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COLLECTING DATA ON SPEED AND PLACEMENT

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

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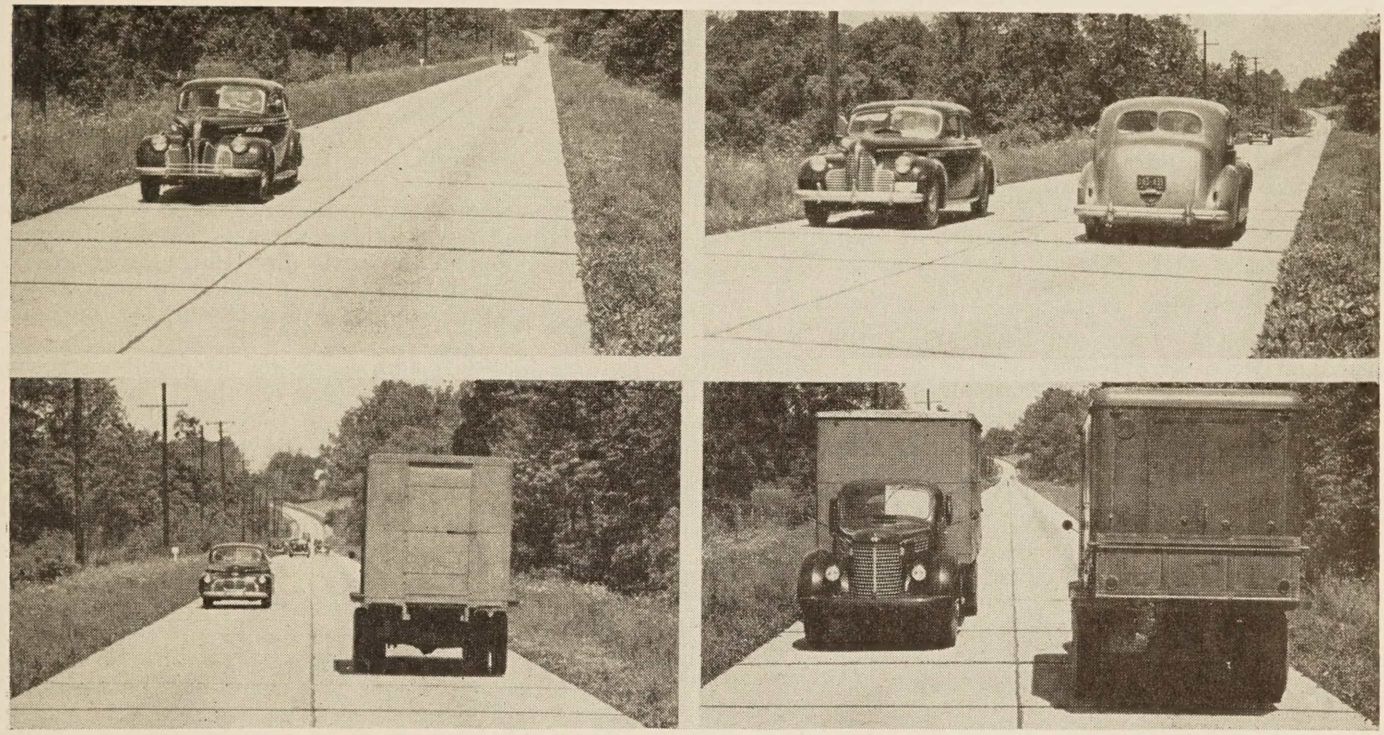
EFFECT OF ROADWAY WIDTH ON VEHICLE OPERATION

A STUDY OF SPEED AND PLACEMENT ON TWO-LANE CONCRETE ROADS

BY THE DIVISION OF HIGHWAY TRANSPORT RESEARCH, PUBLIC ROADS ADMINISTRATION

Reported by A. TARAGIN, Highway Engineer



VEHICLE POSITIONS ON A TYPICAL 22-FOOT HIGHWAY.

TWO-LANE ROADS constitute 95 percent of the 256,000 miles of dustless surfaces on 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 widths of rural highways with traffic of 1,000 or more vehicles per day in 27 States shows that 48 percent of the roads at present have pavement widths less than 20 feet.

To determine operating conditions on surfaces of various widths, extensive speed-placement studies were conducted during immediate prewar years by the Public Roads Administration with the cooperation of the highway planning surveys in 10 States. Preliminary results of these studies on several sections of highway in Illinois were published in the 1943 Proceedings of the Highway Research Board. This report presents the complete analysis of all the data collected in the speed-placement studies on straight, level sections of rural two-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

[1] New Techniques in Traffic Behavior Studies, by E. H. Holmes and S. E. Reymer, PUBLIC ROADS, April 1940.

TABLE 1.—*Study locations and vehicles included in analysis of speed-placement data*

CLASSIFIED BY STATE

State or pavement width	Day		Night		Total vehicles
	Locations	Vehicles	Locations	Vehicles	
	Number	*Number*	*Number*	*Number*	*Number*
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
Total	47	78,459	28	17,130	95,589

CLASSIFIED BY PAVEMENT WIDTH

State or pavement width	Day Locations	Day Vehicles	Night Locations	Night Vehicles	Total vehicles
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

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 opposite directions.

VARIETY OF ROADWAY WIDTHS INCLUDED

The number of sections where studies were made and vehicles observed, classified by the State in which the study was made, and by lighting conditions, are shown in table 1. Speed and placement information for over 95,000 vehicles was obtained at 47 different locations on 18-, 20-, 22-, and 24-foot concrete pavements. At all 47 sites studies were conducted during the day, and at 28 of them observations were also made during several hours of darkness.

