HIGHWAY CAPACITY

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SYNOPSIS

The ultimate objective of highway capacity studies conducted by the Public Roads Administration is to arrive at practical carrying capacities for highways of different widths and alinements and to determine what effect certain design features, motor-vehicle and driver characteristics, and regulations have on the practical capacities. Since the practical or working capacity of a highway is a relative value based on the number of vehicles that a highway can carry without restricting the speed or movement of vehicles more than the drivers can reasonably be expected to tolerate, the analysis of all data gathered prior to 1939, including speeds of some 300,000 vehicles on 2-, 3-, and 4-lane highways and supplemented by more recent data, has been directed toward establishing facts regarding the change in speed and interference between vehicles with increased traffic volumes that will be useful in arriving at practical capacities for any highway condition

The results show that the minimum spacing the average driver allows between his vehicle and a vehicle he is trailing varies for different highway conditions as well as for different speeds, and that the "theoretical" lane capacities, based on the observed spacings, vary accordingly. These capacities may be approached over very short sections of highway that act as bottlenecks in a highway, but the speed at the ultimate capacity in such a case will depend upon the speed of the slowest moving vehicle

As a basis from which to determine practical capacities and the relative amount of congestion, possible capacities or the traffic densities when all vehicles are first required to travel at the same speed as the preceding vehicles are established The possible capacities are about 2,000 vehicles per hour for both lanes of a 2-lane highway, 4,000 vehicles per hour for two lanes of a 4-lane highway, and up to 3,600 vehicles per hour for the best 3-lane highways The total possible capacity of a 4-lane highway will depend upon the distribution of traffic between the two directions but, under normal or usual distributions, it will be 6,000 vehicles per hour. The possible capacity of a 3-lane highway decreases rapidly with a decrease in the design standard and, unless the center lane is wide and smooth enough to encourage its use for passing purposes, the possible capacity even at tangent locations will be little more than for a 2-lane road The same total traffic will be handled more efficiently by a 3-lane road if it is evenly divided by direction than if two-thirds is in the one direction

The speed of traffic when the possible capacity of a highway is reached will be approximately the same as the speed of the slowest vehicles during light traffic densities Grades and an increase in the percentage of trucks using a highway reduce both the possible capacity of the highway and the speed at which all vehicles can travel when the possible capacity is reached

Practical highway capacities depend upon the particular type of traffic the highway serves, the congestion that will be tolerated by drivers in various sections of the country and localities under certain conditions, and economic considerations, such as the funds available for highway construction and the reduction of congestion. Under certain conditions, such as at very short sections through tunnels or on bridges, the practical capacities will approach the theoretical capacities On other relatively short sections of highway with high hourly and seasonal density fluctuations, it may be practical to use values approaching the possible capacities for design purposes, but on rural highways or sections designed for high speed operation, the results of this study indicate that undesirable conditions will exist when the total hourly volumes are in excess of 800, 1,400, and 2,800 vehicles on 2-, 3-, and 4-lane roads having good alinements

The ultimate objective of the highway capacity studies conducted by the Public Roads Administration in cooperation with a number of State highway departments is to arrive at practical carrying capacities for highways of different widths and alinements and to determine what effect certain design features, motor vehicle and driver characteristics and regulations have on practical capacities By practical capacity is meant the working capacity or number of vehicles per hour that a certain highway facility can carry without restricting the speed or movement of vehicles more than the drivers can reasonably be expected to tolerate. The practical capacity of a highway is therefore a relative value that will vary even for the same design and will depend upon (1) the particular type of traffic the highway serves, (2) the congestion that will be tolerated by drivers in various sections of the country and localities under certain conditions, and (3) economic considerations, such as the funds available for highway construction and the reduction of congestion. These factors will result in an unlimited number of conditions. However, before the practical capacity for a particular condition can be determined, it is necessary to know at what speed the vehicles are operated during low traffic densities and to what extent the higher traffic densities restrict the speed and inconvenience the individual vehicle operators. It is also necessary to know the possible capacity of the highway and have available a means of measuring the relative congestion.

This report covers a complete analysis of data for about 300,000 vehicles recorded in Illinois, Massachusetts, and New York prior to 1938 [1] and is supplemented by data obtained during 1939.

[1] Preliminary results of these studies have been published in the February 1939 issue of *Public Roads*, and in abstract in *Proceedings*, Highway Research Board, Vol. 18, p. 359.

SPACING BETWEEN VEHICLES TRAILING EACH OTHER VARY WITH TYPE OF HIGHWAY AS WELL AS WITH THE SPEED

First let us consider the distance allowed by the average driver between his vehicle and a vehicle he is trailing, both vehicles traveling at the same speed and in the same lane. Figure 1 shows the results for about 11,000 drivers on 2-, 3-, and 4-lane highways. All curves are for daytime operation except one which is for a 2-lane highway at night. Insufficient data were obtained to arrive at accurate spacings at low speeds for any but daylight conditions on 2-lane highways. However, at low speeds all curves probably approach the 2-lane curve.

All curves show an increase in the distance spacing with an increase in speed. At night the drivers allowed a greater clearance than in the daytime for corresponding speeds. On 3-lane roads, a greater distance was allowed at the lower speeds and a shorter distance at the higher speeds than on 2-lane roads. On the 4-lane highways the drivers in the left lane allowed shorter spacings than those in the right-hand lane. It is possible that the right-hand lane contained a higher percentage of the cautious drivers or that while a driver was in the left lane he allowed a shorter distance because he felt that the driver of the preceding vehicle was less likely to slow down suddenly.

It is of interest to know that various authors of articles on highway capacity arrive at values of from 40 to 150 ft. at 20 m p h. and 87 to 1,230 ft. at 60 m.p.h. based on assumed reaction times, coefficients of friction, etc.

