use of some local aggregates not meeting all the soundness requirements. These requirements have been modified over a period of years as experience revealed undesirable results with some aggregate combinations. We have experienced stripping with some limestone and gravel aggregate mixes. In areas where this has occurred we are now requiring the use of asphalt meeting "no strip" tests.

In the past 12 years which cover the period of salvage work under discussion, Ohio has salvaged an increasing mileage. In recent years this program has varied from 350 to 500 miles per year. Bituminous concrete for this mileage has varied from 850,000 to 1,000,000 tons per year. In that period we have witnessed practically a 100 to 300 percent increase in construction costs for other types of construction. It speaks well for the highway industry—the highway engineer—the contractor—and the equipment producer, that in this particular branch of highway construction the costs have increased only about 30 percent. New developments and practices have to a great extent offset rising material and labor costs. We, as engineers, have been receptive to new ideas and developments in the salvage type construction which accounts for these improvements. We should likewise have an open mind on all our highway work in order that we do not rule out progressive developments.

DEPARTMENT OF TRAFFIC AND OPERATIONS

WILBUR S. SMITH, *Chairman*

THE EFFECT ON DRIVER BEHAVIOR OF CENTER LINES ON TWO-LANE ROADS

A. TARAGIN, *Highway Engineer, Division of Highway Transport Research, Public Roads Administration*

SYNOPSIS

A driver behavior study revealed that motor vehicle speeds and transverse positions are substantially affected by the presence of pavement markings along the roadway center line. Observations were made on level, straight sections of rural two-lane pavements 18 to 24 ft. wide, with grass or gravel shoulders in average condition. The principal findings made in an analysis of operating data for 18,235 vehicles, recorded at 12 locations in 7 States, are summarized as follows:

1. For each of the pavement widths studied the typical vehicle path is farther to the right on pavements with a center-line marking than it is on similar pavements without center-line markings. The differences observed vary from less than 0.5 ft. to nearly 1.5 ft., depending on pavement width, vehicle type, the presence of other traffic and similar factors.
2. In all cases, vehicles are driven closer to their proper position on the roadway and encroach on the left lane less frequently when they have the center-line marking for a guide.
3. On an 18-ft. pavement without a center-line marking 56 percent of the vehicles encroach on the left lane. This proportion is only 12 percent on the same width pavement with a center-line marking. On wider pavements, the corresponding percentages are lower but in all cases the encroaching action is less frequent on pavements having a center-line marking.
4. The average lateral clearance between the sides of meeting vehicles on 24-ft. pavements is greater by about 2 ft. on sections with center-line marking than it is on similar width pavements without marking.
5. Comparison of the speeds of vehicles on pavements with and without center-line markings shows that generally higher speeds exist on pavements with markings. The over-all difference in average speed amounted to approximately 4 mi. per hr.

A familiar sight to the American motorist is the line marking the center of the roadway. The roadway center-line marking is a consistent aid to driving. With its help the driver gauges the position of his vehicle on the roadway as he negotiates curves, meets other traffic, and exercises the many niceties of judgment required for safe travel over the road.

NATURE AND SCOPE OF DATA

An opportunity was recently afforded to make a comparison of driver reaction to pavement center lines on a number of two-lane, rural roadways, some of which have center-line markings and some of which do not. The selection of roadway sections that were similar as to design and traffic characteristics except for the matter of center-line markings has made it possible to isolate some interesting comparative facts concerning the effect of center-line marking on driver behavior. The data are from studies on level, tangent sections of two-lane, rural highway during daylight hours. Pavement widths considered are 18, 20, 22, and 24 ft. with grass or gravel shoulders in average condition. The performance of 18,235 vehicles recorded at 12 locations in 7 States during the years immediately prior to the war and during the summer of 1947 constitutes the basis for this report.

Because the principal objective of the analysis was to determine the effect of center-line marking on driver behavior, sections of the same width with and without the marking but with similar traffic volumes and other characteristics were selected. The general roadway design and traffic features for the different width pavements, however, were not necessarily similar. The data cannot be used, therefore, to compare driver behavior on the various surface widths. A more complete report dealing specifically with the effect of roadway width on vehicle operation has been published previously.[1]

Table 1 is a summary of the physical and traffic conditions at each of the 12 locations covered by the investigation. The average speeds and average placements are shown for all vehicles. Except for the 18-ft. width, all pavements were bituminous and all center-line markings were white. Section No. 4, shown in Table 1 as an 18-ft. concrete pavement without a center-line marking, did not have the conventional longitudinal center joint to act as a substitute for a pavement marking.

