 2.88 min No. OF DELAYS 11

TOTAL RUNNING TIME 15.31 min. RUNNING SPEED 36.4 mph

No. OF SIGNALIZED 14 NONSIGNALIZED 78 INTERSECTIONS.

TIME IN DELAY

	Signal	Stop Sign	Turning Vehicle	Parked Vehicle	Pedestrian	Other	TOTAL
DELAY	1.85	0.25	0.28	—	—	0.50	2.88 min
% TOTAL	64.2	8.7	9.7	-	—	17.4	100%

CALCULATIONS BY R Benson

DATE 12-21-57

Figure 8. Data sheet for travel time recorder.

mph with the accelerator completely depressed. In the deceleration test the driver was instructed to travel at a speed of 60 mph and at a predetermined point to decelerate at a rate which he considered to be normal and comfortable until the test vehicle was completely stopped. Several tests were conducted with each instrument.

Comparison of Travel on a Bypass and Business Route

The second study was conducted on a bypass and business route in Jackson, Michigan. The bypass is a controlled-access, 4-lane divided highway, while the business route is a considerably longer route through the downtown business district. In this study the driver was instructed to drive at a speed which he considered to be average for the traffic flow.

Evaluation of Two Interstate Highways

U S 16 (Lansing eastward to downtown Detroit) and U S 12 (Albion eastward to downtown Detroit) were the two interstate highways selected for this study. Each route consisted of two portions: the rural portion to the fringe of the De-

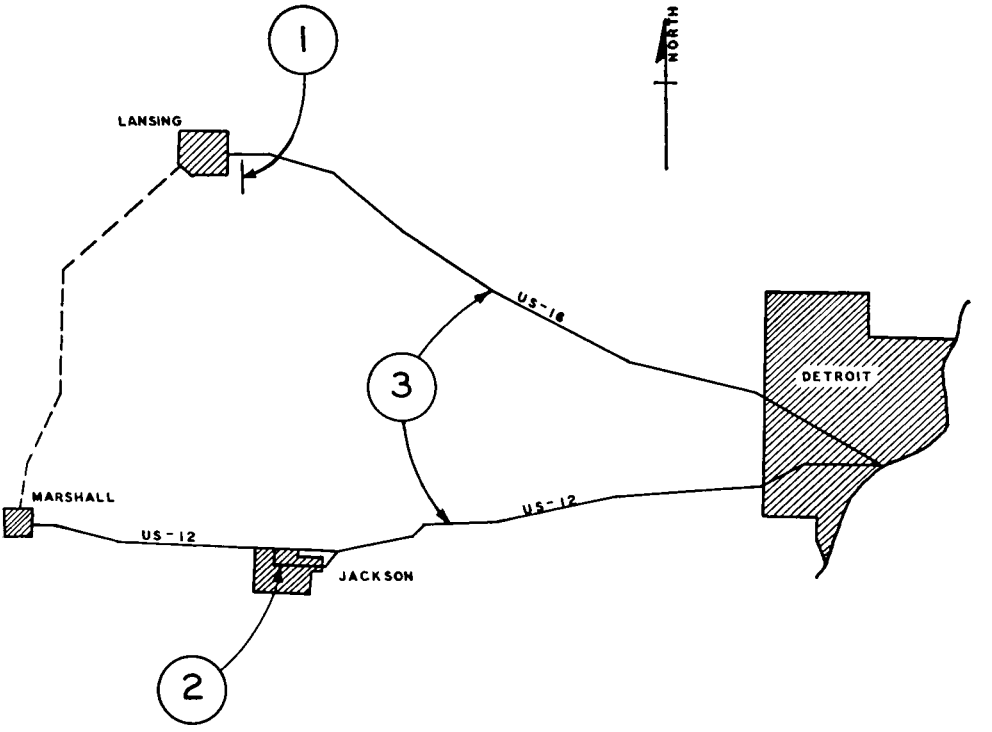


Figure 9. Location of test sections.

troit area, and the urban portion from that point to downtown Detroit. The rural portion of U S 16 is mostly a 4-lane divided and undivided roadway passing through five small to medium sized communities. The urban portion is the congested 8-lane urban arterial, Grand River Ave. The rural portion of U S 12 is a 2-lane, 3-lane, 4-lane undivided, and 4-lane divided highway which does not pass through a city, and the urban portion is through the Detroit area on the Industrial Expressway. The driver was instructed to drive at a speed which he considered to be average for the traffic flow.

PRESENTATION OF RESULTS

The data collected for each test and with each instrument were analyzed. The important aspect of the data is not the numerical results, but the type and amount of data that can be obtained when using a particular instrument. For each set of data as much analysis as possible was made in order to determine the full potential of each instrument.

Acceleration and Deceleration Tests

The statistical instrument was utilized in the acceleration and deceleration test, and the data sheet (similar to Fig. 2) was used in the analysis. The summary of the data collected is shown in Figure 10. The left portion of the figure is obtained directly from the counter readings. The right portion shows the results of calculations for average fuel rate, average speed, average deceleration and acceleration, and total time. The calculations are possible only if the total distance of travel is obtained by field measurement or by using some additional piece of equipment. The total time was obtained directly from the master counter.

The speed and delay meter was used in the acceleration and deceleration test, and data were analyzed using a form similar to Figure 5. Acceleration and de-

celeration are presented (Fig. 11) separately with a vertical scale of speed and a horizontal scale of time and distance. Fuel consumption is also illustrated along the horizontal axis. Total time, distance traveled, and fuel consumed can be obtained directly from the graph. The presentation is quite similar to the speed and delay chart of the original data (Fig. 4). Since the vertical scale is speed and the horizontal scale is time, the slope of the curve is acceleration or deceleration as indicated. Average speed and average fuel rate were also computed and indi-

