THE INFLUENCE OF ALINEMENT ON OPERATING CHARACTERISTICS

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SYNOPSIS

One of the most important features governing the selection of the alinement for a 2-lane road is the influence on operating speeds of horizontal and vertical curves that restrict sight distances to values below those required to pass overtaken vehicles. By applying the results that have been obtained to date from a series of comprehensive studies of driver behavior and vehicle performance sponsored by the Public Roads Administration and conducted in cooperation with several State highway departments prior to the war, it has been possible to determine the effect on operating speeds of sight distances that restrict passing maneuvers.

The design speed of a highway is used in this report to denote the speed at which individual vehicles can travel with safety when the traffic volume is not great enough to cause a reduction in speed. The operating speed of a highway is used to denote the average speed at which drivers can travel under existing traffic densities without exceeding the design speed.

The figures presented show the operating speeds for existing 2-lane highways and the future possible operating speeds on 2-lane highways designed with limited access, separated intersections, and other features favorable to safe travel at high speeds. The possible operating speeds at various traffic volumes and the effect on operating speeds of sight distances that restrict passing maneuvers are shown for existing and probable future conditions.

No direct relation was found between the speed at which vehicles can be operated on a 2-lane highway during periods of appreciable traffic and the speed at which individual vehicles can negotiate the curves. Safe sight distances are important in the selection of the alinement for a modern 2-lane highway. Design speeds that are more than 20 miles per hour higher than the estimated possible operating speed during the fiftieth highest traffic volume in the year after construction is completed, cannot be justified when they increase the construction cost. Two-lane highways, designed for speeds of 70 miles per hour will not provide for operating speeds above 60 miles per hour except at extremely low traffic densities.

The science of highway engineering has advanced rapidly during the past few years. It was not so long ago that the design of a road was limited almost entirely to the static aspect, the only dynamic consideration being the impact of a live load on a given structure. Today, when selecting the alinement for a highway, the engineer can and should take into consideration the volume and type of traffic, the driving characteristics of the vehicle operators and the dynamic effect that curvature, superelevation and other design details will have on the operating features of the completed structure. The alinement that is selected, whether the highway be two, three or four lanes wide, determines to a large extent how effectively the completed facility will meet the demands of traffic.

One of the most important features governing the selection of the alinement for a 2-lane road, about which there has been little or no reliable information available, is the effect on operating speeds of horizontal and vertical curves which restrict sight distances to values below those required to pass overtaken vehicles. By applying the results of a series of comprehensive studies of driver behavior and vehicle performance sponsored by the Public Roads Administration and conducted in cooperation with several State highway departments prior to the war, it has been possible to determine the effect on operating speeds of sight distances which restrict passing maneuvers, without resorting to any theoretical assumptions that cannot be substantiated by available data.

The studies referred to include those dealing particularly with highway capacity and passing practices which show the distribution of vehicle speeds and longitudinal spacings; physical measurements of time and distance involved in passing; the frequency of passing maneuvers; and the variation in these items with changes in road and traffic conditions. The methods used in conducting these studies and some of the results of the various phases have been presented at previous meetings of the Highway Research Board.[1]

One of the primary considerations when trying to provide a satisfactory alinement for a highway is the speed at which drivers would travel if an adequate facility were available Figure 1 shows three cumulative frequency distribution curves of speeds for free moving vehicles traveling on long tangent sections of 2-lane rural highways at locations where speeds are not influenced by crossroads or intersections. The curve to the left represents a speed distribution which is typical for such sections located on the majority of existing main highways. Speeds of individual vehicles range from 21 to 62 m p.h. with 12 per cent exceeding 50 m.p h and 32 per cent traveling less than 40 m p.h.

The curve for high speed existing highways shows a typical distribution of speeds for tangent sections on highways with few curves or grades and relatively few minor side roads and property entrances. Similar speed distributions are generally found on main highways where speeds are not limited by the characteristics of the highways, but only by the speed limitations of the vehicles and the desires of the individual drivers Speeds for individual drivers range from 25 to nearly 80 m p h. with about 40 per cent exceeding 50 m p.h and 17 per cent traveling less than 40 m p h Distributions with somewhat higher average speeds have been reported for certain locations but it is believed that this curve represents an average condition when all drivers can travel at their desired speeds uninfluenced by other traffic and limitations of the highway

It is impossible to predict at what speeds drivers will desire to travel a few years hence. Superhighway speeds of 80 to 100 m p.h. are frequently mentioned, although the basis for setting such limits is not made clear. There is no doubt that after the war it will be possible for automotive engineers to design vehicles capable of higher speeds than those produced before the war. However, other factors, including personal traits or limitations of the drivers, the increased use of the airplane for long distance travel, and economic consideration of highway design, indicate that the tendency in the future on our main highways will be toward increasing average speeds through a reduction in the number of vehicles that travel at the lower speeds by providing highways with limited access and few intersections at grade, rather than by increasing the top speeds. One of the most important factors that will tend to prevent a further increase in top speeds is brought out by this report.

The dashed curve of Figure 1 shows an estimated distribution of speeds for free moving vehicles that is most likely to be typical of future conditions on level sections of 2-lane rural highways constructed to the most modern design standards and with limited access. In this speed distribution, 85 per cent of the vehicles exceed 50 m.p h. and all travel at least 40 m.p h

It may seem that the speeds shown by the curve representing the distribution for the future condition are too low, but that curve represents a considerable increase in speed above the speed on the most modern highways. The lack of adequate highways is often given as the only reason that everyone does not travel faster than 50, 60, or 70 m p h on our rural highways There are, however, long level tangent stretches of highway in the West and Middle-west where sight distance is practically unlimited and other features of the highway are most favorable for high speed Even under these conditions and with light traffic volumes, a considerable percentage of the drivers prefer to travel at speeds below 50 or even 40 m.p.h.

