Development and Use of Maximum-Car Technique for Measuring Travel Time

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During recent years many traffic engineers have been concerned with a need for more accurate and less costly and time-consuming methods of measuring travel time and delay along sections of roadway. Various techniques—the license-plate-matching method, the average-car method, and the floating-car method—have been employed with varying degrees of success, depending primarily on local conditions and available funds. More modern techniques using photography have also been tested.

In an attempt to attain a more satisfactory technique of measuring travel time and delay, the "maximum-car" method was developed within the Highway Research Program conducted by the Civil Engineering Department at North Carolina State College. The method was actually an outgrowth of a more comprehensive research effort investigating the effects of commercial roadside development on traffic flow conducted over a two-year period in cooperation with the North Carolina State Highway Commission and the U. S. Bureau of Public Roads.

This report traces the development of the maximum-car technique, explains the theory on which it is based, and offers suggestions regarding possible applications in the analysis of traffic problems.

Essentially, the method exploits a "test vehicle" for measuring travel time through a given section of roadway. Physical occurrences within and adjacent to the traffic stream affect speed which, in turn, can be related to some standard datum and measured. It is believed that this approach, when properly understood and used, can produce far more significant travel time and delay information than is now possible under current practices.

One commonly employed method of calculating travel time is the "average-car" approach. This car is driven at speeds which, in the opinion of the driver, are representative of the average speed of all the traffic in the stream. Excellent results have been obtained from the use of this method. In research at North Carolina State College, the average-car method was compared with the "license-plate-matching" method, and the average car results were found to be a valid measure of the average speed. The license-plate-matching method, which is a positive measure of the speed of a sample of vehicles from the traffic stream, was used as a standard to check the accuracy of the results of the average-car method. Ninety-five out of 100 times the average car gave the "true" average speed within ±2 mph.

Another test car, employed in traffic analysis, is the "floating car." The driver of this car is instructed to pass as many vehicles as pass the test vehicle. This method is used, most successfully, in low volumes and over long distances, although it has several obvious disadvantages.

The acceptance and use of these two methods in determining average speeds of traffic flow substantiate the validity of the test-car approach in traffic analysis. As will be explained later, these presently used methods have certain disadvantages. To overcome these disadvantages, the maximum-car technique was developed as a test-vehicle approach to the measurement of traffic-stream characteristics.

A search of the literature in this field indicated that little progress has been achieved using a maximum-car approach to travel-time measurement. Donald S. Berry and Forest H. Green, in their investigations of techniques for measuring over-all speeds in urban areas, dealt briefly with a method called the "faster test run." The driver of
this test car maintained maximum speed consistent with safety and existing traffic regulations. Berry and Green, in their work, were primarily interested in average speeds and travel time for vehicles through specific test sites. They concluded that the travel time and speed of this faster car were not representative of the average vehicle in the traffic stream. This conclusion was also substantiated by preliminary studies during research at North Carolina State College.

DEFINITION

For the purposes of this study, the maximum car was defined as a test car driven, consistent with safety, at the posted speed limit unless impeded by actual traffic conditions. For valid comparative results it was essential that the driver of this car understand the definition and attempt to drive with the same attitude in all testing. A safe level of operation was maintained at all times by observing minimum safe-following distances, minimum passing distances, and reasonable acceleration and deceleration. The driver's attitude might be described as that of a businessman on a 300-mi trip, during which time he observes minimum safe-driving practices and desires to drive at the speed limit when not impeded. This qualification of the driver's attitude makes it imperative that the same driver perform all testing for a particular analysis.

In an effort to determine the effects of auto performance characteristics on speeds, automobiles of different horsepower and age were compared using the same driver. The variation resulting from the use of different automobiles was small; but, to eliminate as much error as possible, the same car should be used throughout a particular analysis.

In addition to the requirements for a standard car and driver, the test vehicle must have no distinctive markings such as seals, permanent license tags, or antennas that might indicate a police vehicle and thus arouse the suspicion of a motorist along the route of travel.

