

DISTANCE AND TIME REQUIRED TO OVERTAKE AND PASS CARS

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SYNOPSIS

The results of this investigation are based upon study of 7500 cars whose behavior was recorded by the photographic method described in Volume 13, Proceedings, Highway Research Board. The method was confined largely to two-lane highways where the traffic density varied from 200 to 1300 vehicles per hour. In addition to the analysis of the photographic data, the paper presents a mathematical analysis of the speed and spacing of motor vehicles.

According to the authors conclusions from this investigation, the minimum requirements for safe passing under average traffic conditions are 10 to 11 sec and from 1000 to 1600 ft of clear roadway. Many drivers pass with less than safe distance available, evidently depending upon any approaching vehicle to give way or reduce speed to avoid collision.

Studies of traffic behavior show that 500 vehicles make a sufficient sample from which to draw conclusions and that as few as 100 will exhibit consistent characteristics.

In the panorama of traffic on a busy highway, vehicles are constantly passing or attempting to pass each other. When the clearances between vehicles are not sufficient to permit free passing, not only are the chances of collisions multiplied, but the entire stream of traffic is retarded by the slower moving units. In order that passing will not be undertaken unless there is ample space for the maneuver to be performed safely, the driver should have clear vision for at least the distance needed. Various distances, ranging from 500 to 1000 ft have been regarded as ample in traffic regulations, but apparently without any specific reason. Clearly the distance required for one car to overtake and pass another must be considered in designing roads and in determining safety regulations.

Interesting and valuable information

on the passing of cars has been secured by the Traffic Bureau of the Ohio State Highway Department under the supervision of Harry E Neal, Traffic Engineer. The results of this investigation are based upon the study of the performance of several thousand cars recorded by the photographic method. The conclusion arrived at by analysis of the data is that the minimum spacing required for passing is from approximately 1000 to 1600 ft on a two-lane highway under average traffic conditions with a corresponding minimum time of 10 to 11 seconds.

These results may be compared with those given by Dr H C Dickinson, Chief, Division of Heat and Power, National Bureau of Standards, Washington, D C, in *Highway Research Abstracts*, Number 14, October, 1934. He states that:

"The time required to overtake and pass another car on a substantially level road, starting from a safe distance to the rear, is found to be very nearly 6 seconds and independent of the speed. If these figures are reduced to distances, it is found that for a car to overtake and pass another traveling at 40 miles per hour on a road where speeds of 50 miles per hour may be expected, the driver intending to overtake must have at least 900 feet of clear road ahead if the maneuver is to be performed with safety."

In the Report on *Massachusetts Highway Accident Survey, 1934*, page 110, the passing distance required at 40 miles per hour is given as 818 ft. Acceleration is assumed to be 2 ft per sec, per sec. This distance, however, does not include the space traversed by the approaching car. If the approaching car is traveling at 40 miles per hour, and the maneuver takes 10.5 sec, the additional clear space needed is 40×1.466 (ft per sec) $\times 10.5$ (sec) or 613 ft. On page 106 of the Massachusetts report, the time of movement is given as 12 sec when the passed car is traveling at 40 miles per hour, and acceleration is disregarded.

In the present study, the observations were made under actual traffic conditions so that the distances for passing include a factor of safety, varying according to the judgment of the drivers.

The photographic method by which the data were obtained will not be described since it has already been discussed.¹

As pointed out in those papers, the pictures show not only the number of vehicles passing in a given time, but also reveal the types of vehicles, the paths of their movements, and their rates of travel. The information to be utilized in this report consists of the speeds and the spacings at which cars were found to travel.

TABULATION AND ANALYSIS

In order to facilitate the calculation of the spacings between vehicles the data were transcribed from the films onto the form shown in Table I. The information consisted of: (1) the time (in hours, minutes, and seconds) of the taking of each picture in which a vehicle appeared, (2) the number of the picture (or frame), reckoned according to a continuous count, (3) the position on the arbitrary scale (in feet) of the car in the picture, (4) the spacing to the car ahead (when the leading vehicle appeared in the same picture, the spacing was read directly from the film, but in other cases was calculated by multiplying the elapsed time by the average speed), (5) the distance each vehicle traveled in feet between any two consecutive pictures.