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

AMPLE SIGHT DISTANCES AT ALL LOCATIONS

All the sections were on State routes, and 38 of the sections were on U S numbered highways. Over 65 percent of the locations were at places where the sight distance exceeded 2,100 feet, the minimum passing sight distance for a design speed of 60 miles per hour, as recommended by the American Association of State Highway Officials.[2] All data were taken on sections where the sight distance was 1,200 feet or greater.

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

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

Table 2 shows highway conditions and average vehicle placements observed at the locations selected. 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. Data are shown separately for day and night observations and by pavement widths.

The average placement figures include those for passing vehicles traveling in the left lane. Consequently they are influenced considerably by the relative number of passing vehicles and should not be compared to form conclusions as to transverse placements on pavements of various widths or with different types of shoulder.

VEHICLES GROUPED ACCORDING TO INFLUENCE OF OTHER VEHICLES

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

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

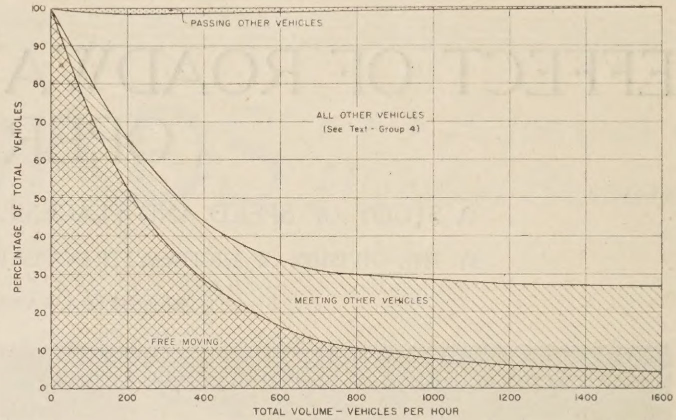


Figure 1.—Distribution of Vehicles by Free-Moving, Meeting, and Passing Groups on Two-Lane Concrete Pavement With Traffic Evenly Distributed in Each Direction of Travel.

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

Drivers in this group were, for practical purposes, uninfluenced by other traffic on the highway when speed and transverse position were recorded.

2. *Meeting vehicles.*—Includes those vehicles that were spaced more than 6 seconds behind any vehicle traveling in the same direction and either had met, or were to meet within 1.5 seconds, a vehicle traveling in the opposite direction.

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 vehicles 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.

3. *Passing vehicles.*—Includes those vehicles that were overtaking and passing other vehicles traveling in the same direction and which crossed the placement detector within 1 second of the passed vehicle. Wherever the term "passing" is used in this report, overtaking and passing is implied.

4. *All other vehicles.*—Includes those vehicles that were spaced less than 6 seconds from the preceding vehicle traveling in the same direction regardless of opposing traffic, and those vehicles that were 6 seconds 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 special classifications, the distribution of vehicles by the four groups is shown in figure 1 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 behavior of over half of the vehicles was uninfluenced by other vehicles at the point of observation. Only 10 percent of the vehicles were uninfluenced at a volume of 800 vehicles per hour.

The percentage of vehicles that were meeting other

TABLE 2.—*Speed, placement, and volume of all traffic on two-lane level tangent sections of concrete pavements*

18-FOOT WIDTH

State	Route number	Study section number	Shoulders		Average volume	Number of vehicles			Average speed			Distance of left wheels from center line		
			Width	Type		Passenger cars	Trucks	Total	Passenger cars	Trucks	Total	Passenger cars	Trucks	Total
			Feet		*Vehicles per hr.*				*Miles per hr.*	*Miles per hr.*	*Miles per hr.*	*Feet*	*Feet*	*Feet*
Daytime:														
Illinois	U S 12	1	5	Grass	555	4,646	70	4,716	41.4	38.9	41.4	1.4	1.0	1.4
Minnesota	S R 100	2	6	Grass	117	311	57	368	38.8	36.6	38.5	1.3	1.4	1.3
	U S 10	3	6	Grass	383	1,300	41	1,341	43.7	40.4	43.6	1.4	1.3	1.4
Iowa	U S 30	4	8	Grass	165	1,457	214	1,671	49.5	40.3	48.3	1.4	1.4	1.4
	U S 30	5	8	Grass	173	1,478	255	1,733	47.0	40.4	46.0	1.2	1.0	1.2
Illinois	S R 13	6	10	Grass	323	819	711	1,530	40.0	34.0	37.2	1.4	1.2	1.3
Illinois	U S 14	7	5	Gravel	268	1,286	88	1,374	46.5	37.1	45.9	1.6	1.7	1.6
	U S 14	8	6	Gravel	440	2,549	51	2,600	44.5	38.1	44.4	1.3	1.5	1.3
Washington	U S 101	9	5	Gravel	121	662	126	788	42.5	38.0	41.8	1.6	1.8	1.6
Massachusetts [1]	S R 114	10	5–6	Gravel	230	1,043	113	1,156	39.1	35.8	38.8	.6	.3	.6
Texas	U S 81	11	6	Gravel	108	407	118	525	44.8	42.3	44.2	1.1	1.5	1.2
Illinois	U S 45	12	5	Bituminous	685	4,336	36	4,372	39.5	35.9	39.5	1.6	1.8	1.6
Iowa	U S 61	13	6	Bituminous	155	433	83	516	48.2	42.5	47.3	1.5	1.6	1.5
Texas	U S 81	14	2+12	Bituminous and caliche.	214	1,189	224	1,413	45.7	40.1	44.8	1.7	2.2	1.8
	U S 83	15	7	Clay	130	717	131	848	42.5	34.8	41.3	1.8	2.0	1.8
Nighttime:														
Illinois	U S 12	1	5	Grass	604	2,174	32	2,206	39.5	41.5	39.5	1.1	.6	1.1
Minnesota	U S 10	3	6	Grass	357	855	20	875	41.6	37.5	41.5	1.5	1.2	1.5
Iowa	U S 30	4	8	Grass	79	570	95	665	45.0	37.6	43.9	1.4	.9	1.3
Iowa	U S 30	5	8	Grass	68	506	105	611	44.3	40.5	43.7	1.6	.6	1.4
Texas	U S 81	11	6	Gravel	73	61	12	73	45.6	41.1	44.9	1.4	1.5	1.4
Iowa	U S 61	13	6	Bituminous	85	256	25	281	45.0	36.9	44.3	1.4	1.3	1.4