The lane capacities based on the spacings given in Figure 1 are shown by Figure 2. Each curve represents a particular condition and shows the number of vehicles that could pass a given point traveling in a single traffic lane if all drivers traveled at the same speed and no space between vehicles exceeded the distance allowed by the average driver while trailing another vehicle.

Although the values shown by the curves are based upon observed spacings, they are "theoretical" lane capacities. The maximum theoretical lane capacity on a 2-lane road is 2,000 vehicles per hour in the daytime and about 1,800 at night, both attained at a vehicle speed of about 33 m p h. The left lanes of 4-lane highways reach their maximum theoretical capacities of about 2,250 vehicles per hour when

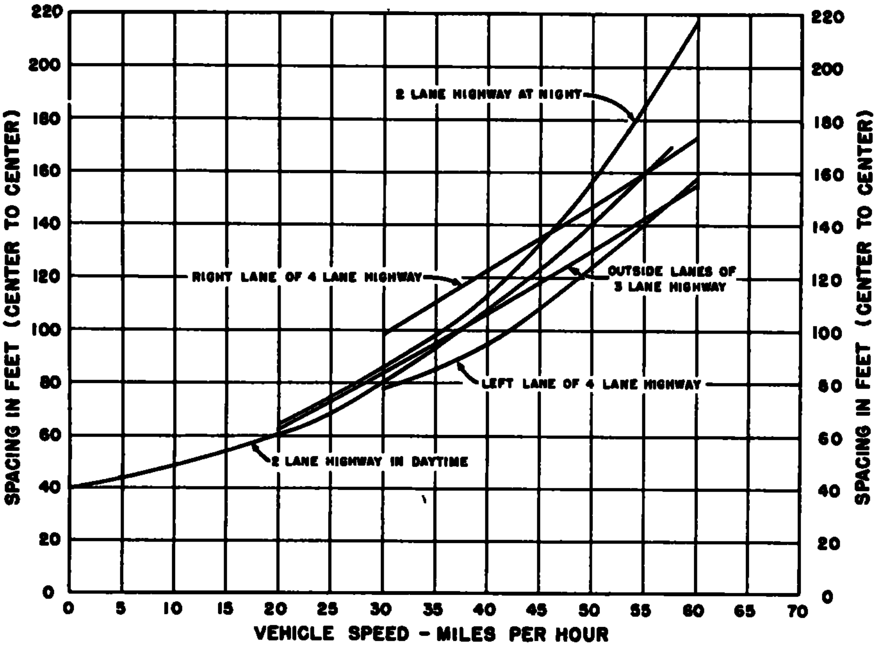

Figure 1. Average Minimum Spacings Allowed by Drivers When Trailing Another Vehicle

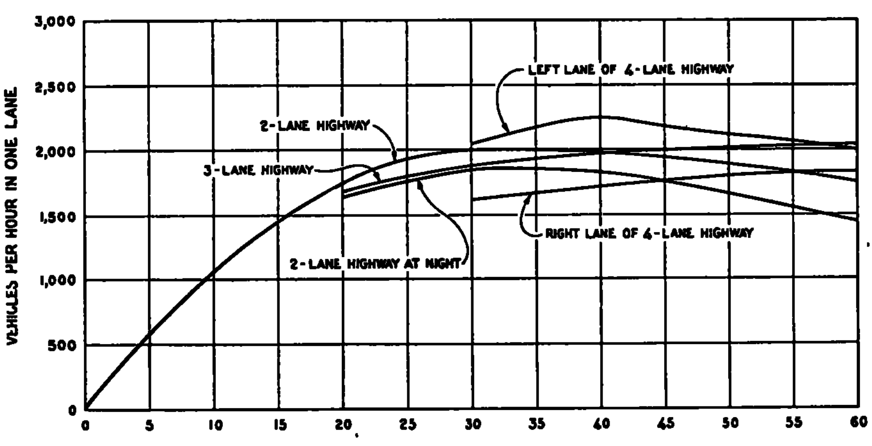

Figure 2. Theoretical Maximum Traffic Capacity with All Vehicles Traveling at the Same Speed. Based on Average Spacings

the vehicles travel at a speed of 40 m p h , while the right-hand lanes and the lanes of 3-lane highways show increased capacities with increased speeds within the range of speeds observed. The values for 3-lane highways refer to the outside lanes. These capacities may be approached over very short sections that act as bottlenecks in a highway and where drivers expect to stay

MEAN DIFFERENCE IN SPEED USED AS INDEX OF POSSIBLE CAPACITIES

In an effort to find a measure of the congestion on a highway from the data available, it was found that the mean difference in speed between succeeding vehicles was the best index available, after trying many others including a very exhaustive study of the drop in speed with

