PERCENTILE SPEEDS ON EXISTING HIGHWAY TANGENTS

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SYNOPSIS

The distribution of speeds of over 260,000 vehicles in normal travel (1934, 1935 and 1937) on 40 different sections of highways of various types in four eastern states has been examined, summarized and analyzed in terms of percentile speeds Curve patterns of the distribution of speeds so expressed were found to be nearly identical over a wide range of highway types, average speeds, and traffic volumes

Since the term "assumed design speed" is defined only with respect to future travel speeds, and the relation of present day travel speeds to future travel speeds is not known, the analysis was made to select a percentile definition of "speed rating" which term is used to denote the speed which bears the same relation to observed travel speeds that the assumed design speed is intended to bear to future travel speeds.

Examination of the range of speeds found on the group of higher speed roads included, with average speeds of 40 to 50 mph, shows that definitions in terms of percentile values of 90 to 98 are necessary if these are to be rated as 60 mph highways. Even higher percentile values are necessary to rate any of them as 70 mph highways.

Analysis of these data to determine a percentile speed value to be used as a definition point for speed rating indicates that an 80 percentile value is too low, a 90 percentile value is questionably low, a 95 percentile value is reasonably desirable, and a 98 percentile value appears to be the desirable definition point.

An assumed design speed is being used to an increasing extent in the geometric design of highways. The A.A.S.H.O. approves the following definition for assumed design speed:[1]

"The assumed design speed of a highway is considered to be the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not necessarily, by the small percentage of reckless ones."

The term "assumed design speed" properly applies only to the design of roads not yet constructed and properly should refer to future travel speeds. We do not know the relation between present travel speeds and future travel speeds. We do not know the precise point in the range of future travel speeds that should be chosen as the assumed design speed. We do know that this point should be such that only a small percentage of drivers will exceed this speed but we do not know just how small this percentage should be

Roads on which the observations here reported were made, doubtless were not designed on the basis of an assumed design speed. Therefore the expression "highway speed rating," or simply "speed rating," is used to denote the speed which bears the same relation to observed travel speeds that the assumed design speed is intended to bear to future travel speeds. Since the speeds of all vehicles on any road can be measured, knowledge of a permissible value for the percentage of vehicles exceeding the highway speed rating would make it possible to determine the actual speed rating for that road. The object of this paper is to analyze speed data for existing roads and determine the percentile value to be used as a definition for highway speed ratings.

The term "percentile", while perhaps unfamiliar, is specific in meaning and is a useful tool in reference to speed distribution data A dictionary definition is:

[1] "A Policy on Highway Classification"—A. A. S. H. O., 1940.

"Any series of values that indicate the distribution of a large group of measurements If the results obtained be arranged in order of magnitude and divided into 100 equal groups, then a value lying just above the first group is the first percentile, one just above the second, the second percentile, etc" A percentile speed refers to the cumulative percentage of the number of vehicles which travel at or below a certain speed It is the highest speed of a lower speed group of vehicles, the number of vehicles in the group being a stated percentile of the total Percentile speed is a general term; only when it is applied to a particular speed distribution can it be expressed in actual miles per hour A 90 percentile speed may be 28 mph on one road, 51 mph on another road, 35 mph on a third; in each case the roads and traffic conditions are totally different yet the speed given is that exceeded only by the faster 10 percent of vehicles.

Data

In a series of studies during 1934 and 1935, the Division of Highway Transport of Public Roads obtained the individual vehicle speeds at a large number of highway locations in three eastern states and cooperated with the Illinois State-wide Highway Planning Survey in a similar study during 1937 While these studies were designed primarily to obtain data for use in determining the traffic capacity for highways of different widths and number of lanes, the data obtained covered such a large number of vehicles and highway locations and have been tabulated in such a form that they have also been useful for a variety of other studies relating to traffic flow. For this particular study, tables were made available showing the frequency distribution of speeds and average speed at each highway location Each study consisted of one or more days record of the speeds of all vehicles passing through a distance of about $\frac{1}{5}$ mile, resulting in speed-volume data for 2,000 to 25,000 vehicles at that location The studies were on 2-, 3- and 4-lane roads, including some divided highways, and were for the most part on level tangent stretches although a few sections were on grades and curves Each study location was selected primarily as a point where high peak hour traffic volumes were anticipated. However, the length of study was sufficient to obtain data for the low traffic volume periods as well Average data for the whole of each study are used

The times of entrance and exit of each vehicle on the measured study length were recorded by manually operated electrically controlled pens on charts revolving at uniform speed, permitting scale reading of the time required to traverse the study section The accuracy of the recording device was such that individual vehicle speeds were determinable to an accuracy of one mile per hour for speeds under 40 miles per hour and from 1 5 to about 3 0 miles per hour for the higher speeds

A major portion of these data was obtained in 34 studies (12, 9 and 13 studies on 2-, 3- and 4-lane roads, respectively) in which speeds were measured for a total of 236,724 vehicles traveling over level tangent, or nearly so, sections of highways These 34 studies include all data obtained on level tangent study sections sufficiently removed from steep grades so that travel speeds were not affected by the grades Also included in the 34 studies are a few made on slight grades or on flat curves Speeds measured in these studies show no appreciable variations from the speeds on level tangent sections

Another group examined consisted of 6 other studies with a total of 12,336 vehicles traveling up grades of 7 and 8 percent and 11,205 vehicles traveling down the same grades

The data used consisted of a summary

of speeds observed on each study section showing the cumulative percentage of total vehicles traveling at or below indicated speeds. Data for each section of the level-tangent group are indicated on Figure 1 by the connected series of served. Appended tabulations of such information for each study show average traffic volumes ranging from 240 to 1,694 vehicles per hour.

Tables 1, 2, 3 and 4 give the pavement width, grade, and alinement on the study

TABLE 1

SUMMARY OF 2-LANE ROAD STUDIES

Study number	Pavement width (feet)	Grade and Curvature		Average speed (mph)	Average volume (vph)	Directional ratio (percent)	Total vehicles included
4 A	22	level	tangent	21.9	1,061	45–55	8,028
5 P	24	level	tangent	29 7	632	44–56	3,678
4 O	24	level	tangent	30 1	860	47–53	6,086
4 N	20	level	tangent	30.2	850	45–55	2,865
5 A	20	level	reverse curve	34.4	649	45–55	9,155
7 F	18	level	tangent	35 9	519	45–55	4,060
5 C	18	level	tangent	37 0	739	47–53	14,709
7 O	20	level	4° curve	37 9	371	45–55	2,591
5 D	18	sl rolling	tangent	38 6	570	46–54	4,088
7 K	18	level	tangent	40 2	547	46–54	4,014
7 B	18	0.4%	tangent	41.7	240	50–50	1,741
5 H	18	level	tangent	42 7	525	48–52	3,737
Total of 12.							64,752

TABLE 2

SUMMARY OF 3-LANE ROAD STUDIES

Study number	Pavement width (feet)	Grade and Curvature		Average speed (mph)	Average volume (vph)	Directional ratio (percent)	Total vehicles included
4 D	30	level	tangent	30 5	1,243	41–59	4,069
4 L	30	level	tangent	33 0	1,254	37–63	8,492
5 R	27	1%	reverse curve	34 6	763	39–61	11,069
5 N	27	low crest	sl curve	35 1	1,284	39–61	18,689
4 M	30	level	tangent	36 9	1,138	33–67	12,128
4 Q	30	level	tangent	37 0	546	31–69	1,818
5 K	30	level	4°	43.3	471	45–55	2,827
5 J	30	level	tangent	45 1	731	45–55	7,717
5 M	30	3%	sl. curve	45 2	463	50–50	3,348
Total of 9.							70,157

dots, producing an S-type curve. The small circles near the center of the curves indicate the average speeds for each of the studies The range of average speeds —from 22 to 47 mph—gives some indication of the diversity of highway and traffic conditions that have been observed.

