A STUDY OF TRAFFIC CAPACITY

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SYNOPSIS

The report presents the results of a traffic capacity study started in June 1934 by the traffic bureau of the Ohio State Highway Department. The work has been conducted under the supervision H. E. Neal, Traffic Engineer in charge of the Traffic Bureau, and J. J. Darnall, Supt. of Traffic Surveys. The data were collected by the photographic method described in Vol. 13 of the Proceedings of the Highway Research Board. After a brief description of the method of collecting and tabulating the information, certain selected data are analyzed to secure a measure of the working capacity of a two-lane roadway and the amount of vehicle time lost under varying degrees of congestion.

The study of 1180 groups of 100 vehicles each, including not over 10 per cent trucks, reveals the average free moving speed to be about 43 miles per hour on either a two or three lane road. When the number of vehicles exceeds 400 to 600 per hour, the average speed decreases and the effect of a few slow moving vehicles is more pronounced. The mean speed of 859 light trucks was 41.0 miles per hour, and of 225 heavy trucks, 32.4 miles per hour. For 18 buses, the average was 41.6 miles per hour.

This report presents the results of a study of traffic capacity undertaken to determine the approximate hourly traffic density on a roadway of given width at which congestion or the slowing of traffic begins, and the amounts by which traffic congestion is increased.

The point at which congestion begins marks the limit of the "working capacity" of a roadway according to Dean A. N. Johnson, of the University of Maryland, who makes the following statement:[1]

> "We can visualize a road carrying but a few vehicles and agree that there is no congestion. But as the number of vehicles increases, there will be a point reached at which some vehicles will be delayed because they are immediately unable to pass other slower moving vehicles. Such a point indicates the beginning of congestion or what may be called 'working capacity' or 'free moving capacity' of the highway."

The present investigation has shown, in general, that as the density on a two lane roadway increases beyond 400 to 600 vehicles per hour, the average speed of all vehicles decreases.

[1] Traffic Capacity, By A. N. Johnson, Proc. Highway Research Board, Vol. 10, p. 218.

This loss of speed may be taken to be a measure of the congestion or loading of the roadway beyond its free carrying capacity. That congestion is caused by slow moving cars in the traffic stream has been shown by the fact that the average minimum spacing between vehicles has been ascertained to be such that if all vehicles moved at the same speed, the density or the number of vehicles that could pass over a section of highway in a given time would increase directly with the speed.[2] For short periods of time both the density and the speed have been observed to increase, but for any considerable length of time, such as

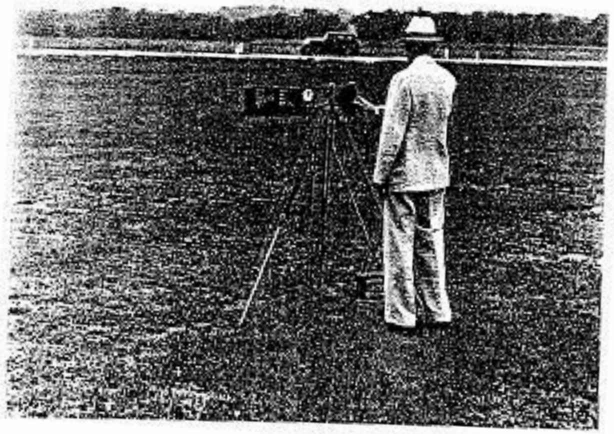

Figure 1. Camera in Operation

an hour or more, there are enough slow moving vehicles to retard traffic if the density is sufficient. The density or number of vehicles passing in a given time such as one hour will not, however, increase beyond a certain limit, for as the speed tends to decrease to zero, the density per hour also approaches zero. (See Fig. 6.)

[2] "The Photographic Method of Studying Traffic Behavior." By Dr. B. D. Greenshields, Proc. Highway Research Board Vol. 13, p. 382.

METHOD OF COLLECTING AND TABULATING DATA

The data for this study, consisting of the speeds, of practically 100 per cent of all vehicles passing the points of observation, were obtained from pictures of moving traffic taken at short definite intervals of time by noting the distance each vehicle traveled during one of these time intervals.

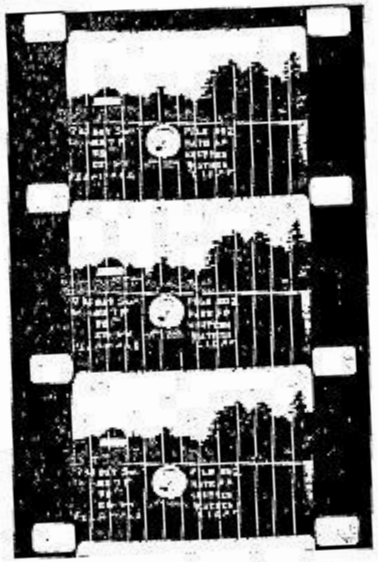

Figure 2. Section of Film. Pictures taken at rate of 88 per minute, superimposed upon a scale to show the distance travelled. Note bulletin board included in each picture.

A 16 m.m. Simplex movie camera, capable of taking single frames of pictures, was set up about 350 feet from the roadway so that each vehicle would appear in at least two successive pictures or frames. Figure 1 shows the equipment in operation. Figure 2 shows three frames of pictures taken at a point on US 23, one mile north of Delaware, Ohio, superimposed upon a scale to show the distance traveled. The camera was "snapped" by a solenoid, the time interval between "snaps" being controlled by an electrical contact made by the pendulum on a metronome at the end of its swing. Nearly all of the pictures were taken at the rate of 88 per minute, since with this time interval between frames,

the distance traveled in feet equals miles per hour. The method of scaling the distance traveled can be understood by referring to figure 2, where the rear car in Frame 1 at the top has advanced 34 feet in Frame 2.

Figure 2 also shows part of a bulletin board included in each picture, giving the location, day, date, hour, type and width of pavement, the interval between exposures, weather conditions, and a clock, showing minutes and seconds of time. Markers were placed on each side of the road to provide a definite scale for each picture.

A detailed description of the photographic method is found in "The Photographic Method of Studying Traffic Behavior," by Dr. Greenshields, The Proceedings, Highway Research Board, Vol. 13, p. 382.

Profilometer readings, showing the profile changes in excess of one-quarter inch in ten feet, were made on each of the sections of roadway investigated, and recorded according to the variations occurring per mile.

The form used in transcribing data from the films is shown in Table I. This table shows the instant to the closest second that each vehicle passes a definite point. Although spacings between cars are not discussed in the present report, in case a restudy should be made, a place has been provided on the form for expressing the time interval between frames in seconds or frames in which successive cars appear, to facilitate the calculation of the spacing between cars.

The data were transferred from Table I to Table II in groups of ten vehicles each. The time interval required for each group to pass is shown. The data from Table II were, in turn, transferred to Table III in groups of one hundred vehicles each, together with the time interval for each group to pass. In taking the groups of one hundred vehicles each, the vehicles in each group starting with the first are: 1–100, 11–110, 21–120, 31–130, 41–140,—and so on. The averages obtained from these groups constitute a "moving average" for the traffic stream. The jump of ten vehicles at a time has been chosen arbitrarily. A change of one vehicle would constitute a different group, but the characteristics of the group would not be significantly different from the previous ones. The change of ten vehicles gives a greater difference and it permits the additions to be easily checked. Every group of one hundred vehicles that passed within the same time interval, to the closest minute, was transferred to Table IV. The time interval for these groups is the average of the time intervals for the separate 100-vehicle groups making up the total. Each of the larger groups, of course, is in even hundreds.