Section No. 5 was the only location where observations were made both before and after painting the center-line marking, but as previously stated, the geometric and traffic

TABLE 1
SPEED, PLACEMENT, AND VOLUME OF ALL TRAFFIC OBSERVED

Study Section Number	Pavement		Shoulders		Color of Center Line, If Any	Average Volume	Number of Vehicles		Average Speed		Average Distance of Left Wheels from Center of Highway.	
	Width	Type	Width	Type			Pass. Cars	Trucks and Busses	Pass. Cars	Trucks and Busses	Pass. Cars	Trucks and Busses
	ft.		*ft.*			*vph.*			*mph.*	*mph.*	*ft.*	*ft.*
1	18	Concrete	6	Gravel	Black	354	3,825	139	45.5	38.6	1.4	1.5
2	18	Concrete	6	Gravel	Black	108	407	118	44.8	42 3	1.2	1.3
3	18	Concrete	5	Gravel	Yellow	121	662	126	42.5	38.0	1.5	1.7
4	18	Concrete	5	Gravel	None	230	1,043	113	39.1	35.8	0.6	0.3
5	18	Bit.	5	Gravel	White	70	334	36	39.1	36.8	1.6	1.0
5	18	Bit.	5	Gravel	None	100	398	32	35.2	33.3	1.0	0.5
6	20	Bit.	7	Grass	White	287	1,382	75	37.1	36.4	2.5	2.3
7	20	Bit.	4	Grass	None	659	2,386	74	35.0	36.4	1.6	1.8
8	22	Bit.	6	Grass	White	120	606	97	44.9	37.8	2.6	2.8
9	22	Bit.	8	Grass	None	388	2,341	45	34.1	34.3	1.6	2.1
10	24	Bit.	12	Caliche	White	365	1,797	266	47.0	40.1	2.9	3.0
11	24	Bit.	6	Caliche	White	175	882	170	48.9	41.2	3.1	3.2
12	24	Bit.	6	Grass	None	204	751	130	44.6	39.6	2.2	2.0

[1] A. Taragin, "Effect of Roadway Width on Vehicle Operation", *Public Roads*, October-November-December, 1945.

characteristics of the other sections compared are the same except for the center-line marking.

In the analysis of the field records, two classes of traffic, free-moving vehicles and meeting vehicles, were considered. Free-moving vehicles are those so positioned in the traffic stream that their actions are affected little if any by other vehicles on the highway. Meeting vehicles are those spaced at least 6 seconds behind the preceding vehicle traveling in the same direction, but not more than 1.5 seconds from a vehicle traveling in the opposite direction. Vehicles in the free-moving and meeting classifications comprise slightly more than half the traffic where the total volume is about 300 vehicles per hour and over 80 percent of the traffic where the total volume is 150 vehicles per hour or less. The effect of center-line markings on vehicles engaged in passing maneuvers and on other more tightly grouped vehicles is subject to considerable variation and it therefore seemed in the interest of clarity to limit the study to the two groups described.

OBSERVED SPEEDS HIGHER ON PAVEMENTS WITH CENTER LINES

The average speeds of free-moving and meeting passenger cars and commercial vehicles on the various sections with and without center-line markings appear in Table 2. It is obvious that speeds are definitely higher on the pavements with marked center lines. The single exception is for free-moving commercial vehicles on a 20-ft. bituminous pavement. The average speed for these vehicles on the marked pavement is about 2 mph. lower than on the unmarked pavement. This inconsistency may have been due to an inadequate sample at one or both of the locations involved.

The differences between passenger car speeds on sections with and without center-line markings are a little greater, on the average, for free-moving vehicles than for meeting vehicles. The data for commercial vehicles are not conclusive as to this point. In one classification and on one width of pavement the difference in average vehicle speed on marked and unmarked sections is as high as 15 mph., and in another instance, as high as 9 mph. These values are exceptional, however, and a value of approximately 4 mph. is more nearly representative of the average condition observed.

