EFFECT OF ROADWAY WIDTH ON TRAFFIC OPERATIONS—TWO-LANE CONCRETE ROADS

Reported by A. Taragin, *Highway Engineer*,
Public Roads Administration

SYNOPSIS

Extensive speed-placement studies were conducted during the immediate pre-war years by the Public Roads Administration in cooperation with the highway planning surveys of several State highway departments. For this report analysis was made on factual data of everyday traffic for over 95,000 vehicles, gathered during day and night operations at 47 different locations on main rural highways in ten States. Included are results for level tangent sections of 2-lane highways with concrete surfaces 18, 20, 22, and 24 ft. wide. Data were segregated into several groups representative of the position of vehicles in the traffic stream, and results are shown separately for passenger cars and commercial motor vehicles. A number of tables and graphs are presented for speeds and transverse placements of vehicles on the various pavement widths, and the effect of grass, gravel, and bituminous shoulders of different widths on vehicle placement is illustrated.

The more important conclusions drawn from the data are that: shoulders wider than 4 ft. do not effect pavement width for moving traffic; grass and gravel shoulders have the same effect on transverse positions of moving vehicles; with 18- and 20-ft. pavements, bituminous shoulders increase the effective width about 2-ft.; lip curbs on 20-ft. surfaces reduce effective width about 1 ft. in the daytime; pavement widths less than 22 ft. are conducive to use of shoulders by moving traffic; pavements less than 22 ft. wide are hazardous even for moderate volumes of mixed traffic; drivers do not reduce speeds when meeting on narrow pavements; to provide desired clearances for commercial traffic a 24-ft. pavement is required.

Two-lane roads constitute 95 per cent of the 254,000 miles of the hard-surfaced primary systems of rural State highways in this country. Nearly one-third of these two-lane roads have a Portland cement concrete pavement. A survey of the surface width of rural highways with traffic of 1,000 or more vehicles per day in 27 States shows that 48 per cent of the roads at present have pavement widths less than 20 ft.

To determine operating condition on surfaces of various widths, extensive speed-placement studies were conducted during immediate pre-war years by the Public Roads Administration with the cooperation of the highway planning surveys in 10 States. Preliminary results of these studies for several sections in Illinois were published in the 1943 Proceedings of the Highway Research Board. This report presents the complete analysis of all the data collected to date in the speed placement studies on level tangent sections of rural 2-lane concrete pavement.

The equipment used in obtaining the field data consisted of combination speed-meters and transverse placement detectors, described in detail in the April 1940 issue of *Public Roads*.[1] With this equipment the transverse position and speed of each vehicle on the highway were recorded simultaneously on graphic recorder charts. Three charts, one for placements and one for speeds in each direction of travel, were synchronized and moved at a uniform speed so that it was possible to determine also the time spacing between successive vehicles, whether they were traveling in the same or in opposing directions.

VARIETY OF ROADWAY WIDTHS INCLUDED

The number of sections and vehicles observed, classified by the State in which the study was made, and by light condition, are

[1] E. H. Holmes and S. E. Reymer, "New Techniques in Traffic Behavior Studies," *Public Roads*, April 1940.

shown in Table 1. Speed-placement information for over 95,000 vehicles was obtained at 47 different locations with 18-, 20-, 22- and 24-ft. concrete pavements. At the 47 sites studies were conducted during daylight, and at 28 of them observations were also made during several hours of darkness.

Surface widths of 18 and 20 ft. are well represented in the sample, but the wider surfaces are less adequately represented because of the difficulty of finding suitable sections of such pavement widths in rural areas.

AMPLE SIGHT DISTANCES AT ALL LOCATIONS

All the sections were on State routes, and 38 were on U. S. numbered highways. Over 65 per cent of the locations were on sections of highway where the sight distance exceeded 2,100 ft., the minimum passing sight distance for a design speed of 60 miles per hour, as recommended by the American Association of

TABLE 1

STUDY LOCATIONS AND VEHICLES INCLUDED IN ANALYSIS OF SPEED-PLACEMENT DATA

State or pavement width	Daytime		Nighttime		Total vehicles
	Locations	Vehicles	Locations	Vehicles	
	number	*number*	*number*	*number*	*number*
Classified by State					
California	2	11,502			11,502
Illinois	9	23,890	4	4,847	28,737
Iowa	11	14,012	11	5,978	19,990
Maryland	2	1,216	2	605	1,821
Massachusetts	4	6,446	1	959	7,405
Minnesota	6	4,871	5	3,384	8,255
Ohio	3	2,811	2	238	3,049
Oregon	1	628			628
Texas	6	10,365	3	1,119	11,484
Washington	3	2,718			2,718
Classified by pavement width					
18 feet	15	24,951	6	4,711	29,662
20 feet	28	49,434	20	11,814	61,248
22 feet	3	1,844	2	605	2,449
24 feet	1	2,230			2,230
Total	47	78,459	28	17,130	95,589

TABLE 2

SPEED PLACEMENT AND VOLUME OF ALL TRAFFIC ON 2-LANE LEVEL TANGENT SECTIONS OF 18-FT. CONCRETE PAVEMENT

State	Route number	Study section number	Shoulders		Average volume	Number of vehicles			Average speed			Distance left wheels were to right of center		
			Width	Type		P.C.	Tks.	All	P.C.	Tks.	All	P.C.	Tks.	All
			ft.		*vph.*				*mph.*	*mph.*	*mph.*	*ft*	*ft.*	*ft.*
Daytime														
Illinois	US12	1	5	grass	555	4,646	70	4,716	41.4	38.9	41.4	1.4	1.0	1.4
Minnesota	SR100	2	6	grass	117	311	57	368	38.8	36.6	38.5	1.3	1.4	1.3
	US10	3	6	grass	383	1,300	41	1,341	43.7	40.4	43.6	1.4	1.3	1.4
Iowa	US30	4	8	grass	165	1,457	214	1,671	49.5	40.3	48.3	1.4	1.4	1.4
	US30	5	8	grass	173	1,478	255	1,733	47.0	40.4	46.0	1.2	1.0	1.2
Illinois	SR13	6	10	grass	323	819	711	1,530	40.0	34.0	37.2	1.4	1.2	1.3
Illinois	US14	7	5	gravel	268	1,286	88	1,374	46.5	37.1	45.9	1.6	1.7	1.6
	US14	8	6	gravel	440	2,549	51	2,600	44.5	38.1	44.4	1.3	1.5	1.3
Washington	US101	9	5	gravel	1,212	662	126	788	42.5	38.0	41.8	1.6	1.8	1.6
Massachusetts[a]	SR114	10	5–6	gravel	230	1,043	113	1,156	39.1	35.8	38 8	0.6	0.3	0.6
Texas	US81	11	6	gravel	108	407	118	525	44.8	42.3	44.2	1.1	1.5	1.2
Illinois	US45	12	5	bit.	685	4,336	36	4,372	39.5	35.9	39.5	1.6	1.8	1.6
Iowa	US61	13	6	bit.	155	433	83	516	48.2	42.5	47.3	1.5	1.6	1.5
Texas	US81	14	2 + 12	bit. & caliche	214	1,189	224	1,413	45.7	40.1	44.8	1.7	2.2	1.8
	US83	15	7	clay	130	717	131	848	42.5	34.8	41.3	1.8	2.0	1.8
Nighttime														
Illinois	US12	1	5	grass	604	2,174	32	2,206	39.5	41.5	39.5	1.1	0.6	1.1
Minnesota	US10	3	6	grass	357	855	20	875	41.6	37.5	41.5	1.5	1.2	1.5
Iowa	US30	4	8	grass	79	570	95	665	45.0	37.6	43.9	1.4	0.9	1.3
Iowa	US30	5	8	grass	68	506	105	611	44 3	40.5	43.7	1.6	0.6	1.4
Texas	US81	11	6	gravel	73	61	12	73	45.6	41.1	44.9	1.4	1.5	1.4
Iowa	US61	13	6	bit.	85	256	25	281	45.0	36.9	44.3	1.4	1.3	1.4

[a] No center-line markings.

TABLE 3

SPEED PLACEMENT AND VOLUME OF ALL TRAFFIC ON 2-LANE LEVEL TANGENT SECTIONS OF 20-FT. CONCRETE PAVEMENT

Daytime

State	Route number	Study section number	Shoulder		Average volume	Number of vehicles observed			Average speed			Distance left wheels were to right of center line		
			Width	Type		P.C.	Tks.	All	P.C.	Tks.	All	P.C.	Tks.	All
			ft.		*vph.*				*mph.*	*mph.*	*mph.*	*ft.*	*ft.*	*ft.*
Iowa	SR60	16	4	grass	112	645	187	832	38.4	35.2	37.7	1.6	1.6	1.6
Illinois	US12	17	5	grass	580	4,081	104	4,185	35.0	33.2	35.0	1.8	2.0	1.8
Iowa	US169	18	6	grass	74	702	142	844	50.6	41.5	49.1	1.4	1.6	1.4
Ohio	US62	19	6	grass	128	468	75	543	46.0	40.7	45.3	1.2	1.1	1.2
Texas	US83	20	6	grass	283	2,376	469	2,845	40.3	35.9	39.6	1.7	2.1	1.8
Iowa	US69	21	8	grass	199	1,673	261	1,934	48.5	41.2	47.5	1.9	1.9	1.9
	US64	22	8	grass	121	1,141	183	1,324	49.4	41.4	48.3	1.2	1.3	1.2
Minnesota	US12	23	8[a]	grass	361	1,193	22	1,215	41.0	35.6	40.9	1.8	2.2	1.8
	US169	24	8	grass	131	310	51	361	49.1	40.7	47.9	1.0	1.5	1.1
	US169	25	8	grass	108	169	37	206	42.4	41.3	42.2	1.6	2.0	1.7
	US12	26	8	grass	488	1,356	24	1,380	37.0	34.4	37.0	1.6	1.8	1.6
Washington	US410	27	8-12	grass	182	841	231	1,072	42.7	39.4	42.0	1.6	1.7	1.6
Illinois	SR13	28	10	grass	299	336	37	373	39.3	30.8	38.5	1.8	2.0	1.8
Texas	US75	29	10	grass	180	953	219	1,172	43.9	37.3	42.7	1.6	2.0	1.7
Illinois	US34	30	5	gravel	257	2,215	295	2,510	34.7	29.0	34.0	1.9	1.9	1.9
Texas	US81	31	6	gravel	345	3,307	255	3,562	44.0	37.8	43.6	2.0	2.2	2.0
Washington	US99	32	8	gravel	275	721	137	858	45.3	40.9	44.6	1.7	1.7	1.7
Massachusetts	SR28	33	2	bit.	371	1,482	169	1,651	37.0	35.1	36.8	2.4	2.3	2.4
	SR28	34	3	bit.	272	935	128	1,063	37.8	34.8	37.4	2.0	1.8	2.0
California	US99	35	6	bit.	249	3,876	985	4,861	44.9	39.6	43.8	2.2	2.1	2.2
Massachusetts	US44	36	2 + 4	bit. & gravel	372	2,356	220	2,576	40.3	37.8	40.1	1.9	1.9	1.9
California	US40	37	2 + 8	"	629	6,288	353	6,641	40.0	38.6	39.9	2.4	2.2	2.4
Pavements with lip curbs														
Iowa	US65	38	6	grass	120	1,012	174	1,186	51.2	42.5	49.9	1.2	1.3	1.2
	US6	39	6	grass	176	1,078	195	1,273	47.8	43.3	47.1	1.3	1.4	1.3
	SR92	40	6	grass	88	416	161	577	46.2	39.4	44.3	1.2	1.2	1.2
	US69	41	8	grass	218	1,834	288	2,122	47.3	40.1	46.3	1.6	1.5	1.6
Ohio	US62	42	6	grass	228	685	125	810	45.5	39.8	44.6	1.7	1.3	1.6
	SR4	43	6	grass	296	1,275	183	1,458	46.7	41.9	46.1	1.4	1.5	1.4

[a] Other shoulder 5-ft. bituminous and 3-ft. earth. Speed and placement the same for both directions.