sections used and traffic data for the vehicles observed. The prefix number 4, 5, or 7 of the study number (left column) indicates the years 1934, 1935 and 1937, respectively. The speed and volume figures are combined averages for the total (two directional) number of

TABLE 3

SUMMARY OF 4-LANE ROAD STUDIES

Study number	Pavement width (feet)	Grade and Curvature		Average speed (mph)	Average volume (vpn)	Directional ratio (percent)	Total vehicles included
4 E	50	level	tangent	30 4	1,694	48-52	22,396
*4 H	28-28	level	tangent	31 9	1,119	42-58	5,909
4 C	40	level	tangent	33 7	1,099	39-61	7,800
4 G	36	level	tangent	34 1	755	49-51	4,433
7 G	40	level	tangent	41 0	475	46-54	3,324
7 U	40	level	5 5° curve	41 2	560	49-51	2,981
7 P	36	level	tangent	41 2	358	45-55	3,177
*7 X	20-20	level	tangent	43 9	1,128	49-51	9,761
7 S	40	level	tangent	44 2	1,051	35-65	17,690
*7 L	22-22	level	tangent	44 2	800	40-60	4,108
7 V	40	level	tangent	44 4	728	44-56	5,457
*7 W	20-20	level	tangent	46 4	964	41-59	5,143
*7 Y	20-20	level	tangent	46 7	1,095	36-64	9,636
Total of 13							101,815

* Divided highway

TABLE 4

SUMMARY OF STUDIES ON GRADES OF 7 & 8 PERCENT (FIGURE 5)

Study number	Pavement width (lanes)	Pavement width (feet)	Grade and Curvature		Average speed (mph)	Average Volume: 1-way studied (vph)	Average Volume: 2-way total (vph)	Directional ratio (percent)	Total vehicles studied	Percent trucks	Percent busses
5 O	3	27	up 7%	tangent	24 4	500	856	42-58	3,641	10 8	0 9
4 K	3	30	up 7%	tangent	32 2	272	553	49-51	1,342	9 2	1 3
5 E	2	18	up 8%	winding	33 6	238	492	48-52	1,588	6 5	0 3
4 J	3	30	up 7%	tangent	33 8	327	706	46-54	2,387	9 1	0 8
5 F	2	18	up 7%	tangent	34 1	252	453	45-55	1,966	5 1	0 3
5 G	2	18	up 7%	tangent	34 2	229	486	47-53	1,412	5 9	0 1
Total 6								Total	12,336		
5 O	3	27	down 7%	tangent	29 2	357	854	42-58	2,308	14 5	1 1
4 K	3	30	down 7%	tangent	35 0	276	553	50-50	1,242	7 2	0 7
5 E	2	18	down 8%	winding	35 7	255	493	48-52	1,716	5 2	0 2
5 F	2	18	down 7%	tangent	36 8	201	453	44-56	1,578	7 4	0 4
5 G	2	18	down 7%	tangent	39 4	248	477	48-52	1,539	4 7	0 2
4 J	3	30	down 7%	tangent	40 4	388	711	45-55	2,822	6 6	0 8
Total 6								Total	11,205		

vehicles shown The directional ratio is the ratio between the percentage of total traffic traveling in one direction and the percentage traveling in the other direction for the total time of study. The studies on grades and on 4-lane divided highways (and study 4E) were made separately for traffic in each direction but sufficient information is available for the total volumes and directional ratios shown. of the effect of volume on the speed distribution curve. Other than this (Table 5) all data used consisted of the combined average for all vehicles studied at each location.

TABLE 5

SUMMARY OF STUDIES BY VOLUME GROUPS (FIGURE 6)

(Data for 10-minute intervals combined into volume groups)

Study number	Pavement width (feet)	Grade and Curvature		Average speed (mph)	Average volume (vph)	Directional ratio (percent)	Total vehicles included
7 F	18	level	tangent	35 7	359	42–58	323
7 O	20	level	4° curve	38 0	340	49–51	1,305
5 C	18	level	tangent	40 7	355	49–51	1,043
7 K	18	level	tangent	44 3	314	29–71	419
Total 4				Average	342	Total	3,090
4 N	20	level	tangent	32 0	528	49–51	761
7 F	18	level	tangent	34.2	566	50–50	1,131
5 A	20	level	reverse curves	34 4	586	32–68	1,894
7 O	20	level	4° curve	37 2	513	32–68	939
5 C	18	level	tangent	38 7	556	50–50	1,510
5 D	18	sl rolling	tangent	38 7	548	43–57	1,628
7 K	18	level	tangent	40.7	559	47–53	1,118
5 H	18	level	tangent	42 5	559	46–54	1,244
Total 8				Average	552	Total	10,225
4 A	22	level	tangent	24 3	716	no data	1,312
5 A	20	level	reverse curves	31 5	765	41–59	2,419
4 O	24	level	tangent	32 0	795		1,216
5 C	18	level	tangent	35 5	752	48–52	2,693
7 K	18	level	tangent	39 1	711	41–59	1,066
5 H	18	level	tangent	41 8	738	50–50	249
Total 6				Average	746	Total	8,955
4 A	22	level	tangent	22 8	1,011	no data	2,823
4 O	24	level	tangent	28 9	1,052	29–71	1,557
5 A	20	level	reverse curves	31 3	1,065	no data	1,293
4 N	20	level	tangent	31.4	1,093	43–57	809
Total 4				Average	1,055	Total	6,482

For purposes of studying highway capacity the basic data had been tabulated in 10-min. interval groupings and combined into various volume groups. Table 5 indicates the only portion of these detailed data used herein for examination

Speed Distribution Curves

Figure 1 demonstrates the form of the combined average speed distribution data for each study The three parts show the data for the various lane-width roads

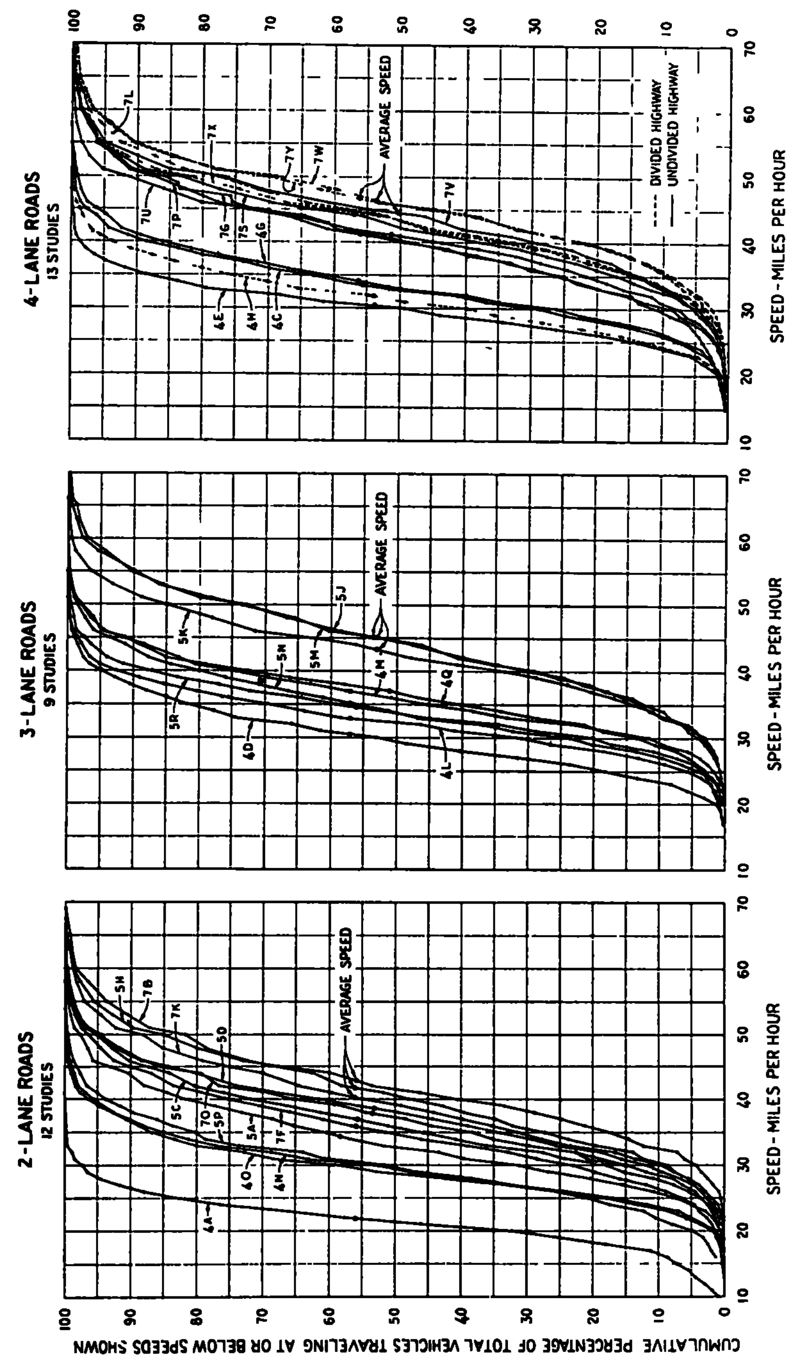
4-LANE ROADS
13 STUDIES
3-LANE ROADS
9 STUDIES
2-LANE ROADS
12 STUDIES
AVERAGE SPEED
DIVIDED HIGHWAY
UNDIVIDED HIGHWAY
SPEED-MILES PER HOUR
CUMULATIVE PERCENTAGE OF TOTAL VEHICLES TRAVELING AT OR BELOW SPEEDS SHOWN
7L
7K
7Y
7W
7U
7P
7G
7S
6G
7V
4E
4M
4C
5J
5K
5N
5M
4M
4Q
5R
4D
4L
5H
7B
7K
5D
5C
7O
5P
5A
7F
4O
4N
4A
0
10
20
30
40
50
60
70
80
90
100