The maximum car, as defined with the stated restrictions, gives a constant measurable consequence that is standard in any given set of physical conditions. The speed reduction or delay that is recorded by the maximum car is a result of physical factors caused by roadway characteristics and the traffic stream. The psychological factors are minimized and standardized by adherence to the definition. The only attempt to measure psychological effects on the traffic stream was to subtract the physical effect, measured by the maximum car, from the total effect, measured by the average car, to obtain the aggregate psychological effect.

THEORY

The basic theory of the maximum-car technique is simply that the method is a measuring device with which it is possible to gage the effects of physical factors on traffic operations. As stated in the definition, the maximum car is operated at the posted speed limit unless impeded by some physical occurrence, such as a slow-moving vehicle or a turning movement by a preceding vehicle. The speed limit acts as a datum from which performance is measured. If a left turn takes place in front of the maximum car, under a given set of conditions, the effect is the same each time these conditions are encountered. Hence, the results will be standard from pass to pass as well as from site to site. In comparison, the only datum remotely possible in the average-car method is the average speed. At best this is a sensitive variable. Under a standard set of conditions and with a mere variance of the population of drivers within the traffic stream, the effect recorded by the average car will change.

The absolute value of the recorded maximum speed is of little value because it represents the driving characteristics of only one man. Hence, this maximum-car method can be used only as a measuring mechanism in the analysis of traffic behavior.

One other important aspect of the theory is the number of runs required to constitute a reliable test. This information should be determined by pilot studies. From data obtained in such studies, the number of runs required to constitute a test can be determined. The findings of this study were based on 2,000 passes through 10 test sites. The total period of time to complete a test is governed by driver fatigue and changing characteristics of the traffic.
DATA COLLECTION EQUIPMENT

A 1959 blue Ford with white sidewall tires, a nongovernmental North Carolina license plate, and automatic transmission was used as the maximum car in this research. As far as could be determined, this car did not arouse undue suspicion during operation in the traffic stream. The automatic transmission provided smooth acceleration for the speed curve on the recorder chart.

The maximum car was equipped with the Model M, Electro-Matic Traffic Speed and Delay Recorder (Fig. 1). This instrument is manufactured on special order by the Automatic Signal Division of Eastern Industries in Norwalk, Connecticut.

The speed and delay recorder transcribes a continuous chart (Fig. 2) of the speed of the vehicle in which it is installed. This speed can be plotted against either time or distance. The time is recorded in 6-sec and 1-min increments, while the distance traveled is plotted in 200- or 400-ft stations. Six coding pens permit the recording of

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Figure 1. Installation of speed and delay recorder.
events encountered during testing. An interchangeable set of drive gears permit varied scales of speed versus time or distance. The recorder was mounted on a platform built into the rear seat of the test vehicle. The speedometer cable of the test vehicle was extended to the recorder and operated both the recording tachometer and the dash-mounted speedometer. Electric power was received from a cigar-lighter plug mounted on the rear floor tunnel. The code buttons were operated by an observer seated in the right-front seat (Fig. 3) who had an unobstructed view of the road ahead or of the chart being produced by the recorder. This observer also used a stop watch to measure travel time through the site. Traffic volumes were obtained from another observer along the site.

FACTORS AFFECTING THE MAXIMUM CAR

Physical and Psychological

To analyze the effects of commercial development on traffic operations, restrictions to traffic were divided into two basic categories—physical and psychological. The physical restrictions are the tangible elements that can be measured quantitatively and examined. The psychological restrictions are, for the most part, the mental attitudes of the driver. For example, the driver may not be accustomed to the speed limit or may feel unsafe at that rate.

Use of the maximum car, as defined, eliminates the psychological factors and records only the effects of the physical restrictions. An exception to this condition develops when the maximum car is operated in extremely high volumes. Under such conditions, the maximum car is unable to pass; therefore, the maximum car is forced to record psychological restrictions being applied to the traffic stream.

The following relationships are useful in the comparison of average and maximum speeds:

1. Any average car could become a maximum car if its driver desires to overcome the psychological restrictions. Therefore, the average speed could equal the maximum speed.
2. The maximum speed without the physical or other restrictions is equal to the speed limit.
3. The operating speed is equal to the speed limit minus the restrictions.

All the data collected by the maximum-car method were analyzed to determine the effect of each physical restriction on the speed of the maximum car. These results are given herein and are representative of the effects that would be found in any maximum-car operation.