TABLE 4

SPEED PLACEMENT AND VOLUME OF ALL TRAFFIC ON 2-LANE LEVEL TANGENT SECTIONS OF 20-FT. CONCRETE PAVEMENT

Nighttime

State	Route number	Study section number	Shoulder		Average volume	Number of vehicles observed			Average speed			Distance left wheels were to right of center line		
			Width	Type		P.C.	Tks.	All	P.C.	Tks.	All	P.C.	Tks.	All
			ft.		*vph.*				*mph.*	*mph.*	*mph.*	*ft.*	*ft.*	*ft.*
Iowa	SR60	16	4	grass	85	435	77	512	33.9	33.0	33.8	1.6	1.4	1.6
Illinois	US12	17	5	grass	507	1,986	16	2,002	34.6	32.8	34.6	2.0	1.5	2.0
Iowa	US169	18	6	grass	41	322	46	368	46.1	41.1	45.5	1.3	1.3	1.3
Ohio	US62	19	6	grass	51	67	10	77	43.4	39.0	42.8	0.8	1.1	0.8
Texas	US83	20	6	grass	201	414	35	449	41.8	36.3	41.4	1.8	2.2	1.8
Iowa	US69	21	8	grass	85	556	78	634	42.2	40.1	41.9	1.8	1.1	1.7
	US64	22	8	grass	56	402	97	499	45.2	40.6	44.3	0.9	0.7	0.9
Minnesota	US12	23	8[a]	grass	469	1,283	21	1,304	42.1	37.5	42.0	1.7	2.4	1.7
	US169	24	8	grass	96	272	33	305	49.2	39.8	48.2	1.1	1.5	1.1
	US169	25	8	grass	51	153	42	195	41.1	37.3	40.3	1.3	1.2	1.3
	US12	26	8	grass	237	694	11	705	41.8	34.9	41.7	1.5	1.5	1.5
Illinois	SR13	28	10	grass	265	409	23	432	40.9	36.0	40.6	1.8	1.6	1.8
Illinois	US34	30	5	gravel	269	206	1	207	32.0	27.5	32.0	1.9	2.5	1.9
Texas	US81	31	6	gravel	298	573	24	597	45.5	38.1	45.2	2.1	2.0	2.1
Massachusetts	US44	36	2 + 4	bit. & gravel	588	942	17	959	34.8	36.3	34.8	1.7	2.6	1.7
Pavement with lip curbs														
Iowa	US65	38	6	grass	65	206	40	246	48.1	42.2	47.1	1.0	0.9	1.0
	US6	39	6	grass	154	845	76	921	40.4	39.6	40.3	1.4	1.0	1.4
	SR92	40	6	grass	45	224	51	275	44.3	38.5	43.2	1.1	0.5	1.0
	US69	41	8	grass	101	851	115	966	43.4	39.4	42.9	1.6	1.1	1.5
Ohio	SR4	43	6	grass	161	140	21	161	41.9	34.9	41.0	1.4	0.6	1.3

[a] Other shoulder 5-ft. bituminous and 3-ft. earth. Speed and placement the same for both directions.

State Highway Officials.[3] In no case was a site included in this report if the section on which it was located had a sight distance below 1,200 ft.

The pavements at all locations were flanked by well-maintained grass, gravel, or bituminous shoulders 4 to 10 ft. in width. There were lip curbs on six of the sections with 20-ft. surfaces and grass shoulders. The data for the lip-curb sections have not been combined with the data for sections without lip curbs.

A center line of either black, white, or yellow separated the two traffic lanes at all of the locations except one section of pavement 18 ft. wide in Massachusetts, which had no lane markings whatever. Placement results for this section are omitted from all the averages presented.

Tables 2 through 5 show the highway and average traffic conditions observed. The speeds and transverse positions are shown for passenger cars and commercial vehicles. Light delivery trucks and station wagons are included with passenger cars, while busses are grouped with commercial vehicles. Table 2 shows data for the 18-ft. pavements during the day and night periods of observation; Tables 3 and 4 show data for the 20-ft. pavements during day and night, respectively; and Table 5 shows data for pavements 22 and 24 ft. in width.

The average placement figures include passing vehicles traveling in the left lane. Consequently these averages are influenced to a large extent by the relative number of passing vehicles and should not be used to compare transverse placements on pavements of various widths or with different shoulder types.

VEHICLES GROUPED ACCORDING TO TRAFFIC CONDITION

In order to permit true evaluation of the effect of various surface widths and shoulder types on vehicle placement for different densities and composition of traffic, data were segregated into the following groups representative of various positions of vehicles in the traffic stream:

1. *Free-moving vehicles*—those that crossed the placement detector at least 6 sec. after the immediately preceding vehicle traveling in the same direction, and at least 5 sec. after and 10 seconds prior to passage across the detector of any vehicle traveling in the opposing direction.

Drivers in this group were for practical purposes uninfluenced by other traffic on the highway when their speeds and transverse positions were recorded.

2. *Meeting vehicles*—those that were spaced more than 6 sec. from the preceding vehicle traveling in the same direction and either had met or were to meet within 1.5 sec. a vehicle traveling in the opposing direction.

TABLE 5

SPEED PLACEMENT AND VOLUME OF ALL TRAFFIC ON 2-LANE LEVEL TANGENT SECTIONS OF 22- AND 24-FT. CONCRETE PAVEMENTS

State	Route number	Study section number	Shoulder		Average volume	Number of vehicles observed			Average speed			Distance left wheels were to right of center line		
			Width	Type		P.C.	Tks.	All	P.C.	Tks.	All	P.C.	Tks.	All
22-ft. pavement during daytime														
			ft.		*vph.*				*mph.*	*mph.*	*mph.*	*ft.*	*ft.*	*ft.*
Maryland	SR586	44	7	gravel	170	387	38	425	45.8	40.5	45.3	2.2	2.1	2.2
Oregon	US99	45	8	gravel	187	557	71	628	48.7	42.4	48.0	2.3	2.5	2.3
Maryland	US522	46	10	clay	203	764	27	791	49.8	42.5	49.6	2.1	1.6	2.1
22-ft. pavement during nighttime														
Maryland	SR586	44	7	gravel	96	290	1	291	48.0	45.0	48.0	1.8	1.5	1.8
Maryland	US522	46	10	clay	126	273	41	314	47.5	39.0	46.4	2.0	1.6	1.9
24-ft. pavement during daytime														
Illinois	US67	47	10	grass	334	1,805	425	2,230	41.5	35.2	40.3	2.5	2.5	2.5

[3] A Policy on Sight Distance for Highways, American Association of State Highway Officials, 1940, p. 25.

The term "meeting vehicles" as defined applies only to those vehicles that might have been directly affected by opposing traffic and were not in any way affected by traffic traveling in the same direction. The transverse positions and the clearances between the bodies of vehicles as they meet are major factors in determining desirable roadway width for safe traffic operation.

Figure 1. Speedmeter and Placement Detectors Installed on a Two-Lane Highway

3. Passing vehicles—those that were involved in overtaking and passing other vehicles traveling in the same direction and which crossed the placement detector within 1 sec. of the passed vehicle.

4. All other vehicles—those that were spaced less than 6 sec. from the preceding vehicle traveling in the same direction regardless of opposing traffic, and those vehicles that were 6 sec. or more from the preceding vehicle traveling in the same direction but which were so spaced with respect to opposing traffic that they could not be classified either as meeting or free moving.

To illustrate the significance of these specialized classifications, the distribution of vehicles by the four groups is shown in Figure 2 for volumes up to 1,600 vehicles per hour when traffic was evenly distributed in each direction of travel. The percentage of free-moving vehicles dropped very rapidly as the volume increased. At a volume of 200 vehicles per hour the traffic behavior of over half of the vehicles was uninfluenced by other vehicles at any one point on the highway. Only 10 per cent of the vehicles were uninfluenced at a volume of 800 vehicles per hour.

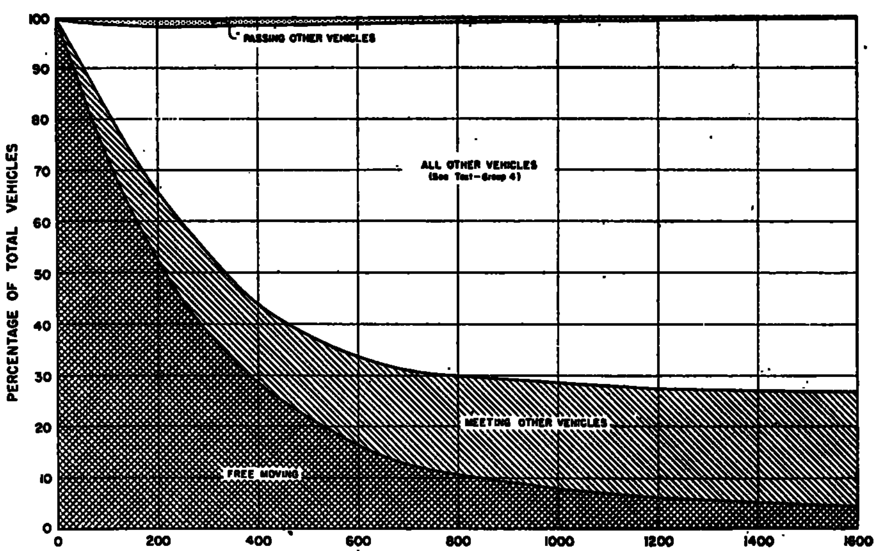

Figure 2. Distribution of Vehicles by Free-moving, Meeting and Passing Groups on 2-Lane Concrete Pavement with Traffic Evenly Distributed in Each Direction of Travel

The number of vehicles that were meeting other vehicles, but had no preceding vehicle within 6 sec. gradually increased with volume. Passings were most frequent at a volume of about 300 vehicles per hour, tapering off at the lower volumes because of the lessened necessity for passing, and at the higher volumes when the increased traffic in the opposite direction afforded fewer opportunities to pass. Although the percentage of passing vehicles may appear to be rather low, it should be remembered, that in this analysis the two vehicles involved, the passing and the one being passed, were traveling within 1 sec. of each other at the observation point to be included in this category. Vehicles that were in earlier or later stages of passing maneuvers were included in the "all other vehicles" category.

At the higher volumes the majority of the vehicles are included in group 4, and could not be used to study the effect of different cross sections on traffic behavior because so many factors influenced their position on the highway. There were, however, few sections that carried traffic densities in excess of 400 vehicles per hour.

TRAFFIC DENSITY AFFECTS VEHICLE TRANSVERSE POSITION

The effect of volume on speeds of vehicles has been definitely determined by the findings

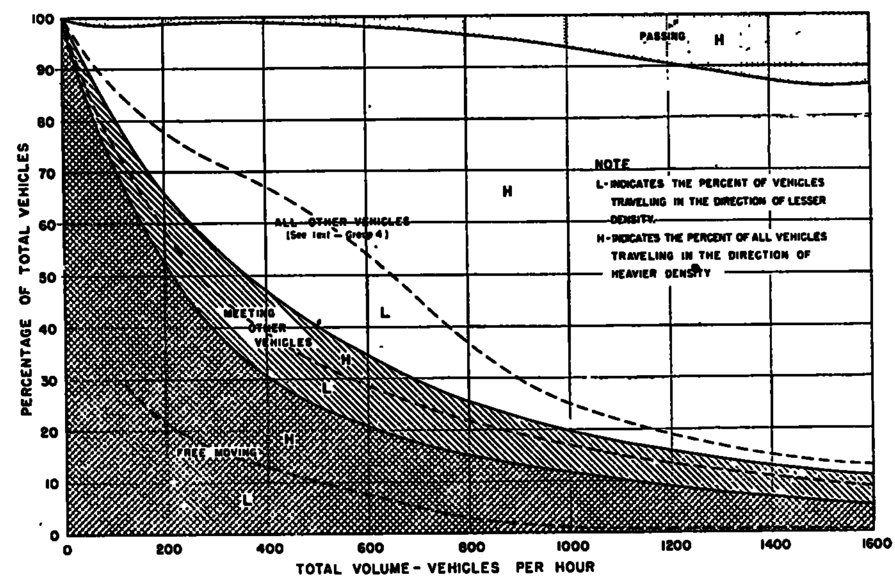

Figure 3. Distribution of Vehicles by Free-moving, Meeting and Passing Groups on 2-Lane Concrete Pavement with Traffic Predominantly Heavy in One Direction (Average Volume for Light Direction of Travel is 120 Vehicles per Hour)

Figure 3 shows the same distribution as Figure 2 for roads where traffic was predominately heavy in one direction of travel. Here the picture is slighly altered. The number of free-moving vehicles did not decrease as rapidly as on roads with the volume evenly distributed in the two directions. Meeting vehicles, as defined in this report, were most frequent at a volume of about 400 vehicles per hour. Fourteen per cent of the vehicles were within 1 sec. of the vehicles they were overtaking or passing in the direction of heavy density when the total traffic volume reached 1,500 vehicles per hour.

of extensive research on highway capacity.[3] In this report, therefore, analysis is directed primarily toward the determination of the effect of traffic volume on the transverse placement of motor vehicles.

The effect of volume on transverse position of the average passenger car traveling on 18- and on 20-ft. pavements is shown by Figure 4. As the traffic on an 18-ft. pavement increased to 700 vehicles per hour (lower half of graph) the distance that the left

[3] O. K. Normann, "Results of Highway-Capacity Studies," *Public Roads*, June 1942, also *Proceedings*, Highway Research Board, Vol. 21, p. 379 (1941).

wheels of the average passenger car were from the center of the pavement also increased until this distance became 1.8 ft. Thenceforth a further increase in density had no effect on the average position of the car. On the 20-ft. pavement (upper half of graph) the rate of change in the position of the average vehicle with volume was the same as on the 18-ft. pavement. At least two-thirds of the added pavement width was utilized to increase edge clearance.