Figure 1

in the group of 34 studies on level tangent highways. A general examination of the data in this form indicates that the speed distribution curves for any road width are of the same general form over a rather wide range of average speeds and volumes. All factors jointly control only the steepness or speed range of the curves. Further, comparing the curves for the different road widths, the range of speeds covered is about the same (with the single exception of the 2-lane study 4A) for considerably different volumes Even the distribution of speeds on the 4-lane divided highway (dashed) with their higher volumes show no marked variation from those on the 4-lane undivided highways Accordingly data for both divided and undivided 4-lane highways are considered jointly

The speed distribution data presented in Figure 1 clearly illustrate the convenience and specific meaning of a percentile value in reference to a group of speed studies. The different highway and traffic conditions on the various locations studied gave speed distribution curves that are similar but widely varied for any actual speed value For instance, the studies on 2-lane roads show a speed of, say, 30 miles per hour (vertical line) for percentages of vehicles ranging from 5 to 98; for each study there is a different percentage at this speed. However, use of any one percentile value, say 90, (horizontal line) determines the same relative point on all of the curves—the speed that is exceeded by only the faster 10 percent of the total vehicles.

The lowest speeds in Figure 1 are about 10 to 15 mph in all cases and top speeds vary widely, from 50 to 90 mph. The average speeds (indicated by small circles) are in all cases less than 50 mph and fall chiefly within a range of 30 to 47 mph. On the speed distribution curve the average speed invariably is slightly above the median speed, falling within the range of 50 to 60 percent of vehicles. That is to say, about 55 percent of the vehicles observed on the highways were traveling at or slower than the average speed of all vehicles.

Examination of the 34 curves of Figure 1 indicates that, regardless of the volume or the lanes of road, the curves for the same average speed are nearly identical. This suggests that combination and analysis of data can conveniently be made in terms of the average speed for each study. This basis is desirable since the term "average speed" is universally used and is not confusing. Most engineers have no immediate conception of highway and traffic conditions identified by a "speed range (say 40 miles per hour between limits of 1 to 99 percent of vehicles) or by a 90 "percentile" speed of 40 miles. But all have some immediate visualization of highway and traffic conditions that result in an average speed of (say) 40 miles per hour on a highway of (say) 2 lanes.

Figure 2 shows the average speed plotted against the average volume for each of the 34 studies on level tangent sections on roads having different numbers of lanes. In this form the data may be said to show a general trend of lower average speeds for higher volumes of traffic (sloping down toward the right) for each width, as we all know should be the case But this trend is not clear cut, particularly for the 4-lane roads. It is, in fact, quite indicative of the usual shotgun diagram obtained with widely varied volumes of traffic. From this chart it can just as logically be stated that, considering all studies jointly, roads of the same average speeds may be carrying almost any volume of traffic. This is in effect a restatement of the apparent conclusion from Figure 1, i.e., that speed distribution curves for different roads with the same average speed are nearly identical, regardless of the traffic volumes or the number of lanes. It is concluded therefore that combination and analysis of these data can logically be made in terms of the average speeds.

Analysis

The method of analysis in terms of the average speed is indicated by Figure 3 Speeds for three percentiles, 98, 95 and 90, are shown from top to bottom for the roads of 2-, 3- and 4-lane widths from left to right Each dot is the speed for one study at which the indicated percentage of vehicles was included plotted against the average speed for the study While only high percentile values are speed divided by the average speed of the study to obtain a ratio, which is designated as K The value of K, then, is a ratio that is the quotient of a selected speed of travel and the average speed for a study It is a speed scale in proportions of the average speed These ratios for a given percentile were then averaged numerically to obtain a group average for different types or combinations of roads, which is referred to as average K for an indicated percentile

In Figure 3 the light solid lines indicate values of K to show the limited spread

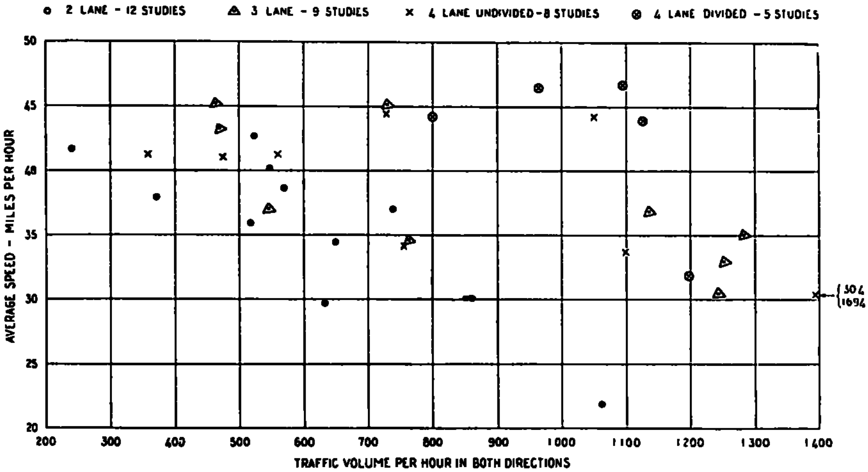

Figure 2

illustrated in Figure 3, the same type of chart relation is found at all percentiles It is apparent in all cases illustrated that there is little error in expressing the percentile speed–average speed relation as a straight line, or that for any percentile speed its ratio to the average speed is nearly a constant for all the studies

This presents a ready means for combining the values of the various studies The procedure consisted of plotting the separate speed distribution curves in the form shown in Figure 1, and rounding the values to a smooth S-curve From this rounded curve the value of the speed was read for a designated percentile and this for the percentile. While the K values vary for the different percentiles there is little variation between the groups of studies for different road widths The slope of heavy line is the average value of K at that percentile, for the group of studies.

Figure 4 presents the average values of K for the whole range of percentiles, with a separate line for each lane-width group of studies The heavy dots indicate the combined average value of K for all 34 studies, the curved line itself being omitted for clearness The calculated values for these four curves are shown in the first five columns of Table 6.