The speed distributions shown by the three curves of Figure 1 are used as a basis for de-

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[1] Preliminary Results of Highway Capacity Studies by O K Normann, 1938 Highway Research Board Proceedings, p. 359;

Procedure Employed in Analysis of Passing Distances by E H Holmes, 1938 Highway Research Board Proceedings, p. 368,

Progress in Study of Motor Vehicle Passing Practices by O. K Normann, 1939 Highway Research Board Proceedings, p 206,

A Symposium on Driving Practice and its Relation to Highway Capacity by the Division of Highway Transport, Public Roads Administration, 1941 Highway Research Board Proceedings, p. 360, and also

New Techniques in Traffic Behavior Studies by E. H. Holmes, and S E. Reymer, April 1940 PUBLIC ROADS, p. 29.

termining the influence of alinement on the operating characteristics of rural highways for the three following conditions:

1. Highways where access is not limited and speeds are eventually influenced by numerous uncontrolled entrances and exits along the highway.

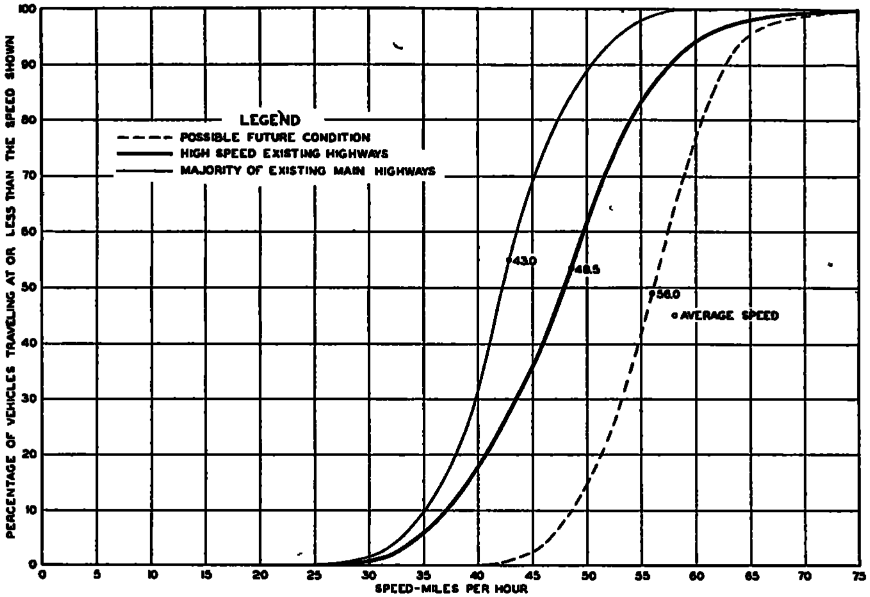

Figure 1. Frequency distribution of travel speed for free moving vehicles on level tangent sections of 2-lane rural highways

2. Highways with limited access or located through areas where there are likely to be relatively few entrances or exits along the highway.

3. A possible future condition that may be brought about by an improvement in operating conditions and a gradual reduction in the number of low speed drivers on roads with limited access, separated intersections, and other design features favorable to safe travel at high speeds.

At the present time, highway engineers should be primarily concerned with highways that are adequate for safe travel at the speeds shown by the heavy line representing existing high speed highways. If this is done, the highways constructed will also be adequate for higher future speeds because these higher speeds are likely to be the result of improved vehicle design and a reduction in the proportion of the lower travel speeds.

When the free speed distribution is known for a 2-lane level tangent highway, the results of the capacity studies conducted by the Public Roads Administration make it possible to estimate the average speed and frequency distribution of speeds at any traffic volume with a high degree of accuracy

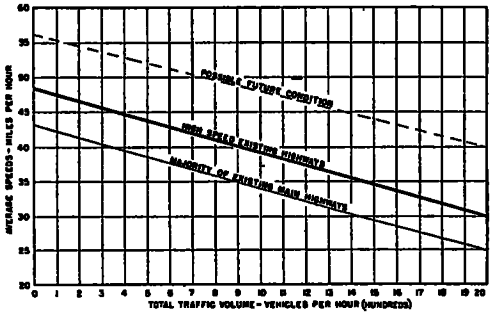

Figure 2. Average speeds of all vehicles on level tangent sections of 2-lane rural highways.

Figure 2 shows the average speeds at different volumes for the three speed distributions shown by Figure 1. At 2,000 vehicles per hour, the possible capacity of a 2-lane level tangent highway, the average speed corresponds to the speed of the slowest group of drivers and a straight line relationship has been found to exist for intermediate volumes This however, will not hold true when the free speeds are influenced by a speed limit. In such a case, the free speeds will be lower and there will be a very slight decrease in the average speed with an increase in the traffic volume until the average speed becomes the same as if there were no speed limit.

Figure 3 shows the distribution of speeds for various traffic volumes on 2-lane tangent highways where the free speed distributions are the same as for the high speed existing highways represented by the heavy solid line of Figure 1. The uniform change in the speed distributions with a change in traffic volume as shown by these curves has never been recorded for any one location, but the combined results from a large number of locations definitely show that the curves as drawn represent actual condition with the variations in speed due to factors other than the traffic volume eliminated. The series of curves illustrates the reduction in the percentage of vehicles traveling at the high speeds as the traffic density increases. A similar series of curves for speeds found on tangent sections of the majority of existing 2-lane rural highways and another series of curves estimated from the free speeds representing the possible future condition were used in the following analysis to determine the number and speed of the vehicles that a driver would be required to pass when traveling at a certain average speed. For example, it can be shown that for a driver to travel at a uniform speed of 50 m.p.h. on a 2-lane high speed existing highway carrying a total of 300 vehicles per hour equally divided in each direction, he would be required to pass an average of 24 vehicles per hour. At a volume of 900 vehicles per hour he would be required to pass 130 vehicles per hour. In the first case, 43 per cent of the vehicles he passed would be traveling at speeds exceeding 40 m.p h. while in the second case only 23 per cent of the vehicles he passed would be exceeding 40 m.p.h.