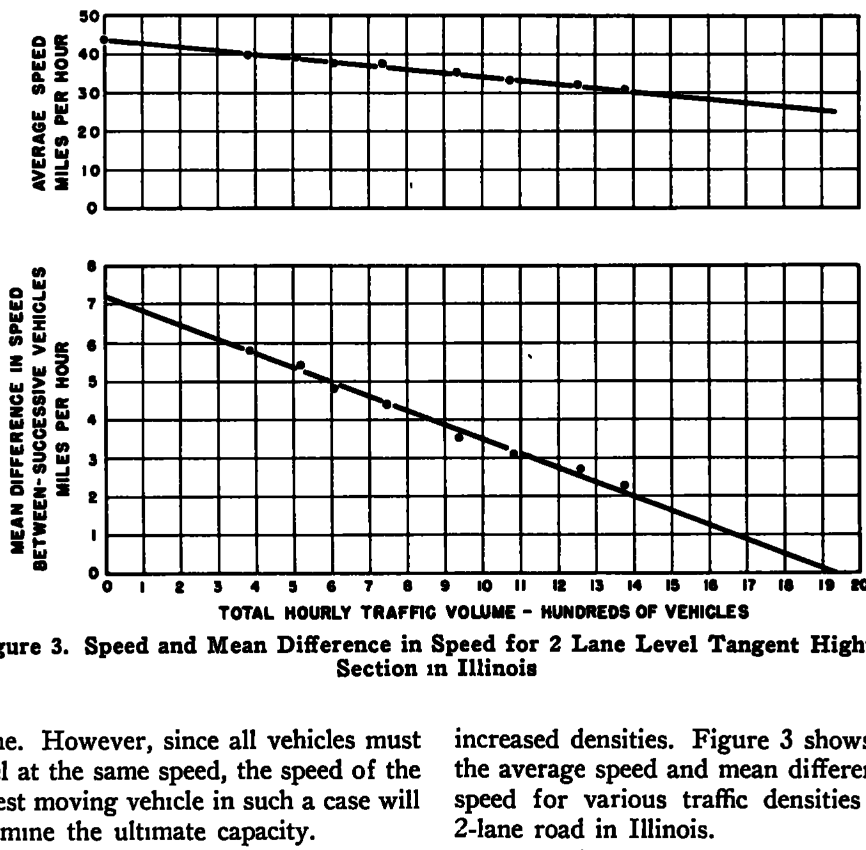

Figure 3. Speed and Mean Difference in Speed for 2 Lane Level Tangent Highway Section in Illinois

in line. However, since all vehicles must travel at the same speed, the speed of the slowest moving vehicle in such a case will determine the ultimate capacity.

To date, very few studies of highway capacity have gone beyond this stage, the main reason being that adequate data have not been available During recent years, we have had the means and have obtained a considerable quantity of reliable data. Now, at least a few of the facts can be presented that will be of assistance in determining practical capacities of 2-, 3-, and 4-lane highways.

increased densities. Figure 3 shows both the average speed and mean difference in speed for various traffic densities on a 2-lane road in Illinois.

At the light traffic densities, when all drivers could travel at their desired speed, the average on this 2-lane highway was 43 m.p.h. and the mean difference in speed between succeeding vehicles was 7.2 m.p.h. As the density increased there was a gradual decrease in the average speed and also in the mean difference in speed, until at a density of 1,380 vehicles per hour the mean difference in speed was only 2.4

m p h., although the average speed had decreased to only 31 m.p h. Since it was evident that for all practical purposes the relationship was a straight line, the line for the mean difference in speed was extended until it intersected zero difference in speed at 1,940 vehicles per hour. It is obvious that when there is a zero difference in speed between succeeding vehicles, no passings can be made and no driver can travel faster than the vehicle immediately ahead. The result is that groups of cars are formed, each following a slow-moving vehicle. If the highway is long enough, one group may catch up to another group, but there is no possibility of filling the spaces between groups by one group passing the other. When this condition occurs, the possible capacity of the highway has been reached, and, although vehicles from side roads may tend to fill the gaps, they cannot travel faster than the group of vehicles ahead. Possible capacities as used in this report, therefore, refer to the number of vehicles per hour that can travel over long stretches of highway that are free from intersections which would further reduce the roadway capacities.

On this particular section of highway, the maximum possible capacity of 1,940 vehicles per hour would be reached when the average speed had decreased to 26 m.p h. With traffic moving at 26 m p h, we would not ordinarily consider the highway as being completely congested. Neither would we believe that a bridge or any other structure is loaded to its capacity until a load necessary to cause a complete collapse is applied, unless we had some type of gauge to measure the stresses. In the case of highways, the mean difference in speed may be used as the gauge. When it reaches zero, even a slight additional load or some other factor, may cause a complete tie-up of traffic or an immediate drop in speed to any value below 26 m.p.h

The Illinois studies included a number of 2- and 4-lane highways and 4-lane divided highways carrying traffic that went directly from one type of highway to another type. Figure 4 shows the distribution of speeds and the average speed for vehicles traveling on each type of highway during very low traffic densities when each driver was free from any restriction in speed by other vehicles. On the 4-lane divided highway, the average speed was 47.5 m.p h. As far as the highway was concerned, there was no reason all vehicles could not have traveled at 60 or 70 m.p.h. In fact, the highway was designed for speed of 100 m p.h. with no intersection at grade and the study location was at the center of a 5-mile level tangent section. When we plot the average speed and mean difference in speed between successive vehicles for each traffic volume, we obtain Figure 5, based upon reliable and detailed data for 81,581 vehicles. Each line represents studies on several highways with similar design features. A 2-lane highway with few trucks had a possible capacity of 1,940 vehicles per hour, at an average speed of 26 m p h, while the same type of highway carrying 17 percent trucks had a possible capacity of 1,500 vehicles per hour at a speed of 26 m p h.

Two lanes of the 4-lane highways had a total possible capacity of 4,200 vehicles per hour, with this value occurring at a speed of 24 m.p h. on the undivided sections and at 33 m p.h. on the divided sections.

