AVERAGE SPEED AND TRAFFIC DENSITY AS A MEASURE OF ROAD CAPACITY

By B D GREENSHIELDS

Associate Professor, Civil Engineering, The College of the City of New York

SYNOPSIS

Measurement of the utility of a highway is its ability to facilitate traffic The comparative utility of various road types may therefore be determined from an accurate measurement of the usual speeds of motor vehicles and the density of traffic on the roadways considered

The average speeds recorded in the investigation were 47.8 miles an hour for passenger cars on pavement, 43.3 miles an hour on treated-type A, 37 1 miles an hour on treated-type B, and 32 6 miles an hour on untreated loose gravel

For each of these values the corresponding average speeds for trucks or heavy commercial vehicles were 37 9 miles per hour on pavement, 32.5 on type A, 30 9 on type B, and 28.2 for loose gravel

From these average speeds the relative capacities were deduced to be for cars, gravel 1, Treated Surface A 1.33, Treated Surface B 1 15, pavement 1 47, for trucks, gravel 1, Surface A 1 30, Surface B 1.23, pavement 1 51

The relative values of time on the various surfaces are also discussed

This report grew out of a study of the speeds and spacings of vehicles on several types of road surfaces and the resultant traffic capacity of the roadways The surfaces included one high type pavement, two treated gravel roads and one of loose gravel

The investigation was conducted in 1933 as a project of the Engineering Research Department of Michigan University R S Swinton, Associate Professor of Engineering Mechanics at the University, was co-worker on the investigation

It is not the purpose of this paper to point to a definite conclusion, but rather to present a question worthy of review and discussion

The measure of the utility of a highway is its ability to facilitate traffic The comparative utility of various roadways may be determined from measurements of the usual speeds of motor vehicles and the density of traffic on the roadways considered

The results obtained from sufficient data to insure reliability gave an average speed on the pavement of 47 85 miles per hour as compared with 43 27 miles per hour for the same cars on one treated road, 37 10 for another group of cars on the other treated surface road, and 32 56 miles per hour on the loose untreated gravel

For each of these values there was a similar analysis for trucks or heavy commercial cars which gave corresponding speeds of 37 94, 32 50, 30 90, and 28 2 miles per hour respectively

The photographic method[1] was used in securing these data A summary of the results obtained on each of the several types of highways, together with a brief statement of the cost of construction and annual maintenance, is taken up in order This is followed by a correlation with principles derived in earlier studies and a more critical study of the reasonableness and limitations of the study

TRAFFIC STUDY ON PAVEMENT

The pavement studied is located about 19 miles west of Midland It carried the same traffic as the treated gravel section with which it is compared There are no intermediate cross roads carrying ap-

[1] Proceedings Highway Research Board, Vol 13, p 382

preciable traffic The average daily traffic in 1932 was 1384 cars and trucks

A roughometer constructed according to the specifications of the U S Bureau of Public Roads [2] and operated on a 1933 Plymouth car at a speed of 35 miles per hour gave an average roughness index of 1 25 to the mile on three round trips over the section

On August 30, from 11 A M to 5 30 P M, 341 cars passed over this road at an average speed of 47 85 miles per hour, while 64 trucks maintained an average speed of 37 94 miles per hour This should be compared with the rate of travel on the treated gravel section carrying the same traffic These are believed to be reliable averages because on a duplicate run made on the 26th of August, 146 cars passed the same observation station averaging 47 67 miles per hour

Traffic Study of the Treated Gravel Section of the Above Road (A) This section carried the same traffic as the pavement On August 30, 1933, from 10 30 A M until 5 30 P M, 361 cars travelled over the section observed at an average speed of 43 27 miles per hour. During the same time 49 trucks passed at an average of 32 50 miles per hour The reliability of these figures may be checked with the average speed of 41 5 miles per hour maintained by 94 cars at the station on August 22 The average speed of 20 trucks was 30 8 miles per hour on that date

The section chosen for each roadway surface was the best unhampered straight-away available The weather had been dry for several weeks A reading of 3 06 was obtained from 6 trials of the roughometer