20-FOOT WIDTH

State	Route number	Study section number	Shoulders		Average volume	Number of vehicles			Average speed			Distance of left wheels from center line		
			Width	Type		Passenger cars	Trucks	Total	Passenger cars	Trucks	Total	Passenger cars	Trucks	Total
Daytime:														
Iowa	S R 60	16	4	Grass	112	645	187	832	38.4	35.2	37.7	1.6	1.6	1.6
Illinois	U S 12	17	5	Grass	580	4,081	104	4,185	35.0	33.2	35.0	1.8	2.0	1.8
Iowa	U S 169	18	6	Grass	74	702	142	844	50.6	41.5	49.1	1.4	1.6	1.4
Ohio	U S 62	19	6	Grass	128	468	75	543	46.0	40.7	45.3	1.2	1.1	1.2
Texas	U S 83	20	6	Grass	283	2,376	469	2,845	40.3	35.9	39.6	1.7	2.1	1.8
Iowa	U S 69	21	8	Grass	199	1,673	261	1,934	48.5	41.2	47.5	1.9	1.9	1.9
	U S 64	22	8	Grass	121	1,141	183	1,324	49.4	41.4	48.3	1.2	1.3	1.2
Minnesota	U S 12	23	[2] 8	Grass	361	1,193	22	1,215	41.0	35.6	40.9	1.8	2.2	1.8
	U S 169	24	8	Grass	131	310	51	361	49.1	40.7	47.9	1.0	1.5	1.1
	U S 169	25	8	Grass	108	169	37	206	42.4	41.3	42.2	1.6	2.0	1.7
	U S 12	26	8	Grass	488	1,356	24	1,380	37.0	34.4	37.0	1.6	1.8	1.6
Washington	U S 410	27	8–12	Grass	182	841	231	1,072	42.7	39.4	42.0	1.6	1.7	1.6
Illinois	S R 13	28	10	Grass	299	336	37	373	39.3	30.8	38.5	1.8	2.0	1.8
Texas	U S 75	29	10	Grass	180	953	219	1,172	43.9	37.3	42.7	1.6	2.0	1.7
Illinois	U S 34	30	5	Gravel	257	2,215	295	2,510	34.7	29.0	34.0	1.9	1.9	1.9
Texas	U S 81	31	6	Gravel	345	3,307	255	3,562	44.0	37.8	43.6	2.0	2.2	2.0
Washington	U S 99	32	8	Gravel	275	721	137	858	45.3	40.9	44.6	1.7	1.7	1.7
Massachusetts	S R 28	33	2	Bituminous	371	1,482	169	1,651	37.0	35.1	36.8	2.4	2.3	2.4
	S R 28	34	3	Bituminous	272	935	128	1,063	37.8	34.8	37.4	2.0	1.8	2.0
California	U S 99	35	6	Bituminous	249	3,876	985	4,861	44.9	39.6	43.8	2.2	2.1	2.2
Massachusetts	U S 44	36	2+4	Bituminous and gravel.	372	2,356	220	2,576	40.3	37.8	40.1	1.9	1.9	1.9
California	U S 40	37	2+8	do	629	6,288	353	6,641	40.0	38.6	39.9	2.4	2.2	2.4
Daytime, pavements with lip curbs:														
Iowa	U S 65	38	6	Grass	120	1,012	174	1,186	51.2	42.5	49.9	1.2	1.3	1.2
	U S 6	39	6	Grass	176	1,078	195	1,273	47.8	43.3	47.1	1.3	1.4	1.3
	S R 92	40	6	Grass	88	416	161	577	46.2	39.4	44.3	1.2	1.2	1.2
	U S 69	41	8	Grass	218	1,834	288	2,122	47.3	40.1	46.3	1.6	1.5	1.6
Ohio	U S 62	42	6	Grass	228	685	125	810	45.5	39.8	44.6	1.7	1.3	1.6
	S R 4	43	6	Grass	296	1,275	183	1,458	46.7	41.9	46.1	1.4	1.5	1.4
Nighttime:														
Iowa	S R 60	16	4	Grass	85	435	77	512	33.9	33.0	33.8	1.6	1.4	1.6
Illinois	U S 12	17	5	Grass	507	1,986	16	2,002	34.6	32.8	34.6	2.0	1.5	2.0
Iowa	U S 169	18	6	Grass	41	322	46	368	46.1	41.1	45.5	1.3	1.3	1.3
Ohio	U S 62	19	6	Grass	51	67	10	77	43.4	39.0	42.8	.8	1.1	.8
Texas	U S 83	20	6	Grass	201	414	35	449	41.8	36.3	41.4	1.8	2.2	1.8
Iowa	U S 69	21	8	Grass	85	556	78	634	42.2	40.1	41.9	1.8	1.1	1.7
	U S 64	22	8	Grass	56	402	97	499	45.2	40.6	44.3	.9	.7	.9
Minnesota	U S 12	23	[2] 8	Grass	469	1,283	21	1,304	42.1	37.5	42.0	1.7	2.4	1.7
	U S 169	24	8	Grass	96	272	33	305	49.2	39.8	48.2	1.1	1.5	1.1
	U S 169	25	8	Grass	51	153	42	195	41.1	37.3	40.3	1.3	1.2	1.3
	U S 12	26	8	Grass	237	694	11	705	41.8	34.9	41.7	1.5	1.5	1.5
Illinois	S R 13	28	10	Grass	265	409	23	432	40.9	36.0	40.6	1.8	1.6	1.8
Illinois	U S 34	30	5	Gravel	269	206	1	207	32.0	27.5	32.0	1.9	2.5	1.9
Texas	U S 81	31	6	Gravel	298	573	24	597	45.5	38.1	45.2	2.1	2.0	2.1
Massachusetts	U S 44	36	2+4	Bituminous and gravel.	588	942	17	959	34.8	36.3	34.8	1.7	2.6	1.7
Nighttime, pavement with lip curbs:														
Iowa	U S 65	38	6	Grass	65	206	40	246	48.1	42.2	47.1	1.0	.9	1.0
	U S 6	39	6	Grass	154	845	76	921	40.4	39.6	40.3	1.4	1.0	1.4
	S R 92	40	6	Grass	45	224	51	275	44.3	38.5	43.2	1.1	.5	1.0
	U S 69	41	8	Grass	161	851	115	966	43.4	39.4	42.9	1.6	1.1	1.5
Ohio	S R 4	43	6	Grass	161	140	21	161	41.9	34.9	41.0	1.4	.6	1.3