The capacity studies in New York and Massachusetts were made under a wider range of highway conditions than those in Illinois. When each of the study locations on level tangent sections of highway were classified by the number of traffic lanes and the average speed and speed difference during very light traffic densities, the location fell into seven different groups, each representing a particular highway condition. Figure 6 shows the free speeds for each condition, while Figure 7 based on the results for about

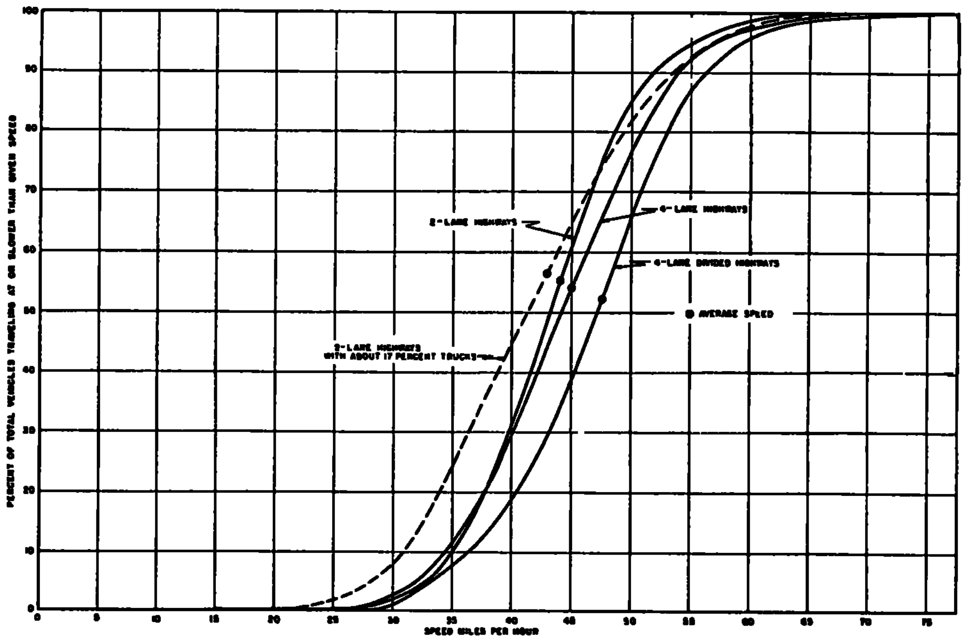

Figure 4. Cumulative Frequency Distribution of Free Speeds on Level Tangent Sections of Illinois Highways Included in Capacity Studies

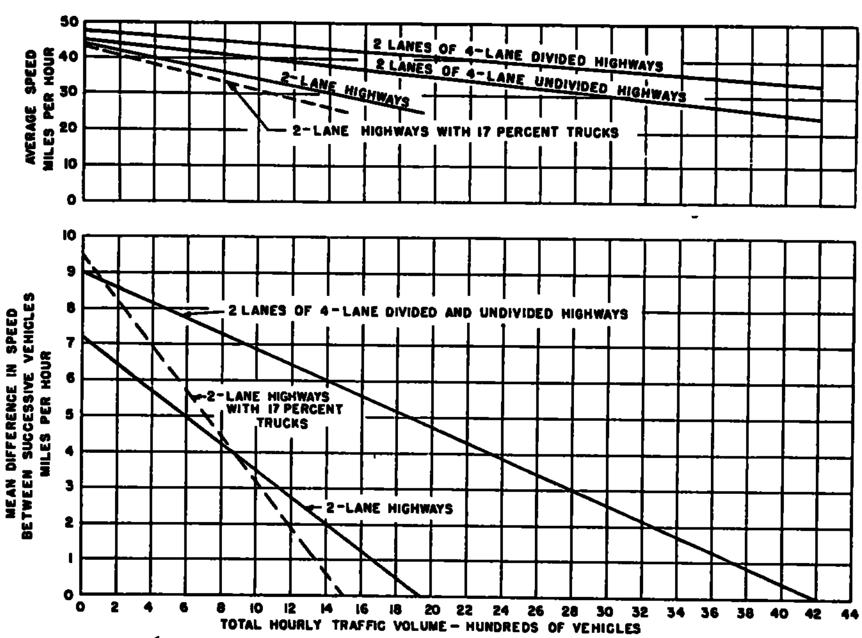

Figure 5. Speeds and Speed Differences on Comparable Level Tangent Highway Sections in Illinois

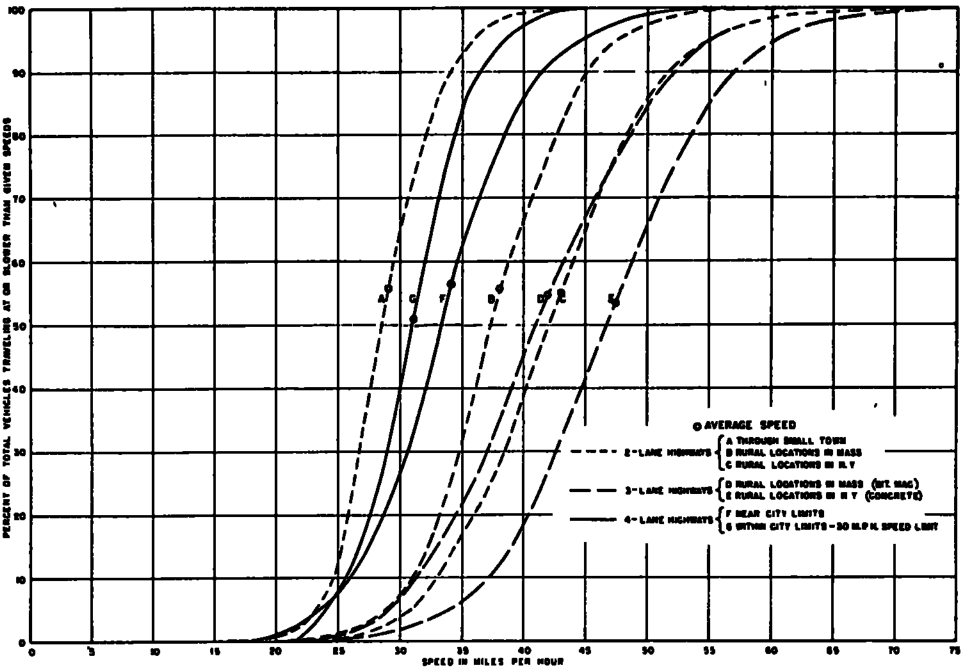

Figure 6. Cumulative Frequency Distribution of Free Speeds on Level Tangent Sections of Highway in New York and Massachusetts