Distribution of Automotive Vehicle Speeds

Since the percentage of vehicles traveling at low speeds is perhaps the most important factor in determining highway capacity, and in order to obtain more significant averages, the percentage of vehicles traveling

TABLE I

Typical Data Sheet

Day: Saturday *Date:* 9/1/34 *County:* Lorain
Location: 2.0 miles West of Oberlin—U. S. No. 20
Weather: Clear *Scale:* Markers 50′ *Time Interval:* 1/38′
Analysis by Ganschow ; Walters
Hours of Observation: 10:30 A.M.–12:02 P.M.
Remarks: 20′ Asphalt Pavement with 6″ concrete edges

Time		Car Position in Feet	Spacing to Car Ahead			Speed Vehicle Travels in Miles per Hour					
						West			East		
HMS	Frame		Sec.	Fr.	Ft.	P	LT	HT	P	LT	HT
10:31–0	1	170				40					
–10	1	180				38					
–16	1	185				58					
	2	150							30		
–12	1	175				40					
	2	180			10	40					
32–29	1	160				45					
	1	230							40		
–35	1	230							48		
–40	1	230							52		
33–6	1	176				39					
	1	135			42	45					
–16	1	215									42
–20	1	235				52					
	4	155				49					
–32	1	170				50					
–40	1	255							60		
–41	1	210							60		
	1	95				47					
	3	125			60	40					
34–0	1	180				43					
–4	1	240							57		
	2	195			100				60		
34–20	1	142			20	28					
	1	162				38					
	1	130			12	38					
–51	1	180							30		
35–13	1	212				57					
	1	176			36	62					
–31	1	210				46					
–46	1	220								47	
36–12	1	167				60					
	1	100			67	50					
–19	1	210					47				
–27	1	176				20					

TABLE II

Time in Hours Minutes Seconds	10-31-0	10-33-4	10-34-9	10-35-45	10-37-35	10-39-6	10-41-27	10-44-30	10-47-51	10-48-30	10-51-30	10-53-15	10-55-0	10-58-55	11-0-17	11-1-25	11-2-38	11-3-16	11-4-52	11-6-35
Time Interval	2 6	54	1 46	1 49	1 21	2 21	3 3	3 21	1 35	2 5	1 45	1 45	1 55	3 22	1 3	1 12	36	1 36	2 43	3 10
Group Interval	1	11	21	31	41	51	61	71	81	91	101	111	121	131	141	151	161	171	181	191
Lane W	6	7	7	4	4	2	5	6	4	3	5	3	6	7	8	7	4	5	8	4
Lane																				
Lane																				
Lane																				
L. Trucks				2						1					2	1				
H. Trucks		1		1			1			1				1				1		
Total T.		1		3			1			2				1	2	1		1		
SPEED IN MILES PER HOUR 10																				
15																				
20				I																
25														I		I		I		
30	I		I I			I	I	I II				I	I					III	I	
35				I	I I	I	I II	I I		I III				I I	II	I	II		I I	
40	I IIII	I I	II	I I	I I II	I I	I	I	I II	I I	II	III	III	I II	II	I III	I	II	III	IIII
		I	I	I	I	II			I I		I		I		I II	I	II			

Note: Bottom of table omitted.

TABLE III

Time in Hours Minutes Seconds	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Time Interval	20 30	20 09	21 40	21 09	22 42	22 19	21 11	18 48	17 00	17 05	18 15	18 37	20 06	20 31	20 33	20 31	21 32	22 08	24 02	26 45
Group Interval	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lane W	45	47	43	42	45	49	54	52	48	51	51	50	48	47	42	40	38	35	39	37
Lane																				
Lane																				
Lane																				
L. Trucks	3	3	3	3	1	3	4	4	4	4	3	3	4	4	4	3	4	5	6	6
H. Trucks	4	4	3	3	3	3	3	2	3	3	2	2	3	4	4	4	5	5	4	4
Total T.	7	7	6	6	4	6	7	6	7	7	5	5	7	8	8	7	9	10	10	10
SPEED IN MILES PER HOUR 10																				
15																				
20	1	1	1	1												2	3	3	4	4
25					1	1	1 1	1 1	1 2	1 2	1 2	1 2	1 2	1 3	1 2	2 2	1 1 2	1 1 2	1 1 1	1 1 1
30	2 5	2 5	2 6	1 6	1 6	1 6	1 5	1 4	5	6	6	6	5	4	6	7	8	8	7	7
35	3 1 9	3 1 9	3 1 9	3 1 9	4 1 9	3 1 10	3 1 10	2 1 10	2 1 9	2 1 10	2 7	2 7	2 7	3 7	3 7	4 5	4 5	4 3	4 3	5 2
40	1 1 5 3 12	1 1 5 3 11	1 1 5 2 12	1 1 3 2 14	1 4 2 17	1 3 1 17	1 3 20	2 3 19	2 2 20	2 2 21	1 2 24	1 2 23	1 2 25	1 2 28	1 1 1 21	1 1 1 22	1 1 21	1 1 22	1 1 1 23	1 1 1 22
	5 3 1	5 3 1	4 3 1	4 3 1	3 3 1	3 5 1	1 4 1	3 1 1	3 6 1	3 5	3 5	1 4 1	4 4 1	4 3 1	4 3 1	3 1 1	3 1	1 1 1	1 2 1	1 2 1

Note: Bottom of table omitted.

TABLE IV

Av. Time Interval for 100 Vehic.	20' 23"	Per cent Slower Than	21' 13"	Per cent Slower Than	22' 19"	Per cent Slower Than	23' 33"	Per cent Slower Than	24' 39"	Per cent Slower Than	25' 31"	Per cent Slower Than	26' 36"	Per cent Slower Than
Total Veh.	600		400		400		400		300		200		100	
Vehic. on West Lane	273		174		168		146		120		85		43	
% on Lane	45.5		43.5		42.0		36.5		40.0		42.5		43.0	
H. Trucks	23		14		18		23		13		8		3	
L. Trucks	21		14		13		18		11		6		2	
Total T.	44		28		31		41		24		14		5	
% Trucks	7.3		7.0		7.8		10.3		8.0		7.0		5.0	
SPEED IN MILES PER HOUR 20	4	0.7	5	1.3	8	2.0	15	3.8	8	2.7	3	1.5	1	1.0
25	5 9	1.5 3.0	1 2 3	1.5 2.0 2.8	2 2 3	2.5 3.0 3.8	4 4 4	4.8 5.8 6.8	2 2 2	3.3 4.0 4.7	1	2.0		
30	4 32	3.7 9.0	4 26	3.8 10.0	2 2 32	4.3 4.8 12.8	3 37	7.5 16.8	1 21	5.0 12.0	2 18	3.0 12.0	1 8	2.0 10.0
35	18 3 44	12.0 12.3 19.7	13 2 33	13.3 14.0 22.3	17 2 2 26	17.0 17.5 18.0 24.5	18 1 14	21.3 21.6 25.0	14 1 12	16.7 17.0 21.0	6 2 12	15.0 16.0 21.0	4 1 7	14.0 15.0 22.0
40	6 4 15 6 113	20.7 21.3 24.0 25.0 43.8	4 3 11 4 70	23.3 24.0 26.8 27.8 45.3	2 9 5 64	25.0 27.3 28.5 44.5	3 4 77	25.8 26.8 46.0	4 2 66	22.3 23.0 45.0	3 2 43	22.5 23.5 45.0	3 20	25.0 45.0
45	25 17 6 68	48.0 50.8 51.8 63.1	12 12 4 43	48.3 51.3 52.3 63.0	10 16 2 40	47.0 51.0 51.5 61.5	9 11 2 38	48.3 51.0 51.5 61.0	5 8 2 30	46.7 49.3 50.0 60.0	3 11 19	46.5 51.5 60.0	1 6 9	49.0 54.0 63.0
50	5 12 16 7 68	63.0 65.0 67.6 68.8 80.1	6 7 11 8 36	64.5 66.3 69.0 71.0 80.0	4 5 11 4 41	62.5 64.5 67.3 69.3 79.5	5 8 3 51	63.0 65.0 65.8 78.5	5 11 1 37	62.0 63.7 65.0 78.3	10 6 2 26	65.0 70.0 71.0 84.0	4 3 1 13	67.0 70.0 71.0 84.0
55	3 11 2 42	80.6 82.5 82.8 89.8	1 13 3 23	80.3 83.5 84.3 90.0	1 11 2 27	79.8 82.5 83.0 89.8	1 39	78.8 88.3	1 29	78.7 88.3	2 8	85.0 89.0	1 4	85.0 89.0

