Studying Traffic Capacity by New Methods

Photographic Surveys of Automobile Travel on Ohio Roads Are Illuminating

By BRUCE D. GREENSHIELDS

ASSOCIATE MEMBER AMERICAN SOCIETY OF CIVIL ENGINEERS
RESEARCH ENGINEER, TRAFFIC BUREAU, OHIO STATE HIGHWAY DEPARTMENT, GRANVILLE, OHIO

FOR years the standard method of taking traffic counts has been to employ observers with stop watches and tally sheets. The new method devised by Dr. Greenshields utilizes a motion picture camera designed to take pictures intermittently, at frequent intervals. Superposed on each exposure is a log record showing the exact time, data, and other details. Besides this scale of time, a scale of distance is fixed by markers on the road itself. Such observations on 22,000 vehicles were taken in Ohio during the summer of 1934 and have since been analyzed in detail by groups of 100 cars. As a result, new relations between speed, spacing, and total density have been found. Up to a density of perhaps 600 vehicles an hour, there were no delays due to traffic. In every instance the average unhampered speed was from 42 to 44 miles an hour on pavements. On two-lane roads the maximum capacity was found to be about 2,500 vehicles an hour, at a speed of about 22 miles an hour. This method of making a graphical tally, with its valuable potentialities, should prove a boon to engineers in the making of traffic analyses.

UNTIL recently traffic surveys have been inadequate for determining the capacity of a roadway of a given width and type. The count and stop-watch system cannot be adapted to obtain complete information, especially if numerous automobiles are moving in opposite directions at a variety of speeds. The photographic method of studying and analyzing traffic problems, as here described, is comparatively new. Thus far it has proved highly successful in overcoming the difficulties of the previous systems.

For one thing, the eye of the camera is accurate, and the instantaneous records, or pictures, can be made the basis of a complete study. The pictures taken by a 16-mm motion picture camera not only show the number of cars passing in a given time, but also reveal the type of cars, the paths of their movements, and their rate of travel. A few simple methods of interpretation disclose the desired information.

To take the pictures, the camera should be approximately 300 ft from the roadway and if possible at right angles to it, thus bringing about 125 ft of the highway within range of the lens. By means of a clock arrangement with an electric switch, the pictures are then taken automatically. For convenience, the time interval between pictures is arbitrarily set at 88 sec, so chosen because a vehicle traveling 1 mile per hr would advance 1 ft in 1/88 min.

White markers are placed on both sides of the road, usually 50 ft apart, longitudinally, to give a scale for the center line of the road. In the case of a two-lane roadway, the scale can be satisfactorily shown when the films are projected by vertical parallel lines equally spaced, which are drawn on the screen. Thus the same scale lines are used for all the films, the throw of the lantern being changed so that the scale lines will fit films taken at different locations. For multiple lanes or where the pictures are not taken at right angles to the road, it may become necessary to construct a scale with converging lines. But this is always possible if enough marked points are in the field of view.

In addition to the markers, each picture shows a bulletin board and clock in the immediate foreground, giving the time, date, location, type and width of pavement, film number, time interval between frames, and weather conditions. Thus the pictures constitute a complete and permanent record which may be analyzed at any time or re-checked for information that may have been overlooked in the first analysis.

![Fig. 1. Speed and Spacing of Vehicles](image)

Point of Zero Velocity Is Average of 143 Observations. Each Other Point Is Weighted Average of 99 Observations. From Proceedings, Highway Research Board, 1933, Page 393

![Fig. 2. Graphic Comparison of Formulas for Determining the Relation Between the Number of Vehicles Passing a Given Point and Their Rates of Speed](image)

Reproduced from Proceedings of the Highway Research Board, 1933, Page 394

Civl Engineering 1935, Vol 5, No 5
shown. In the first, at the top, the rear car appears at position 58 on the scale. In the second picture it is at position 72 and has advanced 34 ft, which means that it is traveling 34 miles an hour. From the first picture it is seen that this car is 82 ft behind the one in front, measured from center to center. From the speed and time at which the cars appear the spacings may be calculated.

Obviously the usual speeds and density of traffic are a measure of the comparative ability of various types and widths of highway to facilitate traffic. It is evident that roads permitting the highest available speeds will carry the maximum amount of traffic.