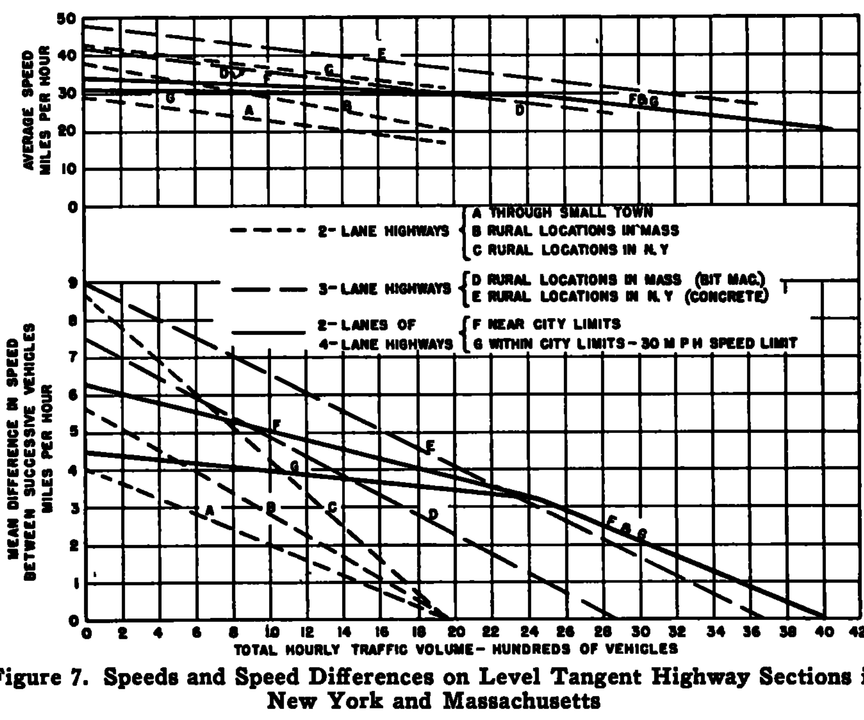

Figure 7. Speeds and Speed Differences on Level Tangent Highway Sections in New York and Massachusetts

131,000 vehicles shows, for each condition, the reduction in speed and difference in speed with an increase in the traffic density. The highways selected do not represent average conditions in each State since the particular locations were chosen to obtain the capacity data for this study rather than to make comparisons between highways in the different States.

The 2-lane highways, A, B, and C have average free speeds or speeds at light traffic densities of 29, 38, and 43 m.p.h., respectively. The lines for the speed differences converge and all reach zero difference in speed at a density of about 1,950 vehicles per hour. The possible capacities are therefore the same for the three conditions, although occurring at an average speed of 16.5 m.p.h. on section A, 20 m.p.h. on B, and 31 m.p.h. on C. The possible capacity of the Illinois 2-lane section without trucks was 1,950 vehicles per hour at an average speed of 25 m.p.h.

Each of the 3-lane highways represented by curve D had a possible capacity of 2,860 vehicles per hour at 24 m.p.h., while each of the 3-lane highways represented by curve E had a possible capacity of 3,660 vehicles per hour at 26 m.p.h.

The speed restrictions on the 4-lane sections F and G caused lower speeds and speed differences at low volumes, but the speed restrictions apparently had no effect when the traffic volume in one direction reached 2,400 vehicles per hour. The possible capacity in both cases was about 4,000 vehicles per hour at a speed of 20 m.p.h.

From these studies it is evident that·

1. Two lane level tangent sections of highway carrying few trucks have a possible capacity of about 2,000 vehicles per hour. With 17 percent trucks, their capacity is reduced about 25 percent.
2. Three-lane level tangent sections of highway apparently do not all have the same possible capacity, as is the case for 2- and 4-lane highways. One group of 3-lane highways with smooth surfaces on all three lanes and the lanes well defined by paint lines had possible capacities of 3,600 vehicles per hour. These factors had a tendency to encourage the use of the center lane for passing purposes. The best 3-lane roads can therefore be expected to have maximum possible capacities of 3,600 vehicles per hour. Since the capacity of each of the other 3-lane roads was only 2,800 vehicles per hour, there apparently is a tendency for the capacity to decrease rapidly with a decrease in the design standard. Unless the center lane is smooth and wide enough to encourage drivers to use it for passing purposes even with oncoming traffic in the outside lane, the possible capacity will be little more than for a 2-lane road.
3. Two lanes of level tangent sections of 4-lane highway carrying few trucks have a possible capacity of about 4,000 vehicles per hour. If it is considered that the possible capacity of a 4-lane highway is reached when the lanes in one direction are carrying their maximum possible capacity, the capacity of the entire roadway depends upon the relative number of vehicles traveling in each direction. With all traffic in one direction during peak periods, the total possible capacity of a 4-lane road is 4,000 vehicles per hour, while with traffic equally divided by direction, the total possible capacity becomes 8,000 vehicles per hour. However, since about two-thirds of the traffic is usually in one direction on most highways during peak periods, the lanes in one direction will be

carrying their maximum possible capacity with a total volume of 6,000 vehicles per hour.

4. The speed at which the vehicles will travel when the possible capacity of a highway is reached will depend entirely upon the speed at which the slowest vehicles on the highway are traveling Usually this will be about the same as the speed of the slowest vehicles during very low traffic volumes.