**Speed and Volume**

An analysis of the maximum-car speeds in commercially developed and undeveloped...
sections of roadway versus traffic volume was accomplished to explore the effect of traffic volume on the speed of the maximum car. A least-squares-regression fit was made for the speed and volume data, and the equations of the curves were computed for the developed and undeveloped sections. A linear model was used that had the form:

\[ y = a - bx \]

in which

- \( y \) = speed of the maximum car per 15 min,
- \( a \) = slope intercept,
- \( b \) = constant, and
- \( x \) = traffic volume in 15-min intervals.

The curve for the developed section is based on 88 observations in 9 test sites and is shown in Figure 4. The equation of this curve is

\[ y = 55.01 - 0.02x. \]

The curve for the developed section is based on 191 observations in 9 test sites and is also shown in Figure 4. The equation of the curve is

\[ y = 53.56 - 0.04x. \]

It is interesting to note that an equal volume change in both sections produces a greater speed change in the developed section. That is, the slope of the curve for the developed section is equal to -0.04, whereas the slope for the undeveloped section is equal to -0.02. The negative slope of each indicates that increasing volumes decrease speed. The differing rate of effect, shown by the comparison of the two slopes, indicates that something other than volume affects the speed of the maximum car in commercially developed sections of roadway.

Very narrow confidence limits were obtained for these curves. The 95 percent confidence interval is shown for the curves in Figure 4. This high degree of confidence was possible because of the low variance and a large number of observations. Within the volume ranges used in this analysis, the average maximum speed in either section can be predicted with a high degree of accuracy.

**Impedance**

The data from the speed and delay recorder concerning the effects of impedance on the maximum car were analyzed in several ways. The most significant summary of this analysis is presented in Figure 5. The following conclusions can be drawn from this analysis:
1. Slow-moving vehicles are by far the largest cause of impedance (69 percent). The only other significant impedances are the right turn (14.9 percent) and left turn (11.6 percent) off the road in front of the impeded vehicle. Figure 5 is a graphical representation of these factors based on the impedance code found in Figure 6.

2. The effect of impedance tends to increase as volume increases with one notable exception. This exception can be explained by the fact that high volumes reduce speeds; therefore, the magnitude of the speed change from the previous speed is not as large.

3. Left turns cause more interference in terms of seconds of delay and speed change than do right turns.

4. Left turns and right turns off the highway affect the traffic over a shorter distance than do slow-moving vehicles.

5. Left turns cause the largest speed change.

These conclusions are based on 8 hr of running time per site for nine sites, or a total of 72 hr of testing.

**Impedance and Speed**

To investigate the relationship between impedance and speed, plots were made of speed versus number of slow-moving vehicles encountered and speed versus number of turning movements encountered. These plots indicated the possibility of a linear relationship between these variables. A least-squares-regression fit was made for these two relationships using the linear model:

\[ y = a - bx \]

in which

- \( y \) = average maximum-car speed per 30 passes,
- \( a \) = intercept,
- \( b \) = slope, and
- \( x \) = total number of turning movements encountered per 30 passes, or the total number of slow-moving vehicles encountered per 30 passes for the second graph.

For each of these curves the correlation coefficient, \( r \), was computed. This coefficient acts as a measure of the linear relationship of the two variables.

The average maximum-car speed versus the number of slow-moving vehicles encountered per 30 passes curve is shown in Figure 7, for which the equation is \( y = 55.08 - 0.366x \), in which the computed \( r \) is equal to -0.67. The 95 percent confidence level is also shown in Figure 7.

The average maximum-car speed versus number of turning movements encountered per 30 passes curve is shown in Figure 8, and the equation is \( y = 51.43 - 0.297x \), in which the computed \( r \) is equal to -0.43. The 95 percent confidence level is also plotted for the curve in Figure 8.

A comparison of the slopes of these two curves indicates that speed is more sensitive to changes in the number of slow-moving vehicles than in the number of slow-moving vehicles encountered.
vehicles encountered than to the number of turns encountered. Also, the association
between the average maximum-car speed and the number of slow-moving vehicles is
more nearly perfect than in the speed versus turning movements relationship. This
fact is seen by the comparison of correlation coefficients.