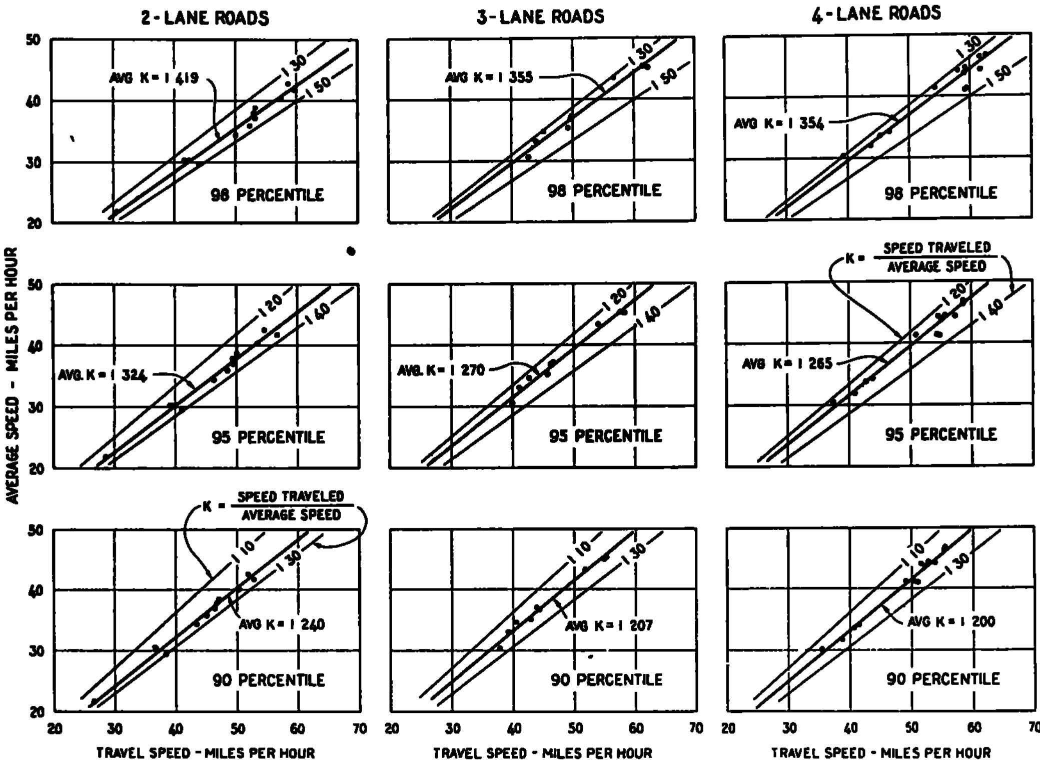

Figure 3

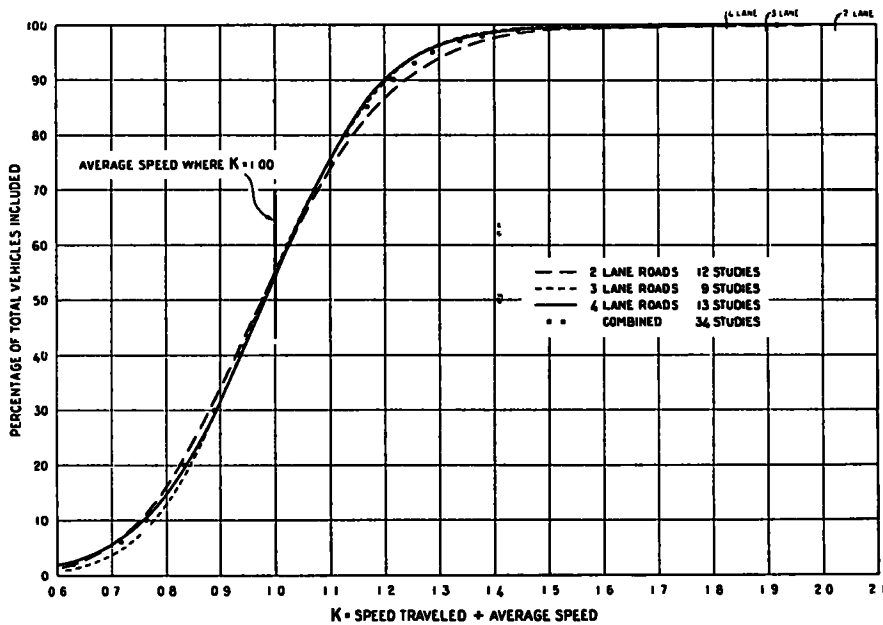

Figure 4

The data at the bottom of this table indicate this combined curve to be the result of observations of 236,724 vehicles at 34 locations, in average study volumes ranging from 240 to 1,694 vehicles per hour and for average speeds ranging from 22 to 47 miles per hour

The average K values for the groups of studies on 3- and 4-lane roads are nearly the same except for less than 20 percent of the vehicles, and even then are not far removed The curve for the group of studies on 2-lane roads is somewhat flatter in slope indicating a greater spread

TABLE 6

SUMMARY OF CALCULATED VALUES OF K (SPEED OF TRAVEL — AVERAGE SPEED)

Percent of vehicles included	Average values of K									
	Major study by road widths				Grade study (1-way)		Volume study			
							Average volume of			
	2-lane roads	3-lane roads	4-lane roads	Combined total	Up 7-8% grades	Down 7-8% grades	342 vph	552 vph	746 vph	1055 vph
100	2 025	1 898	1 826	1 915	1 913	1 718	1 788	1 989	1 807	1 702
99	1 496	1 407	1 420	1 444	1 562	1 420	1 472	1 474	1 488	1 445
98	1 419	1 355	1 354	1 378	1 502	1 357	1 420	1 402	1 418	1 372
97	1 376	1 317	1 318	1 338	1 455	1 320	1 385	1 356	1 372	1 330
95	1 324	1 270	1 265	1 287	1 390	1 275	1 330	1 302	1 310	1 270
93	1 285	1 242	1 235	1 255	1 347	1 245	1 288	1 270	1 267	1 232
90	1 240	1 207	1 200	1 216	1 300	1 205	1 245	1 228	1 225	1 190
85	1 183	1 161	1 158	1 168	1 243	1 158	1 190	1 176	1 167	1 135
80	1 138	1 128	1 125	1 130	1 202	1 127	1 148	1 135	1 127	1 098
70	1 078	1 069	1 070	1 072	1 133	1 072	1 085	1 070	1 057	1 040
60	1 022	1 022	1 024	1 023	1 067	1 025	1 030	1 019	1 003	1 005
50	975	977	981	978	1 002	980	980	975	962	965
40	928	934	937	933	940	938	925	930	922	935
30	878	891	894	888	870	897	868	881	880	895
20	823	842	837	833	783	852	812	828	842	855
15	792	813	802	803	715	818	778	799	812	830
10	752	778	758	761	620	778	738	760	778	795
6	707	737	709	716	512	735	690	716	740	758
2	626	661	607	628	333	652	585	654	663	685
No of studies	12	9	13	34	6	6	4	8	6	4
No vehicles included	64,752	70,157	101,815	236,724	12,336	11,205	3,090	10,225	8,955	6,482
Range of avg speeds										
Low	21 9	30 5	30 4	21 9	24 4	29 2	35 7	32 0	24 3	22 8
High	42 7	45 2	46 7	46 7	34 2	40 4	44 3	42 5	41 8	31 4
Range of avg vols										
Low	240	463	358	240	238/492	201/453	314	513	711	1,011
High	1,061	1,284	1,694	1,694	500/856	388/711	359	586	795	1,093
Plotted on figure	4 & 5	4	4	4 & 7	5	5	6	6	6	6

in the range of speeds. While there is a measurable difference between the three curves, the combined curve is sufficiently close to any one of the three that it alone may be used for further analysis, without appreciably affecting the results.