[1] No center-line markings.
[2] Eight feet of grass on one shoulder only. The other shoulder had 5 feet of bituminous mix and 3 feet of grass. Speed and placement were the same for both sides of road.

TABLE 2.—*Speed, placement, and volume of all traffic on two-lane level tangent sections of concrete pavements*—Continued

22-FOOT WIDTH

State	Route number	Study section number	Shoulders: Width	Shoulders: Type	Average volume	Number of vehicles: Passenger cars	Number of vehicles: Trucks	Number of vehicles: Total	Average speed: Passenger cars	Average speed: Trucks	Average speed: Total	Distance of left wheels from center line: Passenger cars	Distance of left wheels from center line: Trucks	Distance of left wheels from center line: Total
			Feet		*Vehicles per hr.*				*Miles per hr.*	*Miles per hr.*	*Miles per hr.*	*Feet*	*Feet*	*Feet*
Daytime:														
Maryland	S R 586	44	7	Gravel	170	387	38	425	45.8	40.5	45.3	2.2	2.1	2.2
Oregon	U S 99	45	8	Gravel	187	557	71	628	48.7	42.4	48.0	2.3	2.5	2.3
Maryland	U S 522	46	10	Clay	203	764	27	791	49.8	42.5	49.6	2.1	1.6	2.1
Nighttime:														
Maryland	S R 586	44	7	Gravel	96	290	1	291	48.0	45.0	48.0	1.8	1.5	1.8
	U S 522	46	10	Clay	126	273	41	314	47.5	39.0	46.4	2.0	1.6	1.9

24-FOOT WIDTH

State	Route number	Study section number	Shoulders: Width	Shoulders: Type	Average volume	Number of vehicles: Passenger cars	Number of vehicles: Trucks	Number of vehicles: Total	Average speed: Passenger cars	Average speed: Trucks	Average speed: Total	Distance of left wheels from center line: Passenger cars	Distance of left wheels from center line: Trucks	Distance of left wheels from center line: Total
Daytime:														
Illinois	U S 67	47	10	Grass	334	1,805	425	2,230	41.5	35.2	40.3	2.5	2.5	2.5

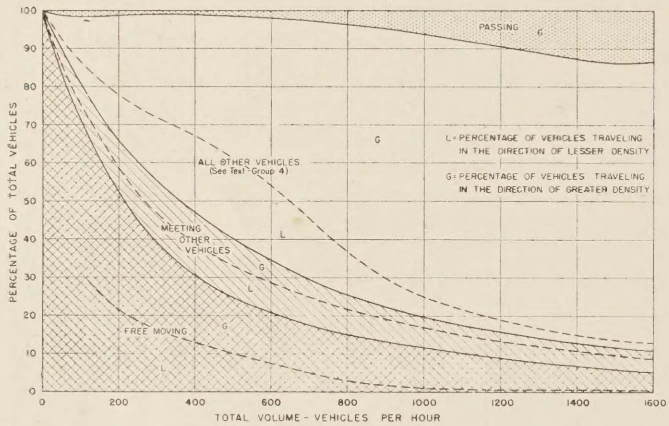


FIGURE 2.—DISTRIBUTION OF VEHICLES BY FREE-MOVING, MEETING, AND PASSING GROUPS ON TWO-LANE CONCRETE PAVEMENT WITH TRAFFIC PREDOMINANTLY HEAVY IN ONE DIRECTION (AVERAGE VOLUME IN DIRECTION OF LESS TRAVEL IS 120 VEHICLES PER HOUR).

vehicles, but were not within 6 seconds of the vehicle ahead, gradually increased with volume. Percentage of passings was highest 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, had to be traveling within 1 second 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.