USE OF THE MAXIMUM-CAR METHOD IN TRAFFIC RESEARCH

Application of the maximum-car method would appear to have great potential in
traffic engineering research. Four specific examples are cited in the following dis­
cussion to explain the possibilities of the method.

Delay Studies

The maximum-car method was used in commercial roadside development research
to obtain a complete analysis of physical impedance on the traffic stream. The follow­
ing information was received by operating the maximum car through developed sections
of roadway:
1. The type of impedance encountered.
2. The magnitude of the speed change for each impedance, both from the speed
limit and from the speed immediately preceding the impedance.
3. The distance over which the speed is affected by each impedance.
4. The seconds of delay caused by each impedance.
5. The location of each turning-movement impedance.
6. Speed of the maximum car.

The impedance data were obtained from the charts produced by the speed and delay
recorder. With this information it was possible to make a detailed analysis of each
type of impedance and to show its relative effect on the traffic stream.

This method could be applied to urban-delay studies as an effective measuring device.

![Figure 7. Effect of slow vehicles on maximum speed.](image)

![Figure 8. Effect of number of turns on maximum speed.](image)

Certain modifications would be required to adjust for the effects of traffic signals and
reduced speed limits. If the average-car data were employed as a supplement to the
maximum-car data, it would be necessary to investigate the effect of the lower speed
limit restrictions on average speed. The case might arise where the average speed
might be above the speed limit. Such a condition would result in higher average-car
speed than maximum-car speed. This negative differential might cause complications
in the data analysis and should be investigated before using the test results.

Before-and-After Studies

The maximum-car method has proved itself most useful in before-and-after studies.
In the spring of 1959, this method was used in a study performed on US 70 east of
Asheville, N. C. Prior to extensive revisions in the traffic control devices and pavement markings, an operational study was conducted on a 12-mi section of this highway. After completion of the revisions and after time had elapsed for driver reorientation, an "after study" was conducted in an attempt to measure any changes in traffic operations. In this particular instance, passing opportunities and turning movements were recorded in detail. The results of this study were used to evaluate the feasibility of the continued use of these changes and their possible use in other sections of the state.

Route Selection Studies

The maximum-car method of travel-time measurement might be employed in route selection studies for both urban and rural conditions. The method would employ the theory that the maximum-car operation is a standard datum from which to measure varying effects caused by differing physical conditions. In addition to these physical effects recorded on the speed and delay recorder chart, valuable user-cost and user-convenience data also could be collected.

The resulting field data could be analyzed to determine the detrimental effects of the physical make-up of one route as compared with an alternate. With regard to its user benefits and physical characteristics measured by the maximum car, this factual comparison would result in an intelligent selection of the best route.

CONCLUSIONS

Probably the outstanding single feature of this maximum-car method in traffic analysis is its versatility. As previously discussed, the method can be adopted to a wide variety of investigations which are essential to the decision-making process of the traffic engineer. Without this method of travel-time measurement and analysis, an adequate investigation of the effects of intensive commercial roadside development would have been a more difficult task. Its use in before-and-after and congestion studies has been explored and found most useful. The adaptation of the maximum-car method to route selection and roadway geometry studies may become effective uses of this procedure. The conclusions drawn from the data collected by this method are based on physically measured facts and not mere hypothesis. It is hoped that this endeavor has laid a foundation on which to base a great variety of new and improved studies.

It is appropriate to re-emphasize the importance of the fact that the success of the maximum-car method is dependent on the mental attitude of the test-car operator. Care must be taken to insure that the operator of the maximum car does not traverse a particular site to the extent that he become over-familiar with the physical conditions of the roadway. Driver fatigue is another important consideration from the standpoint of both safety and driver consistency. The maximum-car observer must become familiar with the established recording procedure, and it is desirable that one observer do all the recording in a study. Once the data is collected, a specific procedure must be established and adhered to in the reduction of the field data to an analytical form. Consistency is imperative in any measuring process, and the maximum-car method is essentially a measuring device.

The lack of basic background data is one of the major criticisms of present-day solutions to traffic problems. It is anticipated that the maximum-car method will be helpful in the collection of this much needed basic information; thereby guiding the traffic engineer to the proper solutions of particular problems.