The construction and use of the scale used with the film are illustrated in Figure 1, where the front of the car in the second frame is at position 252.

For example, let it be required to calculate the distance from the car recorded in Frame 110, Table I, to that of the car ahead. The car in Frame 110 appeared at position 250 feet on the arbitrary scale. Sixty-three frames earlier, the preceding car had appeared at position 245, traveling at the rate of 52 ft between frames or 52 miles per hour. For clearness of explanation, let these two cars be known as car A and car B, respectively. At the time car A was at position 250, car B was at position 245 ft plus (52×63) ft or at position 3521 ft. The distance between the cars, front to front, was then 3521 ft minus 250 ft (scale position of car A) or approximately 3271 ft.

The pictures analyzed gave information on the behavior of over 22,000 cars distributed on straight sections of two, three and four-lane highways in Ohio, but the

¹ Greenshields Proceedings, Highway Research Board, Vol 13, p 382, and Vol 14, p 448

data selected for making a study of passing maneuvers were confined mostly to those of traffic on two-lane highways which showed a tendency toward congestion. The density on these two-lane roadways varied from 200 to 1300 vehicles per hour. From the data representative groups totaling 7500 vehicles were selected for detailed study.

The camera caught very few actual passing maneuvers and it was therefore

more than twice this². Three hundred and eighty-six instances were found in which the distances ranged from a few feet to about 150 ft with a corresponding difference of speed of 5 to 30 miles per hour, the average being 9.7 miles per hour. It was assumed that these vehicles would pass those ahead by taking advantage of the clearance available at that moment.

The opportunity for passing is explained diagrammatically by Figure 2.

TABLE I
TYPICAL DATA FORM FOR CALCULATING VEHICLE SPACINGS FROM PHOTOGRAPHIC TRAFFIC RECORDS

Time		Car Positions in Feet	Spacing to Car Ahead			Distance Vehicles Travel in One Frame Interval Miles Per Hour					
Hr - min - sec	Number or Frame		In Sec	In Frame Interval	In Ft	West			East		
						P	Lt	Ht	P	Lt	Ht
11-36-20	0	130	First	Car	West	35					
-52	47	245	First	Car	East				52		
37-35	110	250	43	63	3271				60		
-50	132	135	90	132	4615	47					
38-28	188	135	38	56	2632	55					
-35	198	165	7	10	520	55					
-43	210	150	8	12	675	49					
-48	217	145	5	7	348	52					
-58	232	150	10	15	775	40					
	233	220		123	7410				38		
39-0	234	240		1	28				35		
39-5	242	112	5	8	408			32			
-35	286	265	30	44	1255				50		
40-5	330	145	67	98	3925	45					
	333	180		3	100	42					
	333	130	0	0	50	41					

decided to select cases by deduction. When a vehicle is following closely behind another, and at a greater speed, the driver evidently intends to pass the vehicle ahead. The point at which the driver must apply his brakes or pull out to pass varies with the speed at which he is traveling and with the time it takes him to react to the situation and to bring his car under control. The average brake reaction-time is about three-fourths of a second, though some persons require

Obviously car A cannot pull over into the opposite lane of traffic until car B has passed car C, and it must get back into its own lane before it meets car D.

The space C-D provides availability for passing from the time car B passes car C until it passes car D. The time in seconds to close the gap (car C to car D)

² "The Photographic Method of Studying Traffic Behavior" by B. D. Greenshields, Proceedings, Highway Research Board, Vol. 13, page 382.

equals distance C-D divided by the speed of B plus the speed of D, (when the units are expressed in feet and seconds). This fact permitted the space-opportunities for passing to be expressed as time-opportunities.