The value of K is 1.0 at the average speed, which is found to be that of 55 percent of vehicles That is, the average speed of travel is a 55 percentile speed, slightly above the median speed (50 percent of vehicles). The maximum or 100 percentile speed is 1.92 times the average speed for the combined curve, while a near maximum or 99 percentile speed is 1.44 times the average speed. The minimum speed is only 0 5 the average speed. Accordingly the range of travel speeds is from 0 5 to 1 9 or about 1.4 times the average speed. By substitution of actual mile per hour values for any one average speed in lieu of the K scale this chart becomes a typical distribution curve for that average speed.

The combined speed distribution curve of Figure 4 is nearly a straight line for speeds between 20 and 80 percentile values (left scale), and is only slightly S-curved between 10 and 90 percentile values. Dividing the K scale roughly into thirds, it is found that almost half of the vehicles travel at speeds in the lower third of the speed range, about half of the vehicles travel at speeds in the intermediate third of the speed range, leaving only a small percentage of vehicles that travel at speeds in the upper third of the speed range. Or, stated otherwise, an overwhelming majority of the vehicles travel at speeds in the lower two-thirds of the speed range. Similarly, it is found that nearly 90 percent of vehicles travel in the lower one-half of the speed range.

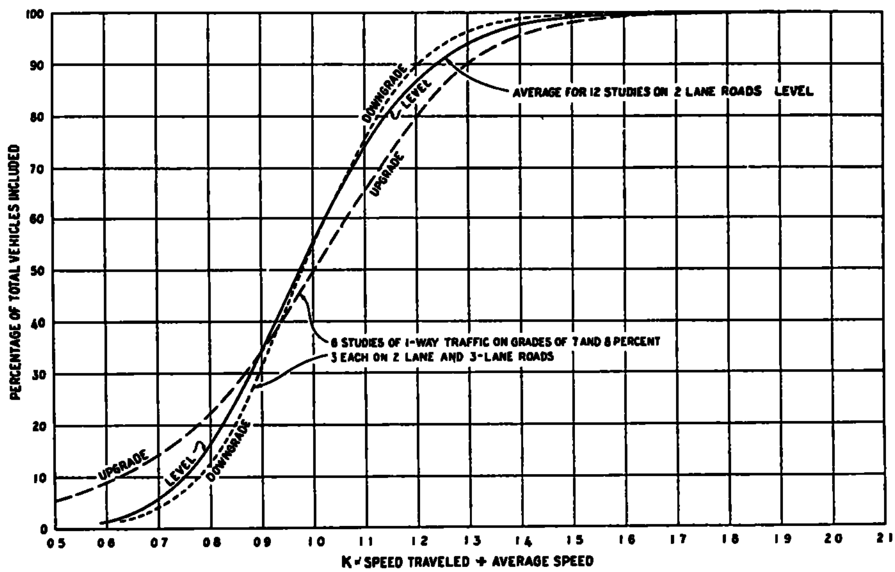

Figure 5

Before proceeding further in a percentile-speed rating analysis it is pertinent to note the effect of grades and of volumes on the type of curves of Figure 4. For the effect of grades Table 4 gives details of six other studies made on 7 and 8 percent grades, the available speed data being for one-way operation. The calculated average values of K are shown in the sixth and seventh columns of

Table 6 and are plotted on Figure 5. The data for these 6 studies on grades showed no appreciable difference between those on 2-lane roads and those on 3-lane roads. Accordingly they are summarized together, and are to be compared with the level groups of the same lane width. Figure 5 shows speed distribution curves for travel in both directions on the grades. The central curve, as indicated, is the average for the 2-lane level roads. The curve for the 3-lane level roads so closely follows the curve for downgrade travel that it was omitted for clarity. Figure 5 indicates that the effect of a steep grade is a decided flattening of the K curve for the travel upgrade and a slight steepening of the curve for the travel downgrade. The flatter curve for the travel upgrade shows a wider range of travel speeds, doubtless due to the lower truck speeds. It is interesting to note that the speeds downgrade are not more extensive in range than those for level 2- and 3-lane highways. The average speeds downgrade are 2 to 6 mph faster than the average speeds upgrade.

For the effect of volume, Table 5 indicates the various volume groupings of data available in the 12 studies on 2-lane roads, consisting of basic data for 10-minute intervals combined into groups of the indicated volumes. Each of these is only a part of the total data for the study as previously used. The last four columns in Table 6 list the calculated average values of K, which are plotted on Figure 6. The four volume groups are indicated by different line symbols and the combined average for 2-lane roads is shown by the heavy dots. This chart indicates that there is relatively little difference in the K values between volume ranges of 342 and 1055. This difference is only slightly greater than that between the 2-lane and 4-lane roads (Fig. 4) and is less than that between the upgrade and downgrade traffic (Fig. 5). The steepening form of curve for the

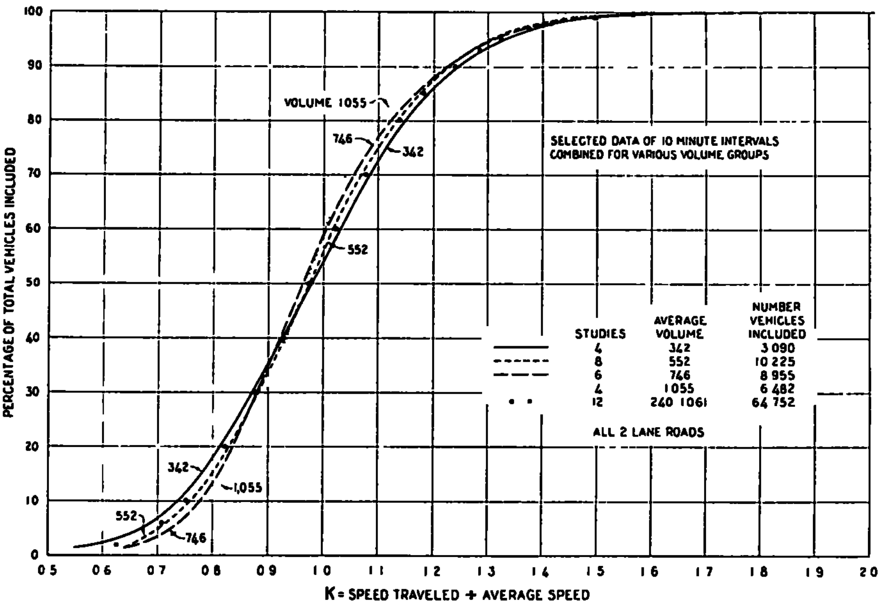

Figure 6

higher volumes (Fig 6) indicates a reducing range of speeds at which the vehicles travel showing the influence of the bunching of vehicles While the various effects of different volumes of traffic may be extensively discussed, it is not the purpose of this analysis to elaborate on such phases. This chart is used primarily to demonstrate that in the form of K values the effect of volumes is relatively small.

The combined speed distribution curve for the 34 studies on level tangent highways has been derived (Fig. 4) in terms of K, which is the speed of travel expressed as a multiple of the average speed. This is a speed distribution in terms of a 55 percentile value as unity, and is shown as the right curve in Figure 7 The combined speed distribution similarly can be presented with other percentile values as unity, i.e., replotting the curve on such proportions on the horizontal scale that the unity point falls on other desired percentile values. The combined speed distribution is shown in Figure 7 with values of unity at 55, 70, 80, 90, 95, 98, 99 and 100 percentiles; these data are listed in Table 7. In this form the combined data may be studied to determine the effect of various percentile values as definitions of the highway speed rating.