A typical set of data representing free-moving traffic on an uncongested roadway was obtained on State Route 2 (U. S. 6) 4.9 miles east of Vermilion, Ohio. This section of new concrete highway is 30 ft wide. Profilometer readings showed an average of only 12 variations per mile in excess of $\frac{1}{4}$ in. in 10 ft. This road is straight, and the view is unobstructed for a long distance, so that it provides an ideal place for high speeds. Its traffic shows the normal tendencies of travel, or what the average driver does on a smooth roadway free from interference from other vehicles. At no time did the road carry sufficient traffic to cause congestion. The data are given in Table I.

**Table I. Significant Traffic Observations on U. S. 6, EAST OF VERNILION, OHIO**

<table>
<thead>
<tr>
<th>Density in Vehicles Per Hr</th>
<th>Number of 100-Vehicle Groups</th>
<th>Mean &quot;Smoothed&quot; Speed</th>
<th>Percentage of Trucks</th>
<th>Percentage Traveling in One Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>279</td>
<td>1</td>
<td>42.5</td>
<td>6.0</td>
<td>45.0</td>
</tr>
<tr>
<td>308</td>
<td>2</td>
<td>41.6</td>
<td>7.5</td>
<td>54.5</td>
</tr>
<tr>
<td>223</td>
<td>6</td>
<td>42.9</td>
<td>8.7</td>
<td>53.9</td>
</tr>
<tr>
<td>330</td>
<td>3</td>
<td>40.7</td>
<td>9.1</td>
<td>54.9</td>
</tr>
<tr>
<td>349</td>
<td>14</td>
<td>43.7</td>
<td>10.6</td>
<td>54.1</td>
</tr>
<tr>
<td>564</td>
<td>7</td>
<td>43.0</td>
<td>8.9</td>
<td>54.7</td>
</tr>
<tr>
<td>393</td>
<td>16</td>
<td>42.5</td>
<td>8.0</td>
<td>55.5</td>
</tr>
<tr>
<td>410</td>
<td>6</td>
<td>42.0</td>
<td>8.7</td>
<td>53.6</td>
</tr>
<tr>
<td>441</td>
<td>11</td>
<td>40.7</td>
<td>9.6</td>
<td>54.0</td>
</tr>
<tr>
<td>494</td>
<td>1</td>
<td>43.2</td>
<td>9.9</td>
<td>55.0</td>
</tr>
<tr>
<td>559</td>
<td>1</td>
<td>40.7</td>
<td>8.0</td>
<td>57.0</td>
</tr>
<tr>
<td><strong>AV. 379</strong></td>
<td><strong>SUM 68</strong></td>
<td><strong>42.4</strong></td>
<td><strong>7.5</strong></td>
<td><strong>54.4</strong></td>
</tr>
</tbody>
</table>

Averages were computed for the total 68 groups. The term "mean smoothed speed" needs explanation. This speed was taken from a curve so drawn on arithmetic probability paper as to give a "smoothed" value. It will be noted that the vehicles were studied in groups of 100 each. If the number passing in any particular time interval, such as 15 min, is taken as a unit for study, it may be found that there are 50 passing in one case and 200 in another case. Fifty vehicles are not sufficient to give a true average, and their performance should not be compared with that of the 200. By referring to the table it is seen that a group of 100 vehicles gives about the same average speed as a much larger group. Therefore such groups were deemed satisfactory for comparison.

On a roadway the traffic pattern shows vehicles travel-
at diverse speeds and spacings. To take this variation into account, the 100-vehicle groups were selected to secure what is known as a "moving" average. The purpose of comparison and analysis, one sample of 100 cars is just as good as any other sample. Suppose one group of 100 vehicles numbered from 1 to 100 just been observed. If the first ten cars of this up, which may have any speeds and any spacings, dropped and ten new ones added, the new group did not have the same characteristics as the first, even though the same 90 cars appear in each group. Plainly, cars in this second group are numbered from 11 to 20, or a third group would be numbered from 21 to 120. Observations were taken at various locations in Ohio brick, concrete, and asphalt pavements, mostly of o-lane width. Profilometer readings showed that

The study likewise furnished information on the distribution of vehicle speeds for different densities, as shown in Table II.

### HOW SPEED AND SPACING ARE RELATED

In securing the maximum theoretical capacity of a highway, the minimum spacing at which vehicles travel at different speeds is important. It may be reasoned, logically no doubt, that a driver maintains a space between his own car and the car ahead sufficient to permit a safe stop should the other meet with disaster. Whether or not he does this can be found out only by observation, such as is possible by the photographic method.