Another way of regarding what is happening is to imagine the space C-D to be stationary and B to pass by at a speed equal to the combined speeds of B and D. Car A to pass must overtake, swing around B and get back into line while B is passing the gap C-D.

In the 386 cases mentioned the car following closely behind the one ahead was assumed to be overtaking and passing it. The clearance on the opposite lane for passing was obtained by observing the time it took the car approaching on the opposite lane to appear in the next picture after a certain definite time interval had elapsed. In other words it was assumed that since the car was traveling at much greater speed than the one ahead it was on the point of passing. The time for passing was then assumed to be the time that the space would remain open on the opposite lane. This space, of course, was being closed up by the car ahead and the approaching car. Figure 2 gives a graphical picture of what vehicles do when passing occurs.

Although there are no clearly indicated examples of impending passing in Table II, the method of examining and selecting the samples may be illustrated. In the west bound lane of travel, about the middle of the table, column 7, there is shown a passenger car traveling at 52 miles per hour which is 3 miles an hour faster than the one ahead which is traveling at 49 miles an hour. The spacing between the vehicles is 348 ft. The space on the opposite lane, which may be thought of as clearance for passing, is 7410 ft. long.

The explanation may be clearer if it is tied in with Figure 2: A would then have a speed of 52 miles per hour (76 ft. per sec.), B, 49 miles per hour (72 ft. per sec.),

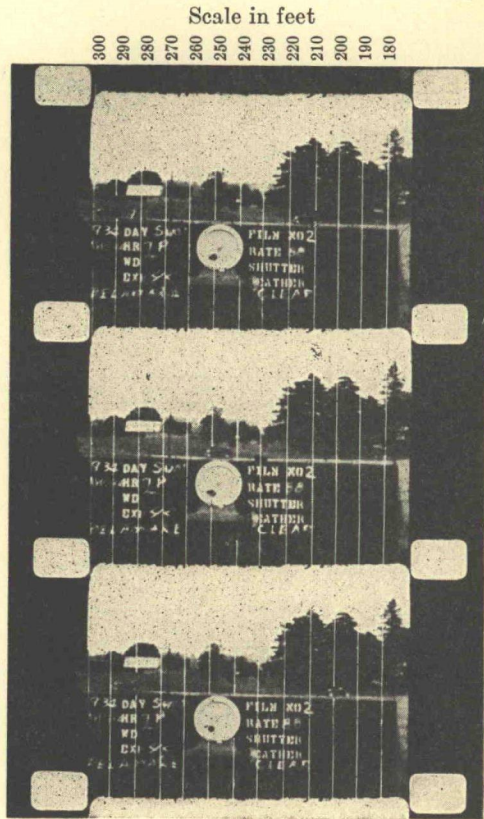


Figure 1. Section of Film. Pictures taken at rate of 88 per minute superimposed upon a scale to show the distance traveled. Note bulletin board included in each picture

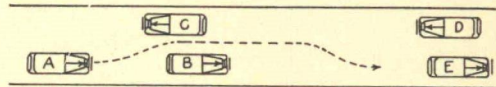


Figure 2

E, 55 miles per hour (81 ft. per sec.), D, 38 miles an hour (56 ft. per sec.) and C, 60 miles an hour (88 ft. per sec.).

In this instance, however, only part of

the space remains available for it is barely 16 frame intervals (233-217) until car D appears before the camera. This means since it is traveling 38 ft in each interval that it is 38×16 ft or approximately 608 ft away. The time-opportunity which car A would have in which to pass car B would be equal to the speed of B plus the speed of the approaching car D, in feet per second, divided into the dis-

within practical limits, for the driver's estimate of distance is far from accurate.