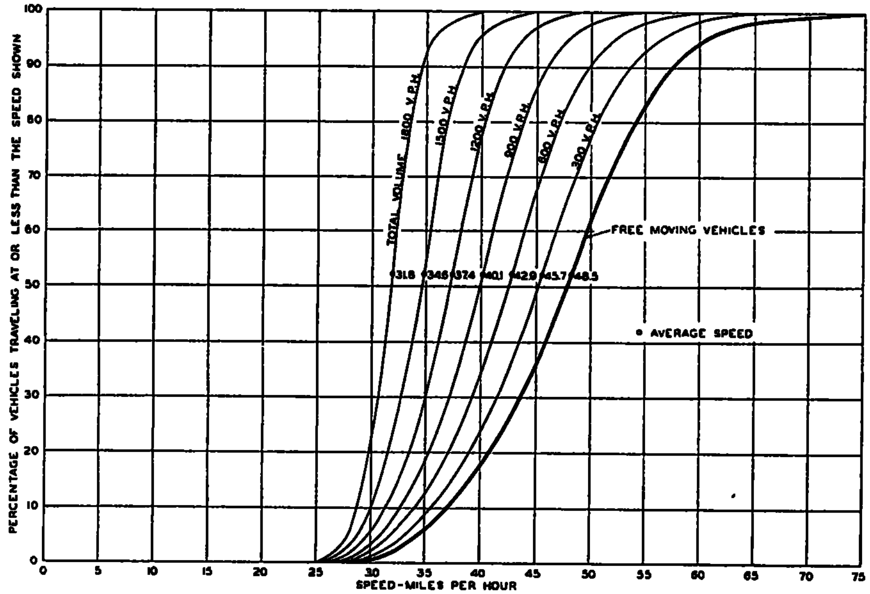

Figure 3. Typical speed distributions at various traffic volumes on level tangent sections of 2-lane high speed existing highways

Under actual operating conditions on a 2-lane highway, the left lane would not always be free of oncoming traffic at the time the driver overtook a vehicle traveling at a slower speed, so even on highways with no sight distance restrictions, he would sometimes be forced to reduce his speed until an opportunity to pass occurs. This delay would cause a decrease in his average speed which in turn would decrease the number of vehicles overtaken within a given time period. The average travel speed for a driver trying to maintain a certain speed on a 2-lane tangent highway during various traffic densities can, therefore, be determined only from accurate information regarding the speed of the other vehicles on the highway, the number and speed of vehicles that will be overtaken, the time and distance required to pass the overtaken vehicles traveling at various speeds, and the frequency of spaces between vehicles in the opposing traffic lane that will permit passing maneuvers to be performed safely. Such information is provided by the driving practice and vehicle performance studies.

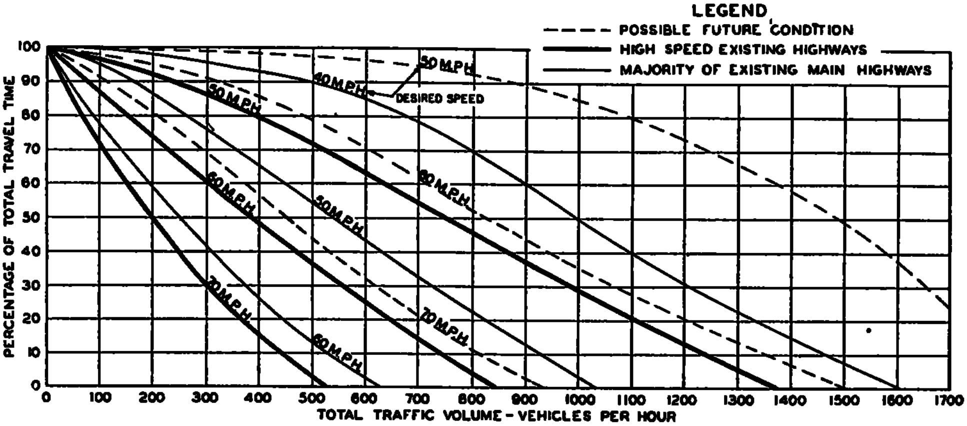

Figure 4. Percentage of time that desired speed can be maintained on 2-lane level highways with no sight distance restrictions

Figure 4 shows the portions of the total time that a driver desiring to travel at a certain speed can travel at that speed on a 2-lane highway with no sight distance restrictions Curves are shown for three different conditions corresponding to the three conditions for which free speeds and average speeds were previously shown by Figures 1 and 2, respectively.

First, let us consider the condition on long tangent sections of our high speed existing highways represented by the heavy solid lines. A driver desiring to travel at 70 m.p.h. can travel at this speed 100 per cent of the time as long as there is no other traffic on the highway. However, when there is other traffic on the highway, he soon overtakes another vehicle traveling at a slower speed and unless there is a space between vehicles in the opposing traffic lane of sufficient length to permit him to pass, he must reduce his speed until such an opportunity does occur, after which he can again increase his speed to 70 m.p.h. At a total traffic volume of 200 vehicles per hour, it will be possible for the driver to travel at 70 m.p.h. 50 per cent of the time if he takes full advantage of his opportunities to pass the slower drivers. At a traffic volume of about 550 vehicles per hour he will not be able to travel at 70 m.p.h. because before he reaches this speed after passing one vehicle he will have to start slowing down to avoid a rear end collision with the preceding vehicle traveling in the same direction or a head-on collision with oncoming traffic in the opposing traffic lane. Likewise, a driver trying to travel 60 m.p.h. can maintain this speed 100 per cent of the time when there is no other traffic, and 50 per cent of the time when the traffic volume is 400 vehicles per hour but he cannot at any time attain this speed when the traffic volume is in excess of 850 vehicles per hour. Also, a driver trying to maintain a speed of 50 m.p.h. can accomplish this 50 per cent of the time with a traffic volume of 750 vehicles per hour and at no time can he travel at this speed when the traffic volume exceeds 1,400 vehicles per hour.

These same curves representing high speed existing highways also show the percentage of time that drivers must travel at various speeds below their desired speeds. For example, with a traffic volume of 400 vehicles per hour, a driver whose desired speed is 70 m.p.h. can travel at this speed 15 per cent of the time, between 70 and 60 m.p h. 35 per cent of the time, between 60 and 50 m p h. 30 per cent of the time and is required to reduce his speed below 50 m p.h. about 20 per cent of the time.

A driver trying to go 70 m.p.h. can travel no faster than a driver trying to go 60 m p h. when the traffic volume exceeds 850 vehicles per hour. The 60- and 70-m p h. drivers can go no faster than the 50-m.p.h. driver when the traffic volume exceeds 1,400 vehicles per hour.