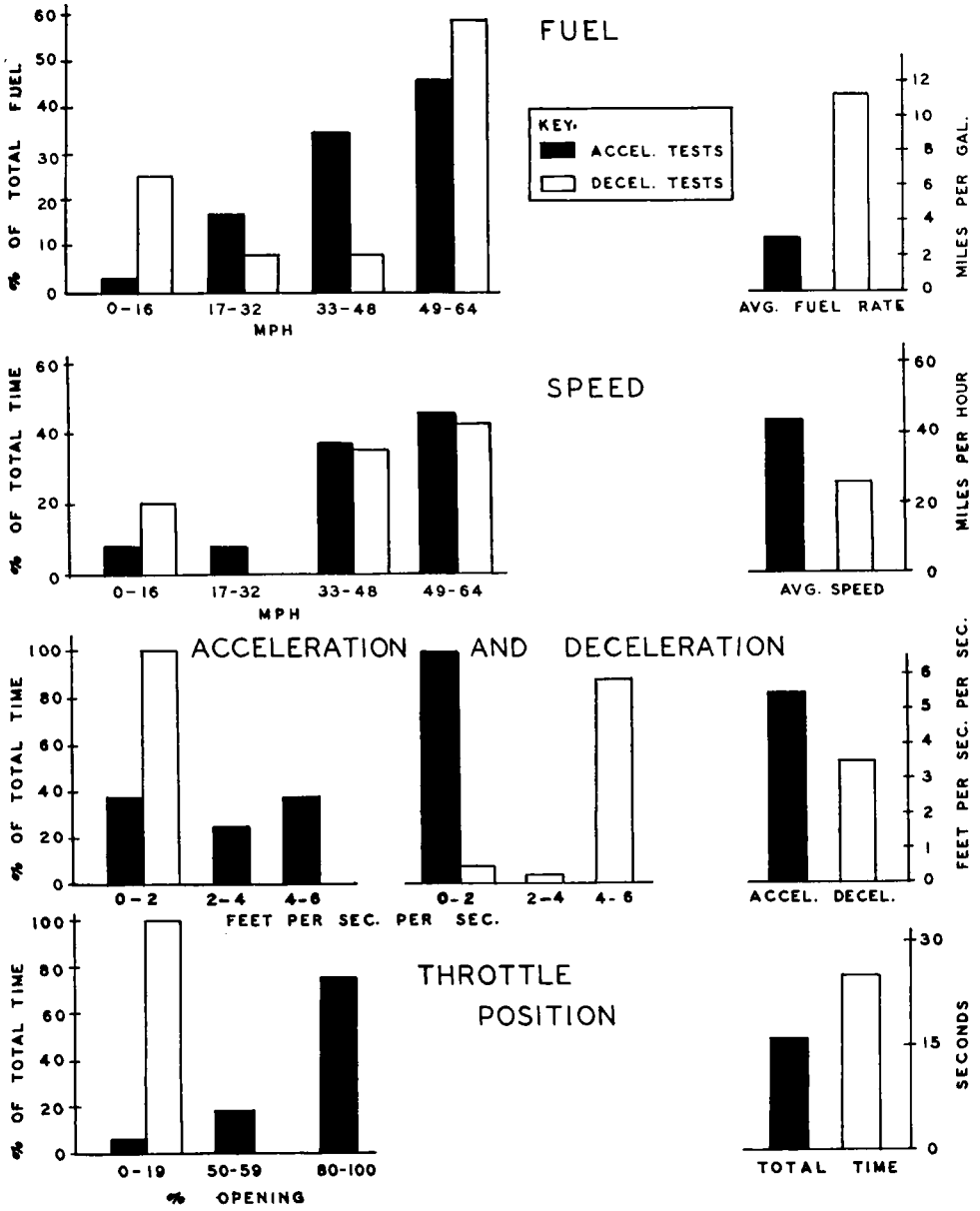


Figure 10. Statistical instrument — acceleration and deceleration tests.

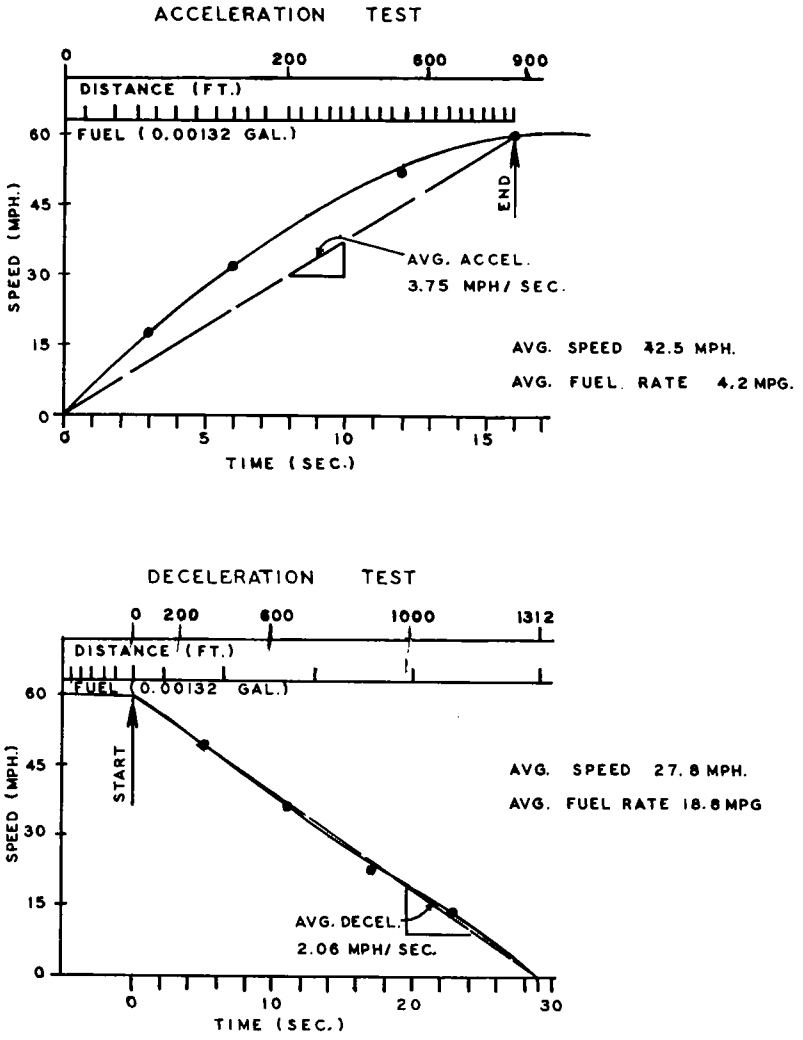


Figure 11. Speed and delay meter — acceleration and deceleration tests.

cated in the figure. It is possible to determine speed, fuel rate, acceleration rate and deceleration rate for any increment of the total test.