In order to estimate the minimum time-opportunity necessary for passing, it was found convenient to arrange the 386 samples in ascending order, starting with the shortest time-opportunity recorded, and then to express in percentage the number of samples equal to or less than each of a series of values. The shortest time-

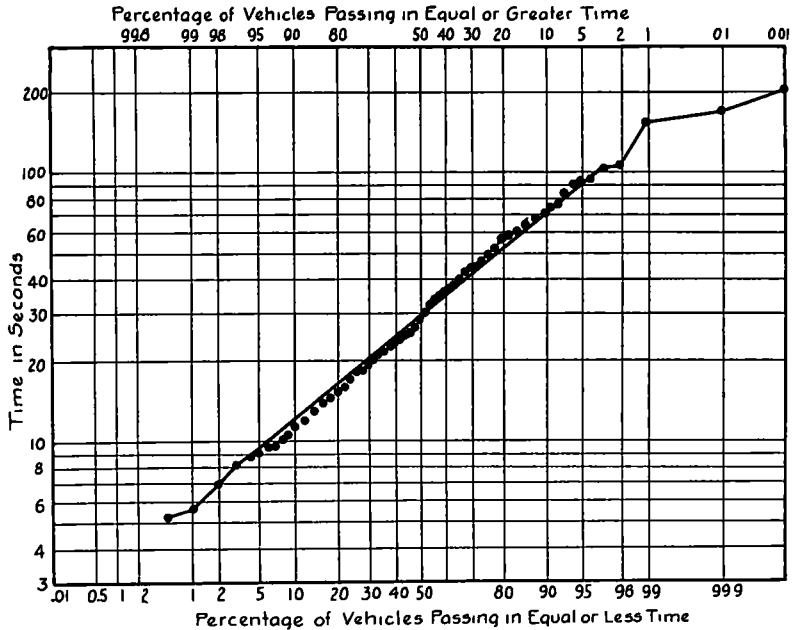


Figure 3 Time Required for Vehicles to Pass in Traffic, Assuming That Those Ready to Pass in the Photographs Proceeded to Do So. 386 Observations

tance between cars B and D. In this case.

$$\begin{aligned} \text{Passing time opportunity} &= \frac{608}{128} \\ &= 4.7 \text{ sec} \end{aligned}$$

In actual computation the positions of the cars are also used. The results, of course, are approximate and based upon the assumption that the speeds remain constant. The accuracy, however, is

opportunity which a vehicle was observed to have available for passing was 5.2 sec. Two per cent had 7 sec or less, 20 per cent had 15.5 sec or less, 30 per cent had 19.2 sec or less, etc.

Obviously the shortest time observed could not be accepted as the average minimum time necessary for passing or as a minimum at all, for in 386 cases one or more instances might have occurred in which a vehicle passed without sufficient

room, causing the approaching car to slow up or pull over

As a means of deciding the least time interval which should be safe for passing, the data were plotted on logarithmic probability paper

With the data at hand, the points fall on approximately a straight line from about the 7 per cent value to the 95 per cent value. Since a positive interval is required for passing in every case, the curve cannot be expected to pass through a zero point or cut the abscissa but must "break" or at least change its slope. The result desired is to find, if possible, the least time interval which a driver may expect to use with safety in passing. The choice of a minimum time interval must of necessity be arbitrary, so far as is known now. Therefore the arbitrary selection was made of that point, where the data show the linear curve ceases to approximate the general relation of number of passings to time interval of passing. With these considerations in mind, 7 per cent of the passings corresponding to $9\frac{1}{2}$ sec or less, have been judged to have been influenced by conditions of better cars, more skilled drivers or several other unusual factors which may have modified the passing time.

To be on the side of safety, 10 seconds may be chosen as the least interval in which the average driver will attempt to pass. Furthermore, if the following car were traveling at the same speed as the leading car, it would take about $\frac{1}{2}$ sec longer to pass.

This time interval in turn may be used to find the distance for passing under given conditions of speed. Let the speed of the vehicle D (Figure 2) on the opposite lane be 40 miles per hour, and the

speed of the car B to be passed 35 miles per hour

$$\frac{\text{Distance}}{(40 + 35) 1466} = 10 \text{ sec or}$$

$$D = 10 \times (40 + 35) 1466 = 10995 \text{ ft}$$

The term $(40 + 35) 1466$ equals the speed in ft per sec at which the distance, or gap, is being closed.