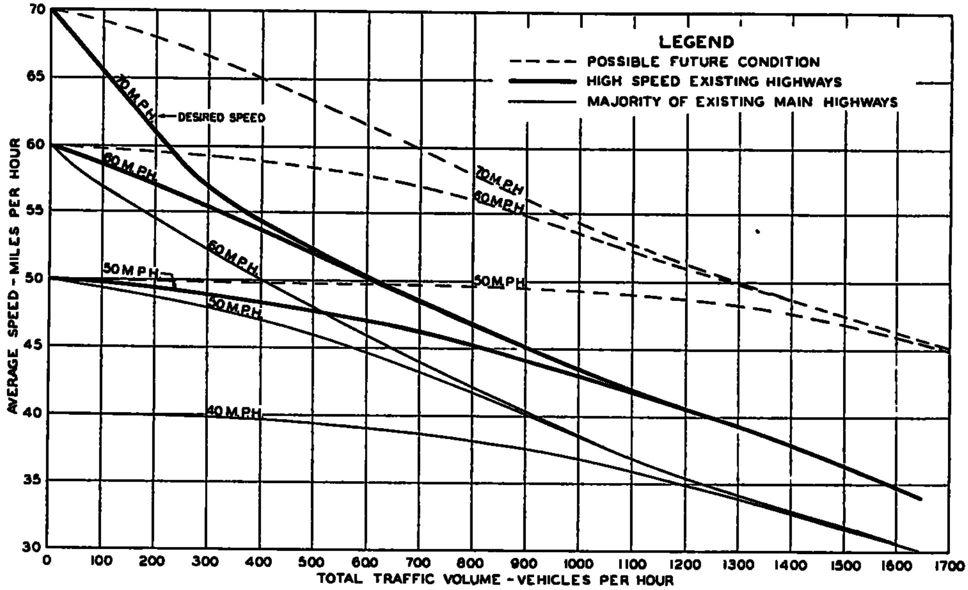

Figure 5. Average speed that can be maintained on 2-lane level highways with no sight distance restrictions

The light solid lines of Figure 4 show similar information for drivers trying to maintain 60, 50, and 40 m p h. on tangent sections of the majority of existing 2-lane highways, and the dashed lines show the same information for desired speeds of 70, 60, and 50 m p h with a distribution of desired speeds in the future as shown by Figure 1.

Figure 5 shows the effect of other traffic on the average speed of drivers trying to maintain a certain desired speed The light solid lines represent conditions on tangent sections of the majority of existing 2-lane highways, the heavy solid lines represent conditions on high speed highways, and the dashed lines represent possible future conditions

On tangent sections of existing high speed 2-lane highways, a driver trying to maintain a speed of 70 m p h without exceeding this speed finds that his average speed decreases rapidly with increase in the traffic density. At a traffic volume of 200 vehicles per hour his average speed is reduced from 70 to 61 m.p h. due to delays while waiting to pass slower moving vehicles, and at 850 vehicles per hour his average speed will be 46 m.p.h. or the same as for a driver trying to maintain a speed of 60 m p h. For all practical purposes the speeds for the 60- and 70-m p.h. drivers are the same when the traffic volume is in excess of 300 vehicles per hour This of course is for conditions when there are no intersections at grade

The curves presented are for traffic volumes equally distributed in the two directions With an unbalanced flow, the difference between the speeds in the two directions was never more than 2 m p h. A driver traveling in the direction of the lower traffic volume is required to make fewer passings to maintain his desired speed than a driver traveling in the other direction, but he also has fewer opportunities to use the left-hand lane for passing

A 70-m p h desired-speed curve is not shown (Fig. 5) for the condition representing the majority of existing 2-lane highways because there would be little difference between a driver's average speeds whether he tried to maintain 70 or 60 m p h

A comparison between the curves for the possible future condition and those for existing conditions illustrate the marked effect that slow moving vehicles have on the average speeds of drivers trying to travel at the higher speeds. It is possible that in the future a driver will be able to average the same speed without exceeding 50 m p h on a 2-lane highway carrying about 600 vehicles per hour, as he can average on high speed highways at the present time with a top speed of 60 m p.h. It will also be just as safe, if 70 m p h. can be considered a safe speed under any condition, for a driver to average 60 m p h. during a traffic volume of 700 vehicles per hour as for him to average this same speed during a traffic volume of 200 vehicles per hour at the present time It should be noted that the curves representing the different desired speeds for the same condition go through a common point located at a traffic volume in the neighborhood of 2,000 vehicles per hour and at a speed corresponding to the speed of the slowest group of drivers in the free speed distribution.

Before the influence of the alinement on operating characteristics of 2-lane highways can be determined from the figures that have been presented and other available data, it is necessary to define certain terms and to set up basic standards of alinement The terms "operating speed" and "design speed" have two entirely different definitions as used in the following analysis The design speed of a highway is used to denote the speed at which individual vehicles can travel with safety when the traffic volume is not great enough to cause a reduction in speed. For example, on a highway with a design speed of 60 m p.h., it would be possible for a driver to travel in comfort at 60 m.p.h. around curves, and sight distances along all points of the highway would be sufficient to enable a driver traveling at 60 m p h to bring the vehicle to a full stop before reaching unexpected obstacles in his path

The operating speed of a highway is used to denote the average speed at which drivers can travel under the existing traffic densities without exceeding the design speed. The operating speed will vary with numerous factors, including the existing traffic volume, the percentage of the highway on which passings can be made safely, and the character of the traffic. From Figure 5, it may be seen that the maximum operating speed on a 2-lane high speed existing highway without grades or curves is 61 m p h when the traffic volume is 200 vehicles per hour, 54 m p h when the traffic volume is 400 vehicles per hour; and 35 m p h. when the traffic volume is 1,600 vehicles per hour Tangent sections on the majority of existing 2-lane roads have maximum operating speeds of 54, 50 and 30 m p.h. at traffic volumes of 200, 400, and 1,600 vehicles per hour, respectively.

It is not essential that the design speed of a highway have a definite relationship with the operating speed at any particular traffic volume, but if a balanced, economical, and safe design is to be obtained, the design speed cannot be selected without regard to the possible operating speed. It would, for example, be difficult to justify the additional expenditure of funds necessary to provide a design that would permit individual vehicles to travel faster on curves than the speed at which they would be likely to travel on tangent sections of the highway during the life of the improvement.