Study of Traffic on Another Treated Surface (B) The average daily traffic on this road was 411 vehicles per day The comparative roughness of this surface was 10 1 per mile One hundred and twenty-five cars were observed on August 24 to pass at an average speed of 37 10 miles per hour The vehicles composing the traffic were on the average older models than on the first two stations observed While the surface was smooth, its texture lacked firmness The slow speed indicates that the texture of the surface may be a more important factor in determining speed than roughness

[2] Public Roads, Vol 7, No 7, Sept 1926

TRAFFIC BEHAVIOR ON LOOSE-GRAVEL ROAD

Two sections on loose-gravel were studied The roughometer recording on the first section was 12 3 The average daily traffic was about 402 vehicles On September 1, 1933, between 9 A M and 5 P M, 105 cars passed at an average speed of 28 95 miles per hour Twenty trucks averaged 29 7 miles per hour

On the other section on August 26, 1933, 186 cars passed at an average speed of 33 65 miles per hour, while 16 trucks had an average speed of 27 01 miles per hour On August 27, 125 cars passed at an average speed of 33 99 miles per hour and 3 trucks at 21 3 miles per hour The average for 416 cars on the two locations was 32 56 miles per hour and for the 39 trucks 28 2 miles per hour

TRAFFIC CAPACITIES OF THE VARIOUS ROAD SURFACES

The maximum number of vehicles that may pass over a section of road in a given time is a function of both the speed and the average spacing maintained between vehicles Previous studies show that the average spacing is 21 feet plus 1.1 times the velocity in miles per hour. At such a spacing, the number of vehicles per hour that will pass a given point equals

$$\frac{5280\,V}{1.1\,V+21}$$

This formula, however, shows only the capacity when the road is completely congested Under such a condition, the speed for all vehicles is the same and there is no minimum or maximum speed, but only the average speed which is maintained by all and determined by the slowest vehicle There is no particular speed which gives a maximum capacity, as was once believed, but speed and capacity increase together Hence the logical tendency to permit higher velocities

Highway capacity has been defined (page 218 Vol 10 Proceedings Highway Research Board) as the ability of a road to permit traffic to move at its normal rate of speed Congestion occurs when vehicles are retarded by those ahead Until such congestion occurs, the capacity of the roadway is a function of the speed of the vehicles The average speed of the traffic is then a measure of the relative capacity The relative capacities of the road surfaces studied are as in Table 1

TABLE 1

RELATIVE CAPACITIES OF ROAD SURFACES

Type of surface	Relative capacity	
	Cars	Trucks
Gravel	1	1
Treated surface (B)	1 15	1 23
Treated surface (A)	1 33	1 30
Pavement	1 47	1 51

THE COST OF TRAFFIC DELAYS

The slow speeds caused by a poor road surface result in a time loss to the vehicle and passengers By making a reasonable assumption of the value of time, the cost to traffic may be estimated In one case the value of a vehicle minute was estimated to be five cents (Report of a "Study of Highway Traffic and the Highway System of Cook County, Illinois, page 16, Bureau of Public Roads, 1925) Mr Fred Lavis estimates the value of time loss as 2 3 cents per minute, and for non-commercial vehicles as one cent per minute (Proceedings of the American Society of Civil Engineers, 1930, page 1369) S Johannesson, in Civil Engineering, March, 1933, page 149, estimates that the average value of a private passenger car minute is 78 cents, and of a truck, 1 49 cents

Mr Johannesson, in arriving at a value of vehicle time, makes use of the economic theory that the value of a thing is what people are able and willing to pay for it

Given the choice of two routes of travel, one shorter but more expensive, a certain percentage of drivers will take the shorter route and pay a toll Studies of toll bridges have verified this fact There is an annoyance factor that should be taken into account Of two alternative routes, the one offering unobstructed travel will attract the most traffic The annoyance factor can probably be measured by the variation in speed over the route In the one case, high average speed would be achieved by excessive speeds over part of the route