Figure 5 shows the effect of traffic volume on the transverse positions of free-moving and higher volumes assumed almost the same position as when they met other vehicles. An increase in volume, therefore, causes a greater change in the position of free-moving vehicles than in the position of vehicles in any other group. This presumably was due to the fact that the length of time the free-moving vehicles remained free moving decreased with the increase in volume. The drivers shifted their vehicles from the free-moving position to the meeting position more frequently as the traffic density increased until a condition was reached when

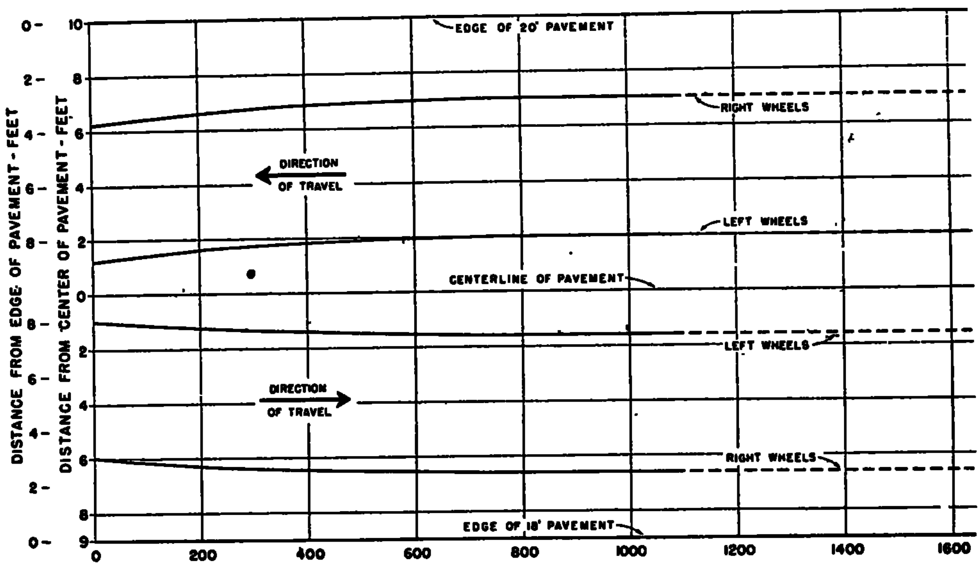

Figure 4. Effect of Volume on Transverse Position of All Passenger Cars on 18- and 20-Foot Concrete Pavements with Grass Shoulders

meeting vehicles on 18-ft. concrete pavement flanked by grass shoulders. In this example, traffic in the light direction remained approximately uniform at 120 vehicles per hour, while the volume in the heavy direction increased. In the direction of heavier travel, the distance that the left wheels of the average free-moving vehicle were from the center of the pavement increased from 1.5 to 2.0 ft., a change of 0.5 ft. to the right, as the total volume increased from 200 to 1,200 vehicles per hour. Meeting vehicles altered their average position only 0.3 ft. Free-moving vehicles in the light direction shifted their position to the right, as the total volume increased, more than twice as much as the vehicles in the heavier direction, and during the average driver found it more convenient to remain in a position almost coinciding with his position when meeting other vehicles. At a volume of 1,200 vehicles per hour the free-moving and the meeting vehicles in the lighter direction traveled with their left wheels 2.4 and 2.6 ft., respectively, from the center of the pavement.

The effect of volume on the transverse placement of free-moving and meeting vehicles on a 20-ft. concrete pavement with traffic evenly distributed in each direction of travel is shown by Figure 6. With an increase in volume from 200 to 1,200 vehicles per hour, free-moving vehicles moved to the right 0.4 ft., while meeting vehicles changed their transverse position only slightly as the volume increased.

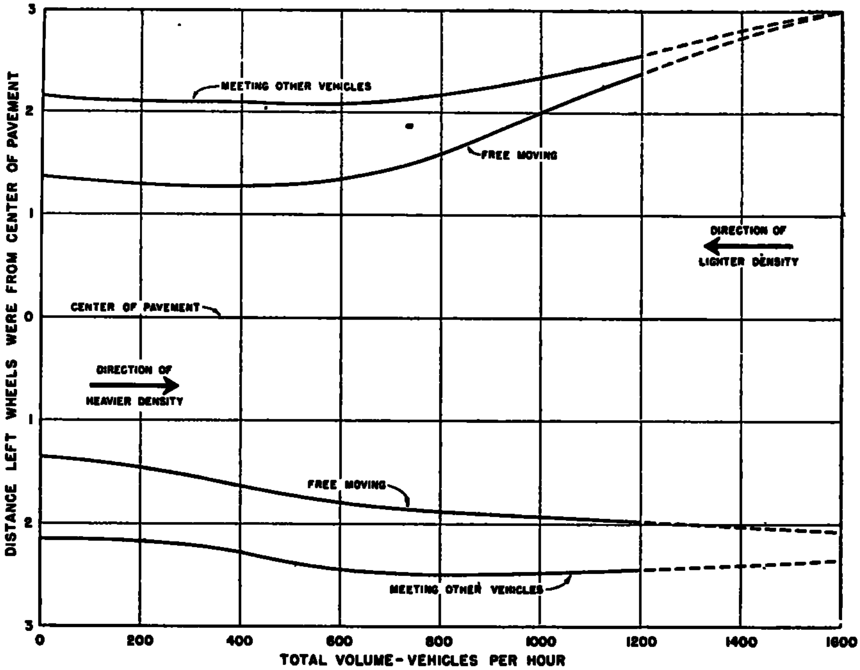

Figure 5. Effect of Volume on Transverse Placement of Free Moving and Meeting Vehicles on 18-Foot Concrete Pavement with Grass Shoulders. Average Density Light Direction 120 Vehicles per Hour

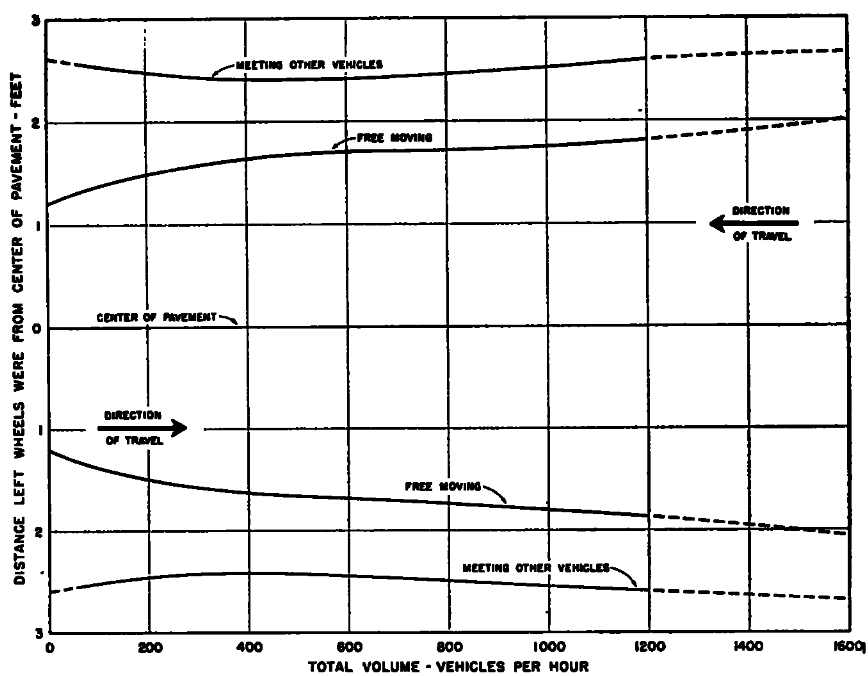

Figure 6. Effect of Volume on Transverse Placement of Free Moving and Meeting Vehicles on 20-Foot Concrete Pavement with Grass Shoulders. Traffic Evenly Distributed in Each Direction of Travel

SPEED UNAFFECTED BY PAVEMENT WIDTH

In an effort to determine the effect of pavement width on vehicle speeds and the relation between the speed of an individual vehicle and its transverse position on the highway, average speeds were compiled for sections with the same surface width; and the average transverse placement for vehicles in each 5-mile-per-hour speed group was tabulated for each study site. Table 6 shows comparable speeds for 2-lane roads having different pavement widths segregated by the various vehicle classifications and shoulder types for day and night operation.

Table 7 shows average speeds for the more important vehicle classifications on the different width surfaces for which the shoulders and other design features were comparable. For the sections included in this study on which vehicle speeds were typical of modern 2-lane highways, pavement width apparently had no consistent effect on the average speeds of either the free-moving vehicles or the vehicles that met oncoming traffic. It is interesting that the speed of the average driver is practically the same when meeting an oncoming vehicle as when uninfluenced by other traffic. Evidently, drivers do not consider it necessary to reduce speed when approaching and meeting opposing vehicles. Speeds at night are practically the same as daytime speeds.

Perhaps the most important consideration is that drivers did not travel more slowly on the narrower than on the wider surfaces. This should not be interpreted to imply

TABLE 6
AVERAGE SPEEDS ON 2-LANE CONCRETE ROADS
Daytime

Vehicle type and traffic condition	18-ft. pavement			20-ft. pavement				22-ft.	24-ft.
	Shoulder type (width in excess of 4 feet)								
	Grass	Gravel	Bituminous	Grass: Lip curb	Grass: No curb	Gravel	Bituminous	Gravel	Grass
	mph.	*mph.*	*mph.*	*mph.*	*mph.*	*mph.*	*mph.*	*mph.*	*mph.*
Passenger cars									
Free moving	45.1	44.5	45.4	48.3	43.8	42.1	41.2	48.1	43.4
Meeting other vehicles	42.8	44.2	44.1	48.6	44.5	43.1	41.0	48.9	41.1
Passing passenger cars	52.1	51.5	54.4	59.3	54.0	51.3	46.5	55.5	46.3
Passing trucks or busses	52.5	48.5	50.0	54.4	57.6	50.0	52.1	67.5	45.5
Being passed	39.0	36.8	37.9	42.1	39.6	36.4	35.5	45.0	36.6
All, except passing	43.8	43.6	44.5	48.0	43.9	42.0	40.5	48.3	41.7
Trucks and busses									
Free moving	38.6	38.3	38.4	41.1	37.9	35.6	37.6	40.6	36.0
Meeting other vehicles	38.8	39.5	38.9	41.8	38.4	37.5	37.4	45.9	34.4
Passing other vehicles	47.7	47.8	45.0	51.0	54.0	47.5	41.9	55.0	52.5
Being passed	33.5	30.8	33.1	37.7	35.5	31.2	32.2	37.5	42.5
All, except passing	38.5	38.6	38.2	41.4	37.0	35.9	37.2	41.8	35.1
Number of vehicles in sample	11,359	6,443	7,149	7,426	18,286	6,930	16,792	1,844	2,230
Nighttime									
Passenger cars									
Free moving	43.9	45.5	45.7	44.2	43.4	40.1	37.1	47.9	
Meeting other vehicles	43.3	45.0	43.9	46.0	41.9	38.8	39.7	47.8	
Passing other vehicles	50.5	[a]	59.2	53.5	49.2	47.3	44.2	[a]	
Being passed	37.0	[a]	39.2	33.8	37.0	34.8	32.5	[a]	
All, except passing	42.8	46.3	45.4	43.7	42.4	39.2	35.0	47.7	
Trucks and busses									
Free moving	40.0	43.0	36.4	39.3	37.6	38.7	37.5	42.5	
Meeting other vehicles	39.8	39.5	36.0	41.6	39.8	30.0	37.5	42.4	
Passing other vehicles	51.7	[a]	[a]	50.2	46.5	[a]	[a]	[a]	
Being passed	34.0	[a]	[a]	35.2	34.4	[a]	[a]	[a]	
All, except passing	38.9	41.1	36.9	38.9	36.6	32.4	36.3	42.0	
Number of vehicles in sample	4,357	73	281	2,569	7,482	804	959	605	None

[a] Sample inadequate.

that the narrower surfaces are as adequate for the desired speeds as are the wider roads. It is more likely that drivers maintain their desired speeds in the face of an apparently greater hazard on the narrow widths.

In analyzing speed-placement data for the several vehicle classification groups, no definite relationship could be found between the speed of the vehicle and its transverse position on the highway at most of the study sections. At a few of the locations, however, the free-moving passenger car drivers who maintained the higher speeds traveled somewhat closer to the center line of the highway than the drivers of the slower moving vehicles. The difference between the transverse positions of vehicles in the fastest speed group and the slowest speed group was, nevertheless, of small magnitude, generally below 0.5 ft. There was no difference in average placements between the speed groups for commercial vehicles or for passenger cars in any of the other classifications. It is apparent, therefore, that the determination of an adequate pavement width for existing traffic speeds can be based on an analysis of the transverse positions on the various widths without regard to the relation between the speeds of individual vehicles and their transverse positions.