Note: Bottom of table omitted.

at or less than various speeds was plotted in Figure 3 on the arithmetic probability paper devised by Hazen, Whipple and Fuller.[3]

The use of this type of paper is advantageous as it is possible to represent the observed data by a straight line. In such a case, the speed given by the intersection of the straight line with the 50 per cent ordinate is the most frequent and average speed, as well as the median. The usual definitions become, for the present problem:

Average Speed—arithmetical mean of all speeds.

Median Speed—speed such that 50 per cent of the speeds are greater, and 50 per cent less.

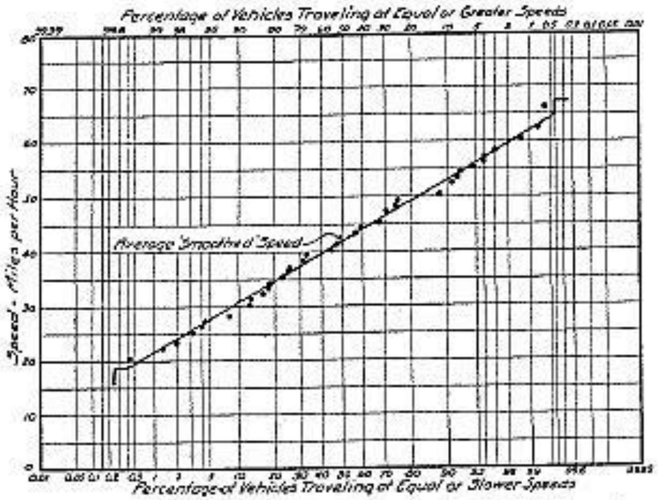

Figure 3. Distribution of Vehicle Speeds. Normal Probability Curve. Average of seven groups of 100 vehicles each. Average density 625 vehicles per hour. Lane distribution 45-55 per cent. Trucks 4.4 per cent.

Modal Speed—the most frequently occurring speed.

The data utilized are the numbers of cars with speeds equal to or less than a given series of equally spaced values. A typical set of figures for 100 vehicles, at speed intervals of five miles per hour is included in Table V the speeds for each mile per hour interval being omitted for the sake of clearness. The fourth column will be explained later.

If the percentage of cars traveling slower than a given speed or equal to it is plotted against speed, the points will fall in an irregular line. This is to be expected, particularly when the number of cars represented

[3] Transactions American Society of Civil Engineers, Vol. 77, p. 1539 (1914).

in one diagram is only 100. If counts are made a number of times under precisely the same conditions of traffic, the percentage traveling faster than, say 40 miles per hour, will never be exactly the same, except by chance. There will be a certain dispersion around the average value for several groups of 100 cars. This may be expressed by saying that the number of cars traveling slower than any given speed in one group of 100 has what is known as a "natural uncertainty" or "probable error." It is a fundamental statistical principle that in plotting and drawing a curve such as the type here considered, the data should be "smoothed" to eliminate the accidental irregularities as far as possible, before being utilized. This means drawing the smoothest curve possible through the plotted points. The points listed in Table V are plotted in Figure 4. It will be seen that they fall in rather irregular fashion, and that at first glance, the position of the 63.5 mile per hour point appears to preclude the possibility of drawing a satisfactory straight line.

TABLE V

Speed in Miles Per Hour	Tabulated Frequency (N)	Percent Equal to or Slower	Natural Uncertainty
20.5	0	0	0.0
25.5	5	5	2.18
30.5	12	12	3.24
35.5	31	31	4.62
40.5	54	54	4.97
45.5	67	67	4.70
50.5	82	82	3.84
55.5	94	94	2.37
60.5	99	99	0.99
63.5	100	100	0.0
65.5	100	100	0.0

First, however, it is important to consider the probable amounts of the "natural uncertainty." This is given for each frequency in the table by the following relation,

$$Z = \text{Natural Uncertainty} = \sqrt{N\,(1 - N/P)}$$

where N is the tabulated frequency or the number of vehicles travelling at or less than a given speed.[4] These values of Z are tabulated in the fourth column of the table. P = Total number of vehicles observed. It is an accepted fact that it is fair to assume in drawing the curve, that the frequency lies somewhere between N and $\pm$ Z the natural uncertainty. Thus, at each plotted point, a horizontal line is drawn representing the allowed range in the value of N. It is then permissible to draw a smoothed curve in such a way that it passes through all the

[4] This formula and its use in checking the feasibility of using arithmetic probability paper was suggested by Dr. Freeman Miller, Head of the Astronomy Department, at Denison University.

horizontal lines, attempting to draw it so that the sum of the deviations from the actually counted values shall be equal.

In the present case, a straight line satisfies all but the 63.5 mile-per-hour point. In the preceding formula, N should really be the mean number of cars with velocity equal to or less than the given amount, found from a great number of sets of 100 cars under the same traffic conditions. In such case, it is fair to suppose that an occasional car travelling faster than 63.5 miles per hour would be found. Then the actual percentage slower than 55 would be slightly less than 100. If, for example, it were 99.5, the natural uncertainty would then be ± 0.7,

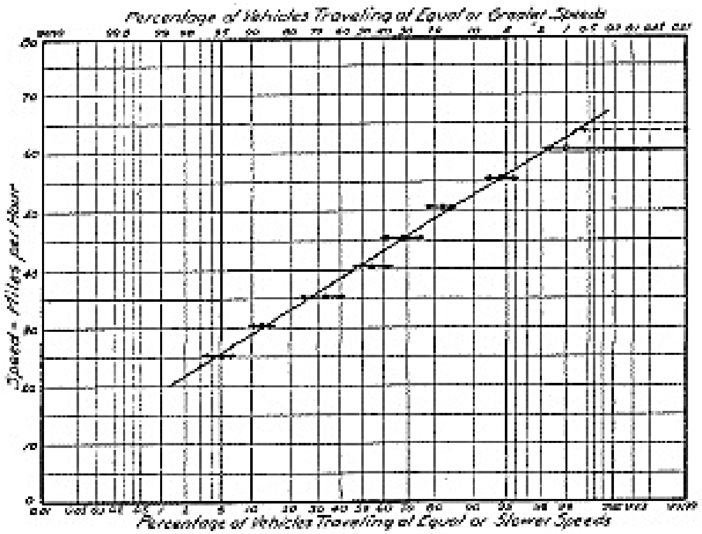

Figure 4. Graph Showing Percentage of Vehicles Travelling Above and Below Various Speeds and the Probable Amounts of the "Natural Uncertainty" of the Plotted Points.

and the point and the dotted line would give the result. In this case, it is evident that the straight line can be passed through all the horizontal lines. This means principally, that the points given by the higher speeds are too erratic and sensitive to accidental fluctuations to be given much weight in the drawing of the curve. Probably all points for percentages less than two and greater than 98 should be ignored in drawing the curve.