The travel time and distance recorder was used in the acceleration and deceleration tests and the data were analyzed on a form similar to Figure 8. The results are shown in Figure 12. Total time, distance traveled, average speed, and acceleration or deceleration rate were computed. Incremental data could be determined, particularly for longer test sections, by actuating the printing mechanism at predetermined points during the run.

Comparison of Travel on a Bypass and Business Route

The results of the data collected using the statistical instrument in the bypass and business route study are shown in Figure 13. The presentation of the data is similar to Figure 10. The only difference in this test was that the average ac-

celeration and deceleration rate could not be computed. Distance was obtained from the vehicle's odometer.

The results of the data collected using the modified speed and delay meter in the bypass and business route study are shown in Figures 14 and 15. Average acceleration and deceleration could not be determined; however, running time, stopped time, average running speed, number and time of brake applications, speed distribution, and minimum and maximum speed were determined. As indicated, the above data can be analyzed for any portion of the total run.

The results using the travel time and distance recorder are shown in Figure 16. Again, the average acceleration and deceleration rate could not be determined; however, running time, stopped time, average running speed, and amount and types of delay were analyzed. The data can be analyzed by increments.

Evaluation of Two Interstate Highways

The results of the data collected using the statistical instrument in the evaluation of two interstate highways are shown in Figure 17. Since the counters of the statistical instrument record only totals for the complete run regardless of the length of the run, the results of all three tests are similar (Figs. 10, 13, and 17).

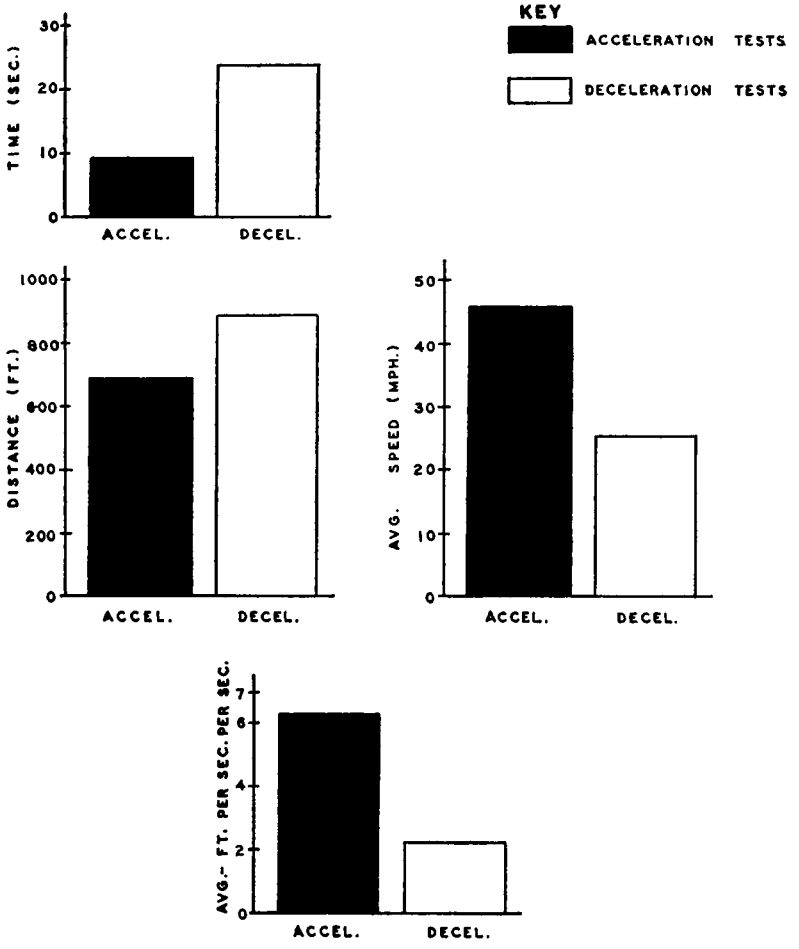


Figure 12. Travel time recorder — acceleration and deceleration tests.