For convenience the data of Figure 7

TABLE 7

COMPARISON OF SPEED DISTRIBUTION IN TERMS OF VARIOUS PERCENTILE SPEEDS (FIGURE 7)
(Combined average of 34 studies)

Percent of vehicles included	Speed of travel as a multiple of							
	55* percentile speed	70 percentile speed	80 percentile speed	90 percentile speed	95 percentile speed	98 percentile speed	99 percentile speed	100 percentile speed
100	1 915	1 786	1 695	1 575	1 485	1 390	1 326	1 000
99	1 444	1 347	1 278	1 188	1 120	1 048	1 000	.754
98	1 378	1 285	1 220	1 134	1 069	1 000	954	719
97	1 338	1 248	1 185	1 100	1 037	971	927	699
95	1 287	1 204	1 140	1 058	1 000	936	893	.674
93	1 255	1 170	1 110	1 032	973	911	869	655
90	1 216	1 135	1 076	1 000	943	883	842	.635
85	1 168	1 086	1 034	961	906	848	807	610
80	1 130	1 054	1 000	930	876	820	783	590
70	1 072	1 000	949	882	832	778	743	560
60	1 023	954	906	842	793	742	708	534
50	978	912	865	804	758	710	677	510
40	933	870	826	767	724	677	646	.487
30	888	828	786	730	689	645	615	458
20	833	777	737	685	646	604	577	435
15	803	747	709	659	621	582	554	.419
10	761	.710	.674	.626	590	552	527	397
6	716	.668	634	589	555	519	496	370
2	.628	.586	556	.517	487	456	435	317

* Average speed.

are shown in the same form but on actual mile per hour abscissae in Figure 8 A speed rating of 60 mph is assumed for this demonstration of various percentile values as definitions The right insert shows the 97 to 100 percent values on an enlarged vertical scale, of particular use in reading the top speed

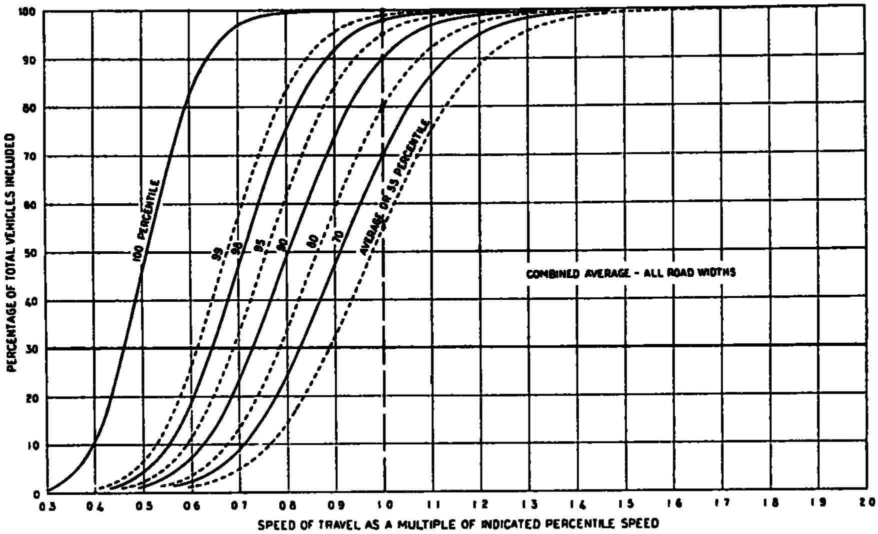

Figure 7

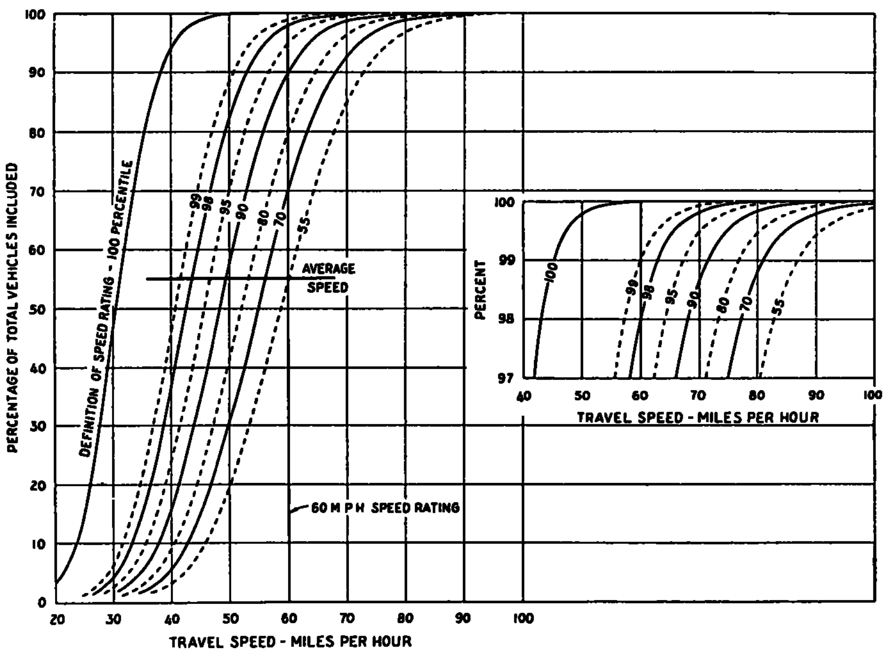

Figure 8

Percentile Definition of Highway Speed Rating

The data presented have demonstrated that for any given highway (and to some extent for any traffic volume upon it) the range of speeds at which all types of vehicles travel upon it and the distribution of the traffic within this range of speeds follow a definite curve pattern when expressed in terms of the average speed or any one percentile speed. This curve pattern is the same whether the combinations of highway, topography and traffic are such as to produce a low average speed or a high average speed The combined distribution pattern is in a form to be examined to determine at what point in the speed range the speed rating should be defined.

To agree with the definition it is apparent that a highway speed rating should be such that only a few of the highest speed vehicles are not included. But the speed rating need not be as high as the top speeds measured Obviously the speed rating should be considerably higher than the average speed, which would include only 55 percent of vehicles A low percentile value results in a low speed rating and consequent low standards to accommodate vehicles at or below it, but a greater proportion of vehicles will exceed the speed rating As the percentile value approaches 100 there is an increase in the speed rating and the standards to accommodate vehicles at or below it, but few vehicles will then exceed the speed rating.

Figure 8 strikingly demonstrates the different speed distributions that can be represented by various percentile definitions of a speed rating of 60 mph. Note first the range of average speeds that these definitions would cover, from 31 mph for the 100 percentile to 60 mph for the 55 percentile. Referring to the original data, Figure 1, the higher speed group of studies showed average speeds between 40 and 50 mph.

Referring to Figure 8 and projecting 40 to 50 mph speeds (lower scale) it is obvious that percentile definitions of 90 to 99 are necessary in order to rate these highways at 60 mph Figure 8 also shows that a percentile definition less than 90 would result in an average speed or a range of speeds well above those so far found on our highways if the rating is to be 60 mph.

The extent of the difference between the speed rating and the average speeds of travel for various percentile values as definitions, Figure 8, gives a clue toward selection of a proper percentile value For percentile definitions of 70, 80, 90 and 95 the speed rating of 60 mph is 4, 7, 11 and 14 mph above the average speed, respectively For 99 and 100 percentile values the speed rating is 19 and 29 mph above, respectively It appears that little would be gained unless the speed rating is at least 10 mph above the average speed, corresponding to a percentile value of about 90 for the 60 mph rating, and it certainly need not exceed about 20 mph above, corresponding to a percentile value over 99. For speed ratings less than 60 mph (not illustrated) higher percentile values yet are necessary in order that the speed rating will be at least 10 mph above the average speed. This means that the speed rating definition should be high enough that not over 10 percent of the vehicles will exceed it, but by the same token it need not be high enough to include all vehicles.

Considering only speeds *above* the speed rating, the distributions in Table 8 are noted from Figure 8 (assumed speed rating of 60 mph).

These data indicate that only the first two percentile values as definitions, 95 and 98, are well within the scope of desired speed ratings The 90 percentile values as a definition might be included, but is on the questionable verge. Lower percentile definitions definitely are beyond the desired limits.