PROPER VEHICLE PATH MORE ACCURATELY HELD ON MARKED ROADWAYS

The most useful information derived from the study concerns the transverse position of vehicles on marked and unmarked pavements. Figures 1 through 5 present the findings in the form of placement distributions for each of the four pavement widths and two pavement types investigated. The bar charts

TABLE 2
AVERAGE SPEEDS OF VEHICLES ON PAVEMENTS WITH AND WITHOUT CENTER-LINE MARKINGS

Vehicle Classification and Pavement Type	With Center-Line Markings	Without Center-Line Markings
	mph.	*mph.*
Free-moving passengers on:		
18-foot concrete	44.9	40.2
18-foot bituminous	39.4	35.6
20-foot bituminous	38.3	37.2
22-foot bituminous	45.0	36.4
24-foot bituminous	48.6	45.1
Free-moving trucks and busses on:		
18-foot concrete	38.5	35.6
18-foot bituminous	36.1	32.5
20-foot bituminous	36.7	38.6
22-foot bituminous	37.3	34.2
24-foot bituminous	40.3	40.2
Passenger cars meeting other vehicles on:		
18-foot concrete	43.4	40.0
18-foot bituminous	37.2	35.0
20-foot bituminous	37.3	36.3
22-foot bituminous	48.5	33.6
24-foot bituminous	47.4	45.9
Trucks and busses meeting other vehicles on:		
18-foot concrete	39.1	36.9
18-foot bituminous	38.3	35.0
20-foot bituminous	37.9	33 7
22-foot bituminous	39 8	36.7
24-foot bituminous	44.3	40.5

in the top half of these illustrations show placement distributions on sections without center-line marking for each of the four traffic classifications. Similar information for sections with center-line marking appears in the lower half of each figure. As the upper and lower sections of these illustrations are compared, it becomes evident that both passenger cars and trucks follow a path which is consistently further to the right on the sections with center-line markings. There are no exceptions to this general finding in any of the free-moving or meeting vehicle classifications or on any of the pavement widths for which data were analyzed.

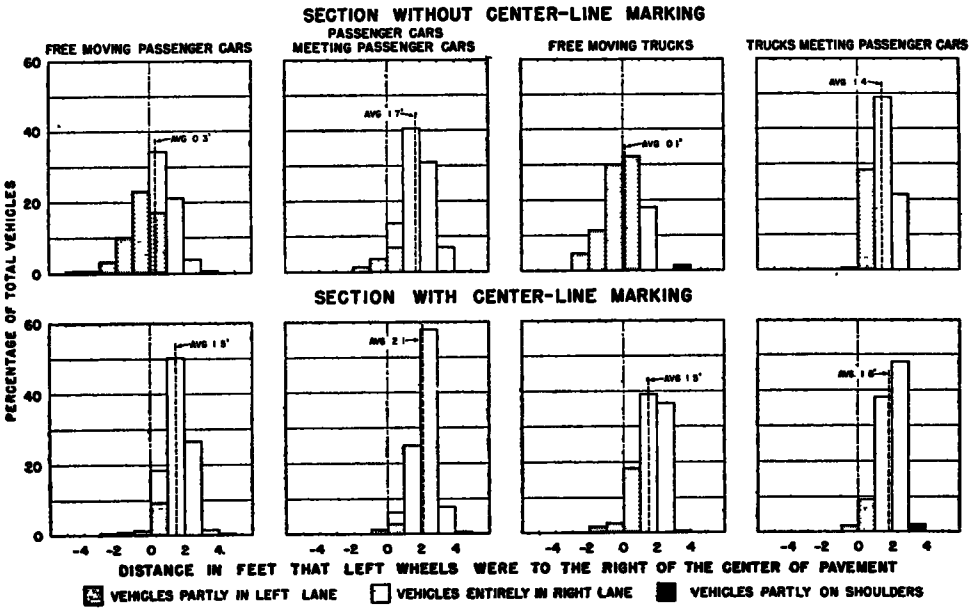

Figure 1. Distribution of Transverse Placements of Vehicles During Daytime on 18-Ft Concrete