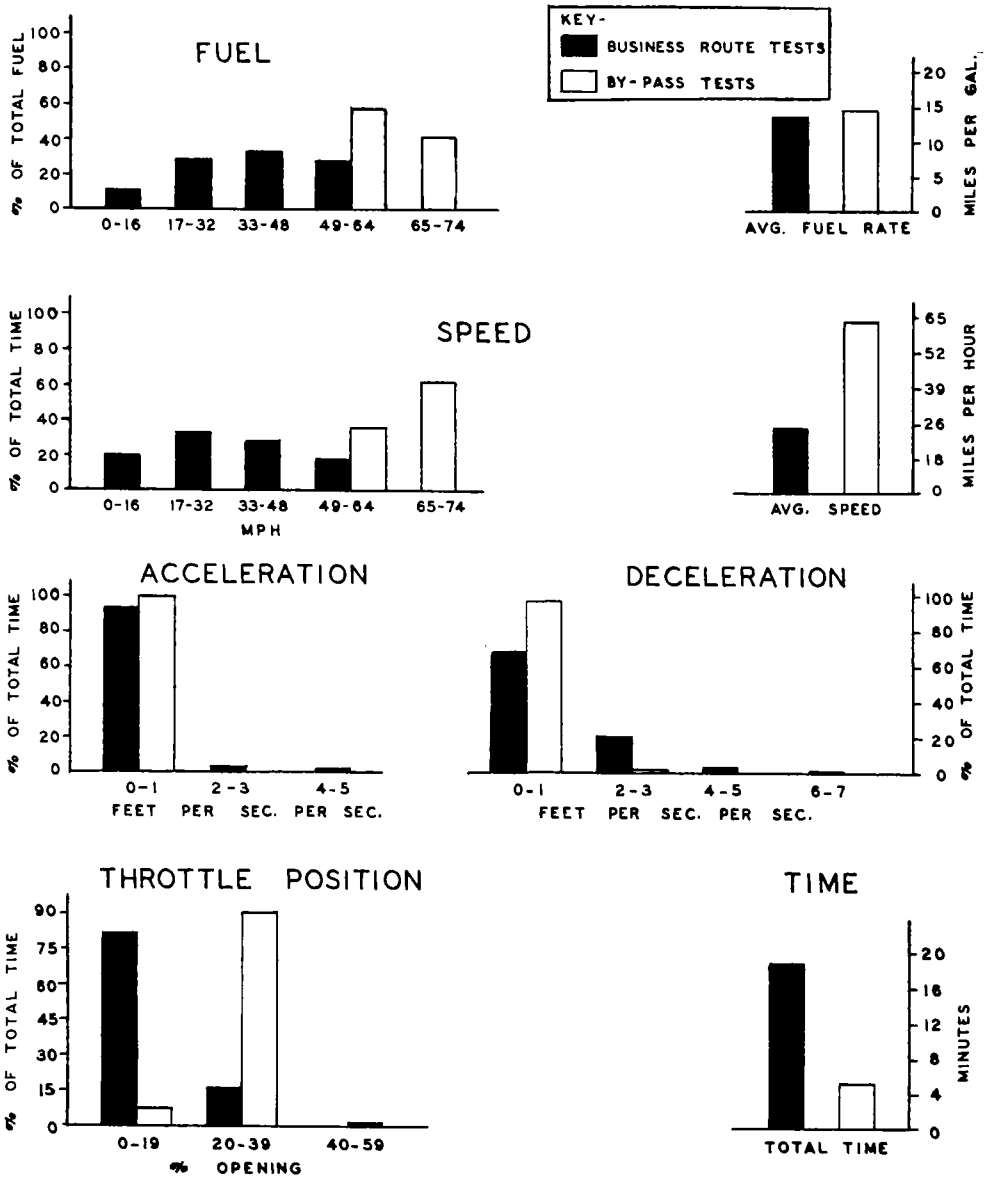


Figure 13. Statistical instrument — bypass and business route study.

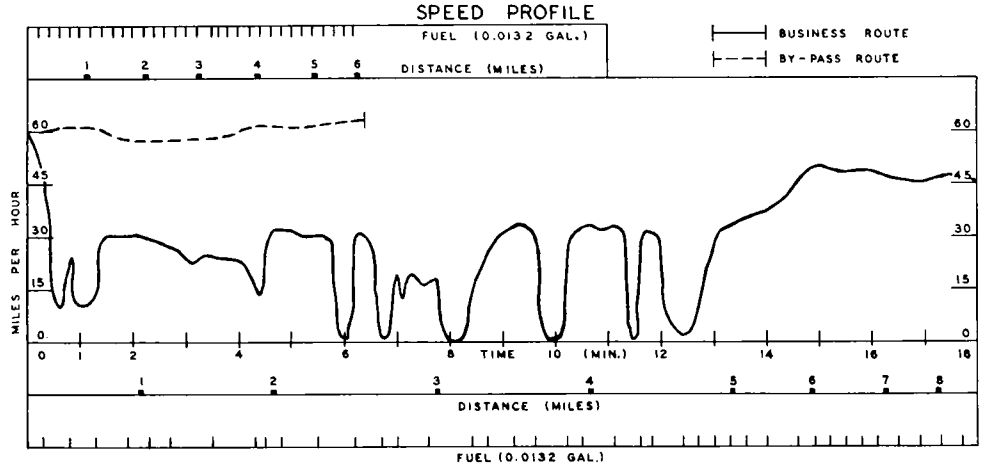
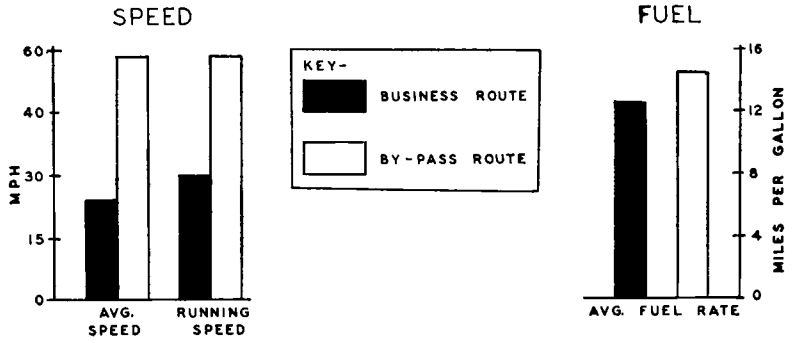
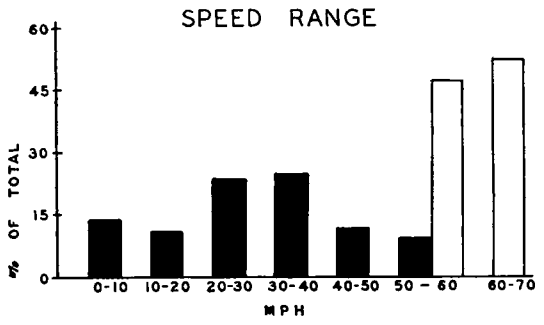


Figure 14. Speed and delay meter — bypass and business route study.





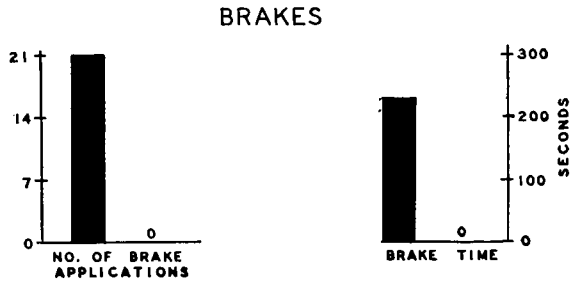


Figure 15. Speed and delay meter — bypass and business route study.