It may be assumed then, that a straight line will generally satisfy the data, and that the "smoothed" values read from the curve are the best ones to use in further analysis.

TRAFFIC CAPACITY OF A TWO LANE ROADWAY

The information needed from the tabulated data to determine the traffic capacity of a two lane roadway consists of, first, the average free speeds on the various types of roadways studied, and second, the amounts by which this free speed is lessened by increased densities of traffic.

TRAFFIC WITHOUT CONGESTION

The average data for the following described uncongested roads are given in Table VI.

TABLE VI

AVERAGE DATA FOR UNCONGESTED ROADS

Route	Density in Vehicles per Hour	Number of 100-Vehicle Groups Observed	Mean Smoothed Speed m.p.h.	Percentage of Trucks	Percentage Traveling in One Direction
U. S. 6, 4.9 Miles East of Vermilion					
Friday, Aug. 17, 1934	379	68	42.4	7.5	54.4
Sunday, Sept. 2, 1934	654	99	38.8	0.8	56.8
Wednesday, Aug. 29, 1934	267	69	45.3	7.7	64.4
U. S. 20, 2.0 Miles West of Oberlin	277	30	43.3	6.9	41.5
U. S. 20, 1.4 Miles West of Monroeville	593	109	44.2	3.7	50.4
U. S. 20, 1.5 Miles West of Bellevue	336	59	42.8	7.5	56.0
U. S. 20, 0.25 Miles West of Oberlin	382	27	37.1	6.8	38.5
U. S. 20, 1.8 Miles East of Perrysburg	134	72	37.0	6.7	39.8
U. S. 20, 2.4 Miles East of Oberlin	300	13	42.9	2.2	49.8

Traffic on U. S. 6—4.9 miles east of Vermilion, Ohio

This section of highway is of newly constructed concrete, thirty feet wide. The profilometer readings showed 12 variations in excess of one-quarter inch in ten feet, per mile. The pavement is straight and the view is unobstructed for a long distance, providing an ideal place for high speed traffic. It is thought that the traffic on this highway shows the normal speed tendencies or what the average driver does on a smooth roadway free from interference of other vehicles. At no time did the road carry sufficient traffic to cause congestion.

The average "smoothed" speed for week day traffic for all observations at this station was 43.9 miles per hour, and the percentage of trucks was 7.6. If the Sunday traffic is assumed double the average week day traffic and weighted accordingly, the average traffic speed was 42.6, and the percentage of trucks 5.9. A total of 3900 vehicles was observed.

The light trucks of which there were 106 averaged 34.1 miles per hour, while 84 heavy trucks averaged 32.8 miles per hour.

To secure the percentage of vehicles travelling at or less than certain speeds, data from one film taken on Friday, August 17, 1934, which, on analysis, gave 24 groups of 100 vehicles each falling in eight different time intervals, was plotted on arithmetic probability paper and the results given in Table VII were read from this composite curve.

The curves plotted for each of the eight different time intervals showed a maximum deviation from the composite curve of 1.6 per cent between the limits of 0.2 and 99.8 percent.

TABLE VII

Composite Data—U. S. 6—4.9 Miles East of Vermilion

Percentage of Vehicles Traveling at or Less than a Given Speed in Miles Per Hour

Speed in Miles per Hour	Percentage of Vehicles Traveling at Equal or Less Speed
10	0.01
15	0.1
20	0.6
25	2.5
30	8.0
35	20.0
40	38.0
45	59.0
50	79.0
55	91.0
60	97.0
65	99.2
70	99.8

Average Smoothed Speed: 43.0 miles per hour.
Percent of Trucks: 6.0.

The 1934 average and maximum daily traffic at this location derived from a traffic survey taken by the Traffic Bureau was:

Passenger Cars	3491
Trucks	398
Total Vehicles	3889
Maximum Daily Total Vehicles	8167
Percent of Foreign Vehicles	17.6

Traffic on U.S. 20—2.0 Miles West of Oberlin, Ohio

This is another location showing free speeds. The section is of asphalt macadam twenty feet wide, with six-inch concrete edges. The traffic at this location on Saturday, September 1, 1934, was not heavy enough to present any feature of highway congestion.

The percentage of vehicles travelling at equal or slower speeds taken from the 30 groups observed is shown in Table VIII and is given for comparison with the similar tabulation in Table VII. The largest variation from the average for any one of the curves was 4.2 percent.

The 1934 average daily density of traffic was:

Passenger Cars	1470
Trucks	265
Total Vehicles	1735
Maximum Daily Total Vehicles	3909
Percent of Foreign Vehicles	30.1

Traffic on U.S. 20—1.4 Miles West of Monroeville, Ohio

A third location showing free speeds was on Route U.S. 20, 1.4 miles west of Monroeville. This section of roadway is of concrete, 20 feet wide, with a very wide shoulder on the north side and an ordinary shoulder on the south. At this location it perhaps might be inferred that there was a slight drop in the traffic speed corresponding to the change in density from 500 to 700 vehicles per hour. The profilometer readings showed 492 bumps per mile. The roughness apparently had little effect on the speeds.

TABLE VIII

Composite Data U. S. 20—2.0 Miles West of Oberlin

Speed in Miles per Hour	Percentage of Vehicles Traveling at Equal or Less Speed
10	0.01
15	0.02
20	0.7
25	2.7
30	8.0
35	18.0
40	35.0
45	55.0
50	74.0
55	88.0
60	95.6
65	98.8
70	99.7

The 1934 average daily density of traffic was:

Passenger Cars	3526
Trucks	436
Total Vehicles	3962
Maximum Daily Total Vehicles	8241
Percent of Foreign Vehicles	24.7

Traffic on U.S. 20—1.5 Miles West of Bellevue, Ohio

The section of roadway 1.5 miles west of Bellevue, Ohio, on Route U.S. 20, is of brick, 22 feet wide with an eight-foot level shoulder on the north side and a very narrow shoulder on the south side. The profilometer readings on this section showed 368 variations in excess of one-quarter inch in ten feet per mile. Since the heaviest observed traffic was 465 vehicles per hour, little congestion may be said to have existed at any time. There appears to be a slight drop in the average speed at about 375 vehicles per hour.

The 1934 average daily density of traffic was:

Passenger Cars	2932
Trucks	405
Total Vehicles	3337
Maximum Daily Total Vehicles	6941
Percent of Foreign Vehicles	28.3

Traffic on U.S. 20—0.25 Mile West of Oberlin, Ohio

This section of highway is of brick, sixteen feet in width, with ten inches of concrete on each side. The profilometer readings for this section showed 126 bumps per mile. This location is quite close to a filling station and to a cross road. The interference of these physical obstructions with traffic is reflected in the speeds observed. Little or no congestion was found. The average speed was 37.1 miles per hour. Observations were made on Sunday September 2, 1934.