Figure 2 shows a road where traffic was predominantly heavy in one direction of travel. The number of free-moving vehicles did not decrease as rapidly as on roads with the volume evenly distributed in the two directions. The percentage of meeting vehicles, as defined in this report, was highest at a volume of about 400 vehicles per hour. Fourteen percent of the vehicles were within 1 second 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.

At the higher volumes the majority of the vehicles are included in group 4, and data on them could not be used

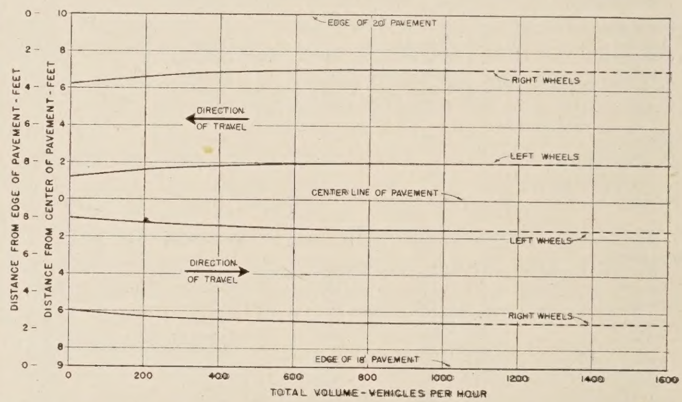


FIGURE 3.—EFFECT OF VOLUME ON TRANSVERSE POSITION OF ALL PASSENGER CARS ON 18- AND 20-FOOT CONCRETE PAVEMENTS WITH GRASS SHOULDERS.

to study the effect of different cross sections on vehicle behavior because so many factors influenced their position on the highway. There were, however, few sections with a traffic volume in excess of 400 vehicles per hour.

TRAFFIC VOLUME AFFECTS TRANSVERSE POSITION OF VEHICLES

The effect of volume on speeds of vehicles has been definitely determined from extensive research on highway capacity.[3] In this report analysis is directed primarily toward 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-foot pavements is shown by figure 3. As the traffic on an 18-foot pavement (lower half of figure) increased to a volume of 700 vehicles per hour the average distance of the left wheels of passenger cars from the center of the pavement also increased until it became 1.8 feet. A further increase in density had no effect on the average position of the car. On the 20-foot pavement (upper half of figure) the rate of change in the position of the average vehicle with volume was the same as on the 18-foot pavement. At least two-thirds of the added pavement width was utilized to increase edge clearance.

Figure 4 shows the effect of traffic volume on the transverse positions of free-moving and meeting vehicles on 18-foot concrete pavement flanked by grass shoul-

[3] Results of Highway-Capacity Studies, by O. K. Normann, PUBLIC ROADS June 1942, also Highway Research Board Proceedings, 1941.

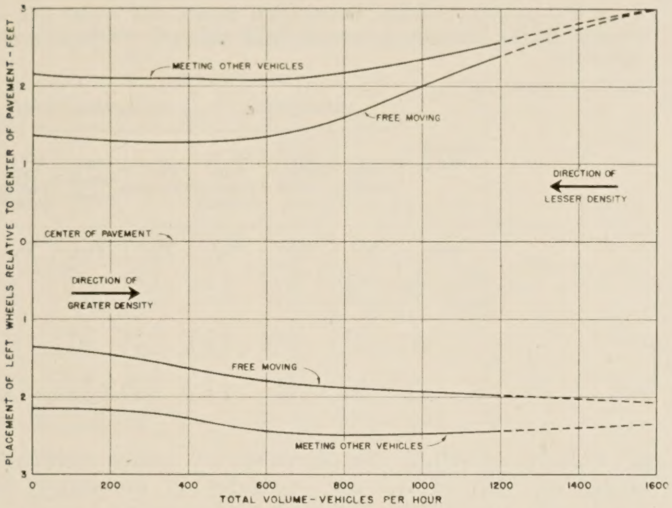


Figure 4.—Effect of Volume on Transverse Placement of Free-Moving and Meeting Vehicles on 18-foot Concrete Pavement With Grass Shoulders, Average Density in Direction of Lesser Movement, 120 Miles per Hour.

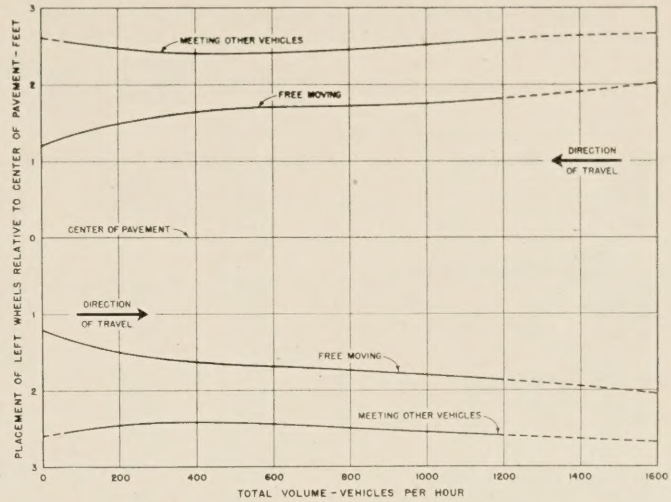


Figure 5.—Effect of Volume on Transverse Placement of Free-Moving and Meeting Vehicles on 20-foot Concrete Pavement With Grass Shoulders. Traffic Evenly Distributed in Each Direction of Travel.

ders. In this example traffic in the direction of lesser movement remained approximately uniform at 120 vehicles per hour, while that in the direction of greater movement increased. In the direction of heavier travel, the distance of the left wheels of the average free-moving vehicle from the center of the pavement increased from 1.5 to 2 feet, a change of five-tenths foot to the right, as the total volume increased from 200 to 1,200 vehicles per hour. Meeting vehicles altered their average position only three-tenths foot.