TABLE 7
AVERAGE SPEEDS ON PAVEMENTS OF VARIOUS WIDTHS

Pavement width	Average speed: Free moving vehicles	Average speed: Vehicles meeting oncoming traffic	Average speed: All, except passing vehicles
ft.	*mph.*	*mph.*	*mph.*
Passenger cars—daytime			
18	44.9	43.4	43.7
20	43.5	44.2	43.6
22	48.1	48.9	48.3
24	43.4	41.1	41.7
Total....	44.4	44.3	44.0
Commercial vehicles—daytime			
18	38.5	39.1	38.5
20	37.5	38.2	36.8
22	40.6	45.9	41.8
24	36.0	34.4	35.1
Total ...	38.1	39.1	37.8
Passenger cars—nighttime			
18	45.2	43.6	43.5
20	44.9	41.5	41.9
22	47.9	47.8	47.7
Total.......	45.3	42.6	42.8
Commercial vehicles—nighttime			
18	40.6	39.5	39.3
20	37.7	38.4	36.0
22	42.5	42.4	42.0
Total.......	38.8	39.0	37.4

EFFECT OF SHOULDER WIDTH AND TYPE

At the time the field studies were in progress, a number of adjacent sites carrying the same traffic and having identical design features except for the shoulder width and type were selected specifically for the purpose of determining the effect of these variables on the average transverse position of vehicles.

TABLE 8
AVERAGE TRANSVERSE POSITION OF VEHICLES ON TYPICAL 20-FT. CONCRETE PAVEMENTS WITH DIFFERENT WIDTH OF GRASS SHOULDERS

State	Shoulder width	Passenger cars: Free-moving	Passenger cars: Meeting passenger cars	Passenger cars: All, except passing vehicles	Commercial vehicles: Free-moving	Commercial vehicles: Meeting passenger cars	Commercial vehicles: All, except passing vehicles
	feet	*(Distance in feet left wheels were to right of highway center-line)*					
Iowa	4	1.5	2.7	1.7	1.4	2.4	1.6
Iowa	6	1.4	2.6	1.5	1.6	2.2	1.6
Iowa.......	8	1.5	2.5	1.7	1.5	2.3	1.6
Illinois.....	5	1.6	2.4	1.9	1.8	2.4	1.8
Illinois......	10	1.5	2.3	1.9	1.6	2.4	2.0
Texas.. .	6	1.8	2.2	1.9	2.0	2.5	2.1
Texas ..	10	1.6	2.5	1.8	1.8	2.6	2.0

Table 8 shows that comparable placement values for sections with 4- to 10-ft. grass shoulders are practically identical. Shoulder width in excess of 4 feet, therefore, does not affect the transverse position of vehicles. This is also borne out by the fact that at some of the sections where the shoulders on one side of the pavements were wider than on the other side, the average position that the drivers assumed was the same for both directions of travel. In no case, however, were there any vertical obstructions immediately adjacent to the outside of the shoulder.

The fact that the portion of a shoulder beyond a point 4 ft. from the pavement edge does not effect the transverse position of vehicles, however, has no relation to the need for providing continuous shoulder width adequate to accomodate standing or moving vehicles entirely off the pavement in emergency.

shoulders and bituminious shoulders, however, were also included to permit analysis of the relative effects of these three shoulder types on the transverse positions of vehicles on concrete pavements 18 and 20 ft. wide.

TABLE 9

AVERAGE TRANSVERSE PLACEMENT OF VEHICLES AND CLEARANCES BETWEEN MEETING VEHICLES ON 2-LANE CONCRETE ROADS

A—Average placements—distance left wheels were to right of center line

Daytime

Vehicle classification	18-ft. pavement			20-ft. pavement				22-ft.	24-ft.
	Shoulder type (width at least 4 ft.)								
	Grass	Gravel	Bituminous	Grass: Lip curb	Grass: No curb	Gravel	Bituminous	Gravel	Grass
	ft.	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*
Passenger cars									
Free moving	1.4	1.5	1.7	1.3	1.5	1.9	2.3	2.1	2.4
Meeting other passenger cars	2.1	2.1	2.5	2.3	2.5	2.6	3.0	2.9	3.1
Meeting trucks or busses	2.3	2.4	2.4	2.6	2.6	2.7	3.3	3.2	3.4
All, except passing	1.6	1.6	1.9	1.6	1.8	2.1	2.5	2.3	2.7
Trucks or busses									
Free moving	1.2	1.5	1.6	1.2	1.6	1.8	1.9	2.0	2.2
Meeting passenger cars	1.8	1.8	2.3	1.9	2.3	2.2	2.5	2.8	2.9
Meeting trucks or busses	1.5	2.2	2.5	2.7	2.5	2.5	2.5	2.9	3.0
All, except passing	1.2	1.6	1.9	1.4	1.8	1.9	2.1	2.1	2.5
Nighttime									
Passenger cars									
Free moving	1.5	1.3	1.5	1.4	1.4	2.0	1.7	1.7	
Meeting other passenger cars	2.1	2.0	2.3	2.6	2.4	2.6	2.9	2.8	
Meeting trucks or busses	2.5	2.5	2.5	2.7	2.5	3.2	3.0	3.0	
All, except passing	1.6	1.4	1.7	1.5	1.6	2.1	1.8	2.0	
Trucks and busses									
Free moving	0.8	1.4	1.1	0.7	1.4	2.0	2.5	1.4	
Meeting passenger cars	1.3	1.5	2.0	1.7	1.9	2.2	3.0	2.4	
Meeting trucks or busses	1.7	[a]	[a]	1.8	2.0	2.5	[a]	[a]	
All, except passing	1.0	1.5	1.3	0.8	1.5	2.2	2.6	1.6	
B—Average clearances between bodies of meeting vehicles									
Daytime									
Passenger cars meeting passenger cars	3.2	3.2	4.0	3.6	4.0	4.2	5.0	4.8	5.2
P. C. and trucks or busses meeting	2.6	2.7	3.2	3.0	3.4	3.4	4.3	4.5	4.8
Tks. or bus. meeting tks. or bus.	1.1	2.5	3.0	3.4	3.0	3.0	3.0	3.8	4.0
Nighttime									
Passenger cars meeting passenger cars	3.3	3.0	3.6	4.3	3.9	4.3	4.8	4.5	
P. C. and trucks or busses meeting	2.3	2.5	3.0	2.9	2.9	4.0	4.5	3.9	
Tks. or bus. meeting tks. or bus.	1.5	[a]	[a]	1.6	2.1	3.0	[a]	[a]	

[a] Sample inadequate.

Tables 9 and 10 show the average transverse placements of vehicles and clearances between the bodies of meeting and passing vehicles segregated by the various vehicle classifications and shoulder types for day and night operation. Values are averaged for all shoulder widths.

A majority of the shoulders on the highway sections included in this study were grass. A sufficient number of sections with gravel

Table 11 shows, for each vehicle classification and for the two surface widths, the difference between the average driver's transverse position on a highway with grass shoulders and his transverse position on a highway with gravel shoulders. A minus value is shown for the particular traffic condition when the average driver traveled closer to the grass than to the gravel shoulder.

The table shows that the difference in

placements for the two shoulder types did not exceed 0.1 ft. for 21 out of a total of 34 values representing the various vehicle classifications and the two surface widths. Most of the values that indicate a larger difference between placements on grass and gravel shoulders are for commercial vehicles or vehicles involved in passing maneuvers which were represented by smaller samples than the other classifications.

with grass or gravel shoulders. To evaluate this driving characteristic in terms of the amount that bituminous shoulders increase the effective pavement width, Table 12 has been prepared.

Comparable values are shown for the effect that bituminous shoulders have on the transverse position of vehicles and the effect that 2-ft. wider surfaces have on the transverse positions. For example, the average

TABLE 10

TRANSVERSE PLACEMENTS OF WHEELS AND CLEARANCES BETWEEN BODIES OF VEHICLES INVOLVED IN PASSING MANEUVERS ON 2-LANE CONCRETE ROADS[a]

Vehicle classification	Daytime									Nighttime						
	18-ft. pavement			20-ft. pavement				22 ft.	24 ft.	18-ft. pavement			20-ft. pavement			
	Shoulder type (width at least 4 feet)															
	Grass	Gravel	Bituminous	Grass, Lip curb	Grass, No curb	Gravel	Bituminous	Gravel	Grass	Grass	Gravel	Bituminous	Grass, Lip curb	Grass, No curb	Gravel	Bituminous
	ft.	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*
A—Passenger cars passing passenger cars[b]																
Passing—p.c.	1.3	1.4	1.3	1.4	1.7	1.7	1.2	2.4	1.7	1.8	2.5	2.1	1.9	1.2	1.0	2.4
Passed—p.c.	2.0	2.0	2.0	1.9	2.2	2.2	2.9	2.5	4.1	1.8	1.5	2.2	1.9	2.2	2.7	2.4
Body clearance	2.3	2.4	2.3	2.3	2.9	2.9	3.1	3.9	4.8	2.6	3.0	3.3	2.8	2.4	2.7	3.8
B—Passenger cars passing trucks or busses[b]																
Passing—p.c.	2.4	2.2	2.5	2.1	1.8	2.3	2.3	1.8	1.7	1.0			0.8	2.0		
Passed—tks. or bus.	1.3	1.8	2.0	1.5	1.9	1.9	2.0	2.5	2.8	1.5			1.5	1.8		
Body clearance	2.2	2.5	3.0	2.1	2.2	2.7	2.8	2.8	3.0	1.0	c	c	0.8	2.3	c	c
C—Trucks or busses passing passenger cars[b]																
Passing—tks. or bus	1.2	1.5	0.8	1.9	1.3	1.0	1.3									
Passed—p.c.	1.4	1.5	2.2	1.4	1.9	2.5	3.1									
Body clearance	1.1	1.5	1.5	1.8	1.7	2.0	2.9	c	c							
D—Trucks or busses passing trucks or busses[b]																
Passing—tks or bus.	3.0	1.5	1.3	2.5	1.2		1.3									
Passed—tks or bus.	1.0	1.5	1.9	1.5	2.5		2.0									
Body clearance	2.0	1.0	1.2	2.0	1.7	c	1.3	c	c							

[a] Passing vehicle within 1.0 second of passed vehicle.

[b] Distance that left wheel of passed vehicle was to the right of center line or distance that right wheel of passing vehicle was to the left of center line.

[c] Sample inadequate.

Similar results were obtained by an analysis of placements at night on sections with grass and gravel shoulders. It may be concluded, therefore, that well-maintained grass shoulders have the same effect on the transverse position of vehicles on 2-lane roads with concrete surfaces as well-maintained gravel shoulders.

On highways with bituminous shoulders, the average driver traveled closer to the right-hand shoulder and farther from the center line of the pavement than on highways

driver of a free-moving passenger car traveled 0.3 ft. farther to the right of the center line on 18-ft. surfaces when there were bituminous shoulders than when the shoulders were grass or gravel. On highways with grass or gravel shoulders, he traveled 0.2 ft. farther to the right of the center line when the surface width was 20 ft. than he did when the surface width was 18 ft. The bituminous shoulder on the 18-ft. surface, therefore, had a greater effect on the transverse position of the free-moving passenger cars than the 2-ft. wider surface. Likewise, there was a greater difference between the transverse position of free-moving passenger cars on 20-ft. surfaces with and without bituminous shoulders than there was between their transverse positions on surfaces 20 and 22 ft. wide with grass or gravel shoulders. Also, bituminous shoulders had the same effect on the transverse position of passenger car drivers when they met other passenger cars as a 2-ft. wider surface.

TABLE 11

DIFFERENCE BETWEEN THE TRANSVERSE POSITION OF VEHICLES ON SECTIONS WITH GRASS AND WITH GRAVEL SHOULDERS DURING DAYTIME

Difference between distances that vehicles were from right hand shoulder[a]

Vehicle classification	18-ft. surface	20-ft. surface
	ft.	*ft.*
Passenger cars		
Free moving	0.1	0.4
Meeting other passenger cars	0	0.1
Meeting trucks or busses	0.1	0.1
Passing other passenger cars	−0.1	0
Passing trucks or busses	0.2	−0.5
Being passed by other passenger cars	0	0
All, except those passing other vehicles	0	0.3
Trucks and busses		
Free moving	0.3	0.2
Meeting passenger cars	0	−0.1
Meeting other trucks or busses	b	0
Being passed by passenger cars	0.5	0
All, except those passing other vehicles	0.4	0.1
Difference between clearances of vehicle bodies[a]		
Passenger cars meeting other passenger cars	0	0.2
Passenger cars and trucks or busses meeting	0.1	0
Passenger cars passing other passenger cars	0.1	0
Passenger cars passing trucks or busses	0.3	0.5
Trucks or busses meeting other trucks or busses	b	0

[a] A minus sign is shown when the vehicle traveled closer to the grass than the gravel shoulder.
[b] Sample inadequate.