The 1934 average daily density of traffic was:

Passenger Cars	1470
Trucks	265
Total Vehicles	1735
Maximum Daily Total Vehicles	3609
Percent of Foreign Vehicles	30.1

Traffic on U.S. 20—1.8 Miles East of Perrysburg, Ohio

This is another location showing the effects of physical features upon speeds. The section is of asphalt macadam, 18 feet wide, with a deep ditch on each side. The profilometer readings show 123 variations in excess of $\frac{1}{4}$ inch in ten feet to the mile. The rather high crown and the deep ditches on both sides evidently slowed traffic to some extent, due to the extra hazard in driving. The pavement was wet during some of the observations but this seemed to have little effect on the average speed. The highest density of 200 vehicles per hour was not sufficient to approach congestion.

The 1934 average daily density of traffic was:

Passenger Cars	1747
Trucks	155
Total Vehicles	1902
Maximum Daily Total Vehicles	3994
Percent of Foreign Vehicles	32.1

Traffic on S.R. 10-U.S. 20—2.4 Miles East of Oberlin

Route U.S. 20, 2.4 miles east of Oberlin is surfaced with 9 ft. of brick plus 4.5 ft. of asphalt macadam on each side. The macadam has feather edges. The profilometer readings showed 370 variations in excess of $\frac{1}{4}$ inch in ten feet to the mile.

TABLE IX

AVERAGE FREE SPEED 434 GROUPS OF 100 CARS EACH

Type of Pavement	Width feet	Comparative Roughness	Groups Observed	Av. Density in Vehicles per Hour	Mean "Smoothed" Speed	Trucks, percent
3 Lane:						
Concrete	30	12	236	462	42.6	5.9
2 Lane:						
Concrete	20	492	109	593	44.2	3.7
Brick	22	368	59	336	42.8	7.5
Asphalt	20		30	277	43.3	6.9
2 Lane			Sum 198	Av. 469	Av. 43.6	Av. 5.3
Total—2 Lane and 3 Lane			Sum 434	Av. 465	Av. 43.1	Av. 5.6

Average Free Speed

The average free speed taken from the locations showing no congestion and no special physical features to retard traffic are given in Table IX.

The average speed for the two lane sections is 43.6 miles per hour for an average density of 469 vehicles per hour. 43.5 miles per hour is taken as the average free speed.

TRAFFIC WITH CONGESTION

Traffic on U.S. 20—2.4 Miles West of Norwalk

This section is of concrete, 20 feet wide, with a curb on the south side to prevent traffic from encroaching onto an interurban railway line. The north side has a fairly good shoulder. The highest observed speed at this location shows the influence of the pavement condition upon the free speed of traffic. There were 285 variations in excess of one-quarter inch in ten feet observed per mile on this roadway. The speeds on this section show increasing congestion.

Table X shows traffic conditions observed on Labor Day, September 3, 1934 and average week-day traffic. On labor day there was a small percentage of trucks and it may be added that there was a large percentage of out-of-state traffic. No light traffic was observed and no free moving speeds are indicated. There is shown a consistant drop in average speeds for the higher densities.

On week days the percentage of trucks is higher while the average free speed is lower. Here again it may be noted that there is a slight drop in speed for the higher densities. The working capacity of the roadway seems to be about 400 vehicles per hour.

TABLE X

TRAFFIC ON U. S. 20—2.4 MILES WEST OF NORWALK

Range of Density in Vehicles per Hour	Average Density in Vehicles per Hour	Number of 100-Vehicle Groups Observed	Average Mean Smoothed Speed	Average Percentage of Trucks	Average Percentage Traveling in One Direction
Labor Day Traffic					
700–899	782	18	39.9	3.6	51.6
900–1099	993	104	38.7	1.1	46.2
1100–1299	1176	39	35.9	0.8	43.4
1300–1499	1324	13	35.6	1.6	46.1
1500–1699	1617	7	32.9	1.43	41.7
Week Day Traffic					
100–199	178	3	37.3	10.7	55.7
200–299	262	98	38.4	9.0	50.3
300–399	322	26	36.4	10.1	48.1
400–499	406	1	35.4	11.0	

The 1934 average daily density of traffic was:

Passenger Cars	3185
Trucks	462
Total Vehicles	3647
Maximum Daily Total Vehicles	7586
Percent of Foreign Vehicles	29.7

Traffic on U.S. 23—1.0 Mile North of Delaware

Another location showing traffic congestion was found on U.S. 23, one mile north of Delaware. This location showed a very small percentage of trucks for the higher densities.

The section of pavement on which observations were taken is 18 feet wide, and of brick covered with asphalt. No profilometer readings were taken. The surface is rather wavy.

At the time the data were taken, the Government had established during the summer of 1934, a cattle ranch about one-quarter mile to the north of the point observed. The speeds show an unusual traffic condition to have existed. Apparently most of the drivers were more interested in looking at the cattle than they were in reaching their destinations. Table XI shows the densities and the corresponding average speeds.

TABLE XI

TRAFFIC ON U. S. 23—1.0 MILE NORTH OF DELAWARE

Density in Vehicles per Hour	Number of 100-Vehicle Groups Observed	Mean "Smoothed" Speed	Percentage Trucks	Percentage Traveling in One Direction
166	1	32.5	11.0	52.0
169	2	32.5	11.5	51.5
177	2	32.4	11.5	49.5
184	3	32.3	12.0	53.0
193	2	30.7	9.5	45.0
279	6	31.8	13.6	51.5
294	3	32.2	14.0	47.7
296	5	32.3	13.5	52.5
305	3	32.3	13.5	54.7
322	1	32.6	13.0	67.0
Av. 247	Sum 28	Av. 32.1	Av. 12.7	51.7
930	7	10.7	11.0	60.7
992	8	11.2	0.7	65.6
1100	26	10.8	1.0	66.0
1260	14	11.5	1.1	62.6
Av. 1103	Sum 55	Av. 11.0	Av. 2.3	64.4

Traffic Observed on North Bound Lane Only

Density in Vehicles per Hour (Twice One Lane)	Number of 100-Vehicle Groups Observed	Mean "Smoothed" Speed	Per Cent Trucks
1130	2	17.5	0.5
1168	2	7.5	0.0
1260	8	17.2	0.5
1278	7	8.2	0.0
1390	1	17.5	0.0
1480	8	7.3	0.0
1556	3	13.7	0.0
1646	15	7.5	0.0
1678	2	8.0	0.0
1722	1	8.0	0.0
1840	2	8.3	0.0
Av. 1471	Sum 51	Av. 10.10	Av. 0.1

Table XI also shows the traffic on one lane only for heavier densities. Since there was no passing, it may be assumed that the traffic at this density may be doubled to represent both lanes as is shown in the first column of that part of the table.

It may be observed that at the higher densities there was considerable fluctuation in the density-speed relationship. This was to be expected, since any slow moving vehicle or other cause of delay would affect the entire traffic stream.

The 1934 average daily density of traffic was:

Passenger Cars	2561
Trucks	338
Total Vehicles	2899
Maximum Daily Total Vehicles	6030
Percent of Foreign Vehicles	9.3

The average before the cattle ranch was established—3 counts, one per month was:

Passenger Cars	1936
Trucks	261
Total Vehicles	2197
Maximum Daily Total Vehicles	4570
Percent of Foreign Vehicles	11.0

During the existence of the cattle ranch 3 monthly counts gave traffic as follows:

Passenger Cars	3187
Trucks	415
Total Vehicles	3602
Maximum Daily Total Vehicles	7492
Percent of Foreign Vehicles	9.8

Traffic on U.S. 25—2.0 Miles South of Dayton, Ohio

This location showed varying amounts of congestion and a larger percentage of trucks than was found west of Norwalk. The road is of brick with two feet of concrete on one edge, making a total width of 18 feet. The condensed data are given in Table XII.