Free-moving vehicles in the direction of lesser movement shifted their position to the right, as the total volume increased, more than twice as much as the vehicles in the denser traffic stream, and during higher total 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. Drivers shifted their vehicles from the free-moving position to the meeting position more frequently as the traffic density increased until 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 meeting vehicles in the direction of lesser movement traveled with their left wheels 2.4 and 2.6 feet, respectively, from the center of the pavement.

The effect of volume on the transverse placement of free-moving and meeting vehicles on a 20-foot concrete pavement with traffic evenly distributed in each direction of travel is shown by figure 5. With an increase in volume from 200 to 1,200 vehicles per hour, free-moving vehicles moved to the right four-tenths foot, while meeting vehicles changed their transverse position only slightly as the volume increased.

SPEED UNAFFECTED BY PAVEMENT WIDTH

In an effort to determine the effect of pavement width on vehicle speed and the relation between the speed of a 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 3 shows comparable speeds for two-lane roads having different pavement widths segregated according to vehicle classification and shoulder type for day and night operation.

Table 3.—*Average speeds on two-lane concrete roads*

DAYTIME

Vehicle type and traffic condition	18-foot pavement			20-foot pavement				22-foot pavement, gravel shoulder	24-foot pavement, grass shoulder
	Grass shoulder	Gravel shoulder	Bituminous shoulder	Grass shoulder: Lip curb	Grass shoulder: No curb	Gravel shoulder	Bituminous shoulder		
	Miles per hour	*Miles per hour*	*Miles per hour*	*Miles per hour*	*Miles per hour*	*Miles per hour*	*Miles per hour*	*Miles per hour*	*Miles per hour*
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

Vehicle type and traffic condition	18-foot: Grass shoulder	18-foot: Gravel shoulder	18-foot: Bituminous shoulder	20-foot: Lip curb	20-foot: No curb	20-foot: Gravel shoulder	20-foot: Bituminous shoulder	22-foot pavement, gravel shoulder	24-foot pavement, grass shoulder
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	(1)	59.2	53.5	49.2	47.3	44.2	(1)	------
Being passed	37.0	(1)	39.2	33.8	37.0	34.8	32.5	(1)	------
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	(1)	(1)	50.2	46.5	(1)	(1)	(1)	------
Being passed	34.0	(1)	(1)	35.2	34.4	(1)	(1)	(1)	------
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	------

[1] Sample inadequate.

TABLE 4.—*Average speeds on pavements of various widths*

Type of vehicle and pavement width	Free-moving vehicles	Vehicles meeting oncoming traffic	All, except passing vehicles
	Miles per hour	*Miles per hour*	*Miles per hour*
Passenger cars during day:			
18 feet	44.9	43.4	43.7
20 feet	43.5	44.2	43.6
22 feet	48.1	48.9	48.3
24 feet	43.4	41.1	41.7
Total	44.4	44.3	44.0
Commercial vehicles during day:			
18 feet	38.5	39.1	38.5
20 feet	37.5	38.2	36.8
22 feet	40.6	45.9	41.8
24 feet	36.0	34.4	35.1
Total	38.1	39.1	37.8
Passenger cars at night:			
18 feet	45.2	43.6	43.5
20 feet	44.9	41.5	41.9
22 feet	47.9	47.8	47.7
Total	45.3	42.6	42.8
Commercial vehicles at night:			
18 feet	40.6	39.5	39.3
20 feet	37.7	38.4	36.0
22 feet	42.5	42.4	42.0
Total	38.8	39.0	37.4

Table 4 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 two-lane highways, pavement width apparently had no consistent effect on the average speeds of either the free-moving vehicles or those meeting oncoming traffic. It is interesting to note that the speed of the average driver is practically the same when meeting an oncoming vehicle as when uninfluenced by other vehicles. Evidently, drivers do not consider it necessary to reduce speed when approaching and meeting opposing traffic. Speeds at night are practically the same as daytime speeds.

TABLE 5.—*Average distance between left wheels and center line of typical 20-foot concrete pavements with different widths 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	Commercial vehicles: All, except passing vehicles
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Iowa	4	1.5	2.7	1.7	1.4	2.4	1.6
	6	1.4	2.6	1.5	1.6	2.2	1.6
	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
	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
	10	1.6	2.5	1.8	1.8	2.6	2.0

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 as implication 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 relation could be found between the speed of the vehicle and its trans-

TABLE 6.—*Average transverse placement of vehicles and clearance between meeting vehicles on two-lane concrete roads*