ANALYTICAL METHOD OF DETERMINING DISTANCE FOR PASSING

The distance required for passing may be determined by a mathematical analysis of the speed and spacing of vehicles. With vehicles traveling at diverse speeds it is evident that the fast moving cars overtake and pass the slower ones. For passing to take place there must be at the instant of overtaking, a sufficient gap on the opposite lane. But common observation proves that the gap may be too small for passing, and it becomes obvious that a fast moving car must slow down behind slower moving vehicles until there is an opportunity for passing. By making certain assumptions, it becomes possible to estimate the least space and time in which a driver will attempt to pass. The fastest moving vehicle will probably accelerate to the highest observed speed when it has space to do so, and then spend whatever time is thus gained in waiting for an opportunity to pass.

For the purpose of illustrating the method of analysis, data taken on Route U S 20-18, 2.4 miles west of Norwalk, Ohio will be used. This section of highway is of concrete, 20 ft wide, with a curb on the south side. The average traffic density (on both lanes) was 880 vehicles per hour. The speed range for the east bound traffic is shown by Figure 4, to have been from about 24.2 miles per hour to 50 miles per hour, the range from the

1 per cent to the 99.8 per cent abscissas being chosen as the extent of the reliability of the data

With the highest observed speed 50 miles per hour, it is assumed that the highest maintained speed would be 10 miles less than this, or 40 miles an hour. This difference approximates the 9.7 miles an hour previously mentioned. The car with the highest speed, averaging 40 miles an hour will approach and pass all slower moving cars or those with average speeds of 39 miles an hour or less. The speeds were observed to the nearest mile per hour

The factor 1.466 changes miles per hour to feet per second

If car A, however, accelerates from 40 to 50 miles per hour, and then maintains this speed as long as possible, it will close the gap in a shorter time. The average acceleration in high gear, and the average deceleration against the engine, may be taken as 3 ft per sec per sec³

From the relation, $V = at$, wherein V equals velocity in feet per second, a = acceleration in feet per second per second and t = time in seconds, it is found that it would require 4.9 sec to accelerate 10 miles per hour (or 14.66 ft. per sec.) and

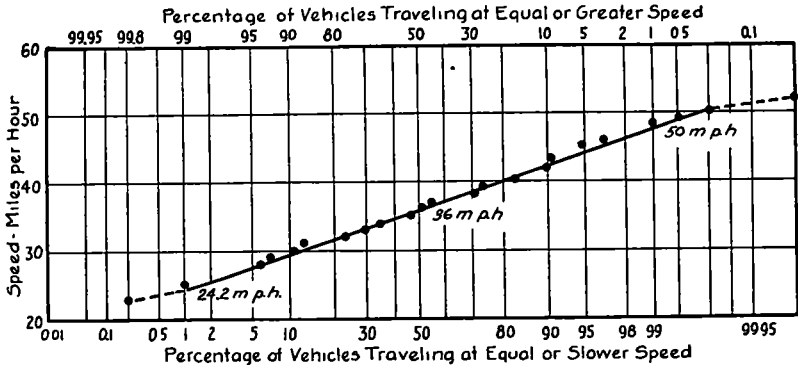


Figure 4. Distribution of Vehicle Speeds Shown on Arithmetic Probability Paper

Referring to Figure 2, it becomes clear that during a performance or cycle of passing, car A starts from behind car B, passes B and approaches to the rear of car E. In this maneuver, car A has closed up on car E a distance equal to the average spacing between vehicles, in this case 406 feet.