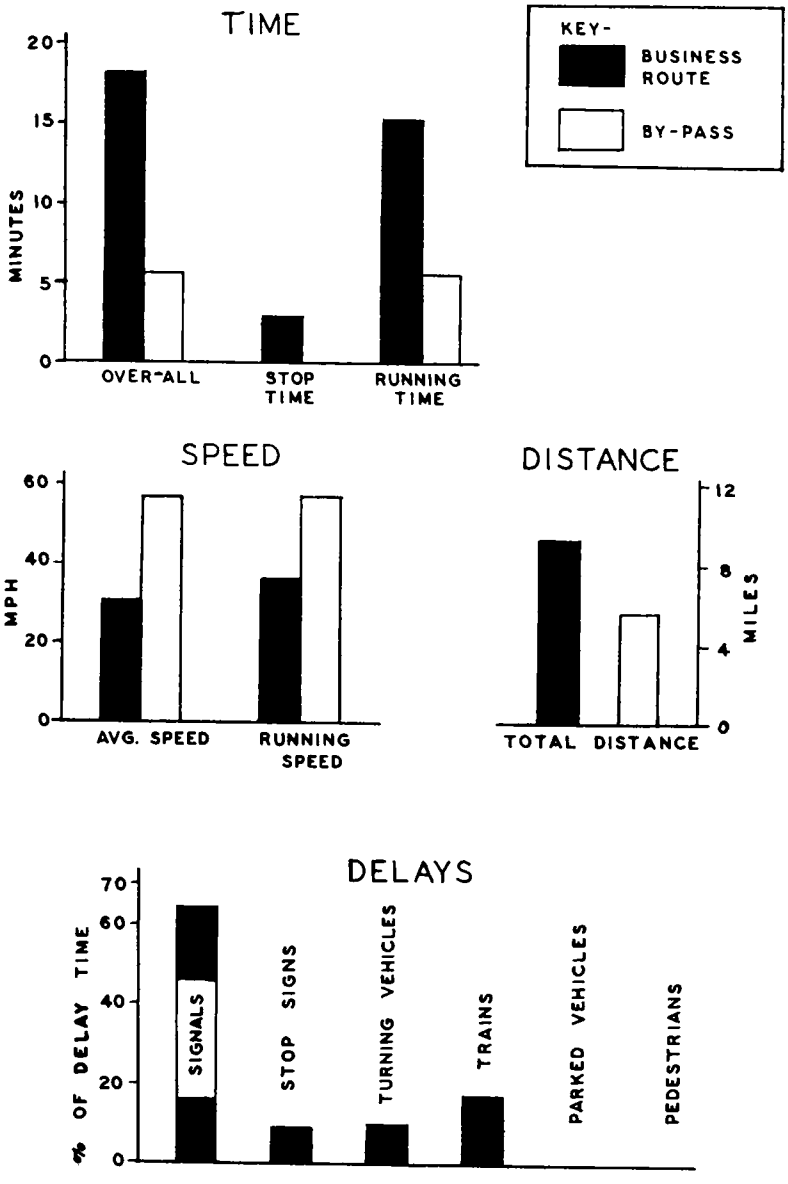


Figure 16. Travel time recorder — bypass and business route study.

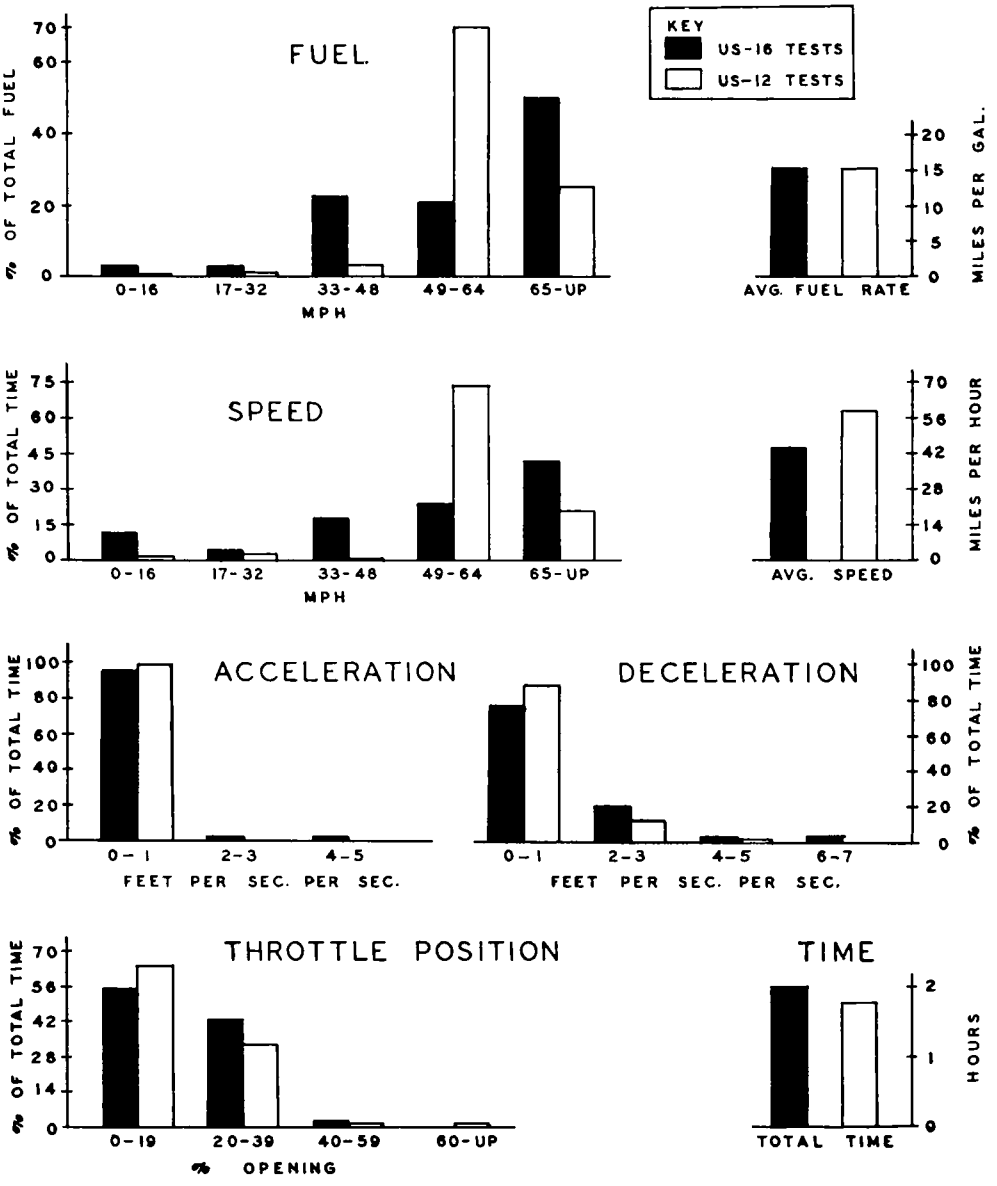


Figure 17. Statistical instrument — interstate route evaluation.