In the investigation of speed and spacing of vehicles, an attempt was made to take pictures only of groups of cars that seemed to be moving at controlled speeds and to exclude all observations where the relative velocity of the front vehicle differed by more than 5 ft per sec from that of the one following. It is evident that on a heavily traveled highway the tendency of traffic is to move in crowds, and that the leading vehicle controls the speed of the entire group. At lighter densities, it is harder to determine whether the speeds are affected by congestion.

Observations secured from 6,000 pictures of spacing for each two-mile variation in speed, averaged and plotted on rectangular cross-section paper in Fig. 1, seem to be fairly well represented by the straight-line equation,

\[ S = 21 + 1.1 V \]

where \( S \) equals the spacing of vehicles from center to center, in feet, and \( V \) equals the velocity in miles per hour. The lower curve in Fig. 1 represents data taken where speeds were slow and in city traffic. This indicates that different driving conditions may affect spacing.

In an effort to rationalize Equation 1, it may be assumed that the first term, 21, is the spacing in feet at which vehicles come to a stop. It has been observed that vehicles waiting for traffic lights to change are spaced at approximately this distance.

If the speed, \( V \), is expressed in feet per second in place of miles per hour, the coefficient of \( V \) in Equation 1 becomes 0.75 instead of 1.1. It is interesting to note that this is about the average time in seconds that it takes a driver to bring his brakes into operation when the occasion arises. In other words, it is the average brake-reaction time. The equation means then that the variation in the average minimum spacing between vehicles

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**Table II. DISTRIBUTION OF VEHICLE SPEEDS**

<table>
<thead>
<tr>
<th>Speed in Miles per Hr</th>
<th>Percentage of Vehicles Traveling at Equal or Lower Speed</th>
<th>Speed in Miles per Hr</th>
<th>Percentage of Vehicles Traveling at Equal or Lower Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.0%</td>
<td>65</td>
<td>09.0%</td>
</tr>
<tr>
<td>15</td>
<td>0.1%</td>
<td>60</td>
<td>09.0%</td>
</tr>
<tr>
<td>20</td>
<td>0.6%</td>
<td>55</td>
<td>09.0%</td>
</tr>
<tr>
<td>25</td>
<td>2.4%</td>
<td>50</td>
<td>09.0%</td>
</tr>
<tr>
<td>30</td>
<td>8.0%</td>
<td>45</td>
<td>09.0%</td>
</tr>
<tr>
<td>35</td>
<td>20.0%</td>
<td>40</td>
<td>09.0%</td>
</tr>
<tr>
<td>40</td>
<td>30.0%</td>
<td>35</td>
<td>09.0%</td>
</tr>
</tbody>
</table>

amount of roughness has little effect on average speeds. Speeds of over 80 miles per hr for passenger cars, of 60 miles per hr for light trucks (net rate capacity of 21/2 tons or less), and of 50 miles per hr for heavy trucks were recorded. The average speed of the buses recorded was 41.6 miles per hr. On the other hand, an investigation of the speeds on gravel roads, in connection with a study in Michigan made in the summer of 1933, gave an average speed of 32 miles per hr, showing that a loose or unstable surface causes loss in speed.

**HIGHWAY TRAFFIC FILM PROJECTED ON SCREEN**

For Study by FERA Students at Denison University. Note Double Exposure of Pictures
depends on reaction time and not on the braking ability of the vehicle. Since deceleration after the brakes have
been applied is practically constant, this minimum spacing is sufficient unless the leading car should come to a
sudden stop. In such cases there is often a collision.

![Graph of Time Lost by Vehicles Due to Reduced Speed on a Congested Two-Lane Highway]