It is interesting to compare the possible capacities with the theoretical capacities. For a 2-lane highway, the possible capacity is about one-half of the theoretical capacity. On 2-lane highways carrying practically all the traffic in one direction, the lane normally used by oncoming traffic provides the means for passing the slow-moving vehicles so that the exceedingly long spaces ahead of the slow-moving vehicles may be filled However, one oncoming vehicle will require all other vehicles to crowd into the one lane, making the total possible capacity equal to the theoretical capacity of one lane. With traffic equally divided, spaces sufficiently long to permit a passing do not exist when there are over 1,000 vehicles per hour traveling in each direction, even if the drivers take full advantage of their passing opportunities.

On 4-lane highways, the possible capacities are very close to the theoretical values. Both lanes can be used to carry traffic and at the same time provide a means of passing slow-moving vehicles so that the long spaces that occur ahead of the slow vehicles can be filled.

On 3-lane highways with practically all traffic in one direction and two lanes filled, the possible capacity of all three lanes cannot exceed the theoretical capacity of two lanes. With traffic evenly divided, the number of passings required to keep both outside lanes from having gaps apparently cannot be made in one lane.

It is common practice to assume that a 3-lane highway is most efficient for locations where at least two-thirds of the traffic travels in one direction during the high volume periods. However, it is also the rule, rather than the exception, that at least twice as many vehicles will be traveling in one direction as in the other on any highway, especially during periods in which the highest densities occur Figure 8 based on 12,119 vehicles shows that under these conditions and on level tangent sections of highway the percentage of the total vehicles traveling in the center lane at any one point increases as the total volume increases to 1,500 vehicles per hour. At 1,500 vehicles per hour, only 15 9 percent were in the center lane, 13 8 percent traveling in the one direction and 2 1 percent in the other. Indications are that under these conditions a maximum of about 300 vehicles per hour will be traveling in the center lane at any one point on the highway when the total hourly volume reaches 2,000 vehicles This fact will be a surprise to anyone who has thought that about one-third of the total traffic would use each lane, that the vehicles in the center lane would consist almost entirely of vehicles overtaking the slow-moving vehicles traveling in the direction of the heavy density, and that these circumstances would be the reason for a most efficient operation of a 3-lane road when two-thirds of the traffic is in one direction

Figure 9 shows the average speeds for the vehicles in the center and outside lanes at different traffic densities The average speed for vehicles in the center lane remained practically constant, while there was a marked decrease in speed with an increase in the total traffic volume for vehicles in the right-hand lanes. Even at rather high densities, the average speed of vehicles while using the center lane for passing was nearly as high as the average speeds for all vehicles on high-speed, 4-lane highways during low traffic volumes.

A similar analysis was made for 3-lane

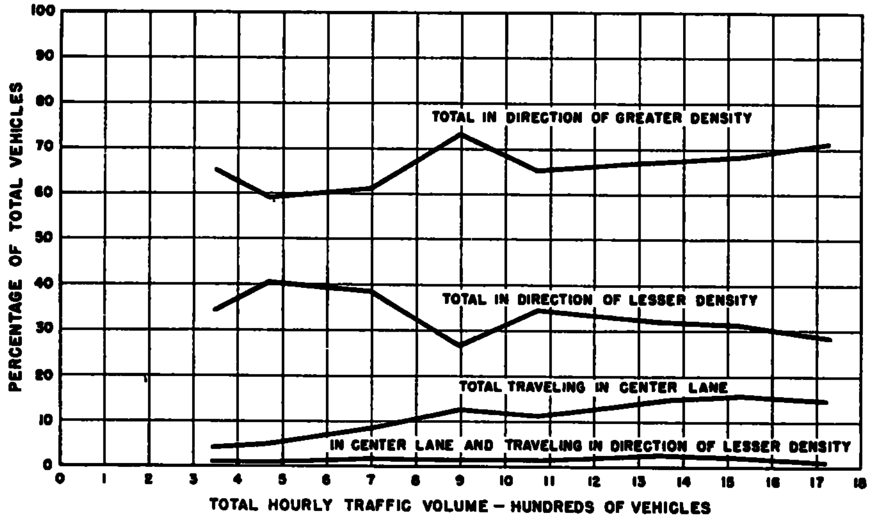

Figure 8. Distribution of Vehicles between Lanes on 3-Lane Level Tangent Highway

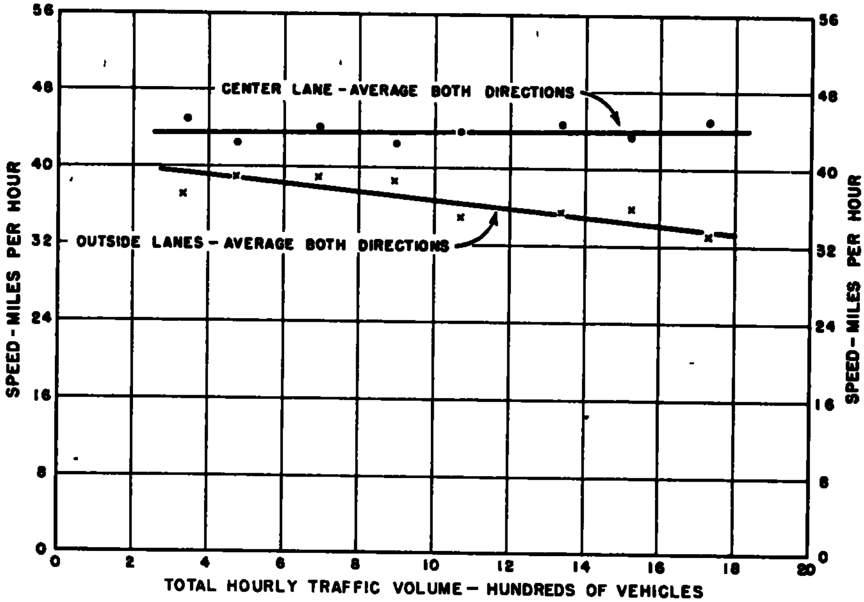

Figure 9. Vehicle Speeds in Center and Outside Lanes on 3-Lane Highways

highways when traffic was nearly equal in both directions. The conclusions reached from both analyses were:

1. At any one point on a 3-lane highway relatively few vehicles are traveling in the center lane. The maximum number that can be in the center lane is about 300 per hour, regardless of the total traffic volume, when up to 70 percent of the total traffic is traveling in one direction.
2. Although there is a very marked drop in the average speed of traffic in the outside lanes with an increase in volume, there is practically no drop in the speeds of vehicles while in the center lane.
3. As long as the hourly volume traveling in one direction does not exceed 70 percent of the total traffic, the center lane will be used by vehicles traveling in both directions.