The results of the speed and delay meter data are shown in Figures 18 and 19. U S 16 data are presented by increments of rural and urban areas and U S 12 data are presented by increments of geometric design type. The data permit analysis in any combination of increments, and the starting and terminal points do not have to be predetermined. Figure 19 shows the comparison of average and running speed, average fuel rate, speed range, and number and time of brake applications for the two routes. The data are quite similar to data presented in the bypass-business route study.

The data collected using the travel time and distance recorder are shown in Figures 20 and 21. Figure 20 shows data similar to the speed and delay meter, except average fuel rate by increments is not included. U S 16 data are shown by urban and rural increments; U S 12, by increments of geometric design type. The starting and terminal points of each subsection had to be predetermined to analyze by increments. Figure 21 shows over-all, stopped, and running time, as well as average speed, running speed, distance traveled, and amount and causes of delay. The data are similar to that presented in the bypass and business route study.

EVALUATION OF METHODS AND EQUIPMENT

Each of the three sets of equipment has certain inherent advantages and disadvantages. It became evident in the study that each was especially adapted to particular types of studies (Table 1).

Statistical Instrument

The major advantages of the statistical instrument were the simplicity of analysis and the completeness of the operating characteristics data for the total

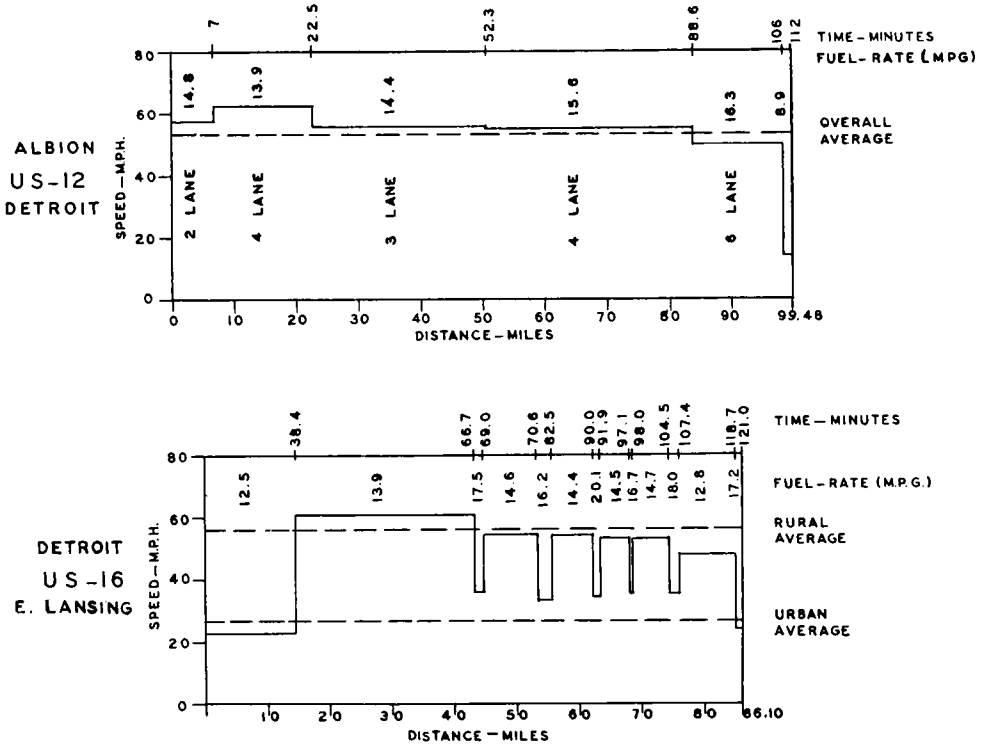


Figure 18. Speed and delay meter — interstate route evaluation.

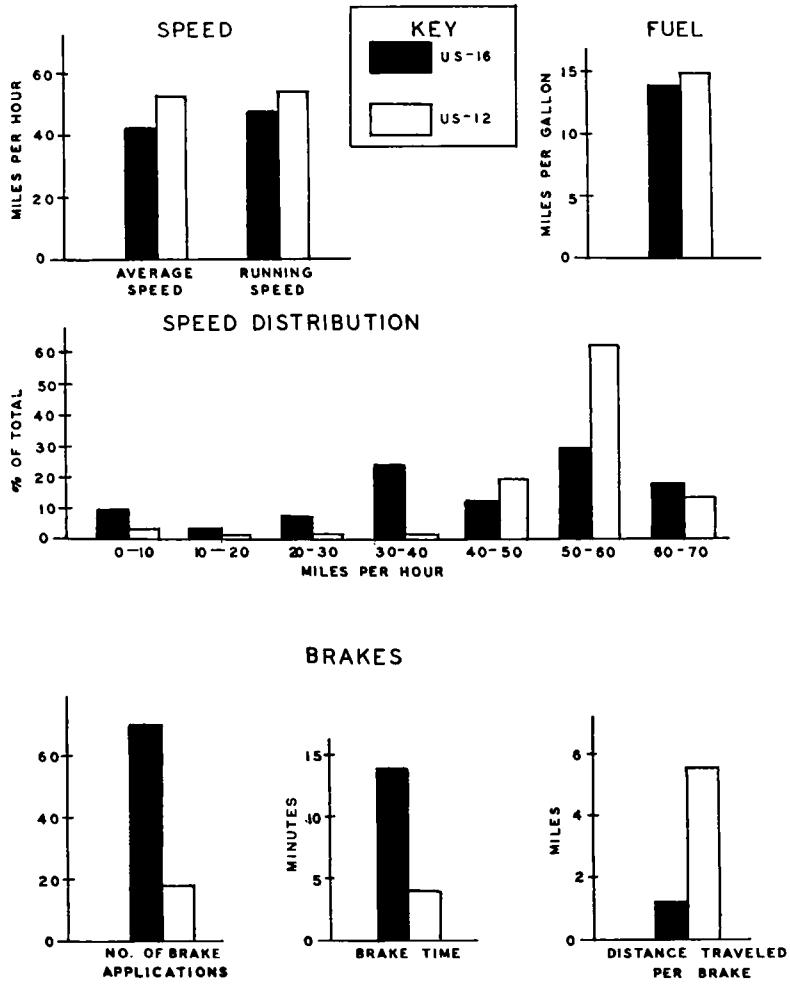


Figure 19. Speed and delay meter — interstate route evaluation.