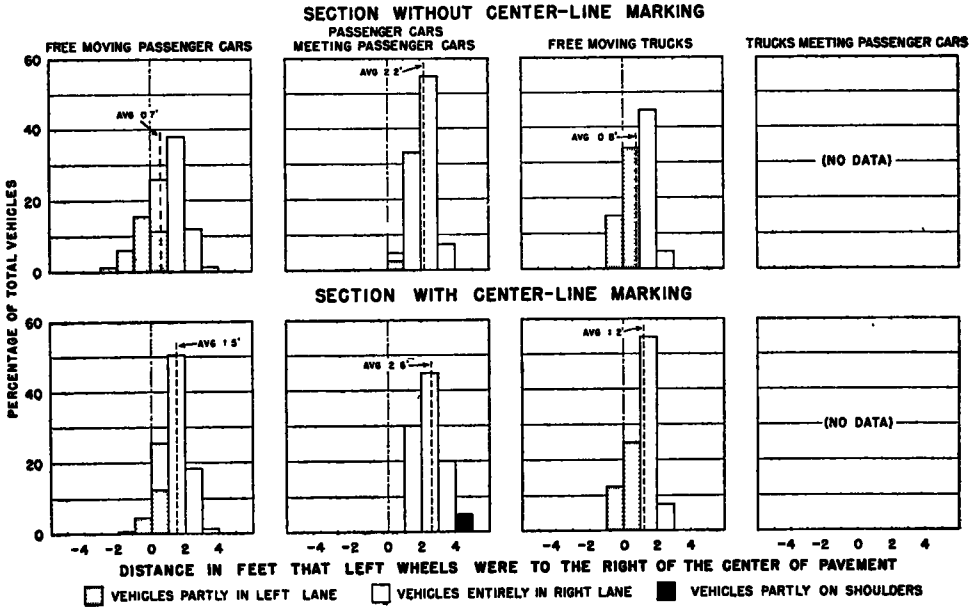

Figure 2. Distribution of Transverse Placements of Vehicles During Daytime on 18-Ft. Bituminous

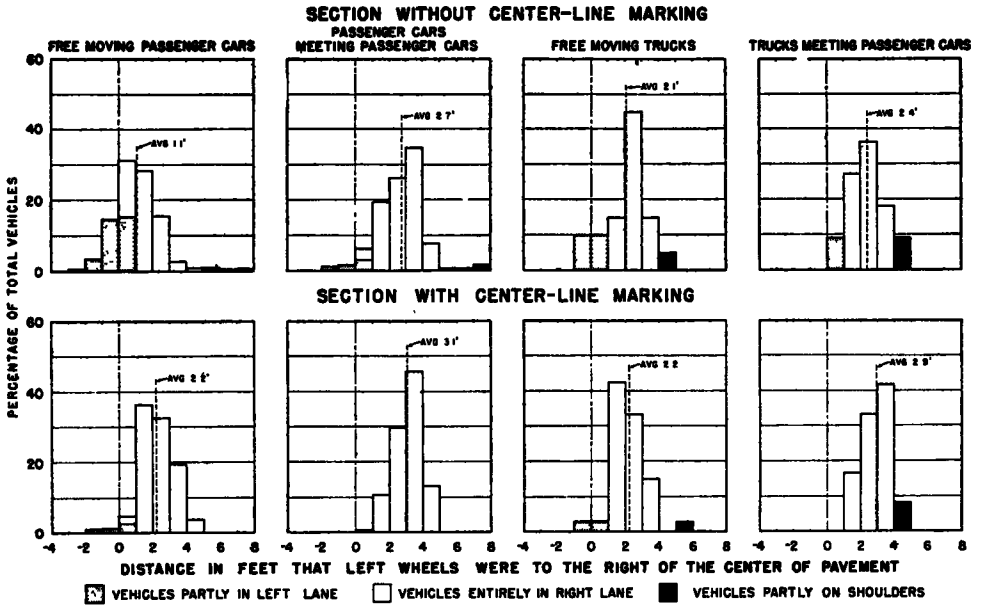

Figure 3. Distribution of Transverse Placements of Vehicles During Daytime on 20-Ft.Bituminous

