PRELIMINARY RESULTS OF HIGHWAY CAPACITY STUDIES

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(In Abstract)*

Realizing that a large amount of detailed data would be required before the relative capacities of highways having various widths and alinements could be determined, the U S Bureau of Public Roads conducted a number of capacity studies on some of the most heavily traveled rural highways in New York and New England during the summers of 1934 and 1935, and cooperated with the Illinois Division of Highways in a similar study in Illinois during 1937

At all study locations the time that each vehicle entered and left a section of highway $\frac{1}{5}$-mile long was recorded on a graphic time-recorder, and each vehicle was classified as a passenger car, bus or truck Each truck was further classified as to weight group and trailer type It was possible to obtain from these basic data the speed of each vehicle, its time or distance spacings from other vehicles, and the exact volume of traffic in each direction during any desired time period The studies were conducted for approximately 8 hr each day, affording a full range in traffic density Data for over 300,000 vehicles have been recorded, mostly on level tangents of rural highways, and from them analysis has to date revealed several significant traffic characteristics.

The theoretical maximum capacity of a traffic lane for various vehicle speeds was first determined for one location by a method similar to that used in many theoretical derivations, but instead of using a calculated uniform spacing between vehicles, the actual spacings obtained by the study were used Of the 8,500 vehicles recorded at this location, 2,055 were traveling at the same speed as the preceding vehicle and were not passed or did not pass another vehicle while in the section By classifying these vehicles into speed groups the modal spacing for each group was determined mathematically and checked by constructing a curve showing the frequency distribution of spacings for each speed At speeds greater than 20 m p h , there was very little difference in the modal time spacings between vehicles

Distance spacings were computed from the time spacings It is of interest to know what percentage of vehicles could stop without hitting the preceding vehicle if it should stop suddenly Assuming the brakes on the following vehicles to be as good as those on the leading vehicles, and that a $\frac{1}{2}$-sec reaction time would be required, 4 4 per cent of the vehicles could not have avoided rear-end collisions This figure increases to 28 per cent for a 1-sec reaction time, and to 50 5 per cent when 1 5 sec are allowed for a combined perception and reaction time These figures illustrate one reason why more than two vehicles are so often involved in one accident

Computing the theoretical maximum number of vehicles per hour that one traffic lane will accomodate at various speeds, if all vehicles travel at the same speed, maximum volume occurs at 33 m p h and does not vary more than 20 per cent from this volume for any speed between 20 and 50 m p h.

The majority of present definitions for maximum capacity, working capacity, practical working capacity and the beginning of congestion are based on the assumption that as the traffic volume increases a point will be reached

* Reported fully in *Public Roads*, February, 1939.

where there will be a sudden and appreciable drop in speed. In most instances this study showed a gradual decrease in average speed with an increase in volume. Traffic volumes and densities at the locations studied varied from values below to values well above those that are definitely known to be in excess of reasonable working capacities for rural highways, yet there was no evidence of a sudden or marked decrease in speed at any particular traffic volume or density

It is apparent that a measure other than average vehicle speed alone must be used to determine the working capacities of highways Were it possible to measure the physical, mental and nervous energy used by the average driver per mile, when traveling in various volumes of traffic, this would be an ideal index for determining working capacities

The most significant index found to measure the relative interference between vehicles on rural highways was the mean difference in speed between successive vehicles. With light traffic, the speed of each vehicle is not governed by the speed of the vehicle immediately ahead

As the traffic volume increases there is an increasing tendency for the speed of the individual vehicles to be governed by the speed of the preceding vehicles, causing a marked decrease in the mean difference in speed between successive vehicles, although the decrease in average speed may be slight.

To illustrate, on one section of 2-lane highway, figures indicated that operators of vehicles at or above a time-spacing of 9 sec from preceding vehicles were not influenced by the speed of the preceding vehicle, while at a spacing of 1½ sec. a large majority of drivers were so influenced.