**Fig. 5. Time Lost by Vehicles Due to Reduced Speed on a Congested Two-Lane Highway**

Calculation of the maximum number of cars that could go over a highway, all traveling at the same speed and
with the average minimum spacing, gives the theoretical maximum capacity shown by the upper curve in Fig. 2.
For instance, if all cars were moving at 40 miles per hr,
the number that could pass on one lane in one hour would be approximately 3,200. This is never realized except
for very short periods of time. The curve does prove, however, that increased average speeds mean increased
highway capacity, and that the reason highways do not have a greater capacity is that in any traffic stream of
any extent there are always enough slow-moving vehicles to decelerate all the others. Other previously derived
curves, also shown in Fig. 2, indicate the considerable
variation that may exist between a theoretically derived measurement and one based on actual observations.
What seems to be the proper method of measuring
highway congestion or the retardation of vehicles due
to heavy traffic is to take actual measurements of the speeds at different densities. A comparatively large
amount of such data was collected in Ohio during the summer of 1934 by the Traffic Bureau of the Ohio State-
Highway Department. This study, based on the ob-
servation of over 22,000 vehicles, was analyzed in 1,180
groups of 100 vehicles each. The results show that as the density in vehicles per hour on a two-lane highway
increases beyond 400 to 500 vehicles per hour, the average
speed of all vehicles decrease. This density is what
may be termed the “free-moving” or “working” capacity
of the highway. In other words, 400 to 600 vehicles per hour marks the beginning of congestion.
In Fig. 3, arrived at by plotting the density, \( \varphi \), or the number of vehicles passing in one hour, against recorded
speeds, is given the average speed corresponding to any
density. For example, at a density of 1,600 vehicles per hour the speed is equal to 33 miles per hr. Then, as
the speed continues to decrease due to crowding, the
density increases proportionally up to approximately
2,000 vehicles per hour, which represents the maximum
carrying capacity of the road. If crowding continues,
both speed and density decrease until at a speed of 10.5
miles per hr, the density is again 1,600 vehicles per hour.
For a short time a roadway may become so packed with
vehicles that all must stop. The density then is zero.
If the speed is plotted against average spacing, the
curves in Fig. 4 is obtained. This spacing may be ex-
pressed as \( \varphi' \), the number of vehicles per mile of
pavement. The spacings may be secured from observation,
but \( \varphi' \) is also the result of dividing the density, \( \varphi \), by the
average speed. For example, if the density, \( \varphi \), is 400 vehicles per hour, and the average speed is 40 miles
per hr, then the number of vehicles per mile is 10. That is,
\( \varphi' = 400 \div 40 = 10 \). The curve for \( \varphi' \) in Fig. 4,
drawn from the same data as Fig. 3, is a straight line.
Since a straight line is fixed by two points, it is theoreti-
cally necessary to have data for only two traffic condi-
tions. Owing to the fluctuations in traffic movements,
however, conclusions should be drawn from ample data.
Although the curves in Figs. 3 and 4 would not hold for
other localities, they may form the basis of estimates.
Economically speaking, congestion is costly. The
\time lost, in vehicle-hours for each hour on a mile of
pavement, resulting from the speed drop shown in Fig. 3,
is plotted in Fig. 5. At a density of 400 vehicles per
hour, corresponding to the free speed of about 42 miles
per hr, there is no time loss. The great waste is shown
to occur as congestion takes place, especially in aggra-
vated form.

Since time has an economic value, as proved by the
fact that people are willing to pay for the saving of it,
it becomes the obligation of highway commissioners to
study traffic congestion. By so doing they may deter-
mine when a roadway should be widened to meet the
needs of the public in reference to economy in time as
well as to safety.

**FURTHER APPLICATIONS FEASIBLE**

Use of the photographic method is reasonable in cost,
with the price of 16-mm films on 50-ft rolls about $8 each.
A roll with its 2,000 single frames is sufficient to record
the movements of about 800 cars. More can be re-
corded if the traffic is dense enough for more than one
car to appear in each frame or picture. An expensive
camera is not necessary but it is desirable, for the better
the camera, the better the pictures.

Accident prevention has not been mentioned, but all
traffic movements have some relation to accidents. The
minimum spacing maintained by drivers does not allow
time for stopping should the car ahead come to a sudden
halt. Slow-moving cars cause not only congestion but
also accidents when faster vehicles attempt to pass.
Perhaps on busy highways everyone should be required
to travel at the same speed.

This brief report has shown that much valuable
information about traffic behavior may be gained by the
proper approach. Other phases of the subject immedi-
ately present themselves for investigation. How do curves, horizontal and vertical, affect speeds? What is
the sight distance and the clearance on the opposite lane
required for passing a car ahead? Without doubt, further
research is not only desirable but necessary if knowl-
dge of traffic is to keep up with the increase in traffic
problems. Highways, built to last at least 20 years, are
far behind the perfection of the modern motor car, yearly
improved and guaranteed to have a speed of from 80 to
100 miles per hr. Safe driving is still subject to the
mental perceptions and physical limitations of drivers.

This study has been carried on under the supervision of
H. E. Neal, traffic engineer, and J. J. Darnall, superin-
tendent of traffic surveys, both of the Traffic Bureau,
Ohio State Highway Department.

Part of the general substance of this article was pres-
ented before the Highway Research Board—at the 1933
annual meeting, published under the title, “The Photo-
graphic Method of Studying Traffic Behavior,” in the
Proceedings of the organization, Vol. 13 (1934), page 382;
and before the December 1934 annual meeting under