Nathan Cherniack, Special Traffic Consultant, Port of New York Authority, in a "Report of Traffic and Revenue Potentialities and Probable Traffic Characteristics of the Proposed Battery-Hamilton Avenue Vehicular Tunnel", March 15, 1937, gives the following monetary values as appearing to be those placed by motorists upon running time and avoidance of waiting

	Passenger cars	Trucks
a Savings in running time	1 1¢ per min	
b Avoidance of waiting time at ferries	5 3¢ per min	8 0¢ per min

If the most conservative of these values for time be applied to the various average speeds observed on the surfaces studied, the relative costs of time lost per 100 vehicles are as shown in Table 2 No time loss is assumed for the pavement as it shows the highest average speed

ECONOMICS

Example 1

Let it be required to estimate the value of the time that might be saved by changing the loose gravel to Surface Treatment (A)

Taking average traffic of 402 vehicles per day of which 15 per cent are trucks the daily difference in time cost between the two roads may be computed as follows

45 cents—9 4 cents = 35 6 cents = the excess cost for 100 passenger car miles on Loose Gravel over Treated Surface (A)

82 cents—29 5 cents = 52 5 cents = the excess cost for 100 truck miles on Loose Gravel or Treated Surface (A)

Of the daily traffic of 402 vehicles 85 per cent or 342 are passenger cars and 60 are trucks

For the existing traffic therefore the estimated daily saving in time value by changing from Loose Gravel to Treated Surface (A) would $= 3\ 42 \times 35\ 6¢ + 0\ 6 \times 52\ 5¢ = 153¢ = \$1\ 53$ per mile The estimated annual saving would be $558 per mile

Example 2

Let it be required to set up a traffic load, based upon maintenance, capital, and time loss costs, at which a change from a treated gravel surface to pavement becomes desirable (see Table 4)

TABLE 2

VALUE OF TIME LOST

Type of surface	Value of time lost per mile per 100 passenger cars	Value of time lost per mile per 100 trucks
	Cents	*Cents*
Pavement	0 00	0 00
Treated surface (A)	9 4	29 5
Treated surface (B)	27 6	54 2
Loose gravel	45 0	82 0

TABLE 3

A STUDY OF TRAFFIC SPEED ON DIFFERENT ROAD SURFACES

	Treatment B	Ordinary Gravel	Treatment A	Pavement
Roughness*, units per mile	10 1	12 3	3 06	1 25
Number of cars	125	416	361	341
Average speed of cars, miles per hour	37 1	29	43	48
Number of trucks	48	39	49	64
Average speed of trucks, miles per hour	30 9	28	33	38
Comparative car capacity	1 15	1	1 33	1 47
Comparative truck capacity	1 23	1	1 30	1 51
Estimated value of time savings† per mile over ordinary gravel for 500 cars per day for 4 good-weather months	$106 14	0	$217 16	$274 50
For 70 trucks per day for 4 months	23 74	0	44 84	70 03

*Measured by a roughometer constructed according to specifications of the U S Bureau of Public Roads (Public Roads, Volume 7, September, 1926)

†Based on the estimates of S Johannesson, *Civil Engineering*, March, 1933, Page 149

TABLE 4

Item	Pavement	Treated Surface A
	Annual cost per mile	Daily cost per vehicle mile per day
Amortization of cost in 25 years at 5 per cent	$1,420	
Maintain	150	$1 00
Operation loss		0 46
	$1,570	$1 46

T—daily traffic at which a change becomes desirable $= \frac{1570}{1\ 46} =$ 1,075 vehicles per day

These costs are not offered as authentic and each solution should be made from data furnished by parties concerned Only the method is of interest The cost of the change is estimated at $20,000 per mile

SUMMARY

The ability of a road to facilitate traffic is increased by improving the surface or removing other physical hazards, such as sharp curves, to permit increased speeds The monetary value of the time saved becomes a factor in the justification of the improvement The number of vehicles that can pass over a roadway at a rate of speed determined by the excellence of the vehicle and the skill or desire of the driver unhindered by the road hazards is the true measure of highway utility