Vehicle classification	18-foot pavement: Grass shoulder	18-foot pavement: Gravel shoulder	18-foot pavement: Bituminous shoulder	20-foot pavement: Grass shoulder, Lip curb	20-foot pavement: Grass shoulder, No curb	20-foot pavement: Gravel shoulder	20-foot pavement: Bituminous shoulder	22-foot pavement: Gravel shoulder	24-foot pavement: Grass shoulder
DISTANCE OF LEFT WHEEL FROM CENTER LINE DURING THE DAY									
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
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
DISTANCE OF LEFT WHEEL FROM CENTER LINE AT NIGHT									
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	.8	1.4	1.1	.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	[1]	[1]	1.8	2.0	2.5	[1]	[1]	----------
All, except passing	1.0	1.5	1.3	.8	1.5	2.2	2.6	1.6	----------
CLEARANCE BETWEEN BODIES OF MEETING VEHICLES DURING DAY									
Passenger cars meeting passenger cars	3.2	3.2	4.0	3.6	4.0	4.2	5.0	4.8	5.2
Passenger cars and trucks or busses meeting	2.6	2.7	3.2	3.0	3.4	3.4	4.3	4.5	4.8
Trucks or busses meeting trucks or busses	1.1	2.5	3.0	3.4	3.0	3.0	3.0	3.8	4.0
CLEARANCE BETWEEN BODIES OF MEETING VEHICLES AT NIGHT									
Passenger cars meeting passenger cars	3.3	3.0	3.6	4.3	3.9	4.3	4.8	4.5	----------
Passenger cars and trucks or busses meeting	2.3	2.5	3.0	2.9	2.9	4.0	4.5	3.9	----------
Trucks or busses meeting trucks or busses	1.5	[1]	[1]	1.6	2.1	3.0	[1]	[1]	----------

[1] Sample inadequate.

TABLE 7.—*Transverse placements of wheels and clearances between bodies of vehicles involved in passing maneuvers on two-lane concrete roads* [1]

Vehicle classification	Daytime									Nighttime						
	18-foot pavement			20-foot pavement				22-foot pavement	24-foot pavement	18-foot pavement			20-foot pavement			
	Grass shoulder	Gravel shoulder	Bituminous Shoulder	Grass shoulder		Gravel shoulder	Bituminous shoulder	Gravel shoulder	Grass shoulder	Grass shoulder	Gravel shoulder	Bituminous shoulder	Grass shoulder		Gravel shoulder	Bituminous shoulder
				Lip curb	No curb								Lip curb	No. curb		
PASSENGER CARS PASSING PASSENGER CARS[1]																
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Passing passenger car	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 passenger car	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
PASSENGER CARS PASSING TRUCKS OR BUSSES[2]																
Passing passenger car	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 trucks or busses	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	(3)	(3)	.8	2.3	(3)	(3)
TRUCKS OR BUSSES PASSING PASSENGER CARS[2]																
Passing trucks or busses	1.2	1.5	.8	1.9	1.3	1.0	1.3	-	-	-	-	-	-	-	-	-
Passed passenger car	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	(3)	(3)	-	-	-	-	-	-	-
TRUCKS OR BUSSES PASSING TRUCKS OR BUSSES[2]																
Passing trucks or busses	3.0	1.5	1.3	2.5	1.2	-	1.3	-	-	-	-	-	-	-	-	-
Passed trucks or busses	1.0	1.5	1.9	1.5	2.5	-	2.0	-	-	-	-	-	-	-	-	-
Body clearance	2.0	1.0	1.2	2.0	1.7	(3)	1.3	(3)	(3)	-	-	-	-	-	-	-

[1] Passing vehicle within 1 second of passed vehicle.
[2] 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.
[3] Sample inadequate.

verse position on the highway at most of the observation points. At a few of the locations those drivers of free-moving passenger cars that maintained the higher speeds traveled somewhat closer to the center line of the highway than did drivers of slower moving vehicles. However, the difference between the transverse positions of vehicles in the fastest speed group and the slowest speed group was of small magnitude, generally below five-tenths foot. 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 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.

SHOULDER WIDTH IN EXCESS OF FOUR FEET DOES NOT AFFECT TRANSVERSE POSITION OF VEHICLES

While the field studies were in progress, a number of adjacent sections of road carrying the same traffic and having identical design features except for the shoulder width and type were selected for study to determine the effect of these variables on the average transverse position of vehicles.

Table 5 shows that comparable placement values for sections with 4- to 10-foot grass shoulders are practically identical. Shoulder width in excess of 4 feet does not seem to 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 assumed was the same for both directions of travel. In no case were there any vertical obstructions immediately adjacent to the outside of the shoulder.

The fact that the portion of a shoulder more than 4 feet from the pavement edge does not affect the transverse position of vehicles has no relation to the need for providing shoulder of a width adequate to accommodate standing or moving vehicles entirely off the pavement in emergency.

Tables 6 and 7 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 shoulders and bituminous shoulders were included to permit an analysis of the relative effect of such shoulders on the transverse positions of vehicles on concrete pavements 18 and 20 feet wide.

Table 8 shows, for each vehicle classification and for two surface widths, the difference between the average driver's position on a highway with grass shoulders and his position on a highway with gravel shoulders. A minus value is shown when the average driver traveled closer to the grass than to the gravel shoulder.

The table shows that the difference in placements for grass and gravel shoulders did not exceed one-tenth foot for 21 out of a total of 34 values representing the various vehicle classifications and the two surface widths. Most of the differences greater than one-tenth foot are for commercial vehicles or vehicles involved

Table 8.—*Difference between the transverse positions of vehicles on sections with grass and with gravel shoulders during day*

DIFFERENCE BETWEEN DISTANCES THAT VEHICLES WERE FROM RIGHT-HAND SHOULDERS [1]

Vehicle classification	18-foot surface	20-foot surface
Passenger cars:	*Feet*	*Feet*
Free moving	0.1	0.4
Meeting other passenger cars	0	.1
Meeting trucks or busses	.1	.1
Passing other passenger cars	−.1	0
Passing trucks or busses	.2	−.5
Being passed by other passenger cars	0	0
All, except those passing other vehicles	0	.3
Trucks and busses:		
Free moving	.3	.2
Meeting passenger cars	0	−.1
Meeting other trucks or busses	(2)	0
Being passed by passenger cars	.5	0
All, except those passing other vehicles	.4	.1