Since, for the high densities, a large percentage of traffic was on one lane, it is tabulated below, the first column representing twice the density for one lane, or the possible density for two lanes.

One Lane Traffic

Density in Vehicles Per Hour	Number of 100-Vehicle Groups Observed	Mean "Smoothed" Speed	Per Cent Trucks	Per cent Traveling in One Direction
1434	1	31.5	1.0	100.0
1582	4	32.5	1.5	100.0
1874	5	31.7	2.8	100.0
2082	2	30.2	3.0	100.0
Av. 1775	Sum 12	31.7	2.3	100.0

These data are shown as curve C in Figure 7, and perhaps represent a common traffic composition.

TABLE XII

Traffic on U. S. 25—2.0 Miles South of Dayton

Vehicles per Hour		Groups Observed	Mean "Smoothed" Speed	Per Cent Trucks	Density in Vehicles per Mile of Pavement
Mean	Range				
325	200–400	83	40.4	12.2	8.0
464	400–500	39	38.2	7.0	11.9
548	500–600	24	37.5	6.5	14.6
664	600–700	15	34.0	3.7	19.5
792	700–800	10	34.8	3.9	22.8
0	800–900	0			
937	900–1000	4	33.9	3.0	27.6
1125	1126	8	31.5	4.3	35.7
1257	1267	4	30.9	4.0	41.0

The mean speeds and the arithmetical average speeds for the traffic by hours observed at this location on July 6, 1934, may be of interest.

	Hours 10–11	11–12	12–1	1–2	2–3	3–4	4–5	5–6	6–7
Mean Speed in Miles per Hour	41.2	40.6	40.0	35.7	32.3	36.2	36.8	38.3	38.2
Average Speed in Miles per Hour	40.35	41.55	41.08	36.39	33.38	37.66	38.45	38.95	39.68
Density (Total Vehicles Both Lanes)	334	338	312	317	703	499	406	450	387

The 1934 average daily density of traffic was:

Passenger Cars	7768
Trucks	405
Total Vehicles	8173
Maximum Daily Total Vehicles	17,363
Percent of Foreign Vehicles	7.6

DERIVATION OF EQUATION FOR EXPRESSION OF RELATION OF SPEED AND DENSITY

In plotting speeds and corresponding densities, it will be found convenient if the densities are expressed in vehicles per mile of pavement. This density, D' is found from D, the density in vehicles per hour by dividing D by the average speed in miles per hour.

The plotted points shown in Figure 5; seem to represent a straight line relationship between speed and density per mile. The data for the points for the upper part of this curve are found in Table X, and "One Lane Traffic" page 465. The data for the "51 point" are taken from one lane traffic observed at a point one mile north of Delaware on U.S. 23, (Table XI). The upper part of the curve beyond free speed (F)

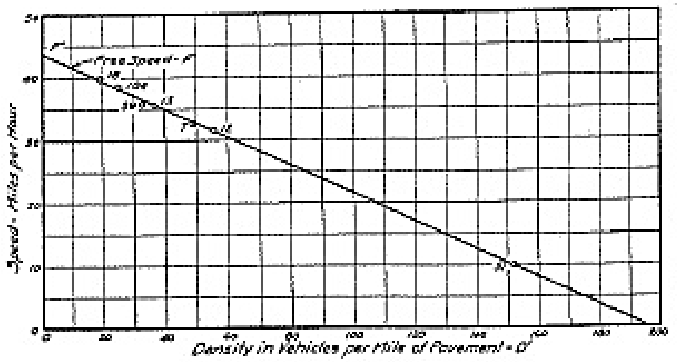

Figure 5. Speed in Miles Per Hour Corresponding to a Given Average Density in Vehicles per Mile of Pavement.

evidently cannot be used since no speed drop has been found to occur much before the density reaches 400 vehicles per hour.

Referring to Figure 5 again it will be noted that since the curve is a straight line it is only necessary to determine accurately two points to fix its direction. Practically, these points should be the free speed or a point in that region and a point near the maximum density, since a point at each end of the line gives it the most accurately. It thus becomes necessary to have observations showing only these two traffic conditions to determine the effect of congestion for all different densities. At greater densities there is less consistency owing to the fact that a few slow moving vehicles retard the whole traffic stream. This means that the data for the higher density must be ample.

Let F' represent the speed (43.8 for this particular curve) where the

curve cuts the zero ordinate in Figure 5, then the speeds for any given density

$$S = F' - mD' \qquad (1)$$

where D' equals the density in vehicles per mile and m, the slope of the curve (0.221 for this case). Since D' equals D/S, the equation may be written:

$$S = F' - mD/S$$

or

$$S^2 - SF' + mD = 0$$

or

$$S = \frac{F' \pm \sqrt{F'^2 - 4mD}}{2} \qquad (2)$$

The curve showing the relationship of S to D may be plotted as shown in Figure 6.

Referring to Figure 5, the equation for expressing the total time lost for any density, D, may now be written. F − S equals the speed lost per vehicle per mile, where F equals the free speed. The time lost in minutes per vehicle per mile is:

$$T' = 60/S - 60/F \qquad (3)$$

where 60/F equals the time (in minutes) required to travel one mile at the speed F, and 60/S equals the time required to travel one mile at the speed S for the given density D.

The total time lost (T) in hours for all vehicles per mile is:

$$T = D\,(1/S - 1/F) \qquad (4)$$

Substituting the value of S given in equation (2), there results:

$$T = D\left(\frac{2}{F' \pm \sqrt{F'^2 - 4mD}} - 1/F\right) \qquad (5)$$

F' may be found from F by multiplying the value of D' (9.5 from curve approx.) corresponding to F, by the slope m of line (tangent of angle between line and horizontal axis) and adding this to the value of F.

$$F' = 9.5m + F \text{ (approx.)} \qquad (6)$$

It should be noted that the total time cannot be estimated from D, the density in vehicles per hour, because there are two speeds at which the same density may occur as shown in Figure 6. If the roadway becomes loaded beyond its maximum carrying capacity of about 2200 vehicles per hour, the vehicles become so crowded that the number passing per hour becomes less. It is necessary to know the approximate spacing between vehicles or whether the road is loaded beyond its maximum carrying capacity before it is possible to know which part of the curve to use in estimating the time loss.

Using the value of m from figure 5, which equals 0.221, a graph showing the time lost for different densities may be plotted as shown in Figure 8.

Figure 7 gives two estimates of the value of m for traffic with different percentages of trucks. The value from curve A, 1% to 5% trucks, equals 0.232 (slope of curve) and the value from B, 2% to 12% trucks, equals 0.272. The value of F in each case is taken to be 43.5, the average free speed in miles per hour secured from observations of traffic on the open highway. The points where the two curves cut the 0 speed line, 197 and 167 are based respectively upon the curve in Figure 5, and curve c plotted from data given in Table XII.

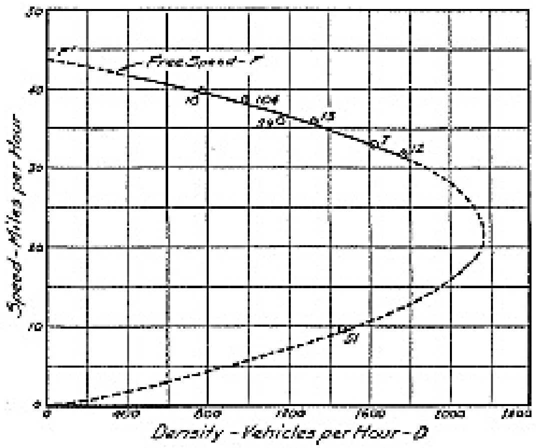

Figure 6. Speed in Miles per Hour Corresponding to a Given Density in Vehicles per Hour on a Two-lane Highway.