Similar comparisons between the effect of bituminous shoulders and the effect of wider surfaces on the transverse position of other vehicle classifications are not always consistent with one another, especially for the vehicle classifications represented by the smaller samples. In general, however, bituminous shoulders at least 4 ft. wide on sections with 18- and 20-ft. surfaces increased the effective surface widths during the daytime approximately 2 ft.

None of the pavements wider than 20 ft. had bituminous shoulders, and comparatively little data were recorded at night on the 18- and 20-ft. surfaces. Analysis of the daytime data and the limited nighttime data for 18- and 20-ft. surfaces does indicate, however, that bituminous shoulders increase the effective pavement width as much at night as in the daytime; and their effect on transverse positions of moving vehicles for the wider surfaces is somewhat less than for the narrower surfaces.

LIP CURBS INFLUENCE VEHICLE PLACEMENTS

To determine the effect of lip curbs on traffic, a total of six locations on 20-ft. concrete surfaces with lip curbs and comparable sections without lip curbs were selected for study in Iowa and Ohio. Driver-behavior data were recorded for 10,000 vehicles on the lip curbed pavements and for a somewhat larger number of vehicles on the locations without lip curbs.

Table 13 shows the effect of lip curbs on the transverse positions of vehicles on 20-ft. pavements with grass shoulders for daytime operations. Vehicles in nearly all the classifications traveled closer to the center of the highway and farther from the edge on sections with lip curbs than on sections without lip curbs. The average difference in the distance between the vehicle bodies and the highway center line due to lip curbs was 0.2 ft. for passenger cars and 0.4 ft. for commercial vehicles. These differences are similar but somewhat less than those found when transverse placements on 20-ft. pavements without lip curbs were compared with placements on 18-ft. pavements also without lip curbs.

It may be noted that in a few of the vehicle classifications, the lip curbs had the same effect, or a greater one, as a reduction of 2 ft. in the pavement width. On an average, however, especially for the more important conditions that govern pavement width, including body clearances between meeting vehicles, the effect of lip curbs is about half as great as a reduction of 2 ft. in the surface width. In the daytime, lip curbs, therefore, reduce the effective pavement width approximately 1 ft.

Comparative data also show that lip curbs affect the transverse positions of commercial vehicles at night as much as during the day; however, lip curbs apparently do not have any appreciable effect on the transverse positions of passenger cars at night.

TABLE 12
EFFECT OF BITUMINOUS SHOULDERS ON THE TRANSVERSE POSITION OF VEHICLES COMPARED WITH THE EFFECT OF SURFACE WIDTH

Increase in the distance between vehicle and center-line of highway

Vehicle classification	Effect of bituminous shoulders (compared to grass or gravel shoulders)		Effect of surface width (on sections with grass or gravel shoulders)	
	18-ft. surface width	20-ft. surface width	20-ft. surface compared to 18-ft. surface	22-ft. surface compared to 20-ft. surface
	ft.	*ft.*	*ft.*	*ft.*
Passenger cars				
Free moving	0.3	0.7	0.2	0.2
Meeting other passenger cars	0.4	0.5	0.4	0.3
Meeting trucks or busses	0.1	0.7	0.3	0.5
Passing other passenger cars[a]	0	−0.5	0.4	0.7
Passing trucks or busses[a]	0.2	0.4	−0.4	−0.5
Being passed by other passenger cars	0	0.6	0.2	0.3
All, except those passing other vehicles	0.3	0.7	0.2	0.2
Trucks or busses				
Free moving	0.3	0.3	0.3	0.2
Meeting passenger cars	0.5	0.2	0.5	0.6
Meeting other trucks or busses	0.7	0	0.7	0.4
Being passed by passenger cars	0.5	0.1	0.4	0.6
All, except those passing other vehicles	0.5	0.3	0.4	0.2
Increase in clearance between vehicle bodies				
Passenger cars meeting other passenger cars	0.8	1.0	0.8	0.6
Passenger cars and trucks or busses meeting	0.6	0.9	0.8	1.1
Passenger cars passing other passenger cars	0	0.1	0.6	1.0
Passenger cars passing trucks or busses	0.7	0.5	0	0.1
Trucks or busses meeting other trucks or busses	1.4	0	1.4	0.8

[a] Increase in distance to left for passing vehicles, to right for all others.

EFFECT OF SURFACE WIDTHS

Free-moving vehicles—Figure 7 shows the average daytime positions of free-moving vehicles on 2-lane concrete pavements. In this figure as well as in all the succeeding figures and tables the values shown refer to the average vehicle placements for the highway sections with grass and with gravel shoulders. This procedure is possible because the previous analysis showed no measurable difference between operating characteristics on pavements with those two shoulder types.

On the right side of Figure 7 are values for passenger cars and on the left for commercial vehicles. The average width of passenger car bodies as obtained by measurements of various makes and models of cars was found to be 6.0 ft. A width of 8.0 ft. for bodies of commercial vehicles is used. The tread widths of 4.9 ft. for passenger cars and 6.0 ft. for trucks and busses were determined from the wheel placements recorded in this study.

Free-moving passenger cars and commercial vehicles steadily increase their distance from the center of the pavement as wider pavements are made available. The added width provided by the 20-ft. over the 18-ft. pavement is utilized by drivers of free-moving passenger cars almost entirely to increase their distance from the pavement edge, while

TABLE 13
EFFECT OF LIP CURBS ON THE TRANSVERSE POSITIONS OF VEHICLES ON 20-FT. PAVEMENTS WITH GRASS SHOULDERS

Differences in distance between vehicle bodies and the highway center line

Vehicle classification	20-ft. pavement without lip curbs compared with 20-ft. pavement with lip curbs	20-ft. pavement compared with 18-ft. pavement (no lip curbs)
	ft.	*ft.*
Passenger cars		
Free moving	0.2	0.1
Meeting other passenger cars	0.2	0.4
Meeting trucks or busses	0	0.3
Passing other passenger cars	0.3	0.4
Passing trucks or busses	0.3	−0.6
Being passed by other passenger cars	0.3	0.2
All, except those passing other vehicles	0.2	0.2
Trucks and busses		
Free moving	0.4	0.4
Meeting passenger cars	0.4	0.5
Meeting other trucks or busses	−0.2	1.0
Being passed by passenger cars	0.4	0.2
All, except those passing other vehicles	0.4	0.6
Difference in clearance between vehicle bodies		
Passenger cars meeting other passenger cars	0.4	0.8
Passenger cars and trucks or busses meeting	0.4	0.8
Passenger cars passing other passenger cars	0.6	0.6
Passenger cars passing trucks or busses	0.1	0
Trucks or busses meeting other trucks or busses	−0.4	1.9

the distance from the center of the pavement increases only 0.2 ft. or to a value of 1.6 ft. The added widths provided by the 22- and 24-ft. surfaces, however, are utilized to increase the distance from the center as well as distance from the edge by 0.7 ft. and from the center by 0.3 ft.

Apparently drivers judge the position of their vehicles, when uninfluenced by other traffic, by their distance from the center

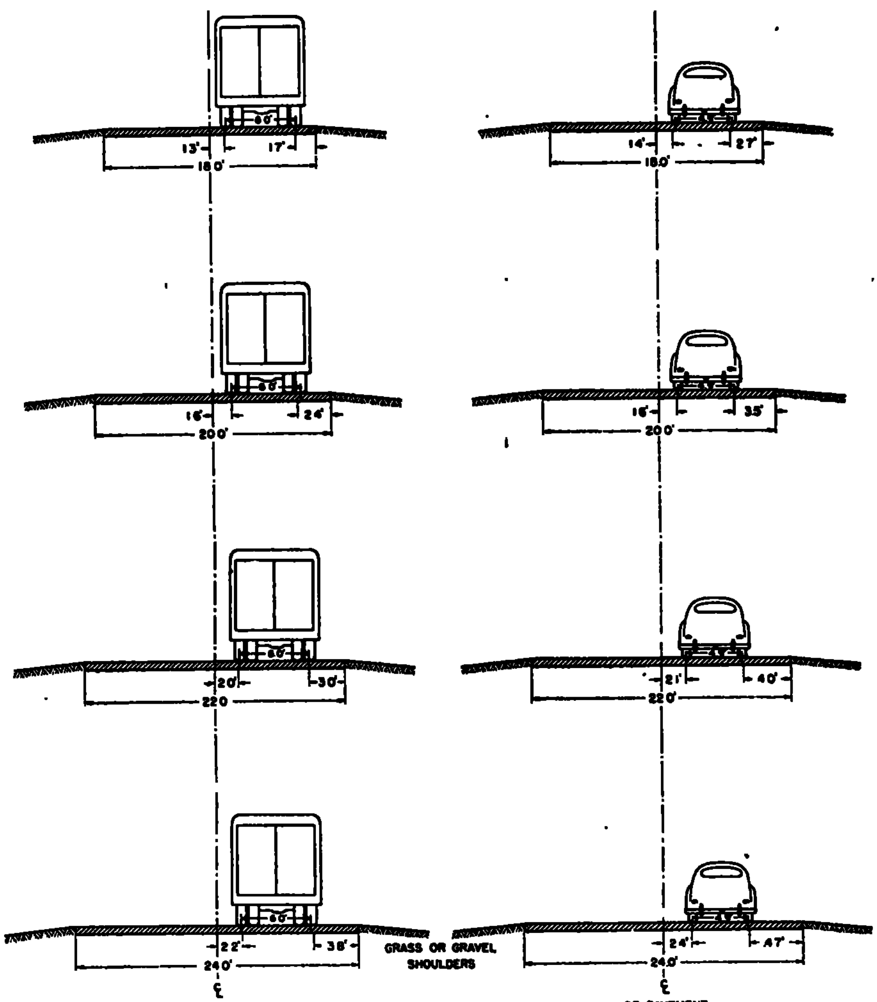

Figure 7. Average Position of Free Moving Vehicles on 2-Lane Concrete Pavements during Daytime

from the edge. Commercial vehicle drivers utilize the added widths more to increase the distance from the edge than to increase their distance from the center line as pavements wider than 18 ft. are made available. For each foot of added lane width, commercial vehicle drivers, on the average, increase the line, since this distance is about the same for both passenger cars and commercial vehicles on similar width pavements. The narrower tread width naturally results in greater edge clearance for passenger cars than for trucks. Passenger car drivers keep the centers of their vehicles approximately 1 ft. to the

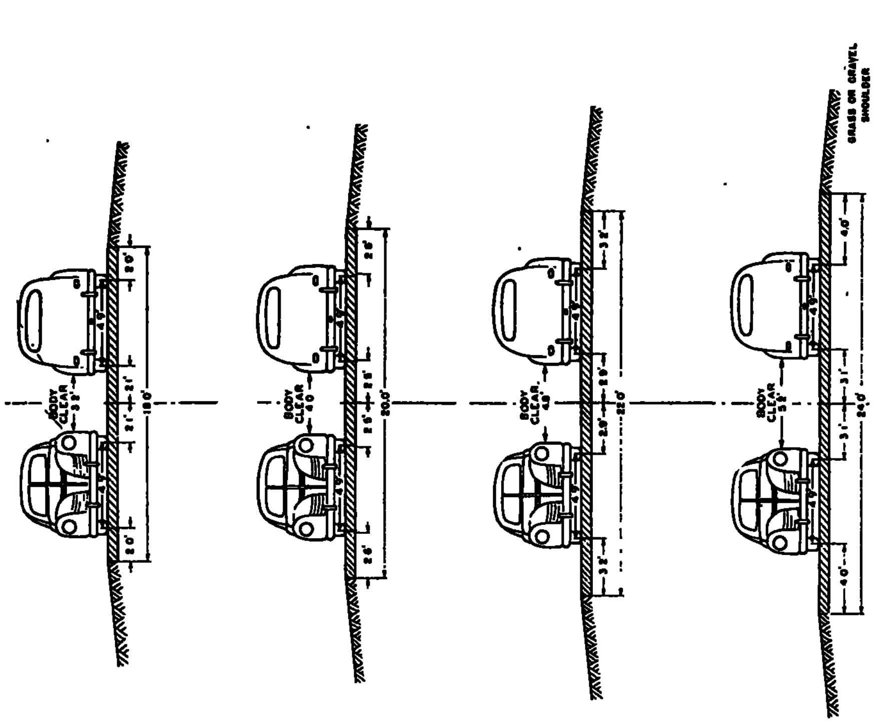

Figure 8. Average Position of Passenger Cars When Meeting Passenger Cars on 2-Lane Concrete Pavements during Daytime