TABLE 1
SUMMARY OF EQUIPMENT EVALUATION

Compared Items	Statistical Instrument	Speed and Delay Meter	Travel Time Recorder
Equipment cost	High	Moderate	Low
Installation	Difficult	Moderate	Easy
Preparation before run	Little	Some	Some
Field manpower required	2	2	2
Office analysis time	15-30 min	1-10 Hr	½ to 5 Hr
Analysis by increments	No	Excellent	Good
Completeness of data	Good	Excellent	Fair

trip. The analysis time in the acceleration and deceleration tests was only 15 min, and averaged only 30 min in the bypass, business, and interstate routes. The percent of time spent at various acceleration and deceleration rates was available only from the statistical instrument. Since the data were recorded by counters, tapes or graphs did not have to be inserted, ink wells filled, graphical recorders wound, or pens cleaned and changed. Other than warming-up of the instrument, no pre-run time was needed to prepare the equipment for recording.

The primary disadvantage of the statistical instrument was that operating characteristics data could not be analyzed by increments as illustrated in the bypass-business route study and the in-

terstate route study. Furthermore, the statistical instrument is more of a semi-permanent installation and requires skilled personnel for installation and removal. The cost is approximately 10 to 20 times greater than that of the other equipment. Since distance is not recorded, either another instrument measuring distance or the vehicle's odometer (if the accuracy is satisfactory) must be utilized. Another operating problem was the turning on and off of the equipment in regards to the fuel counters. In approaching the test section with the statistical instrument "off" and the fuel valve under the hood "open," the fuel counters recorded fuel consumed before the start of the run. The second person in the car was instructed to reset the individual fuel counter to zero when the beginning point was reached. Similar difficulty was encountered at the terminal point. On short runs, and particularly with a variable speed approach, some error in fuel consumed was realized. On longer runs this error was insignificant. At the present time, no equipment of this type is available commercially.

Several modifications might prove to be beneficial. Some attempts were made to photograph the 51 counters at selected points along the route and at regular increments of time. Difficulty was encountered because of the large spacing between counters and the relatively small-sized digits. With a rearrangement of the counters, the photographic technique might have some possibilities. Counters recording distance traveled at various speed ranges would be helpful in computing rates based upon distance and would also permit computation of fuel rate consumption by speed range. Consideration might also be given to overcoming the difficulty of manipulating the fuel counters at the starting and terminal points.

Modified Speed and Delay Meter

The primary advantages of the speed and delay meter are the pictorial presentation of the operating characteristics and the potential of analyzing any increment of the test run without predetermining which increments will be ana-

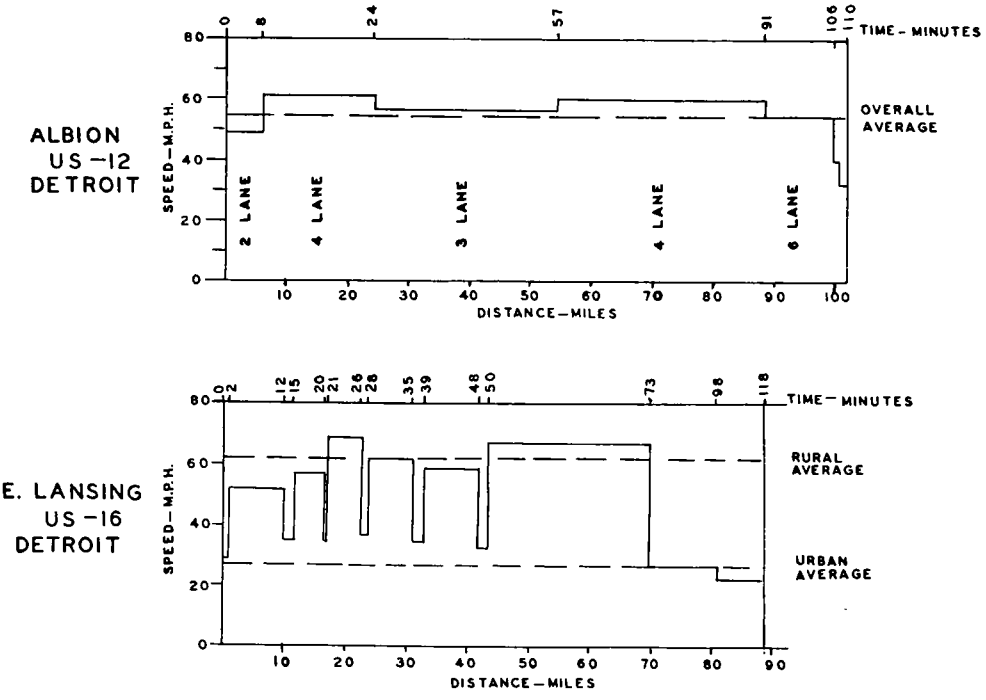


Figure 20. Travel time recorder — interstate route evaluation.