The maximum number of vehicles per hour that can travel over various rural highway types before all vehicles must start traveling at the same speed as the preceding vehicle was computed for several locations On a particular 2-lane tangent this volume was 1,980 in one direction, and 1,100 in each direction with balanced traffic. For an even distribution of traffic, the following comparison of speeds and maximum traffic volumes were computed for one 2-lane tangent, 1,880 vehicles per hour at a speed of 23 m p h , and for another, 2,200 vehicles at 25 m p h Maximum capacity for a 3-lane road was 2,540 vehicles at 12 m p h , while one 4-lane road could carry 4,150 at 22 m p h , and another 8,600 at 11 m p h One of the 4-lane divided highways could accommodate a maximum number of 5,400 vehicles at 15 m p h , and another 7,300 at 40 m p h

These particular sections cannot be considered typical for all 2-, 3-, and 4-lane highways, but were selected to illustrate that in determining the practical working capacity of a highway, consideration must be given to the speed at which vehicles will be able to travel, and the relative interference between vehicles

Other observations of traffic behavior showed that although the percentage of vehicles traveling below the average speed varies for different highways, the percentage traveling below the average speed on any particular highway does not change appreciably with a change in traffic volume

Study of vehicle time spacings for a number of highway locations showed that (1) as the volume of traffic on any particular highway increased there was a fairly uniform change in the frequency distribution of the time spacings; (2) except for the very short time spacings, the frequency distribution of the spacings for any particular volume of traffic in one direction was practically the same on one highway as another, regardless of the average speed that the vehicles were traveling, (3) at any traffic volume, from two-thirds to three-fourths of the vehicles were at less than the average time-spacing from the preceding vehicle

Traffic cannot move freely on a highway unless it is possible for faster moving vehicles to overtake and pass slow moving vehicles. On two-lane highways passing is not possible even on tangent sections except during periods when the left lane is not occupied by oncoming traffic Time-spacing data may be used to determine opportunities to pass Characteristic patterns of time spacing distributions can be used to determine the number of times per hour that any given time-spacing between succeeding vehicles in the opposing lane will be exceeded The percentage of the total time that a vehicle is opposite a time-spacing in the opposing traffic which exceeds a certain magnitude may also be determined

The results that have thus far been obtained by analyzing a comparatively small portion of the data furnish sufficient proof to conclude that

1 Neither maximum nor practical working capacities can be determined solely from the relation between average speed and volume

2 Consideration must be given to both speed and the relative interference between vehicles in determining practical working capacities.

3 All highways of the same width or number of lanes will not have the same maximum possible capacities or the same practical working capacities

4 Although there is a wide variation in the driving characteristics of individual vehicle operators, certain fundamental principles of traffic behavior can be developed that will be generally applicable The results may be entirely different from those derived by assuming average conditions

5 The various study sections for which data have been obtained do not cover a sufficient range of highway designs and alinement to obtain the effect of all the variable factors on practical working capacities Further data are necessary, especially as to the time required for vehicles to pass one another under various conditions

DISCUSSION ON HIGHWAY CAPACITY

Dr. B. D Greenshields, *College of the City of New York*· Did I understand you to say that the time spacing distribution of cars along the highway did not follow a normal distribution?

Mr. Normann. They follow a definite distribution which is very skewed rather than normal For a certain volume, there is almost a constant distribution of time spacings The sections we have analyzed indicate that from $\frac{2}{3}$ to $\frac{3}{4}$ of the vehicles will always be spaced at less than the average time spacing With 600 vehicles per hour in one direction, from $\frac{2}{3}$ to $\frac{3}{4}$ of them will be spaced at less than the average spacing of six seconds and 40 to 50 per cent of the vehicles will be spaced at less than one-half of the average spacing or less than three seconds apart This will also hold true regardless of the average speed On one highway, the average speed may be 20 miles per hour and on another 50 miles per hour and yet the time spacing distributions will be practically the same with equal volumes although the distribution of the distance spacings will not be the same

Prof. Greenshields. I found the same thing in 1933, that is, that the time spacings were fairly constant I believe you stated also that the minimum time spacing was a constant factor even though the distance would vary

Mr Normann The minimum spacing with vehicles following one another at equal speeds is always about $1\frac{1}{2}$ sec. center to center whether the speed is 20 or 50 miles per hour.