Any restriction in the sight distance is assumed for the following analysis to have the same effect on operating speeds when caused by a horizontal curve as when caused by a vertical curve. Grades have a somewhat different effect on operating speeds than curves but the primary reason that they reduce operating speeds is because they generally cause certain restrictions in the sight distance The fact that trucks travel at slower speeds on grades than on a level has a tendency to increase the number of passings required by a vehicle trying to maintain a certain speed but if the sight distance was not also reduced by the existence of the grade, the reduced speed of the truck would have only a slight effect on the operating speeds of the other vehicles

Table 1 shows the standards used in this analysis for the various design speeds. The safe stopping distances shown in the second column are somewhat greater than corresponding figures proposed by the A.A S.H.O. in "A Policy on Sight Distance for Highways." The results of recent tests on brake performance indicate that these greater distances are necessary The figures in the third column correspond to the passing sight distances proposed by the A.A.S.H.O. and agree closely with the results that have been obtained thus far from the passing practice studies. In this analysis, it was also assumed that the sight distance from a driver's eye 4.5 ft. above the road surface to a point 4 in. above the road surface would not be less for a particular design speed than the safe stopping distance; and that there would be points on the highway where the sight distance would at least equal the minimum passing sight distance for the particular design speed.

TABLE 1

SIGHT DISTANCES USED IN THIS ANALYSIS AS STANDARDS FOR VARIOUS DESIGN SPEEDS ON 2-LANE HIGHWAYS

Design speed	Sight distance standards			Assumed average length of a restricted section	
	Minimum at any point on the highway for safe stopping	Minimum on unrestricted sections of the highway	At locations where no-passing line is used	Portion with no-passing line	Total
mph	*ft*	*ft*	*ft*	*ft*	*ft*
70	700	2,600	700–1,500	2,000	3,000
60	525	2,200	525–1,200	1,600	2,400
50	400	1,500	400– 900	1,200	1,800
40	300	1,000	300– 600	800	1,200

Since it is the practice to mark no-passing lines on 2-lane roads at locations where it is unsafe to pass, it was assumed that there would be no-passing lines wherever the sight distance was less than a certain value. To obtain the most satisfactory operating conditions, the length of the line should be based on the operating speeds determined after the highway is constructed. The lines should be extended far enough beyond the point of the minimum sight distance and in the direction of approaching traffic to prevent the most dangerous passing maneuvers and not far enough to restrict passing maneuvers that can be made in comparative safety when the vehicle to be passed is traveling at a speed considerably below the normal speed of most of the vehicles.

The sight distances used in this analysis to determine the no-passing zones are shown by the fourth column of Table 1. They are based on the design speeds rather than on the probable operating speeds, using the design speed for the speed of the vehicle approaching from the opposite direction, and 25, 30, 35, and 40 m.p.h. as the speeds of the fastest vehicles that can be passed if the passing is started just before reaching the beginning of the no-passing line on the 40-, 50-, 60-, and 70-m.p.h. designs, respectively.

The values for the average length of the restricted sections which are shown in the two right-hand columns of Table 1 are believed to be reasonable for the conditions that will exist on future highways that are built to the sight distance standards given in the other columns of the table. There will be locations where the restricted sections are considerably longer than these values such as where short sight distances continue for several hundred feet, but these will probably be counterbalanced by short sections where the sight distances are only slightly less than those necessary for passing

It is assumed that passings will not be started during the time a driver is adjacent to a no-passing marking and that only the passing maneuvers which can be performed safely will be started within the portions of the restricted sections that do not have no-passing lines A restricted section is defined as a portion of the highway where the sight distance is less than the passing sight distance (column 4 of Table 1) for the design speed.

On a highway of 70-m p.h. design with no restrictions, a driver would have a clear view ahead from any place on the highway to a point 4½ ft. above the surface at least 2,600 ft ahead. On a 70-m p.h design that was 20 per cent restricted, the minimum sight distance would never be below 700 ft.; a driver would have a clear view ahead for at least 2,600 ft on 80 per cent of the highway, and the clear view ahead would be fairly evenly distributed between 700 and 2,600 ft. on the remaining 20 per cent of the highway. The clear view ahead on a 70-m.p.h. design that was 100 per cent restricted would be fairly evenly distributed between 700 and 2,600 ft

One important feature of the following analysis is the fact that the accuracy of the curves which are presented (Fig. 6 and 7) does not depend directly upon the accuracy of the values in Table 1. For example, if the desirable stopping sight distance for a 70-m.p h. design is 600 ft. rather than 700 ft. or if the safe passing sight distance is 2,000 ft rather than 2,600 ft., these values would be used in determining the percentage of the highway where passing was restricted The possible operating speed under the percentage restriction thus determined can be found by reference to these same curves without appreciable error. The construction of new curves would not be necessary.