Considering the distribution of traffic speeds *below* the speed rating, Figure 8 shows the data in Table 9 (assumed speed rating of 60 mph). The data of Table 9 indicate the undesirable low proportion of vehicles, 6 to 42 percent, that would be traveling slower than speeds of 40 to 50 mph (i.e., 0.67 or 0.83 times the speed rating) if the speed rating were to be defined as one of the lower percentile values. It appears desirable

TABLE 8

Percentile value as a definition of speed rating	Percent of vehicles exceeding speeds of				
	60 mph	65 mph	70 mph	75 mph	80 mph
98	2	0.6	0.2	0.06	0.02
95	5	1.7	0.5	0.2	0.05
90	10	4	1.3	0.5	0.2
80	20	9	4	1.4	0.5
70	30	16	7	3	1.2

TABLE 9

Percentile value as a definition of speed rating	Percent of vehicles traveling at or below speeds of				
	40 mph	45 mph	50 mph	55 mph	60 mph
98	37	63	82	94	98
95	24	48	71	86	95
90	16	35	58	78	90
80	9	22	42	63	80
70	6	16	31	51	70

to so "peg" the speed rating that about half of the vehicles are traveling slower than speeds in the range of 0.7 to 0.8 of it (Figure 7), or about 40 to 50 mph as shown in figure 8. Again only the 95 and 98 percentile values are as desired for definition, and the 90 percentile value is just on the edge. Lower percentile definitions will not suffice.

Choice of a percentile value for use as a definition of speed rating would be simple if the combined speed distribution curve (Fig. 4, 7 or 8) had a decided break in the upper region. There is no marked point of change in curvature, but it is possible roughly to determine at what percentile value increment changes begin to increase rapidly. Such analysis indicates that the more abrupt change in curvature occurs in the 96 to 98 range of percentile values. Below these values a unit increment in the percentage of vehicles included results in a nearly proportionate increase in the speed. But above these values a unit increment will result in a much greater increase in speed. The higher speed rating to include the few vehicles going faster than these percentile speeds appears entirely out of proportion to their number. It therefore appears desirable to use a 96 to 98 percentile value as a definition point for the speed rating.

Another confirmation of the choice of a percentile definition in the high nineties may be found in the risk involved in vehicles traveling at speeds higher than the speed rating. If the sharpest curves are such that vehicles traversing them at the rated speed can hold the road by using only the side friction considered safe in design, and the vehicles traveling at higher speeds do not slow down when rounding these curves, then the percentile definition should be such that the higher speed vehicles are not only few in number but that their speeds, while somewhat hazardous, are not great enough to require friction approaching that at impending skid to keep them on the road.

Minimum radius of curve for a given speed may be calculated by the formula

$$R_{min} = \frac{.067\,V^2}{E + F}$$

where

V is the speed in mph

E is the maximum superelevation, feet per foot, and

F is the friction factor.

The limiting value of E generally is considered to be 0.10. The amount of frictional resistance to transverse sliding that may be developed with safety by a vehicle traveling around a curve is represented by a value of F of 0.16 for speeds of 30 to 60 mph and by a value of 0.14 for a speed of 70 mph.[2] Omitting the relatively minor effect of the latter value, the expression for the minimum radius then is:

$$R_{min} = \frac{.067}{0.26} V^2$$

Substituting for R_{min} the speeds are in the ratio:

$$\frac{V_x^2}{V^2} = \frac{.067}{0.26} \times \frac{(0.10 + F_x)}{.067} = \frac{0.10 + F_x}{0.26}$$

or

$$\frac{V_x}{V} = \sqrt{\frac{0.10 + F_x}{0.26}}$$

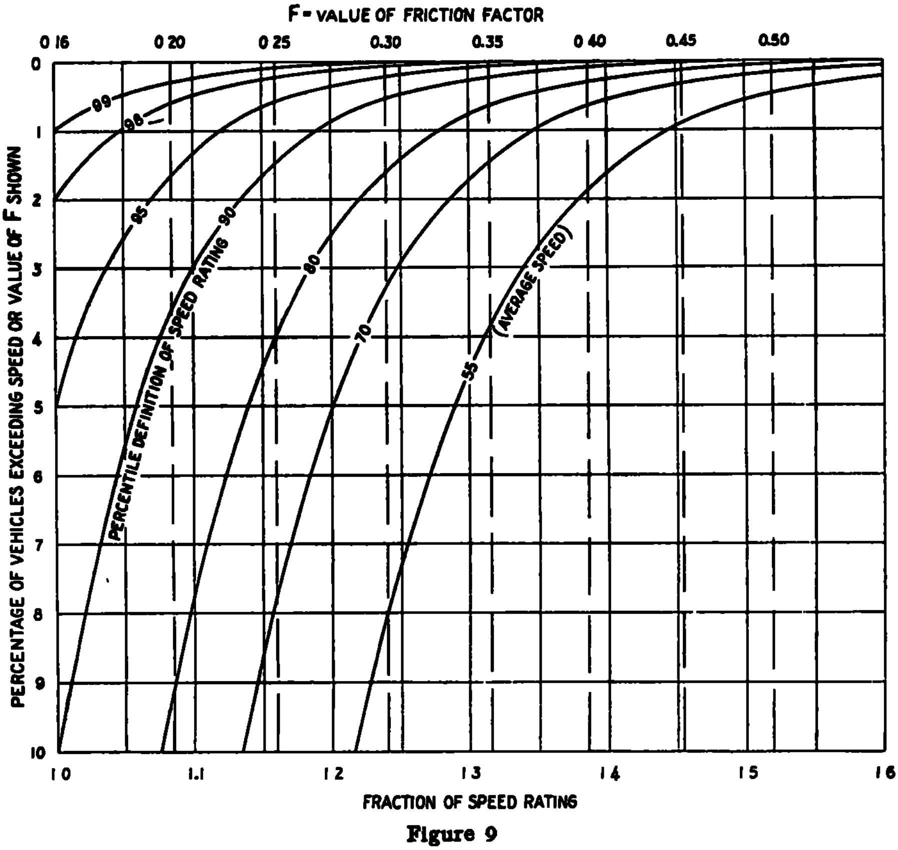

Figure 9

Let V_x represent any speed higher than V and F_x the factor for the friction developed when rounding the above curve at speed V_x Then

$$V_x^2 = \frac{R_{min}(0.10 + F_x)}{.067}$$

[2] "Safe Side Friction Factors and Superelevation Design" by J Barnett *Proceedings*, Highway Research Board, Vol 16, 1936.

For any assumed value of the friction factor (F_x) the ratio of the speed corresponding to this factor to the speed corresponding to a friction factor of 0.16 can be found by the foregoing formula. By superimposing this ratio on the upper portion of the curves of Figure 7 (K multiple greater than 1) the percentage of vehicles traveling faster than these higher speeds can be found for each percentile value as a definition of speed rating These relations are plotted in Figure 9 and are tabulated as follows for three values of the higher friction factor

Percentile value as a definition of speed rating	Percentage of vehicles exceeding speed indicated by		
	F_x = 0.25	F_x = 0.30	F_x = 0.35
98	0.2	0.07	0.01
95	0.6	0.2	0.08
90	1.5	0.5	0.2
80	4.0	1.6	0.6
70	7.8	3.3	1.4

Use of a 90 or higher percentile value as a definition of speed rating will result in less than 0.5 percent of vehicles traversing curves at the near critical friction factor of 0.30 and less than 1.5 percent at the only slightly less critical factor of 0.25 Use of lower percentile definitions result in 1.6 to 7.8 percent of vehicles at the corresponding excess speeds A 99 percentile value as a definition will assure that all vehicles do not exceed friction factors of 0.35.