Using the value of m, 0.232, a density of 1000 vehicles per hour, gives a time loss of 2.2 hours or 148.0 hours depending upon whether the traffic has exceeded the maximum carrying capacity of the roadway or not. Using the value of m taken from curve B, 0.272, a density of 1000 vehicles per hour, gives time losses of 2.5 hours or 122.0 hours.

Curve C shows an extensive extrapolation owing to the lack of data for higher densities. Two assumptions are made; first, that the data may be represented by a straight line, and, second, that the larger percentage of trucks causes the slope to be different from that of curve A.

Greater densities of traffic occurred at the hours when the Frigidaire Plant, located South of Dayton, changed shifts. At these hours the traffic was composed almost entirely of passenger vehicles and largely of drivers intent on reaching either their homes or the factory. It is

believed that the speeds observed for the higher densities were greater than may usually be expected and that this accounts for the fact that

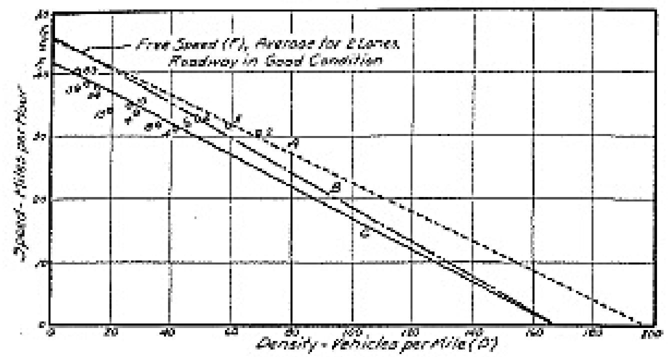

Figure 7. Speed Corresponding to a Given Average Density. A. Estimated curve for traffic with percentage of trucks ranging from about five per cent at lower densities to one per cent at the maximum. B. Trucks ranging from about 12 per cent at lower densities to two per cent at the maximum. C. Data taken two miles south of Dayton on U. S. 25; figures show the number of 100-vehicle groups observed for each point (Table XII).

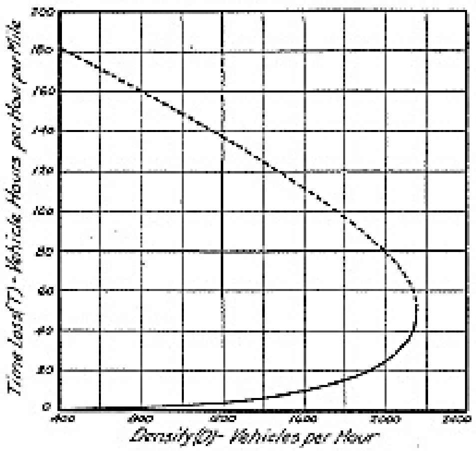

Figure 8. Vehicle Time Loss Due to Congestion on a Two-lane Highway.

curve C, according to the limited amount of data shown, would curve upward.

It has been assumed in drawing curves A and B that a roadway on which the free speed is less than on an open highway due to physical surroundings, will not show a loss in speed due to congestion as greatly as the open road. This may be explained in the following manner: a density of 1550 vehicles an hour reduces the average speed on an open highway from 43.5 to 33.5 miles an hour, but on another roadway with a free speed of only 35 miles an hour, a density of 1775 vehicles an hour is required to reduce the average speed to 25 miles an hour.

ESTIMATING CONGESTION

Having arrived at the ratios of the increase of congestion to increasing densities, it is possible to estimate the congestion or time loss for any given location provided the average traffic density is known.

For example, the average daily traffic on U.S. 20, 2.4 miles west of Norwalk is given as 3647 vehicles. Let it be required to estimate the time loss for the hour 3 to 4 P.M., on a Sunday in August.

Correlation of hourly, daily and seasonal variations of traffic expressed in factors used by the Traffic Bureau, proves that for this hour there would be about 800 vehicles passing. The total vehicle time loss for this density is about 1 hour.

CONCLUSION

It may be concluded from the study of 1180 groups of 100 vehicles each, taken from over 22,000 vehicles observed, that the average free moving speed of vehicles on a first class roadway in dry weather with the percentage of trucks varying from zero to ten is very nearly constant and equal to approximately 43 miles per hour. This speed holds for either a two or three lane highway. The bumps per mile on one location were twelve and on another 492, showing that a certain amount of roughness has little effect on the speed. Passenger speeds of over 80 miles per hour and truck speeds of 60 miles per hour were recorded.

The average free speed of 18 buses observed was 41.6 miles per hour.

The mean "smoothed" speed of 850 light trucks (net rate capacity of 2½ tons or less) was 41.0 miles per hour and of 225 heavy trucks (net rate capacity of 3 tons or more), 32.4 miles per hour. The speed range of the light trucks taken from a normal probability curve was as follows:

Speed Range of Light Trucks

Speed in Miles Per Hour	Percentage of Light Trucks Traveling at or less than Given speeds
20	3.6
30	20.0
40	55.0
50	88.0
60	98.0

The speed range of 225 heavy trucks was as follows:

Speed Range of Heavy Trucks

Speed in Miles Per Hour	Percentage of Heavy Trucks Traveling at or less than Given Speeds
15	1.0
20	5.0
30	28.0
40	85.0
50	99.2

The speeds recorded show that as congestion increases there is less consistency in the speed-density ratio. As the space between vehicles becomes less, the effect of a few slow moving vehicles becomes pronounced, which means that with the same average speed, the density may vary considerably.

TABLE XIII

Traffic on Ohio 2, U. S. 6-20—Edgewater Park—Cleveland

Density in Vehicles Per Hour	Number of 100-Vehicle Groups Observed	Mean "Smoothed" Speed	Percent Vehicles on Each Lane			
			West			East
			1	2	3	4
1343	12	35.9	18	38	34	10
1606	10	35.4	17	37	32	14
2278	30	35.1	14	37	36	13
3535	8	35.0	13	37	41	9
Av. 2170	Sum 60	Av. 35.3	Av. 15.1	Av. 37.2	Av. 35.6	Av. 12.0

Mean "Smoothed" Speed for Lane 1—33.0 Miles Per Hour.
Mean "Smoothed" Speed for Lane 2—36.7 Miles Per Hour.
Mean "Smoothed" Speed for Lane 3—38.4 Miles Per Hour.
Mean "Smoothed" Speed for Lane 4—32.5 Miles Per Hour.

TRAFFIC ON A FOUR LANE ROAD

Traffic data taken on routes Ohio 2—US 6—20 at Edgewater Park in Cleveland, gave some indication of the traffic capacity of a four lane highway. Since no trucks are allowed on this boulevard, the results cannot be applied to mixed traffic. The speed range was observed to be relatively uniform, ranging between 20 and 50 miles per hour. The drop of 0.9 miles per hour is not sufficient to show the beginning of congestion. The data are shown in Table XIII.

SPEED RANGE FOR DIFFERENT DENSITIES

The data for different densities taken 2.4 miles west of Norwalk on US 20 (Table XIV) show that as the density increases the speed range decreases. There was a larger percentage of trucks for the lower densities which probably accounts for the comparatively large percent of vehicles traveling at low speeds for the lower densities.