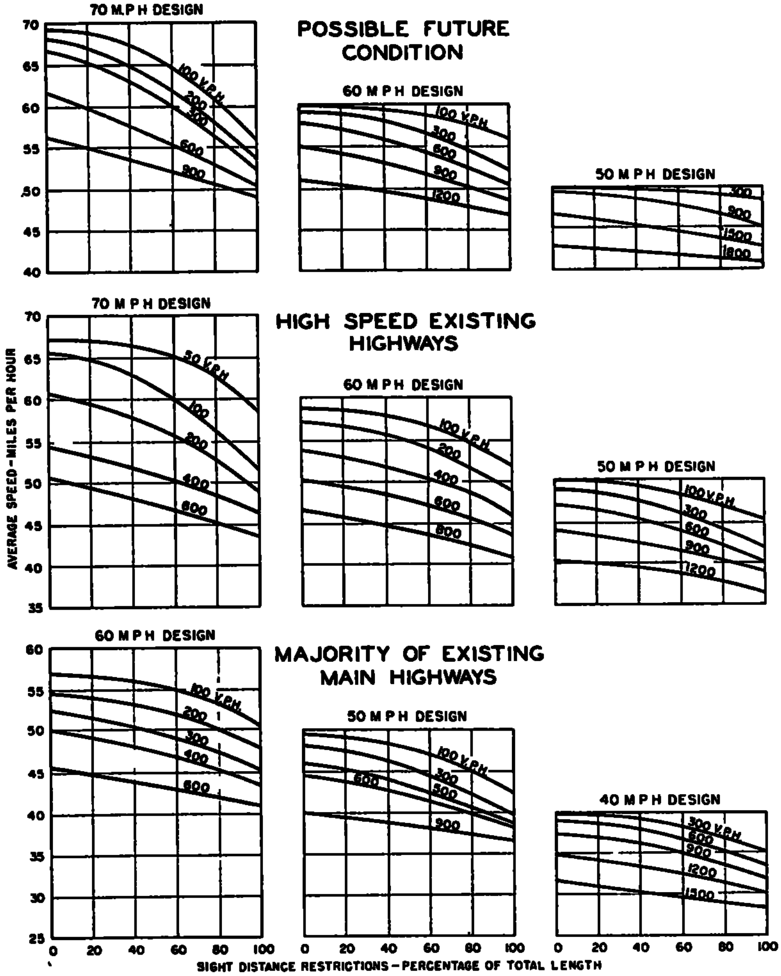

Figure 6. Possible average speed at different traffic volumes for drivers trying to travel at the design speed when the sight distances on various portions of the highway are less than the passing sight distance.

Figure 6 shows the possible operating speeds on 2-lane highways when the sight distances on various portions of a highway are less than the safe passing sight distance for the particular design speed. A series of curves representing different traffic volumes is shown for three design speeds for each of the three conditions represented by the distributions of desired speeds.

A driver who tries to travel 70 m.p.h. whenever he has the opportunity to travel at this speed on a highway with a 70-m.p.h. design and where free speeds are the same as on tangent sections of the existing high speed highways, will be able to average 61 m.p.h. during a traffic volume of 200 vehicles per hour when the highway has no sight distance restrictions; 56 m.p.h. when the sight distance is restricted on 60 per cent of the highway; and 48 m.p.h. when the sight distance is restricted on 100 per cent of the highway. With a traffic volume of 600 vehicles per hour his average speeds for corresponding conditions become 51, 47, and 43 m.p.h., respectively.

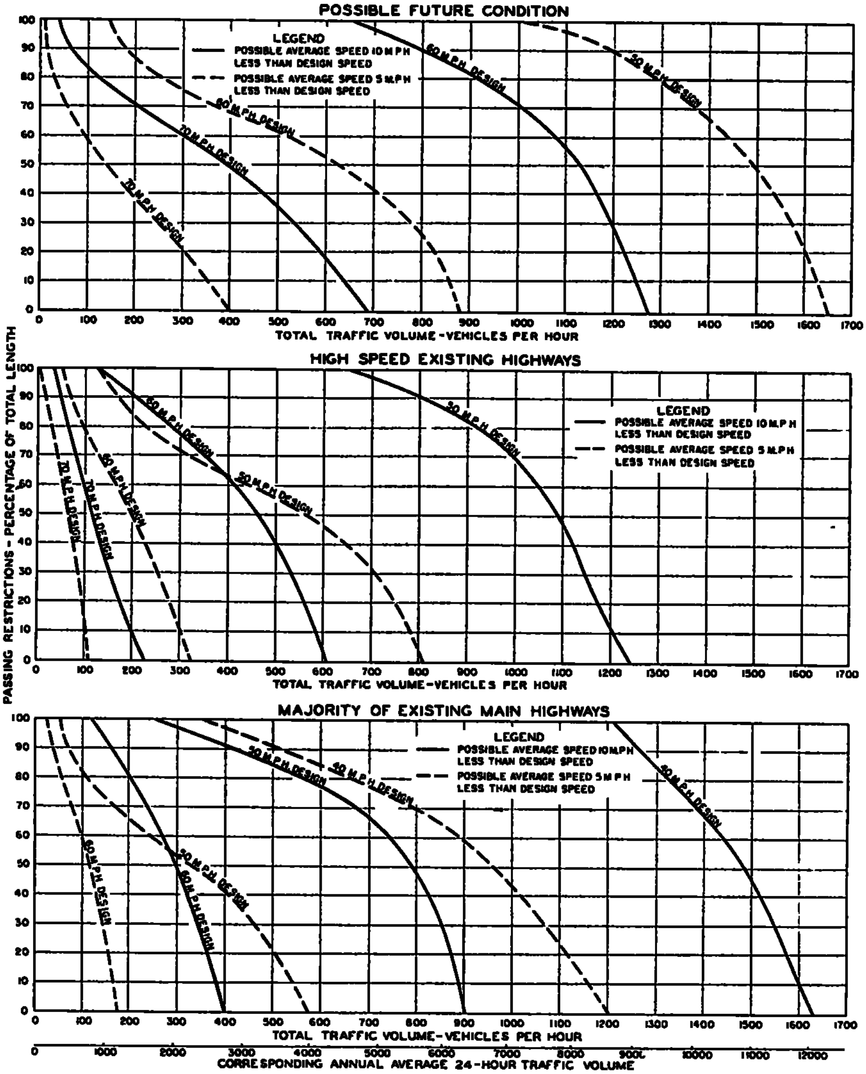

Figure 7. Portion of highway that may have sight distances shorter than the passing sight distances and still permit drivers trying to travel at the design speeds to average 5 m.p.h. and 10 m.p.h. less than those speeds for various traffic volumes.

Likewise, a driver trying to maintain a speed of 60 m p h hour on a 60-m p.h design will be able to average 57 m p h. during a traffic volume of 200 vehicles per hour if there are no places on the highway where the sight distance is below 2,200 ft. and 49 m p h when the sight distance is below 2,200 ft. 100 per cent of the time. It should be noted that it is only at the very low traffic volumes and when the sight distance restrictions are a low percentage of the total length that the operating speeds for a 70-m p h. design are appreciably higher than those for a 60-m p h. design. The slight effect that the better alinement for the high speed design has on the operating speeds at the higher traffic volumes is offset by the increased length of the no-passing zones. This illustrates the importance of governing the length of the no-passing zones by operating speeds rather than by design speeds.

The operating speeds for the condition representing high speed existing highways are consistently higher than the operating speeds for the condition representing the majority of existing main rural highways and lower than the operating speeds representing the possible future condition.