If car E is traveling 39 miles an hour, the time for car A traveling at a constant speed of 40 miles an hour to close this gap would equal.

$$\frac{406 \text{ ft}}{(40 - 39) 1.466 \text{ ft per second}} = 277 \text{ sec}$$

the same time to decelerate, or 9.8 sec in all

During this 9.8 seconds car A is averaging 45 miles per hour and the gap (406 feet) to the car E ahead, which is traveling 39 miles an hour, is being closed at the rate of $(45 - 39) = 6$ miles an hour, or 8.8

³ Such an estimate of the accelerating ability of two popular makes of cars was given by the respective car manufacturers, for 1928 to 1935 models. This estimate also agrees with that included in "A Photographic Method of Investigating Traffic Delays," by Dr. Bruce D. Greenshields, Proceedings of the Twentieth Annual Michigan Highway Conference, (pp 16-36)

feet per second Thus 9.8×8.8 or 86.2 feet of the gap is closed during the 9.8 seconds The remainder of the gap, $406 - 86.2 = 319.8$ feet, is closed at the rate of $(50 - 39) = 11$ miles per hour, so that it takes

$$\frac{319.8 \text{ ft}}{(50 - 39) 1.466 \text{ (ft per second)}} = 19.8$$

seconds

The net time gained by increasing the speed equals:

$$\text{Time} = \frac{406 \text{ ft.}}{(40 - 39) 1.466 \text{ (ft per second)}} - (9.8 + 19.8) = 247.4 \text{ seconds}$$

The first term equals the time to close the gap at a speed of 40 miles an hour, and

shown on the horizontal axis, Figure 4 This range in percentage may be assumed to represent 100 cars, which is about the least number that would give all representative speeds, or any larger number.

The fact that equal increments along the X axis are not represented by equal spaces makes it impossible to find by integration the total time gained For this reason it was found expedient to calculate the time gained in overtaking vehicles with speeds differing by some suitable interval such as $1, 2$ or 5 miles an hour and then to plot the results to give the curve shown in Figure 5, where the per cents corresponding to those in Figure 4 are represented by equal intervals along the X-axis The area under the curve

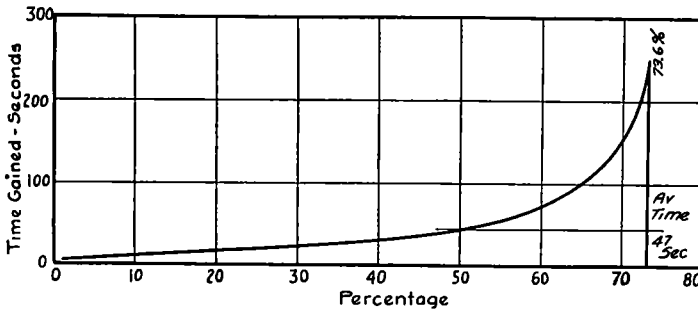


Figure 5. Percentage of vehicles averaging 40 miles per hour, which, by increasing speed to 50 miles per hour in overtaking the car ahead, would gain time equal to or less than that shown by the ordinates in passing the vehicles traveling at 24.2 to 39 miles per hour in the same direction under traffic density of 880 vehicles per hour for both lanes.

$9.8 + 19.8$ equals the time required at the increased speed

The time gained in overtaking any other car traveling at a slower speed such as 35 miles an hour would be found by substituting 35 in the calculations in place of 39 The slowest car to be passed as shown by the speed distribution curve would be one traveling 24.2 miles an hour.

The speed range, 24.2 miles an hour to 39 miles an hour, corresponds to a range of from 1 to 73.6 per cent of the traffic as

which may be measured with a planimeter, represents the total time gained in passing all slower cars This area divided by the length along the X-axis gives the average height of the curve which in this case equals 47.0 sec, the average time gained in overtaking the car ahead by increasing speed This is the average time which may be used in waiting for an opportunity to pass without lessening the average speed

The space-opportunities for passing

that occurred on the opposite lane were arranged in ascending order and the percentage of spaces equal to or less than each of a series of spacing-in-feet values were plotted on semi-logarithmic paper, Figure 6. The average number of opportunities for passing which would occur during the average 47.0 sec of waiting

approaching vehicle. With the average speeds on the two lanes 40.5 and 36 miles per hour the time of closing the space-opportunity becomes

$$\frac{546 \text{ ft.}}{(36 + 40.5) \cdot 1.466 \text{ (ft per second)}} = 4.87 \text{ seconds}$$