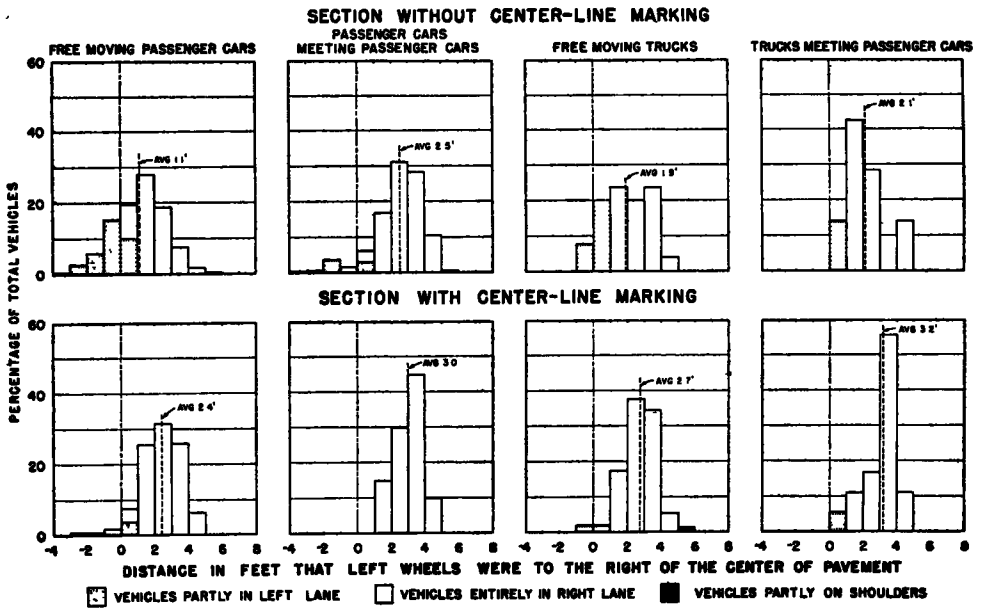

Figure 4. Distribution of Transverse Placements of Vehicles During Daytime on 22-Ft. Bituminous

The magnitude of the differences in average transverse placement of vehicles on roadways with and without center-line marking, Figures 1 through 5, is generally in the range from 0.4 to 1.4 ft. The average difference of 0.1 ft. for free-moving trucks on 20-ft. pavement is the only exception. There is no reliable indication from the average transverse position values that drivers of free-moving vehicles react any differently to center-line markings than do drivers of meeting vehicles. This is equally true for passenger vehicles and trucks.

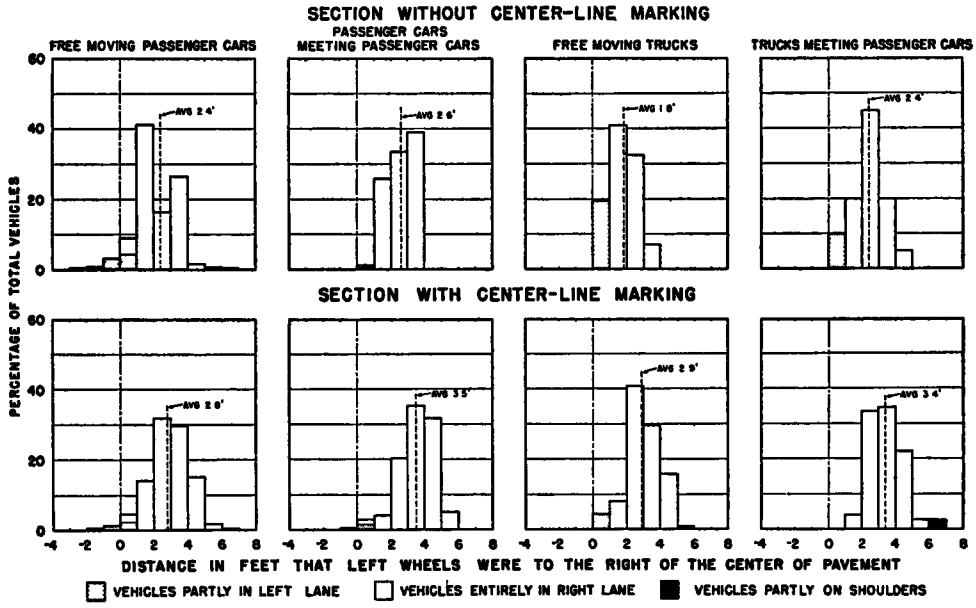

Figure 5. Distribution of Transverse Placements of Vehicles During Daytime on 24-Ft. Bituminous

The bar charts in Figures 1 through 5 contain stippled areas to indicate the vehicles encroaching on the left lane and black areas to denote vehicles partly on the shoulder. With respect to vehicles on the shoulder, it might be thought that because the typical vehicle path on marked pavements is to the right of that followed on unmarked pavements, the use of the shoulders would be considerably more extensive on the marked pavement. This is not true, as will be seen by comparing the black areas in the charts at the top with those at the bottom in each figure.