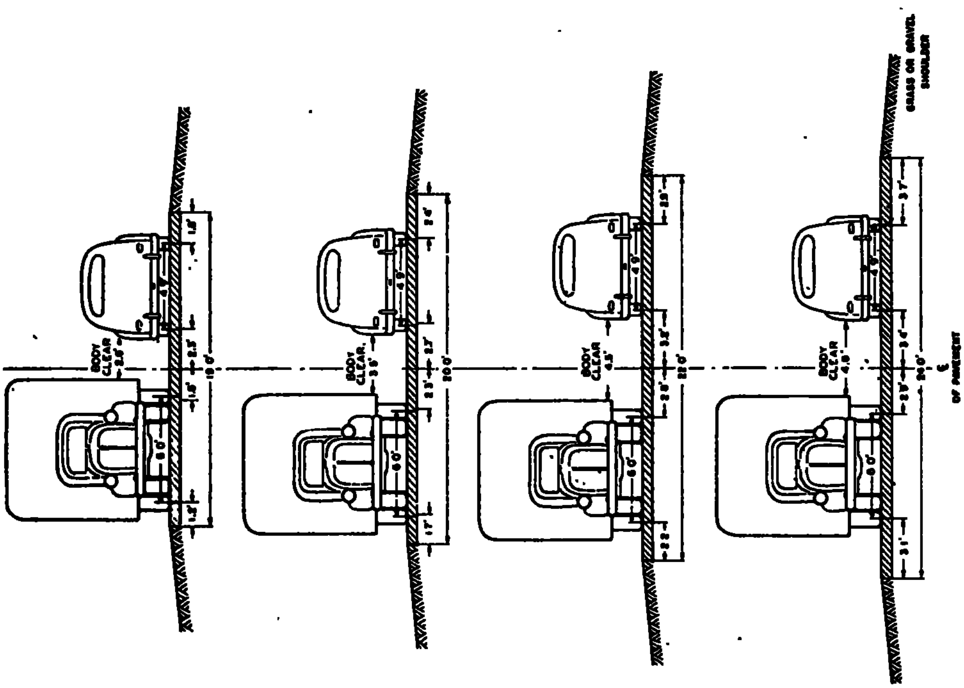

Figure 9. Average Position of Passenger Cars and Commercial Vehicles When Meeting on 2-Lane Concrete Pavements during Daytime

left of the center of their lane, while commercial vehicle drivers keep the centers of their vehicles about 0.5 ft. to the left. The distance between the center of the vehicle and the center of the lane increases, however, as wider pavements are made available.

Passenger cars meeting passenger cars—Figure 8 shows the average position of passenger cars that meet other passenger cars during daytime. These vehicles travel approximately in the center of their respective lanes on the 18- and 20-ft. pavements. On 18-ft. surfaces the positions are such that drivers allow a wheel-track distance of 2.0 ft. from the edge and 2.1 ft. from the center of the road, thus allowing a body clearance between vehicles of 3.2 ft. When 20-ft. pavements and also when 22-ft. pavements are provided, the added width is used by drivers to increase both the clearance between vehicles and the distance from the edge. However, the additional pavement width provided by the 24-ft. surface is used by drivers almost entirely to increase the distance from the edge. This indicates that the desired clearance between bodies of meeting passenger cars is about 5.0 ft., since this clearance is nearly obtained on 22-ft. surfaces and does not increase materially on 24-ft. surfaces.

Passenger cars meeting commercial vehicles—Figure 9 shows the average position of passenger cars and commercial vehicles when meeting. The fact that passenger cars on 18- and 20-ft. pavements do not move farther to the right to allow greater clearance when meeting commercial vehicles than when meeting passenger cars is a strong indication that even 20-ft. roads are entirely too narrow when there is an appreciable amount of truck traffic. Body clearances of 2.6 and 3.5 ft. for passenger cars meeting commercial vehicles on 18- and 20-ft. pavements, respectively, appear to be inadequate for safety since from an analysis of the distribution of vehicle clearances it was found that 12 and 5 per cent of the vehicle drivers were observed to allow vehicle body clearances of 1 ft. or less when meeting on 18- and 20-ft. pavements, respectively. Clearances of 2 ft. or less were allowed by 47 and 11 per cent of the drivers, on 18- and 20-ft. pavements, respectively.

The influence exerted by passenger cars traveling in the one direction on the transverse position of vehicles traveling in the opposing direction is shown by Figure 10. On the 18-ft. pavement, when passenger cars meeting other vehicles travel 1 ft. to the left of the center line, and a small but significant number of cars do assume this position, the average position of the vehicles being met is 2.7 ft. to

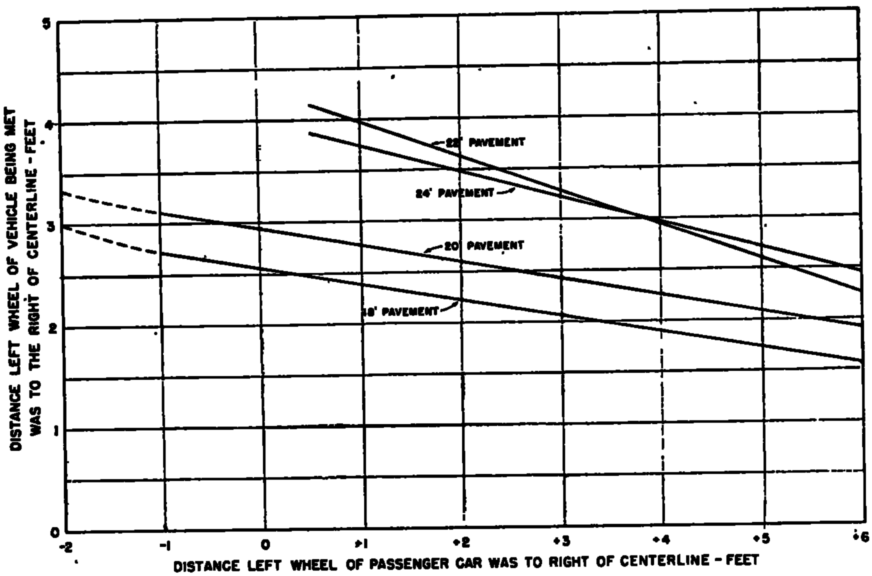

Figure 10. Effect of Transverse Position of Passenger Cars on the Position of the Meeting Vehicles —Concrete Pavement with Grass or Gravel Shoulders

the right of the center line. This allows a clearance of only 0.7 ft. between the bodies of the meeting vehicles. Similarly, on the 20-ft. pavement, when passenger cars encroach on the left lane when meeting other vehicles, the body clearances are only about 1 ft. Such low body clearances are entirely inadequate for safe operation.

On 22- and 24-ft. pavements, passenger car clearances are considerably greater than on 20-ft. pavement. When passenger cars in one direction of travel are 0.5 ft. to the right of the center line on 22-ft. pavements, vehicles they meet travel 4 ft. on the other side of the center line, thus allowing a body clearance of 3.5 ft.

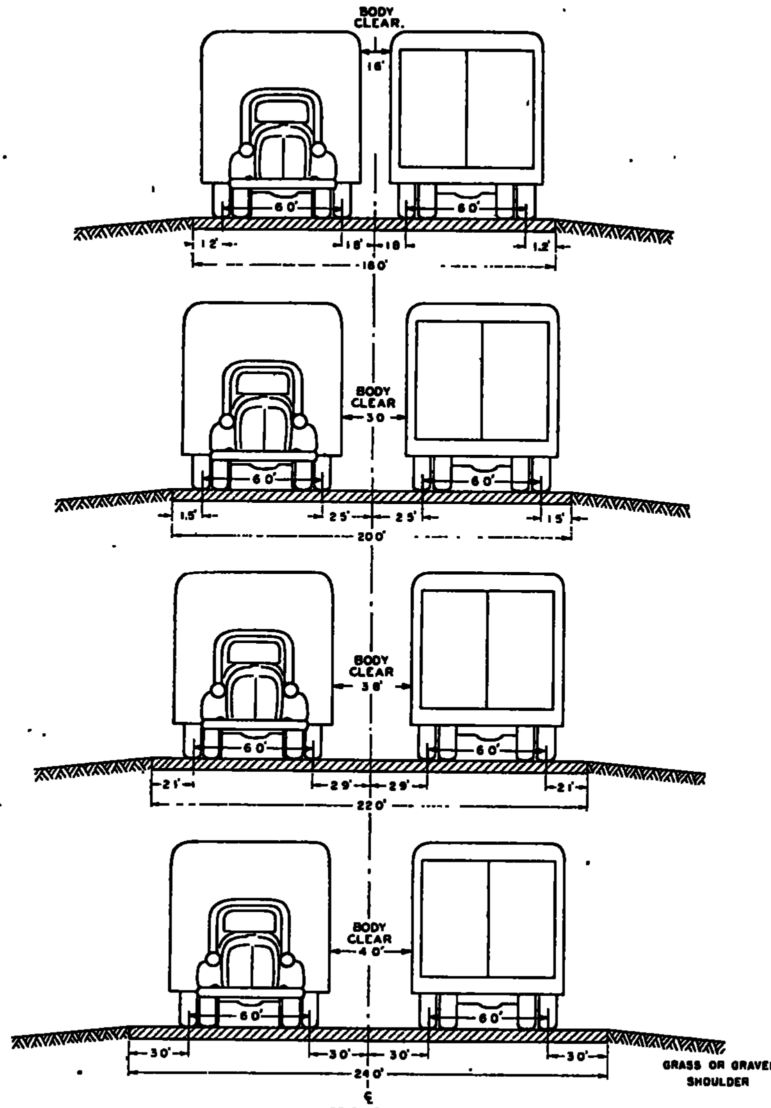

Figure 11. Average Position of Commercial Vehicles When Meeting Commercial Vehicles on 2-Lane Concrete Pavements during Daytime

Commercial vehicles meeting commercial vehicles—Figure 11 shows the average position of commercial vehicles when meeting other commercial vehicles during daytime.

Eighteen-foot pavements are so inadequate for these wide vehicles that the average body clearance is only 1.6 ft.

Although truck drivers travel closer to the edge of the pavement than passenger car drivers, they also sacrifice center clearance to avoid too little edge clearance. On 18-ft. pavements the average truck driver does not travel closer than 1.2 ft. from the edge. The additional width provided by the 20-ft. surface is used mostly to increase the clearance between vehicles, whereas the extra width provided by the 24-ft. pavement compared to the 22-ft. pavement is utilized to increase the distance from the pavement edge. Only on the 24-ft. surface do commercial vehicles travel in the center of their respective lanes.

The relation between the transverse position of meeting vehicles and the pavement width on level tangent sections of highways is shown in Figure 12. The curve for commercial vehicles meeting other commercial vehicles shows that they travel closer to the center of the lane on 18-ft. and on 20-ft. pavements. The drivers have no other choice if they wish to maintain some edge clearance.

If it is assumed that the pavement is of adequate width when meeting vehicles travel in the centers of their respective lanes a 19-ft. pavement is adequate in the daytime for traffic consisting only of passenger cars; a 23-ft. pavement is adequate for the passenger cars when there is mixed traffic; and a 24-ft. pavement is adequate for commercial vehicles. If provision is made for the majority of the drivers rather than for the average driver, wider surfaces would be needed.

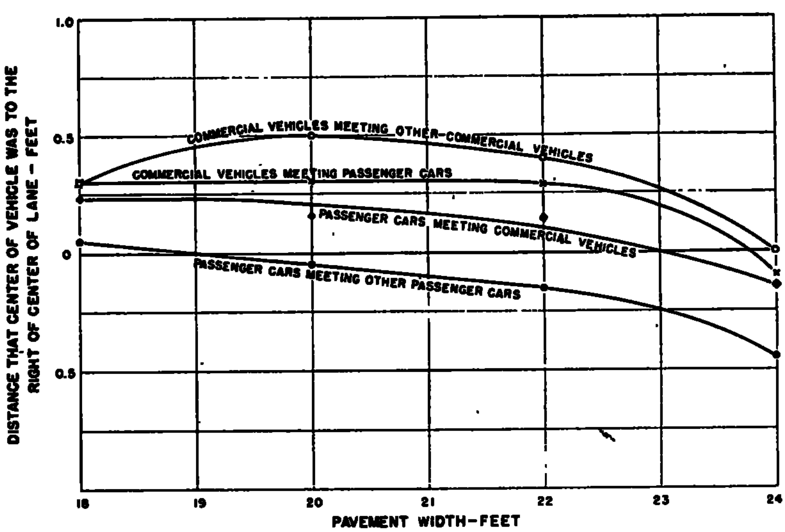

Figure 12. Effect of Pavement Width on the Position of Vehicles Meeting Other Vehicles Traveling in the Opposite Direction

RELATION BETWEEN REQUIRED PAVEMENT WIDTH FOR TRUCKS AND FOR PASSENGER CARS

The results show that free-moving vehicles regardless of the width of the pavement travel closer to the center line than to the right-hand edge and except during heavy traffic volumes there is always an appreciable difference between the position of vehicles in the free-moving and meeting classifications. The body and edge clearances for meeting vehicles or perhaps for passing vehicles are, therefore, the critical factors that determine adequate pavement width.