The average time gained, 47.0 seconds (average height of curve, Figure 5), divided by 4.87 seconds, the time for the average space interval of 546 feet to be

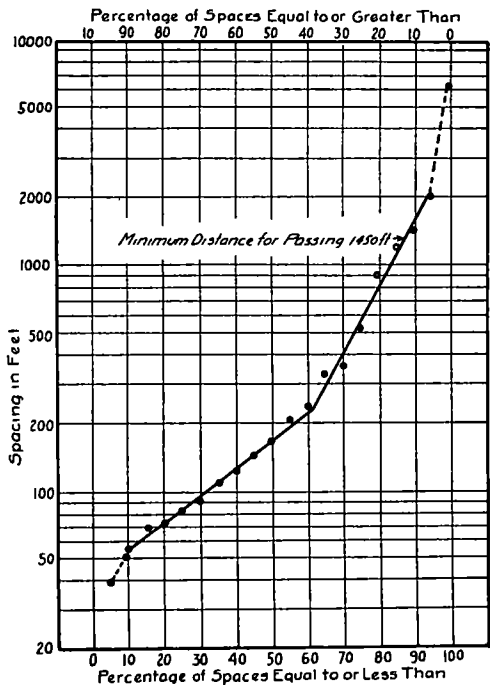


Figure 6 Spacing in feet between vehicles. West Bound Lane, U. S. 40 West of Norwalk, Ohio.

would equal the number of spaces that became available during 47 sec.

The average distance between the cars approaching on the opposite lane in the example being used was 546 ft.

The time for each average space interval of 546 feet found on the opposite lane to be closed would equal 546 divided by the combined average speed in feet per second of the vehicle to be passed and the

TABLE II
SUMMARIZED REFERENCES RELATIVE TO VEHICLE DENSITIES AS CORRELATED WITH MINIMUM PASSING SPACES

Density in Vehicles Per Hour—Both Lanes	Minimum Spacing in Feet for Passing	Average Speed in M P H	Minimum Time in Sec for Passing	Number of Veh Observed
1094	1250	37	11.1	100
	1125	39.5	10.0	100
880	1450	36	13.2	413
	1050	39	9.5	387
836	1260	36	11.2	2682
	1160	41	10.3	2518
745	1300	35.5	11.4	100
	1500	42	13.1	100
Averages	1262	38.1	11.2	
590	2150	40		339
	1650	43.5		381
337	2500	41.6		217
	2200	40.2		203

closed, equals 9.6, the average number of opportunities for each passing. If the driver has 9.6 opportunities and can see far enough ahead he will logically select the largest one. This would be represented on Figure 6 by the space corresponding to $100 - \frac{100}{9.6}$ or 89.6 per cent which equals about 1450 feet. This is the largest opportunity for passing that will present itself during the 47 sec that can be used for waiting without lessening average

speed It may therefore be considered to be the average minimum space that should be used for passing under the conditions of the traffic sample being used in this case Traveling in the other direction the corresponding distance for passing derived by using the observations taken on the opposite lane was found to be 1050 feet

In a similar manner minimum passing distances and times were determined for various traffic densities with the results shown in Table II

It will be noted that when the density drops to about 600 vehicles per hour, the spacings available for passing are greater than the minimum required

CONCLUSION

Motorists in passing where they can see ahead and when car speeds average 35 miles an hour, appeared in these studies to allow themselves a minimum of 10 seconds and 1000 feet

For the sake of safety, therefore, passing should be prohibited where the clear-sight distance does not extend beyond 1000 feet Where higher speeds prevail,

the distance should be greater Many cars undoubtedly pass with less than the safe minimum distance The approaching car is evidently depended upon to give way or reduce speed in order to avoid an accident