Conclusions

This analysis of speed distribution data for nearly a quarter million vehicles on 34 sections of level-tangent highways shows a definite curve pattern for speed–percent-of-vehicles relation when expressed in terms of any percentile speed These curve patterns are nearly identical over a wide range of highway conditions, pavement widths, average speeds and traffic volumes Lowest speeds were about 0.5 and highest speeds about 1.9 times the average speed. Nearly 90 percent of vehicles were traveling at speeds in the lower half of the total range of speeds observed

Since the term "assumed design speed" is not specifically applicable to speeds on existing roads, the term "speed rating" or "rated speed" is used to denote the speed which bears the same relation to observed travel speeds that the assumed design speed is intended to bear to future travel speeds

Examination of the range of speeds found on the group of higher speed roads included, with average speeds of 40 to 50 mph, shows that definitions in terms of percentile values of 90 to 98 are necessary if these are to be rated as 60 mph highways Even higher percentile values are necessary to rate any of them as 70 mph highways

Analysis of these data to determine a percentile speed value to be used as a definition point for speed rating indicates that an 80 percentile value is too low, that a 90 percentile value is questionably low, that a 95 percentile value is reasonably desirable, and that a 98 percentile value appears to be the desirable definition point As a concrete example, a highway on which the distribution of speeds shows a lowest speed of 25 mph, an average speed of 45 mph and a top speed of 85 mph would have a 98 percentile value or speed rating of 60 mph

DISCUSSION ON PERCENTILE SPEEDS ON HIGHWAYS

DR B D GREENSHIELDS, *Brooklyn Polytechnic Institute:* In the paper it is shown that at present with average speeds ranging from 20 to 47 m p h, there is a certain distribution and range of speeds If we boost that average speed up to 60 m p h, what would the top speed be? In other words, would the curve stay just the same?

MR LOUTZENHEISER: You raise a point that is beyond the scope of this study and is entirely a matter of conjecture It was found in this study that average speeds on highways do not exceed 50 m.p.h. Yesterday Dr. DeSilva reported average speeds of only 44 to 46 miles an hour on open highways under relatively high speed conditions It will be helpful to know if the distribution of speeds for traffic under freeway conditions—as will be found on the Pennsylvania Turnpike—follow the same pattern as that on other roads While the whole range of speeds would be higher I would guess that they will follow the same general distribution pattern found here.

This report should be considered only a first step in a broad project of research on speeds to be used in design. It will be necessary to carry out studies for many other factors and conditions before the whole field has been covered.

Dr. Greenshields: This paper has shown that the "curve patterns of the distribution of speeds are found to be nearly identical over a wide range of highway conditions, pavement widths, average speeds, and traffic volumes." This is the important finding, and Mr Loutzenheiser has used it to determine what percentile speed to use in design. But it has other and to my mind just as important significance.

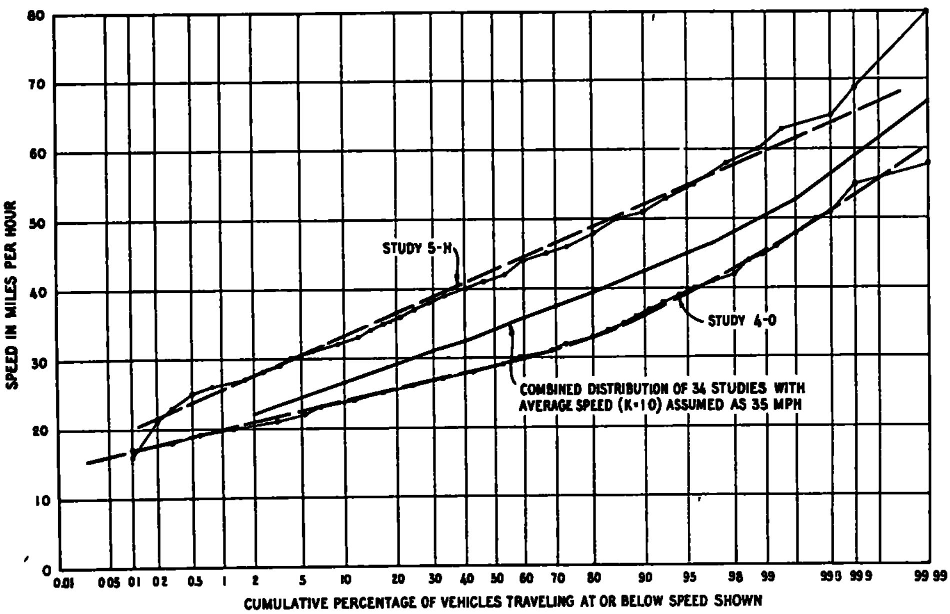

Figure 1

A knowledge of traffic flow patterns has made it possible to use short-traffic counts to determine traffic flow with sufficient accuracy for all practical purposes Knowing the pattern of the distribution of the speeds of vehicles a comparatively few observed speeds, say 100, should in most cases give all the necessary information about speeds at any particular location If conditions warrant more accurate information several 100-car samples taken at different times of the day give a more accurate result than the same number taken at one time

Mr Loutzenheiser has demonstrated that the speeds at which people drive when plotted according to frequency, fall into that characteristic "S" shaped curve of a random or normal distribution This is to be expected for it has been found to apply to many measurements such as the heights of persons, the length of ears of corn, the size of grains of sand, the precipitation of rain and to human abilities as measured by examination or other means

The "S" shaped curves 4-O and 5-H of Figure 1 of Mr Loutzenheiser's paper have been plotted on arithmetic probability paper in Figure 1 of this discussion It will be noticed that the points in 5-H fall in nearly a straight, and in 4-O in a slightly curved, line This makes plotting easier It also suggests that speed recordings should be made by classes or groups such as those less than 30, 40, 50, 60, 70 and 80 miles per hour A count of the vehicles traveling in each of the class intervals would make the arrangement of data for plotting a short and simple process Preliminary design work and field trials are being conducted on a selective speed recorder based upon this principle It seems to me that, say, five points would be sufficient to plot such a curve

The mathematical basis for Mr Loutzenheiser's use of the quotient of the speeds divided by the mean speed is given by W A Adams, author of "Road Traffic Considered as a Random Series," Journal of Institution of Civil Engineers, November 1936 He states in a letter to the writer that according to a result first demonstrated by Whitworth "Choice and Chance" that the probability of any interval exceeding "s" (speed) is $e \frac{-s}{M}$ where M is the average "speed" This implies that the percentage of speeds exceeding "s" will be $1000\, e \frac{-s}{M}$.

Mr Loutzenheiser The "S" shaped speed distribution curves are skewed rather than normal distribution curves They are not correctly approximated as straight lines on arithmetic probability scales, particularly for the higher values The skewed distribution can best be illustrated by plotting bell-shaped curves for noncumulative percentages The use of probability and also logarithmic scales was considered early in the study, but was discarded; with such scales it is difficult directly to make and demonstrate the conclusions drawn The central line has been added to Figure 1 of Dr Greenshields' discussion to show the average K value for the 34 studies (Table 6) expressed in terms of a unit value of 35 m p h (in order to be on the same scale and fall between the two studies shown in detail) Note that while the values below 90 per cent are nearly a straight line, the higher values curve upward

I question the accuracy of the use of observed speeds of only 100 vehicles to determine a speed distribution curve. Such short traffic counts could be applied only to determine an average (or selected central percentile) speed, which value would serve to determine the exact location of a predetermined general speed distribution curve, such as derived in this study Most studies show a large difference between average speeds for successive groups of 100 vehicles, even during conditions of similar traffic volume and directional flow concentrations. Several 100 vehicle counts at different times during the day, prorated as necessary, appear desirable to determine the average speed for the whole of the day.

A speed distribution curve could be approximated on arithmetic probability paper with five or more points distributed over the range of values, eliminating the need for a greater number of points to correctly plot the "S" type curve. But in either case the speeds of all vehicles in the sample must be determined, either separately for unit increments or in successive speed groups. Speed meters with cumulative counters that automatically group the vehicle speeds into desired speed ranges already are in use.