The results shown by Figure 6 illustrate the difference between design speeds and operating speeds on 2-lane highways The design speed of a highway or the speed that a driver can maintain during very light traffic volumes varies with the maximum curvature, the superelevation, the width and smoothness of the surface and the minimum sight distance. The operating speed of the highway varies with all these characteristics and in addition the operating speed also varies with the traffic density, the distribution of the desired speeds of all drivers using the facility, and the percentage of the total length on which the sight distances are sufficient to permit the faster drivers to pass vehicles traveling at the slower speeds.

The selection of the design speed that should be used to obtain a certain operating speed when a highway goes through any but the flattest terrain, and the selection of the operating speed that can be justified by the type and volume of traffic are two of the most difficult problems facing highway engineers drawing plans for post-war projects It is believed that Figure 7 which is based on the data shown by Figure 6 will be of some assistance in the solution of these problems.

Figure 7 shows the portion of a highway that may have sight distances shorter than the passing sight distances and still permit drivers trying to travel at the design speeds to average 5 m p h and 10 m p h. less than those speeds during various traffic volumes. The dashed lines show the passing restrictions that will result in operating speeds that are 5 m.p h. lower than the design speeds, and the solid lines show the passing restrictions that will result in operating speeds that are 10 m p h. lower than the design speeds On high speed existing highways, for example, the solid line for the 60-m p h design shows that an operating speed 10 m p h lower than the design speed, or 50 m.p h , is possible at a traffic volume of 600 vehicles per hour when there are no sight distances that restrict passing maneuvers. This same operating speed is also possible at traffic volumes of 400 and 150 vehicles per hour when there are passing restrictions on 62 per cent and 100 per cent of the highway, respectively.

The dashed line for the 60-m p.h design shows that a driver cannot average 55 m.p.h. using a top speed of 60 m p h when the traffic volume exceeds 330 vehicles per hour. When the sight distance restricts passings on 50 per cent of the highway, he cannot average 55 m p h during traffic volumes in excess of 200 vehicles per hour.

The curves for high speed highways show that there is a great reduction in the capacity of a 2-lane highway with an increase in the desired operating speed. The maximum traffic volumes that a 2-lane highway can carry and still permit a driver to average 40, 50, or 60 m p h. are 1,240, 610, and 230 vehicles per hour, respectively In addition to the alinement providing sight distances along the entire highway that will permit a driver to pass vehicles traveling at these speeds, there must be no important intersections at grade and few minor intersections. In most localities, unless access to the highway is controlled, there will soon be numerous entrances or exits to the adjoining property which will create hazards to traffic, and safe speeds will be reduced. This will result in reducing the possible operating speeds to values at least as low as those shown by the curves representing the majority of existing main highways.

One of the most important findings from previous studies regarding seasonal daily and hourly variations in traffic flow has been that the design of a highway should provide for the fiftieth highest hourly traffic volume that occurs during one year.[3] The lower horizontal scale, near the bottom of Figure 7, shows the annual average 24-hr. traffic volumes that occur on the average highway in the United States when the fiftieth highest hourly volume corresponds to the values of the other scale. By applying the lower scale, it may be seen that on an average a 2-lane highway is inadequate for operating speeds of 40, 50, and 60 m.p.h. during the fiftieth highest traffic volumes in one year, regardless of the alinement, when the annual average volume exceeds 9,000, 4,300, and 1,500 vehicles per day, respectively. Since these values are maximums, lower values must be used for design purposes when a perfect alinement cannot be obtained, but the magnitude of the seasonal, daily and hourly variations in traffic flow should be considered in each instance when annual average daily traffic volumes are used for design purposes.

In a particular locality, it is obviously more difficult to satisfy the standards for a high design speed than to satisfy the standards for a low design speed. It is also more important that the passing restrictions be limited to a low percentage of the total length of the highway when designing for a high operating speed than when designing for a low operating speed. The traffic capacity of a 2-lane highway for an operating speed of 60 m.p.h. (using a 70-m p h. design) is reduced about 50 per cent when there are passing restrictions on 50 per cent of the length, while on a highway designed for an operating speed of 50 m.p.h. (using a 60-m.p h. design), the capacity is reduced only 25 per cent when there are passing restrictions on 50 per cent of the length. When designing for operating speeds above 55 m.p h., it is important that an alinement be selected which will not restrict passing maneuvers, but when designing for operating speeds below 55 m.p.h. there is little justification for the added expense to obtain an alinement which permits passing maneuvers at the design speed on more than 50 or 60 per cent of the total length.

The curves at the top of Figure 7, which are for possible future conditions, show that the alinement of a highway will have the same general effect in the future on operating speeds as at the present time. However, for operating speeds at or above 50 m.p.h., the same alinement will accommodate hourly traffic volumes 2 to 4 times as high as can be accommodated at the present time; or, with the same traffic volume, a 2-lane highway will be adequate for operating speeds about 10 m.p.h. higher than at the present time.

It should be remembered that the difference between the set of curves shown for high speed existing highways and those shown for possible future conditions is based on the assumption that there will be little or no increase in top speeds but that there will be a reduction in the number of vehicles traveling at the slower speeds and a demand for highways that will permit higher operating speeds. The operating speeds shown for possible future conditions could be approached at the present time by discouraging travel at extremely low speeds. However, with such a small percentage of our present highways designed for safe operation at high speeds and with the motor vehicle accident rate continuing to mount, at least until travel was restricted by wartime conditions, officials have not deemed it advisable to encourage minimum speed regulations except in a few isolated cases. The general tendency has been to encourage rather than to discourage travel at the lower speeds.

With a greater mileage of high speed highways having limited access, and grade separations at important intersections (two features of highway design that are essential for safe travel at speeds desired at the present time on main highways), there will probably be a natural tendency toward a reduction in the number of slow moving vehicles on high speed highways and there will be a greater justification for minimum speed limits

With these points in mind, the results shown by Figure 7 indicate that highways designed for safe travel at present speeds and traffic densities will also be adequate in the future for safe travel at higher operating speeds and at somewhat higher traffic volumes. If this is true, the difficulty in providing for future traffic volumes and for higher operating speeds on a basis of present performance is greatly reduced. In any case, the results of these

[3] Application of Automatic Traffic Recorder Data on Highway Planning; by L. E Peabody and O. K. Normann, 1940 Highway Research Board Proceedings, p 200

studies show that the present tendency is to place too much emphasis on designs that will permit vehicles to travel at high speeds during low traffic volumes and not enough emphasis on designs that will provide reasonable operating speeds at the traffic volumes likely to occur during the life of the improvement.