It is freely admitted that the results obtained in this investigation are only approximate and that some of the assumptions and perhaps even the methods of analysis are open to criticism It is believed, however, that an approximate answer based upon observed behavior is better than a purely theoretical one If the paper has done nothing more than to suggest a new method of attack on traffic problems it has served its purpose

Studies of traffic behavior continually confirm the judgment that 500 vehicles constitute a sufficient sample from which to draw conclusions, and that as few as 100 will show consistent characteristics With this fact established it becomes easier to determine fundamentals of traffic behavior, such as the one taken up in this report It is believed that a thorough knowledge of these fundamentals is a prerequisite to successful highway design and traffic regulation

DISCUSSION ON "DISTANCE AND TIME REQUIRED FOR PASSING VEHICLES"

DR H C DICKINSON, *National Bureau of Standards* In your statement, do you mean the distance that the one car will travel in 10 or 11 seconds or the distance two will travel in 10 or 11 seconds?

DR GREENSHIELDS Two cars, the car approaching on the opposite lane must be considered

DR DICKINSON Then I must disagree I am afraid there is a discrepancy somewhere and I should like to clear up just where it is

DR GREENSHIELDS In answer to your question, I may say that possibly your answer of 8 sec corresponds to the 10 sec that I got A person may pass in 8 sec but the average person will usually allow himself 10 sec to clear the car coming from the opposite direction

MR C N CONNER, *U S Bureau of Public Roads* Were your tests all made on independent locations up and down a road or on a selected strip?

DR GREENSHIELDS They were taken in 6 or 7 locations but we tried to pick out tangents

DR DICKINSON In your studies would you be able to draw any conclusions as to what safe sight distance would be

DR GREENSHIELDS About 1600 feet

DR DICKINSON At what speed?

DR GREENSHIELDS About 50 miles per hour I do not know what the average person might say I am giving what the average person apparently thinks is safe, as indicated by his performance

DR DICKINSON Frankly, I do not think that indicates the average person's observation at all

DR GREENSHIELDS In our analysis we made no attempt to pick individual cases We took some observations in heavy traffic and some in light We know that cars traveling at various speeds on one lane of travel must pass each other They must pass in the space opportunity that is available and that space must be somewhere near the average that they use We determined by our methods of analysis what average minimum space was used in passing By one method we secured 10 seconds and by the other 11 seconds

DR DICKINSON. It seems to me that speed is important In our observations each test was made by a driver starting from a safe distance behind the car which he was to pass, and travelling at the same speed, then accelerating past the other car The time recorded is the time during which the left hand lane was obstructed by the passing car The maneuver was always made as rapidly as practicable as if there were another car approaching The distance or time required to pass is the same for the speeds from 10 miles per hour to 50 miles per hour. If you take all observations and average them up you get a constant

result We have done it time and time again and repeated it under the same conditions, with several different drivers and with different cars and different speeds The results are all surprisingly close They are all in the range 5 to 7 You just cannot get anything else I do not think any assumption about what people actually do under conditions that do not call for prompt action really tell you anything

MR CONNER Dr Dickinson, were your tests made at any time whatever or when traffic was light or heavy?

DR DICKINSON: We had nothing to do with traffic The maneuver was always made as if traffic were heavy but actually there was not much opposing traffic Tests could not have been made rapidly if there had been much traffic

MR CONNER There is a large difference between your tests and the other tests You had practically a clear road with more or less selected drivers The conditions were not exactly comparable

DR DICKINSON. We made the tests under conditions that do exist all the time, whether adversely or otherwise The fact that there wasn't any car coming to require getting back in the right lane to avoid crowding it made no difference The driver was instructed to get back in the lane as soon as it was safe to do so

MR W A SHELTON, *U S Bureau of Public Roads* If you take actual travel, he would have to consider whether the other car might speed up You did not have any such consideration

DR DICKINSON We made no tests in which the other car speeded up Such tests would have little significance as they would depend on how much speeding up was done If the other driver accelerates it may be impossible to pass at all, but in this case it usually is an easy matter to drop back in time to avoid trouble.