Other obvious facts are:

1. At points where the sight distance is restricted, the use of the center lane for passing is dangerous, so in effect a 3-lane highway will carry only two lanes of traffic.
2. A 3-lane highway having even one restricted sight distance cannot carry more vehicles per hour in one direction than the number that can crowd into one traffic lane.

From the facts gathered by these analyses, it appears that a 3-lane highway is more efficient when traffic is evenly divided by directions than when two-thirds of the traffic travels in one direction. There is a possibility that a two directional 3-lane highway would be more efficient when practically all traffic moved in one direction than with traffic evenly divided, but the percentage traveling in one direction in such a case would be closer to 100 than to 67. However, since no data were available for this condition, this possibility could not be verified.

CURVES AND GRADES EFFECT HIGHWAY CAPACITY

The possible capacity of a 2-lane road occurs on tangent sections of highway when vehicles cannot pass one another. Therefore, an individual curve will cause no reduction in the possible capacity of a highway since it will impose no further restriction to passing than already exists However, at lower traffic densities, a curve with a restricted sight distance prevents passing maneuvers that could otherwise be performed safely. Of the few curves for which the data have been analyzed, the one with the greatest degree of curvature and the shortest sight distance that had no apparent effect on traffic was a 4-deg. curve with a minimum sight distance at one point of about 900 ft. The pavement was 20 ft. wide and had a superelevation of 0.06 ft per ft. There were only slightly fewer passings performed on the curve than on an equal length of tangent section under similar traffic densities. As a comparison, during low traffic densities an 11-deg curve with a minimum sight distance of 400 ft caused passenger cars to reduce their speed from 43 to 35 m.p.h., busses from 48 to 35 m p.h., trucks from 37 to 32 m p h, and tractor-truck semi-trailers from 33 to 30 m p.h

Table 1 shows the average speeds of free moving trucks, busses and passenger cars while traveling over 3-, 5-, and 7-percent grades that were approximately one-fourth mile long and had level tangent approaches. Excluding the vehicles on the level sections, a total of 1,611 trucks, 133 busses, and 21,036 passenger car speeds were used to obtain these averages.

Figure 10 shows the distribution of truck and passenger car speeds on the various grades. When comparing these distributions, one must remember that (1) the speed distributions include all trucks on the highway, both loaded and empty, (2) no vehicle was restricted by any other vehicle, (3) the grades were only one-fourth mile long, and (4) the speeds at the bottom of the grades were not necessarily the same as on the level sections since the drivers could see the grades for some distance and may have increased their speed before reaching the bottom of the grade.

TABLE 1
FREE SPEEDS ON GRADES
With Level Tangent Approaches and About One-Fourth Mile Long

Grade	Trucks	Buses	Passenger cars
Level	36 9	45 9	45 8
Downgrade:			
3 per cent	37 6	46 4	46 5
5 per cent	38 9	41 4	42 1
7 per cent	34 1	37 4	40 2
Upgrade.			
3 per cent	34 3	37 0	43.5
5 per cent	26 6	29 3	39.5
7 per cent	24 6	26 6	34 4

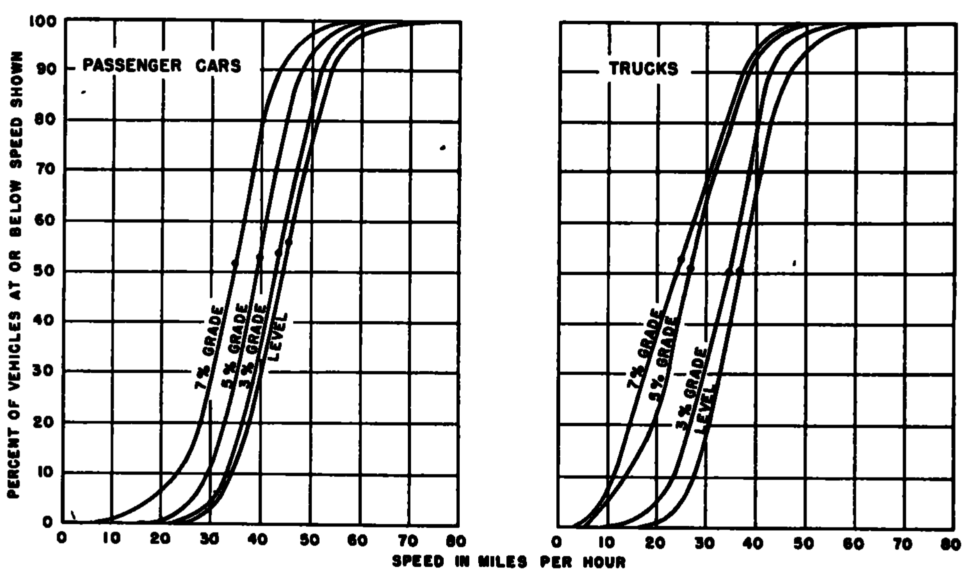

Figure 10. Cumulative Frequency Distribution of Free Speeds Up Grades ¼ Mile Long with Level Tangent Approaches

From the available data on grades, it has been possible to determine capacity figures for only two highway conditions. One condition represents 7-percent grades one-fourth mile long on 2-lane highways that carry few trucks and have level tangent approaches to the grades. The other condition represents 7-percent grades one-fourth mile long on 3-lane highways that carry 11 percent trucks and have curved approaches to the grades.