The data available on the films, it is believed, will, when properly analyzed, give the answer to other traffic problems. For instance, the distance required for one car to pass another, together with the clearance on the opposite lane, is evidently contained in the data at hand.

Other phases of traffic behavior, such as the effect of curves upon speeds, immediately present themselves and without doubt further investigation is not only desirable but necessary if the knowledge of traffic is to keep abreast of the problems arising from the fact that driving on improved highways with speedier and more powerful vehicles is still subject to the physical limitations and mental perceptions of the driver.

TABLE XIV

SPEED RANGE FOR DIFFERENT DENSITIES

U. S. 20—2.4 Miles West of Norwalk

Average Density in Vehicles per Hour	Percentage of Vehicles Traveling at or less than Given Miles per Hour				
	Miles per Hour				
	20	30	40	50	60
	Percent				
275	1.2	15.0	56.0	92.0	99.5
762	0.5	10.0	60.0	89.0	99.4
927	0.3	10.0	54.0	92.0	99.5
1097	0.5	14.0	62.0	95.5	99.0
1295	1.2	22.0	70.0	95.6	
1617	3.2	34.0	86.0	99.4	

DISCUSSION—TRAFFIC CAPACITY

MR. J. ROWLAND BIBBINS: I would like to inquire if any of you have used the simple method of getting *over-all* speeds over a stretch of highway by recording the tag number of the vehicle entering the stretch and checking the *same* tag number on leaving. I used this method to advantage in Chicago on the Lake Front Highway and found plenty of vehicles that were reaching the Jackson Park exit at speeds of 50 m.p.h. and upwards. Even during rush hours the speeds would average pretty close to 47 and as a matter of fact they had to roll along pretty near 50 or get pushed out of line. It seemed much easier to jog along with the crowd at 50 miles. This method was challenged in court and I had some difficulty in substantiating the accuracy of the test because it was not a 100 per cent count. We noted the tag numbers every 5 or 10 second intervals at Grant Park and caught them at the end. Of course some error might occur in the run with those vehicles caught at the

beginning of the interval at one end and at the end at destination. The opposing lawyer claimed that this was so inaccurate that it "meant nothing." But the method seemed to me very reasonable. We were also able to locate observers and find the speeds to and from intermediate points on the Lake Front Highway run. By this method we discovered the astounding fact that rush-hour traffic-way speeds were higher than even counter-traffic rush or mid-day speeds on these express highways, but just the reverse on normal city streets.

MR. W. S. CANNING, *Keystone Automobile Club:* I have made some speed runs by placing my own vehicle in a group of vehicles running on a particular street. The instructions to the driver were to keep in position in the group. If a vehicle at normal speed passed our car, we would pass one vehicle. Two watches were used, one a stop watch. The time of crossing certain intersections was noted by standard watch for a distance of 1 mile, 2 miles, 5 miles, checking each third or fourth intersection. If stops were made, the stop watch came into play and the length of time the vehicle was actually at a standstill—the time until it began to move again—was noted, together with the reason for that stop. In that way a chart was developed which would show the reasonable average running speed between the two extreme points and at any points in between and also the delays and the reasons for those delays. I don't know whether that method, crude as it may be, would apply to the case of which Mr. Bibbins speaks, but it has worked for me.

MR. H. HERSHEY MILLER, *Pennsylvania Department of Highways:* It is rather difficult to determine the traffic capacities of two, three or four lane roads from observation stations without a rather elaborate set-up. This is demonstrated in Professor Greenshield's paper. But when you are driving a car you know when traffic is delaying your progress.

Heavy traffic on main highways will probably be confined to areas adjacent to large centers of population at certain peak load periods. If four traffic lanes are provided each lane could accommodate one thousand (1000) vehicles per hour without serious traffic impediment except where cross traffic is of sufficient magnitude to require stop-go traffic control, or traffic police. When this condition prevails serious delays will result that will cause traffic congestion.

At less frequented sideroads the main traffic arteries will prove a serious barrier to crossing or turning traffic.

Where the volume of traffic at any point approaches the theoretical maximum road capacity, it might be advisable to provide grade separation for intersecting roads.

The determining feature is an economic one and must be based on a traffic analysis that will include not only the traffic flow in each direction but also the average delays that will be occasioned during these peak periods to each vehicle involved.

Another factor in traffic flow that requires study is belt line construction to divert through traffic from city streets. Here again studies must be made to determine the time saved, the cost involved and the savings effected in vehicle operating costs.

The widening of through routes as they approach thickly populated centers to accommodate local traffic requires the same analysis.

These problems may be analyzed by means of traffic counts and the progress of an automobile in traffic. The record of the progress may be

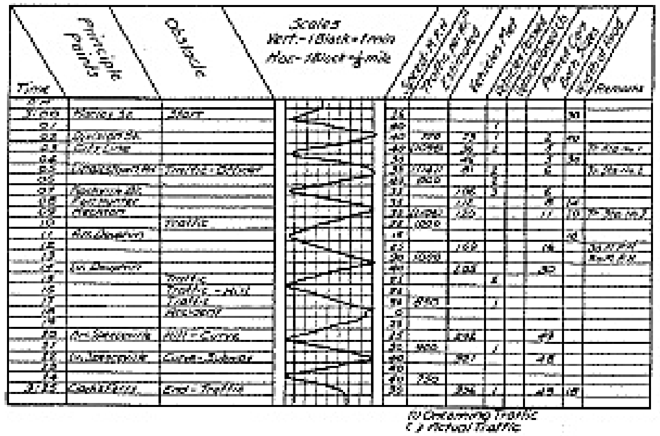

Figure 1. Trip from Maclay St. Harrisburg to Clark's Ferry Bridge, Sunday November 2, 1930, 12.9 Miles.

secured by means of an instrument attached to the automobile which marks a graduated ribbon indicating the speed of the vehicle and the time lost due to cross traffic, stop lights, slow moving traffic, congestion, road conditions, etc.

In Pennsylvania we have equipped a number of touring cars with Recordographs that indicate the speed of a car graphically on a ribbon. Observers in the car record the reason when speed is reduced or when delays are encountered. By plotting this information on a special form a graphic picture of traffic conditions is presented.

By correlating this information with ground stations it is possible to obtain accurately the traffic capacity of roads of various widths.

As a result of recordograph studies it is apparent that with traffic not

exceeding 600 vehicles per hour the two-lane road provides ample capacity to carry the traffic except when slow moving traffic is encountered. With this volume of traffic it is very hazardous to attempt to pass due to the volume of oncoming traffic which is at the rate of about one car every twelve seconds.

On the three and four lane roads traffic movement was singularly free from signs of congestion with traffic up to 1900 vehicles per hour and from observations and counts made at five minute intervals with traffic at the rate of 3,000 vehicles per hour no congestion was noted.

The three lane road presents a certain traffic hazard due to cars in opposite directions trying to pass at the same time, but with careful driving and due regards to the rights of other operators this hazard is reduced to a minimum. There will of course always be the hazard of the irresponsible speed addict who uses the center lane as a speedway. This type operator must be eliminated by revoking the driving privilege.

The recordograph traffic analysis is an accurate method of determining the traffic capacity of highways and a valuable aid in determining traffic conditions.

Figure 1 indicates how the material is assembled for analysis.

The trip shown represents Sunday traffic on Route 11, Harrisburg to Clarks Ferry Bridge. The distance was 12.9 miles, theoretical time 20.3 minutes, actual time 25 minutes. The return trip was made in 26 minutes.

With traffic exceeding 700 vehicles per hour a noticeable impediment to free movement was apparent on the two lane road; the three and four lane roads were not congested.