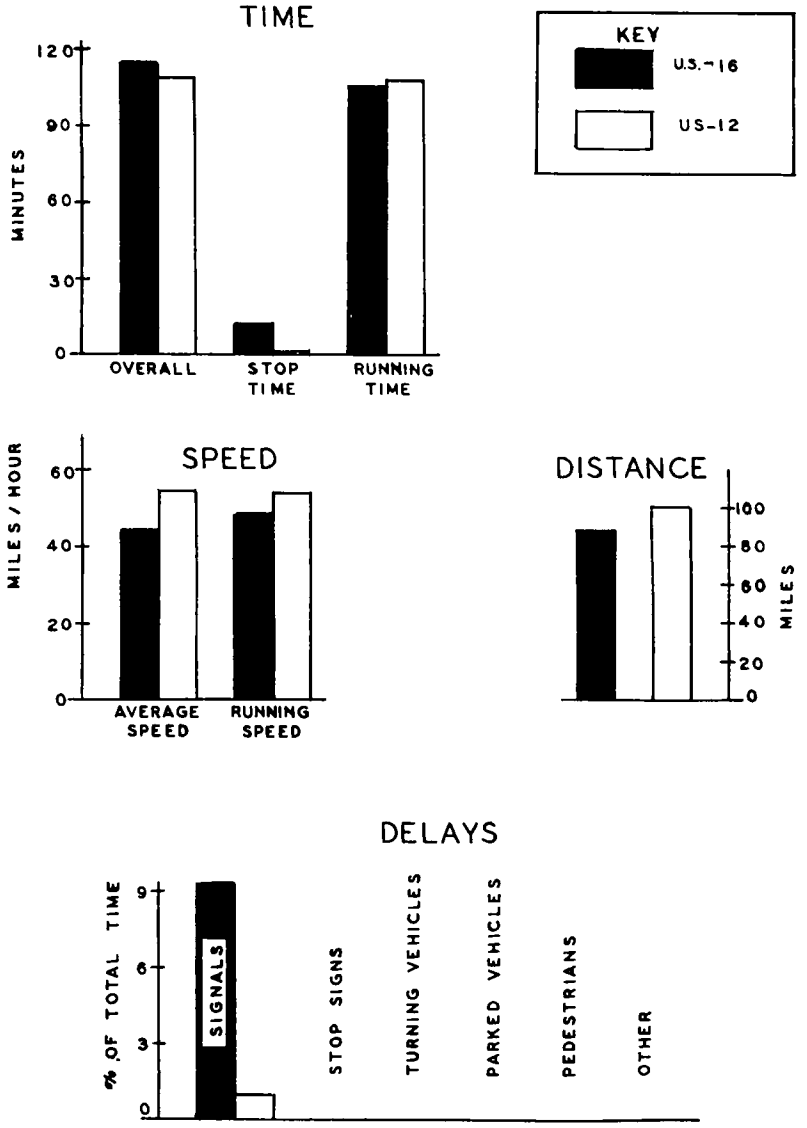


Figure 21. Travel time recorder — interstate route evaluation.

lyzed. The graph is a permanent record of the particular test run, and is easily understood. Before-and-after studies are particularly adapted to the speed and delay meter. It pinpoints exact locations where operating characteristics change. This instrument can be quickly removed from the test vehicle.

A major disadvantage of this instrument is the relatively greater amount of analysis time, particularly on longer routes when analyzing by increments. The analysis of the acceleration and deceleration tests and bypass-business route study required approximately 30 to 45 min per test run, while the interstate route required 10 hr for analysis. Some difficulties were encountered when the

end of the graph was reached in the middle of the test run and also when pens were occasionally clogged before or during a test run.

No further modifications are suggested other than a fuel meter connection and a tail light circuit connection.

Travel Time and Distance Recorder

The primary advantages of the travel time and distance recorder are its capacity to collect data by increments of the test route and its relatively lower cost. It can be quickly removed from the test vehicle and, on short test sections with few intermediate control points, the data can be analyzed in 15 or 30 min per test section.

The major disadvantage is that it records only time and distance, and does not include fuel, acceleration, brake, or deceleration data. There must be an adequate length of tape, before each run, and the printer must be operating satisfactorily. The analysis of the tape on long distance test runs with numerous control points is time consuming; the analysis of the interstate routes required 5 hr per test run.

As a modification, it might be advantageous to print fuel consumed with each time and distance printing. Furthermore, one of the code buttons could be actuated by the application and release of the brake pedal to record the number of brake applications and time of each application.

SUMMARY

The purpose of this paper has been to compare the statistical instrument, speed and delay meter, and travel time recorder by using each in acceleration and deceleration tests, a bypass and business route study, and an interstate route evaluation study. The study revealed that each instrument gave dependable and satisfactory service, and could be used effectively in a great number of traffic studies. It became apparent that each had certain advantages and disadvantages. The speed and delay meter and the travel time recorder are currently available commercially.

REFERENCES

1. Carmichael, T. J., and Haley, C. E., "A Study of Vehicle, Roadway and Traffic Relationships by Means of Statistical Instruments," *Proc. H.R.B.*, Vol. 30 (1950).
2. Haley, C. E., "Statistical Instruments for Traffic Engineers," *Traffic Eng.*, 21:12 (September 1951).
3. Bone, A. J., "Travel Time and Gasoline Consumption Studies In Boston," *Proc. H.R.B.*, Vol. 31 (1952).
4. Saal, C. C., "Operating Characteristics of a Passenger Car on Selected Routes," H.R.B., Bull. 107 (1955).
5. May, A. D., Jr., "Economics of Operation on Limited-Access Highways," H.R.B., Bull. 107 (1955).
6. Stonex, K. A., "Survey of Los Angeles Traffic Characteristics," *Proc. H.R.B.*, Vol. 36 (1957).
7. Mueller, E. A., "Recent Speed and Delay Instruments," *Traffic Eng.*, 25:3 (December 1954).
8. Greenshields, B. D., "Quality of Traffic Transmission," *Proc. H.R.B.*, Vol. 34 (1955).
9. Institute of Traffic Engineers, "Traffic Engineering Handbook," Second Edition, 1950.
10. Berry, D. S., "Evaluation of Techniques for Determining Over-All Travel Time," *Proc. H.R.B.*, Vol. 31 (1952).
11. Berry, D. S., "Techniques for Measuring Over-All Speeds in Urban Areas," *Proc. H.R.B.*, Vol. 31 (1952).
12. Youngs, R., Jr., "The Traffic Chronograph," *Traffic Engineering*, May 1953.
13. Berry, D. S., and Van Til, C. J., "Traffic Delays-Measurement-Equipment," *Traffic Engineering*, 25:3 (December 1954).

14. BERRY, D. S., "Field Measurement of Delay at Signalized Intersections," *Proc. H.R.B.*, Vol. 35 (1956).
15. CLIFFORD, E. J., "The Measurement of Traffic Flow," *Traffic Engineering*, 26:3 (March 1956).
16. BARRIERE, J., "Analysis of a Typical Speed and Delay Study," *Proc.* Canadian Good Roads Assoc., October 2-5, 1956.
17. "M.S.U.'s Safety Dream Car," *Public Safety*, May 1957.