From Figures 8 and 9, however, it is apparent that passenger car drivers are not satisfied with the clearances permitted by an 19-ft. pavement, when meeting other passenger cars. Instead they desire either a body clearance of about 5 ft. or a clearance between their left wheels and the center line of about 3 ft. These clearances cannot be attained until the pavement width reaches 22 ft.

If, then, it is assumed that a 22-ft. pavement represents a desirable width for traffic consisting entirely of passenger cars, it can be found from Figure 12 that the corresponding width for mixed traffic is 24 ft., and for traffic including a high percentage of commercial vehicles a slightly greater width.

meeting oncoming traffic, a surprisingly large number, 11 per cent of the truck drivers and 5 per cent of the passenger car drivers fail to keep their vehicles within the proper traffic lane. These percentages decrease rapidly with an increase in pavement width. Only 1 per cent of the vehicles encroach in the left lane when meeting other vehicles on 24-ft. pavements.

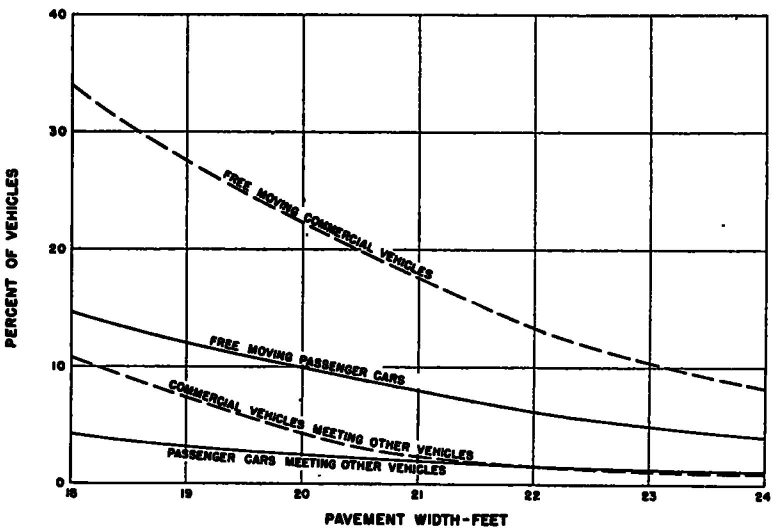

Figure 13. Per Cent of Vehicles with Their Bodies Extending to Left of Highway Centerline

TABLE 14
PERCENTAGE OF VEHICLES THAT ENCROACH ON SHOULDER WHEN MEETING OTHER VEHICLES DURING LIGHT TRAFFIC VOLUMES

Pavement width	Pavement with grass or gravel shoulders		Pavement with bituminous shoulders	
	Passenger cars	Commercial vehicles	Passenger cars	Commercial vehicles
ft.	*per cent*	*per cent*	*per cent*	*per cent*
18	0.2	5.5	4.7	17.3
20	0.1	1.4	1.9	6.5

To further illustrate driver behavior on different width surfaces, the percentages of vehicles that encroach into the lane for oncoming traffic and the vehicles that encroach on the shoulder are shown by Figure 13 and Table 14, respectively.

On 18-ft. pavements 34 per cent of the truck drivers and 15 per cent of the passenger car drivers encroach on the left lane even when uninfluenced by other traffic. When

The need for pavements wider than 20 ft. is further illustrated by the large increase in the percentage of vehicles that travel off the pavement as they meet other traffic when bituminous shoulders are provided (Table 14).

PASSING VEHICLES DO NOT INCREASE NECESSARY PAVEMENT WIDTH

Although relatively few vehicles are engaged in passing maneuvers at any one point on a 2-lane highway, they are an essential feature of 2-lane highway operation. The position that the average passenger car driver assumes when overtaking and passing other vehicles is shown in Figures 14 and 15. Included are only those passing vehicles that were definitely known to be approximately abreast of the vehicle being passed when their lateral positions were recorded.

Figure 14 shows the average positions of passenger cars when passing other passenger cars in daytime. The average clearance between the vehicles increases from 2.3 ft. on

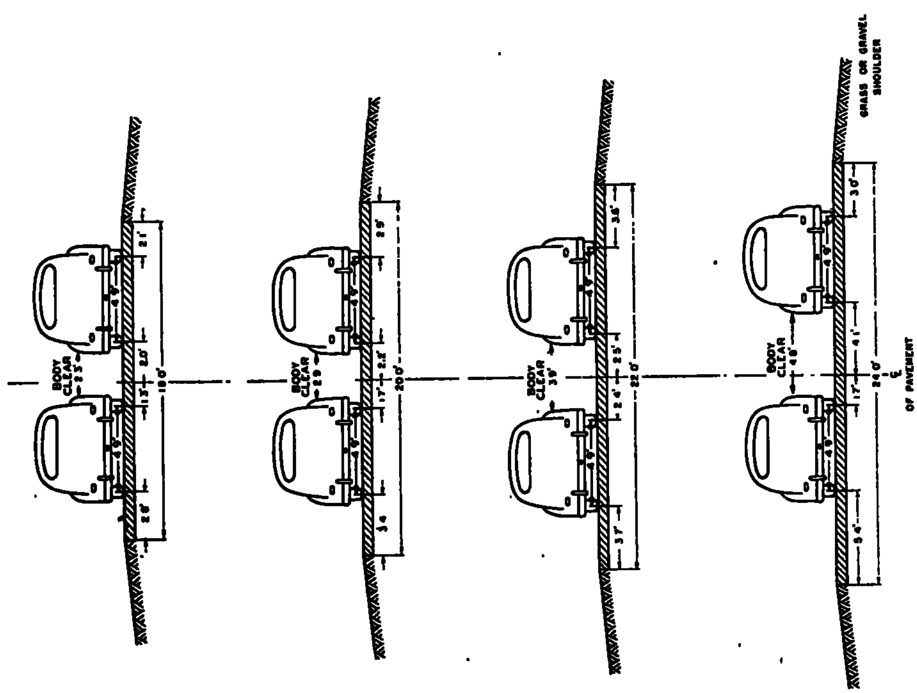

Figure 14. Average Position of Passenger Cars When Passing Passenger Cars on 2-Lane Concrete Pavements during Daytime

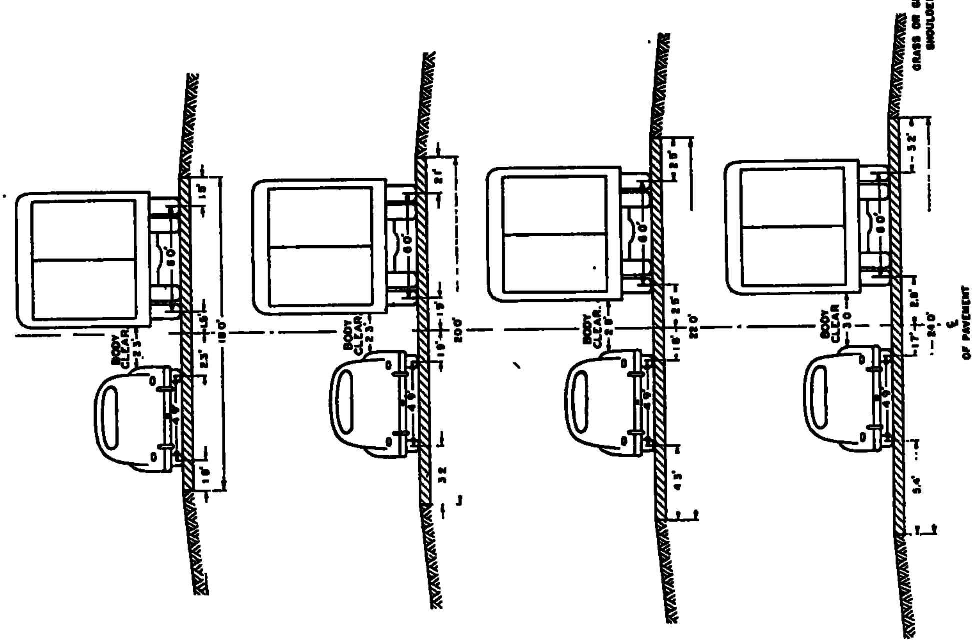

Figure 15. Average Position of Passenger Cars When Passing Commercial Vehicles on 2-Lane Concrete Pavements during Daytime

an 18-ft. pavement to 4.8 ft. on a 24-ft. pavement. These values are from 0.7 to 1.4 ft. less than the clearances between meeting passenger cars. This difference is to be expected because the difference in the speeds of passing vehicles is generally only a small fraction of the combined speeds of meeting vehicles.

On concrete pavements the driver of the passing vehicle apparently gauges his transverse position by the center of the roadway, because as soon as the right wheels of his vehicle are about 1.5 ft. in the left lane, regardless of the pavement width, he has the clearance he desires for the maneuver. The driver of the passed car, in most cases, moves his vehicle laterally to the right 0.5 ft., as compared with his free-moving position.

Figure 15 shows the average position of passenger cars when passing commercial vehicles. Even though the driver of the passing vehicle moves laterally to the left more when passing commercial vehicles than when passing other passenger cars, the body clearances are smaller when commercial vehicles are involved. The clearance between vehicles on similar pavement widths in this case is also less than when these vehicles meet one another traveling in opposing directions.

It may be concluded, therefore, that on 2-lane highways, pavement widths adequate to accommodate vehicles as they meet opposing traffic are more than adequate to accommodate passing manuevers.

VEHICLE POSITIONS AT NIGHT

At night, free-moving passenger cars travel farther from the edge of the pavement than in the daytime (Table 9). When passenger cars meet other passenger cars at night, however, their transverse positions are practically the same as in the daytime. Commercial vehicle drivers apparently prefer greater edge clearance at night than during the day for most of the several traffic conditions. Consequently, clearances between bodies of commercial vehicles when meeting other vehicles are slightly lower at night than in the day. Also, the percentage of vehicles that encroach in the left lane, both when free-moving and when meeting other vehicles, is higher at night, especially on the narrower pavements. For example, on a percentage basis, three times as many commercial vehicles encroach into the left lane when meeting other vehicles on 18-ft. pavements at night as in the daytime.

Shoulders are not used to any appreciable extent at night except on the sections with 18-ft. pavements. About 2 per cent of the vehicles use the shoulders on sections with 18-ft. pavements. Bituminous shoulders likewise are not used to an appreciable extent at night, although they increase the effective pavement width to the same extent as in the daytime.

The average body clearance between passing and passed vehicles is greater for passenger cars at night than in the daytime, primarily because the driver of the passing vehicle swerves more to the left at night. Passing maneuvers involving commercial vehicles were too few at night to obtain an adequate sample (Table 10).

The only definite conclusion regarding necessary surface widths for night driving is that 18-ft. pavements are more inadequate at night than during the day for similar traffic densities. The wider surfaces appear to be as adequate at night as during the day.

PATH OF PASSING VEHICLES

During the conduct of the speed-placement studies at each site, the transverse positions of the vehicles were recorded at only one point on the highway. The path of any one vehicle, therefore, as it overtook and passed a slower moving vehicle was not recorded. It is possible, however, to determine the path of the average vehicle as it overtakes and passes other vehicles traveling at various speeds by correlating the lateral and longitudinal positions of a large number of different vehicles with the relative positions of the vehicles being overtaken and passed. For this analysis data for only those vehicles uninfluenced by oncoming traffic were used. The combined results for four locations on 20-ft. pavements in California and Texas are shown in Figures 16, 17, and 18.