Figure 11 shows that passing was not

possible on the grades when the density reached 1,400 and 1,560 vehicles per hour on the 2- and 3-lane grades, respectively. However, in the one case the vehicles averaged 30 m.p h. on the grade, and in the other they averaged 14.5 m p h. The trucks and the curved approaches reduced the possible capacity of the 3-lane highways to a value nearly as low as that for the 2-lane highways and caused a much larger reduction in speed Vehicles ceased to pass on the 2-lane grades at only seven-tenths of the density that they stopped passing on level sections.

PRACTICAL CAPACITIES VARY FOR DIFFERENT CONDITIONS

At certain locations such as through tunnels, over bridges, and on other short sections of highway that are bottlenecks in a system of highways but which cannot be eliminated economically, the practical capacities will approach the theoretical capacities. At other relatively short sections where there is an exceedingly high hourly daily or seasonal fluctuation in the traffic volume, the practical capacities may approach the values given as the possible capacities but since all drivers are required to govern the speed of their vehicles by the speed of the slowest moving vehicle when a highway is carrying its possible capacity, it is generally desirable to use values considerably lower than the possible capacities for design purposes to permit drivers some individual freedom of movement even during peak density periods. While it is impossible to determine practical capacities for all conditions without considering local factors, the information secured by this study, especially the results shown by Figures 4 through 7, indicate practical capacities for certain general conditions and provide a basis for determining practical capacities for other conditions.

Referring to Figure 7, it may be seen that the practical capacity for conditions F and G is 2,450 vehicles per hour in one direction on 4-lane highways since any value lower than this will result in only a slight increase in the average speed or freedom of movement for the individual vehicles while there is a marked reduction in both speed and freedom of movement as the density increases above 2,450 vehicles per hour However, for the other highway conditions shown by Figures 5 and 7, there are no breaks in the curves to indicate definite values for the practical capacities although the curves showing the mean difference in speed do indicate the restriction during the various traffic densi-

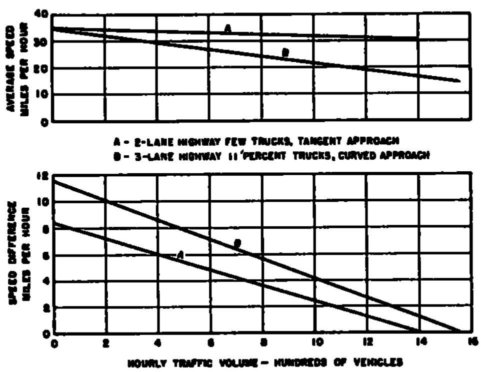

Figure 11. Average Speeds and Speed Differences on Straight 7 Percent Grades ½-Mile Long.

ties as compared to the restriction when all vehicles are required to stay in line.

When we consider the variation in traffic density that exists on the average highway, the percentage of vehicles affected by other vehicles and the percentage of time that passings may be started, a total traffic volume of 800 vehicles per hour seems to be the highest density that can be considered as the practical capacity of a 2-lane rural highway. At this density 70 percent of the drivers will be required to govern their speed to some extent by the speed of other vehicles,[2] and passings requiring 10 seconds in the opposing

[2] Figures 7 and 20, *Public Roads,* February 1939

traffic lane cannot be started more than 30 percent of the time.[3] It is also significant that on a 2-lane rural highway carrying 800 vehicles per hour, the average driver is restricted to nearly the same extent as when traveling during light traffic densities within the limits of a city where there is a 30-m.p.h. speed limit.

Eight hundred vehicles per hour was about 40 percent of the possible capacity of the 2-lane highways. A corresponding percentage of the possible capacities of the 3-lane highways was 1,120 vehicles per hour for those in Massachusetts and 1,460 vehicles per hour for those in New York. Forty percent of the possible capacity of two lanes of the 4-lane sections in Illinois was 1,680 vehicles per hour or a total of 2,520 vehicles per hour for all 4 lanes assuming that two-thirds of the traffic will be traveling in the direction of the heavier density. However, at these densities the speed differences on the 3- and 4-lane roads were higher than on the 2-lane roads. For corresponding speed differences, the 4-lane Illinois highways would carry 3,150 vehicles per hour and the 3-lane highways in Massachusetts and New York 1,600 vehicles per hour, but since the speed differences were higher on the 3- and 4-lane roads during low volumes than on the 2-lane roads during low volumes, it seems reasonable that the drivers will expect a greater freedom of movement on the 3- and 4-lane roads than on the 2-lane roads. Practical capacities for 2-, 3-, and 4-lane roads with good alinements and carrying few trucks are therefore in the neighborhood of 800, 1,400, and 2,800 vehicles per hour, respectively.

A study of the fluctuation in traffic density due to hourly season and daily variations[4] showed that it is not economical to design for a higher traffic volume than the traffic volume that is exceeded for 30 hours during a year. The use of the foregoing values for design purposes will not only permit reasonable freedom of traffic movement practically all the time but the possible capacities of the highways will not be exceeded even during the high densities for which it is not economical to design.

Curves and limited sight distances will undoubtedly reduce the practical capacities of 2- and 3-lane highways to a much greater extent than they reduce the practical capacities of 4-lane highways, but before their effect can be fully evaluated, the results of the passing practice studies must be correlated with this analysis and the speed studies on curves.

[3] Figure 2, *Public Roads*, February 1939.

[4] "Applications of automatic traffic recorder data in highway planning," *Public Roads*, January 1941.