Operating speeds 15 and 20 m p h. lower than the design speeds are not included in Figure 7 but can be plotted from Figure 6. When the traffic volume used in the design is high enough to reduce the operating speed 20 m.p.h. below the design speed, it would be far more economical to reduce the design speed about 10 m.p.h. There would be little difference in the resulting operating speeds during either the high or low traffic densities and the cost of construction might be considerably lower.

TABLE 2

OPERATING SPEEDS ON 70- AND 60-M P H DESIGNS.

Hourly Traffic volume	Frequency during one year	Operating speeds	
		70-m p h design 40 percent restricted	60-m p h design 40 percent restricted
vehicles	*hours*	*miles per hour*	*miles per hour*
Above 800	1	Below 45	Below 45
700–800	3	45–47	45–47
600–700	11	47–48	47–48
500–600	35	48–49*	48–49
400–500	200	49–52	49–52
300–400	450	52–54	52–54
200–300	1,400	54–58	54–56
100–200	3,240	58–63	56–58
Below 100	3,420	63–70	58–60
Total	8,760		

* Operating speed at 50th highest hourly volume is 22 m p h lower than the design speed

To illustrate this point, it is necessary to select a specific example. The hourly traffic volumes during a year on the average road in the United States carrying a traffic volume of 3,300 vehicles per day is shown by the first two columns of Table 2. The third column shows the possible operating speeds at the different traffic volumes for a 70-m.p.h. design and the fourth column shows the operating speeds for a 60-m p h. design, the restrictions in both cases being 40 per cent.

It may be noted that only during the lowest traffic volume hours is there any appreciable difference in the operating speeds. Most of these volumes would occur at night or during the winter season. Basing the length of the no-passing markings on the operating speeds, rather than on the design speeds, would result in a greater improvement in operating conditions at the higher traffic volumes on the 70-m.p.h design than on the 60-m p h. design, but the change would be slight in either case. There probably would be less difference for the two design speeds at low traffic volumes than the table indicates since more drivers would exceed the design speed on tangent sections of the 60-m.p h design than on tangent sections of the 70-m p h design The values shown on Table 2 are for operating speeds when the drivers do not exceed the design speed at any time.

In flat terrain it is obviously desirable to use design speeds considerably higher than the operating speeds when there is little or no additional cost involved as compared to the cost of using a lower design speed. In rolling or rough terrain, the design speed should not be more than 15 miles per hour above the operating speed and in some cases it might be advisable to employ design speeds that will result in operating speeds only 5 m.p.h. lower than the design speeds.

CONCLUSIONS

This analysis of the influence of highway alinement on operating speeds has been based on the results that have been obtained to date from a number of related studies. Its purpose has been primarily to show the application of the results to the solution of some of the problems encountered in the selection of a satisfactory alinement for a 2-lane highway. Further analysis of the original data is necessary before other important factors influencing operating speeds can be determined.

The following are the most significant conclusions of this analysis.

1. There is not a direct relation between the speed at which vehicles can be operated on a 2-lane highway during periods of appreciable traffic and the speed at which individual vehicles can negotiate the curves. An alinement that provides for high speed operation of individual vehicles will not necessarily provide more satisfactory operating speeds at the higher traffic volumes than an alinement on which individual vehicles must travel at somewhat lower speeds.

2. Sight distances that will permit passing maneuvers to be performed safely are just as

important a consideration in the selection of the alinement for a modern 2-lane highway as the standards for curvature, gradient, superelevation, or non-passing sight distance.

(As far as is known, there is only one State highway department that has been recording sight distances on highway plans and those shown are limited to values below 1,000 ft There are however a few other state highway departments that determine sight distances as the layout plans are prepared. Sight distances in both directions that are less than the passing sight distance for the particular design speed selected should be recorded on the plans or on accompanying charts for 2-lane rural highways to be constructed on a new alinement or when major improvements are planned It will then be possible to study the operating characteristic of the facility and determine the changes that should be made in the alinement, if any, to produce a balanced and economical design)

3 Design speeds that are more than 20 m p.h higher than the estimated possible operating speed during the fiftieth highest traffic volume in the year after construction is completed, cannot be justified when they increase the construction cost.

4 Two-lane highways, designed for speeds of 70 m p.h will not provide for operating speeds above 60 m.p h except at extremely low traffic densities.

5. Access to highways on which high operating speeds are desired must be both limited and controlled, and the grades at important intersections must be separated. Frequent intersections at grade or frequent access points will inevitably result in an unduly high proportion of slow speed vehicles.

TRANSVERSE PLACEMENT OF VEHICLES AS RELATED TO CROSS SECTION DESIGN

By A. Taragin, *Assistant Highway Engineer, Public Roads Administration*

SYNOPSIS

Highway engineers have long recognized the need for information relative to the transverse positions and speeds of vehicles as they are customarily driven in the normal traffic in order to determine appropriate lane widths of pavements and the influence of various highway and roadside conditions The Public Roads Administration in cooperation with a number of State Highway departments collected speed-placement data for a large number of vehicles on pavements of various surface and roadside conditions. This report is based on day and night observations of 17,000 vehicles on five sections of 18-, 20-, and 24-foot concrete pavements with grass shoulders

The results show the transverse positions and speeds of passenger cars and commercial vehicles when moving freely, when meeting other vehicles, and when engaged in passing maneuvers. The distance from the center of the pavement that free-moving passenger cars travel did not increase with a change in the surface width until a 24-ft pavement became available Drivers of commercial vehicles steadily increased their distance from the center of the road as wider pavements were made available. The free-moving passenger cars swerved to the right the greatest amount when meeting trucks and busses. The lateral movement was about 1 0 ft. for the passenger cars and 0.5 ft for the commercial vehicles.

Under the highway conditions studied the average passenger car would not travel closer than 1 9 ft. to the edge of the pavement and trucks 1 4 ft even at the expense of greatly restricted clearance between meeting vehicles An edge clearance of approximately 3 ft. was required before added pavement