It is significant that the sections with center-line markings have a higher percentage of vehicles traveling in their proper lateral position on the roadway. This is as true for wide as it is for narrow pavements. The percentage of vehicles encroaching on the left lane of the roadway, shown by the stippled areas in Figures 1 to 5, is consistently less on the roadways with center-line markings. Table 3 provides some comparative facts on this condition, showing the average placement of the left wheels of the vehicles with respect to the center line and the percentages of the vehicles encroaching on the left lane. In the case of free-moving passenger cars and commercial vehicles, one-third to more than three-fourths of these vehicles were found to be encroaching on the left lane on pavements up to 22 ft. in width when there were no center-line markings. In only one instance, however, did more than a fourth of these vehicles encroach on the left lane when center-line markings were present. The percentages in Table 3 indicate that roadways with center-line markings usually have considerably less than half as many vehicles encroaching on the left lane as do roadways without the center-line marking.

CLEARANCE BETWEEN BODIES OF MEETING VEHICLES GREATER ON CENTER-LINED ROADWAYS

It is most important that vehicles stay in their own lane when meeting oncoming traffic. In addition to determining the percentage of meeting vehicles encroaching on the left lanes of roadways with and without center-line markings, the average clearance between bodies of meeting vehicles has been calculated and appears in Table 4. A lateral distance of 3 ft. has been determined from previous studies to be the minimum desirable clearance between vehicle bodies and the percentage of meeting vehicles having this clearance or less is shown for the sections studied.

TABLE 3

AVERAGE POSITION OF VEHICLES AND PERCENTAGE OF VEHICLES ENCROACHING UPON THE LEFT LANE OF TRAFFIC ON PAVEMENTS WITH AND WITHOUT CENTER-LINE MARKINGS

Vehicle Classification and Pavement Type	Average Transverse Placement[a]		Vehicles Encroaching Upon Left Lane	
	With center-line markings	Without center-line markings	With center-line markings	Without Center-Line Markings
	ft.	ft.	%	%
Free-moving passenger cars on:				
18-foot concrete	1.5	0.3	12.1	55.7
18-foot bituminous	1.5	0.7	17.5	35.8
20-foot bituminous	2.2	1.1	5.0	34.6
22-foot bituminous	2.4	1.1	6.7	33.4
24-foot bituminous	2.8	2.4	4.6	8.7
Free-moving trucks and busses on:				
18-foot concrete	1.5	0.1	23.6	80 0
18-foot bituminous	1.2	0.8	37.5	50.0
20-foot bituminous	2.2	2.1	6.0	20.0
22-foot bituminous	2.7	1.9	3.4	28.0
24-foot bituminous	2.9	1.8	4.7	19.7
Passenger cars meeting other passenger cars on:				
18-foot concrete	2.1	1.7	4.7	12.8
18-foot bituminous	2.6	2.2	0	2.4
20-foot bituminous	3.1	2.7	0.2	5.7
22-foot bituminous	3.0	2.5	0	8.9
24-foot bituminous	3.5	2.6	1.7	0.6
Passenger cars meeting trucks or busses on:				
18-foot concrete	2.4	2.1	3.1	10.0
18-foot bituminous				
20-foot bituminous	3.2	2.1	5.0	17.1
22-foot bituminous	3.5	2.2	4.2	11.4
24-foot bituminous	3.8	3.0	2.0	4.0
Trucks and busses meeting passenger cars on:				
18-foot concrete	1.8	1.4	11.5	29.4
18-foot bituminous				
20-foot bituminous	2.9	2.4	0	9.1
22-foot bituminous	3.2	2.1	5.6	14.3
24-foot bituminous	3.4	2.4	0	10.0

[a] Distance left wheels of vehicles were to right of pavement centerline.