Figure 16 shows the paths of passing vehicles with respect to the passed vehicle for three conditions. The abscissae indicate the time spacings to the vehicle being overtaken. Plus values denote that the faster car is still behind the vehicle being passed and the minus values indicate the faster vehicle has already passed and is returning to its own lane. The ordinates indicate the distances that the left wheels of the faster passenger cars are from the center of the pavement, with minus values follow the same path as the preceding vehicle if the time spacing between vehicles exceeds 2 sec. When the spacing falls below 2 sec., that is, when the distance between centers of

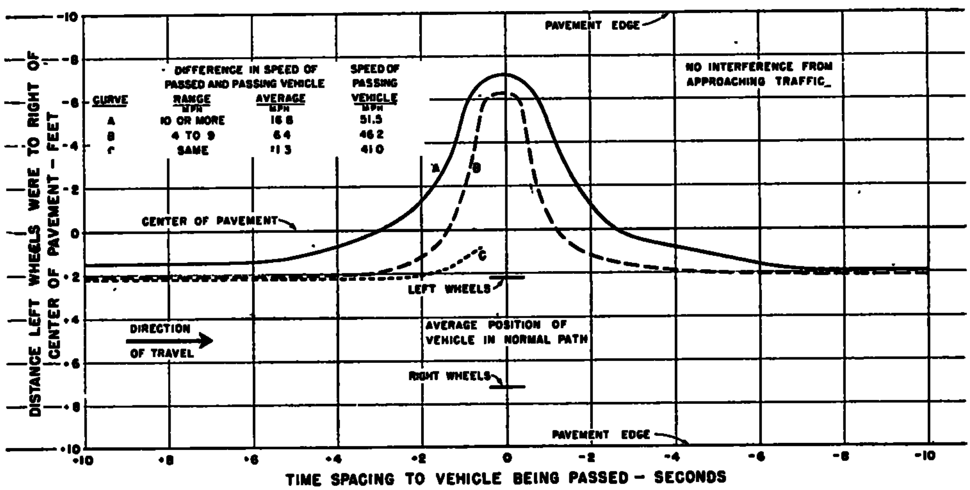

Figure 16. Effect of Time Spacing between Successive Vehicles on the Transverse Position of Passenger Cars Traveling on 20-Foot Concrete Pavement

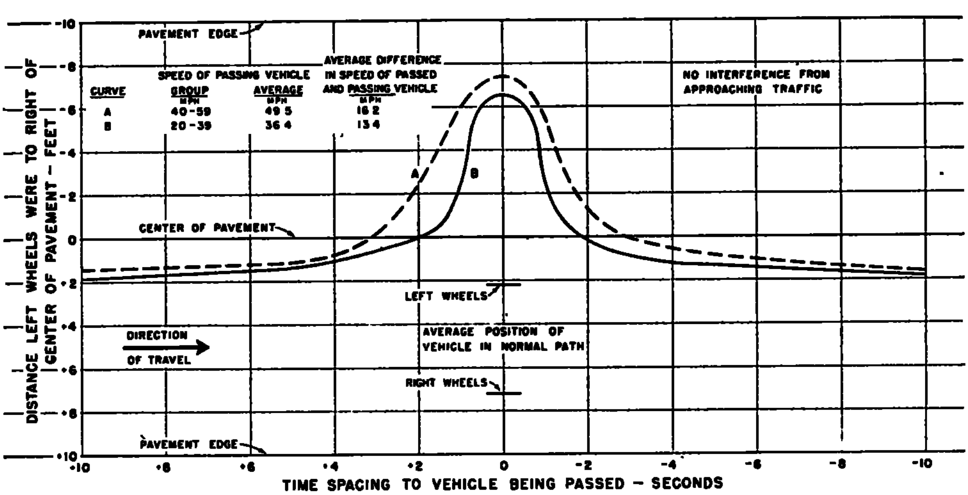

Figure 17. Effect of Time Spacing between Successive Vehicles on Transverse Position of Passenger Cars Traveling 10 or More M.P.H. Faster Than Vehicle Being Passed on 20-ft. Concrete Pavement

signifying that the vehicle is encroaching in the left lane.

Curve C shows the position of the left wheels of passenger cars traveling at the same speed as the vehicle ahead. The average speed was observed to be 41.0 miles per hour. Drivers of these passenger cars cars averages 120 ft., the drivers of the trailing cars begin to move toward the center of the pavement. When immediately behind, the rear passenger car is about 1.0 ft. closer to the center of the road than the vehicle ahead. Included in this group are cars that seek the opportunity to pass, but are trailing at the same speed. As soon as conditions are favorable they increase their speed for a passing maneuver. The positions of vehicles that travel at speeds higher than the vehicles being passed are shown in curves A and B.

Curve B shows the path of the left wheels of passenger cars traveling 4 to 9 miles per hour faster than the vehicle being overtaken. The average speed of the passing car and the difference in speeds of passing and passed vehicles are 46.2 and 6.4 miles per hour, respectively. The passing cars travel somewhat closer to the center of the pavement than those in curve C, and begin to veer toward the hour faster than the vehicles being overtaken. The passing cars are driven at an average speed of 51.5 miles per hour, which is 16.8 miles per hour higher than the vehicle being passed. These vehicles travel much closer to the center of the pavement and move to the left lane much sooner than the vehicles in the lower speed differential groups. At a time spacing of 5 sec., or when about 375 ft. behind the slower vehicle, they begin a gradual transverse shift toward the left lane, encroaching on the left lane at a time spacing of 3 sec. When abreast of the vehicle they are overtaking, their left wheels travel at a transverse distance

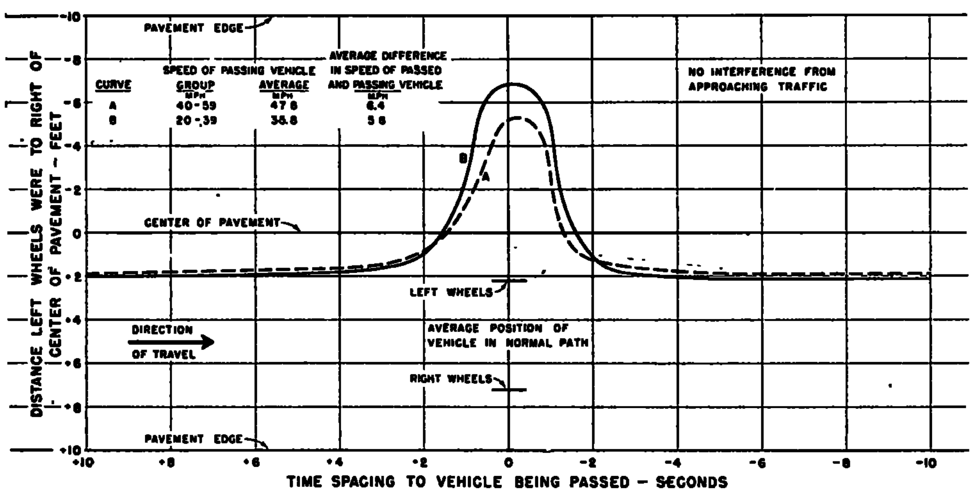

Figure 18. Effect of Time Spacing between Successive Vehicles on Transverse Position of Passenger Cars Traveling 4 to 9 M.P.H. Faster Than Vehicle Being Passed on 20-ft. Concrete Pavement

center at a time spacing of 3 sec., or when the average distance between centers of cars is about 200 ft. The faster cars encroach on the left lane when the time spacing to the preceding vehicle is 1.5 sec., and return to the right lane after overtaking the slower vehicle when the time spacing between vehicles is 1.4 sec. However, these cars assume their original transverse position on the pavement only when they are 5 sec. ahead of the vehicle overtaken and passed. When these vehicles are entirely in the left lane and abreast of the vehicle being passed, their left wheels are 3.8 ft. from the left pavement edge, and the body clearance is, on the average, 3.0 ft.

Curve A shows the path of the left wheel of passenger cars traveling 10 or more miles per of 2.9 ft. from the left pavement edge, allowing a clearance of 3.4 ft. between the bodies of the two vehicles. The passing cars return to the right lane when at a time spacing of 2.6 sec. ahead of the slower vehicle.

The curves in Figure 16 are the paths for vehicles that maintain a constant speed during the entire passing maneuver. Under actual operating conditions some passing maneuvers are performed in this manner but generally the driver of the passing vehicle accelerates as he encroaches in the left lane. The actual path of the passing vehicle that accelerates would be governed by the time spacing to the vehicle being passed when the maneuver is started, by the speeds of the vehicles, and by the rate of acceleration. For example, as a vehicle traveling at the same speed as the vehicle to be passed accelerates, his path might shift from curve C to curve B and then from curve B to curve A before getting abreast of the passed vehicle.

In Figure 16, the controlling factor for each of the curves is the speed differential between the passed and passing vehicles. Data for passing vehicles traveling at all speeds are combined. Figure 17 shows the effect of speed on the paths of the passing vehicles when there is a speed differential of at least 10 miles per hour. Figure 18 shows the effect of speed when there is a speed differential between 4 and 9 miles per hour. These figures show that for the same speed differential, the portion of the pavement width that is utilized varies with the speed of the passing vehicles.

DISTANCE COMPUTED FOR OCCUPATION OF LEFT LANE BY PASSING VEHICLES

Although Figures 16 through 18 show the relative transverse position of vehicles in sequence on the highway, they do not show the distance that the faster vehicles travel in the left lane; however, this distance can easily be calculated from the curves. For example, curve A of Figure 16 shows that the faster car while traveling in the left lane gains 5.6 sec. on the vehicle being passed, 3.0 sec. of which are gained from the time the passing vehicle encroaches on the left lane until it is abreast of the passed vehicle, and 2.6 sec. are gained while returning to the right lane. At 51.5 miles per hour a gain of 5.6 sec. represents a gain of $5.6 \times 51.5 \times 1.47$, or 423 ft. In other words, the faster car is 227 ft. behind when it enters the left lane to pass the slower moving vehicle, and 196 ft. ahead of the slower vehicle when it returns to the right lane. The time spent by the faster vehicle in the left lane equals the distance divided by the difference in speed. Thus, time spent in left lane is $\frac{423}{16.8 \times 1.47}$ or 17.2 sec. During this elapsed time, the faster car travels 1,299 ft. in the left lane while the slower vehicle travels 876 ft. Similarly, curve B shows that a passenger car traveling 4 to 9 miles per hour faster than the vehicle being overtaken gains 2.7 sec. and travels at an average speed of 46.2 miles per hour. The faster car travels 1,322 ft. in the left lane while the slower vehicle travels 1,139 ft.

Table 15 shows, in adition to the speed and transverse position of the passing vehicle, the time and distance traveled by passenger cars occupying the left lane while overtaking slower vehicles on 2-lane concrete pavement 20 ft. wide.

This analysis of vehicle paths during passing maneuvers supplies information which cannot be obtained by any other practical procedure. The results augment those of the passing studies in which more comprehensive data regarding the travel time in the left lane and speeds at various stages of the passing maneuvers were recorded and analyzed.[4]

TABLE 15

SPEED, PLACEMENT, AND DISTANCE TRAVELED BY PASSENGER CARS OCCUPYING LEFT TRAFFIC LANE WHILE OVERTAKING SLOWER VEHICLES ON 2-LANE CONCRETE PAVEMENTS 20 FT. WIDE

Speed		Average difference in speed	Travel in left lane		Distance gained while in left lane	Transverse[a] position when abreast of slower vehicle	Body clearance when abreast of slower vehicle
Range	Average		Time	Distance			
mph.	*mph.*	*mph.*	*sec.*	*ft.*	*ft.*	*ft.*	*ft.*
Passenger cars traveling 4 to 9 miles per hour faster than vehicles being overtaken							
20–39	35.8	5.8	19.8	1,040	168	3.1	3.2
40–59	47.8	6.4	20.1	1,409	189	4.7	1.6
18–72 (All)	46.2	6.4	19.5	1,322	183	3.8	2.5
Passenger cars traveling 10 or more miles per hour faster than vehicles being overtaken							
20–39	36.4	13.4	10.5	561	206	3.4	2.9
40–59	49.5	16.2	18.3	1,329	326	2.6	3.7
18–72 (All)	51.5	16.8	17.2	1,299	423	2.9	3.4

[a] Distance left wheels were from left edge of pavement.

CONCLUSIONS

Based upon the results of extensive studies of traffic operations at a large number of

[4] E. H. Holmes, "Procedure Employed in Analyzing Passing Practices of Motor Vehicles," *Public Roads*, January 1939.

O. K. Normann, "Progress in Study of Motor Vehicles Passing Practices," *Public Roads*, February 1940.

C. W. Prisk, "Passing Practice on Rural Highways," *Proceedings*, Highway Research Board, Vol. 21 (1941).

highway locations, the following are the more important conclusions that apply to level tangent sections of 2-lane highway with concrete surfaces:

1. Shoulder width in excess of 4 ft. does not influence the effective pavement width for moving traffic when there are no vertical obtructions immediately adjacent to the shoulders. This must not be interpreted that shoulders wider than 4 feet are not necessary for other important factors influencing traffic movement.

2. Well-maintained grass shoulders have the same effect on the transverse position of moving vehicles as well-maintained gravel shoulders.

3. Bituminous treated shoulders 4 ft. or more in width adjacent to 18- and 20-ft. pavements increase the effective surface width approximately 2 ft.

4. Lip curbs on 20-ft. pavements reduce the total effective pavement width in the daytime approximately 1 ft. At night this is true only for commercial vehicles.

5. Shoulder use increases rapidly with a decrease in pavement width below 22 ft. An insignificant number of moving vehicles use the shoulders on pavements of that width. On 18-ft. pavements, however, 4.0 per cent of the commercial vehicles encroach on grass or gravel shoulders as they meet oncoming traffic. The corresponding value is 15.0 per cent on sections with bituminous shoulders.

6. Hazardous traffic conditions exist on pavements less than 22 ft. wide that carry even moderate volumes of mixed traffic. On 18-ft. pavements with grass or gravel shoulders, 11 per cent of the truck drivers and 5 per cent of the passenger car drivers fail to keep their vehicles within their proper traffic lane even when meeting oncoming traffic.

7. Drivers do not reduce their speeds when meeting other vehicles on narrow pavements even though body clearances are definitely inadequate.

8. When passenger cars meet commercial vehicles a pavement 22 ft. wide permits desired center and edge clearances for the passenger cars but not for the commercial vehicles. To permit desired clearances for commercial vehicles a 24-ft. pavement is required.