Examination of the average values shows that clearances between meeting vehicles on the sections with marked center lines were from 0.6 to 2.2 ft. greater than on unmarked roadways. Table 4 shows that substantially fewer vehicles have a clearance of 3 ft. or less as they meet on a marked pavement than when they meet on a unmarked pavement. For example, on the 18-ft. bituminous pavements, the percentage of passenger cars with less than a 3-ft. clearance when meeting is 48.1 on pavements without marking and 20.0 on pavements with marking, a ratio of about two and a half to one. On the 20-ft. bituminous pavements, the corresponding percentages are 36.7 on pavements without the marking and 5.6 on pavements with the marking, a ratio of six and a half to one. The corresponding ratios on 22- and 24-ft. pavements are nine to one and thirteen to one, respectively.

TABLE 4

AVERAGE CLEARANCE BETWEEN BODIES OF MEETING VEHICLES AND PERCENTAGE OF VEHICLES ALLOWING A CLEARANCE OF 3 FEET OR LESS ON PAVEMENTS WITH AND WITHOUT CENTER-LINE MARKINGS

Vehicle Classification and Pavement Type	Average Clearance		Vehicles with a Clearance of 3 Feet or Less	
	With Center-Line Markings	Without Center-Line Markings	With Center-Line Markings	Without Center-Line Markings
	ft.	ft.	%	%
Meetings between passenger cars on:				
18-foot concrete	3.2	2.3	64.0	90.0
18-foot bituminous	4.0	3.4	20 0	48.1
20-foot bituminous	5.1	4.2	5.6	36.7
22-foot bituminous	5.0	4.3	2.6	23.7
24-foot bituminous	6.2	4.2	1.5	19.6
Meetings between passenger cars and trucks or busses on:				
18-foot concrete	2.6	1.9	84.1	96.3
20-foot bituminous	4.8	3.0	8.7	56.0
22-foot bituminous	5.0	2.8	9.8	57.1
24-foot bituminous	5.9	4.0	4.6	30.9

From this it might be assumed that markings have their greatest value in improving clearances on the wider pavements. This is not the case, however, because the low clearances on narrow unmarked pavements are much greater in number and much closer

to critically low values than are those on the wider unmarked pavements. The data in Table 4 show that the average clearance between meeting vehicles is almost one foot more on an 18-ft. pavement with center lines than on an 18-ft. pavement without center lines. The corresponding difference on the 24-ft. pavements studied is approximately 2 ft. However, the actual clearance distance on the 24-ft. pavement without center-line marking is in the neighborhood of 4 ft., whereas on the 18-ft. concrete pavement there is an average clearance between meeting passenger vehicles of only 2.3 ft. on unmarked sections and 3.2 ft. on marked sections. Increasing the critically low clearances on narrow pavements seems certain to be a greater traffic and safety benefit than increasing clearances that are already reasonably adequate.

CONCLUSIONS

Data for vehicle speeds and transverse positions on rural two-lane roadways have been presented to show some of the advantages of center-line markings on driver behavior in measured quantities. The conclusions are based upon the performance of over 18,000 vehicles. Only those samples exceeding 100 vehicles were considered. The principal facts derived from the study are summarized as follows:

1. For each of the pavement widths studied, 18, 20, 22, and 24 ft., the typical vehicle path is further to the right on pavements with a center-line marking than it is on similar pavements without center-line markings. The differences observed vary from less than a 0.5 ft. to nearly 1.5 ft., depending on pavement width, vehicle type, and the presence of other traffic. It is significant that shifting the vehicle path to the right does not result in an increase in the use of the shoulder.

2. Center-line markings bring a general improvement in the transverse positioning of vehicles. On the average, vehicles are driven closer to their proper position on the roadway and encroach on the left lane much less frequently when they have the center-line marking for a guide.

3. As might be expected, it is on the narrower pavements that the center-line marking is most effective in reducing the tendency of vehicles to encroach on the left lane.

4. The average lateral clearance between the sides of meeting vehicles on 24-ft. pavements is greater by about 2 ft. on sections with center-line marking than it is on similar width pavements without the marking. Although the comparable difference in the average clearances on 18-ft. pavements with and without center-line markings is only about 1 ft., or half as much, the benefit is considerably greater since the lateral clearances are so small that they are regarded as critical.

5. The average speed of vehicles on the marked pavements was 4 mph. higher than on the unmarked pavements.