DIFFERENCE BETWEEN CLEARANCES OF VEHICLE BODIES [1]

Vehicle classification	18-foot surface	20-foot surface
Passenger cars meeting other passenger cars	0	0.2
Passenger cars and trucks or busses meeting	.1	0
Passenger cars passing other passenger cars	.1	0
Passenger cars passing trucks or busses	.3	.5
Trucks or busses meeting other trucks or busses	(2)	0

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

Table 9.—*Effect of bituminous shoulders and effect of increase in surface width on the transverse position of vehicles*

INCREASE IN THE DISTANCE BETWEEN VEHICLE AND CENTER LINE OF HIGHWAY

Vehicle classification	Bituminous shoulders compared with grass and gravel shoulders		Effect of increase in surface width on sections with grass or gravel shoulders	
	18-foot surface width	20-foot surface width	20-foot surface compared with 18-foot surface	22-foot surface compared with 20-foot surface
Passenger cars:	*Feet*	*Feet*	*Feet*	*Feet*
Free moving	0.3	0.7	0.2	0.2
Meeting other passenger cars	.4	.5	.4	.3
Meeting trucks or busses	.1	.7	.3	.5
Passing other passenger cars [1]	0	−.5	.4	.7
Passing trucks or busses [1]	.2	.4	−.4	−.5
Being passed by other passenger cars	0	.6	.2	.3
All, except those passing other vehicles	.3	.7	.2	.2
Trucks or busses:				
Free moving	.3	.3	.3	.2
Meeting passenger cars	.5	.2	.5	.6
Meeting other trucks or busses	.7	0	.7	.4
Being passed by passenger cars	.5	.1	.4	.6
All, except those passing other vehicles	.5	.3	.4	.2

INCREASE IN CLEARANCE BETWEEN VEHICLE BODIES

Vehicle classification	18-foot surface width	20-foot surface width	20-foot surface compared with 18-foot surface	22-foot surface compared with 20-foot surface
Passenger cars meeting other passenger cars	0.8	1.0	0.8	0.6
Passenger cars and trucks or busses meeting	.6	.9	.8	1.1
Passenger cars passing other passenger cars	0	.1	.6	1.0
Passenger cars passing trucks or busses	.7	.5	0	.1
Trucks or busses meeting other trucks or busses	1.4	0	1.4	.8

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

in passing maneuvers which were represented by smaller samples than the other classifications.

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

On highways with bituminous shoulders, the average driver traveled closer to the right-hand shoulder than on highways with grass or gravel shoulders. To evaluate this increase in the effective pavement width, table 9 has been prepared.

Table 10.—*Effect of lip curbs on the transverse positions of vehicles on 20-foot pavements with grass shoulders*

DIFFERENCE IN DISTANCE BETWEEN VEHICLE BODIES AND THE HIGHWAY CENTER LINE

Vehicle classification	20-foot pavement without curbs compared with 20-foot pavement with lip curbs	20-foot pavement compared with 18-foot pavement (both without curbs)
Passenger cars:	*Feet*	*Feet*
Free moving	0.2	0.1
Meeting other passenger cars	.2	.4
Meeting trucks or busses	0	.3
Passing other passenger cars	.3	.4
Passing trucks or busses	.3	−.6
Being passed by other passenger cars	.3	.2
All, except those passing other vehicles	.2	.2
Trucks and busses:		
Free moving	.4	.4
Meeting passenger cars	.4	.5
Meeting other trucks or busses	−.2	1.0
Being passed by passenger cars	.4	.2
All, except those passing other vehicles	.4	.6

DIFFERENCE IN CLEARANCE BETWEEN VEHICLE BODIES

Vehicle classification	20-foot pavement without curbs compared with 20-foot pavement with lip curbs	20-foot pavement compared with 18-foot pavement (both without curbs)
Passenger cars meeting other passenger cars	0.4	0.8
Passenger cars and trucks or busses meeting	.4	.8
Passenger cars passing other passenger cars	.6	.6
Passenger cars passing trucks or busses	.1	0
Trucks or busses meeting other trucks or busses	−.4	1.9

Comparable values are shown for the effect that bituminous shoulders have on the transverse positions of vehicles and the effect that 2-foot wider surfaces have on the transverse positions. For example, the average driver of a free-moving passenger car traveled three-tenths foot farther to the right of the center line on 18-foot surfaces when there were bituminous shoulders than when the shoulders were grass or gravel. On highways with grass or gravel shoulders, he traveled two-tenths foot farther to the right of the center line when the surface width was 20 feet than he did when the surface width was 18 feet. The bituminous shoulder on the 18-foot surface had a greater effect on the transverse position of the free-moving passenger cars than an increase in surface width of 2 feet. Likewise, bituminous shoulders instead of grass or gravel shoulders improved the transverse position of free-moving passenger cars on 20-foot surfaces to a greater extent than did increasing surface width from 20 to 22 feet with grass or gravel shoulders. Also, bituminous shoulders induced as much increase in clearance between passenger cars meeting other passenger cars as did an increase of 2 feet in surface width.

Results of similar comparisons between the effect of bituminous shoulders and the effect of wider surfaces on the transverse position of vehicles under other traffic conditions are not always consistent, especially for those conditions represented by small samples. In general, however, bituminous shoulders at least 4 feet wide adjacent to 18- and 20-foot surfaces increased the effective surface widths during the day approximately 2 feet.

None of the pavements wider than 20 feet had bituminous shoulders, and comparatively little data were recorded at night on the 18- and 20-foot surfaces. An analysis of the daytime data and the limited nighttime data for 18- and 20-foot surfaces does indicate, however,

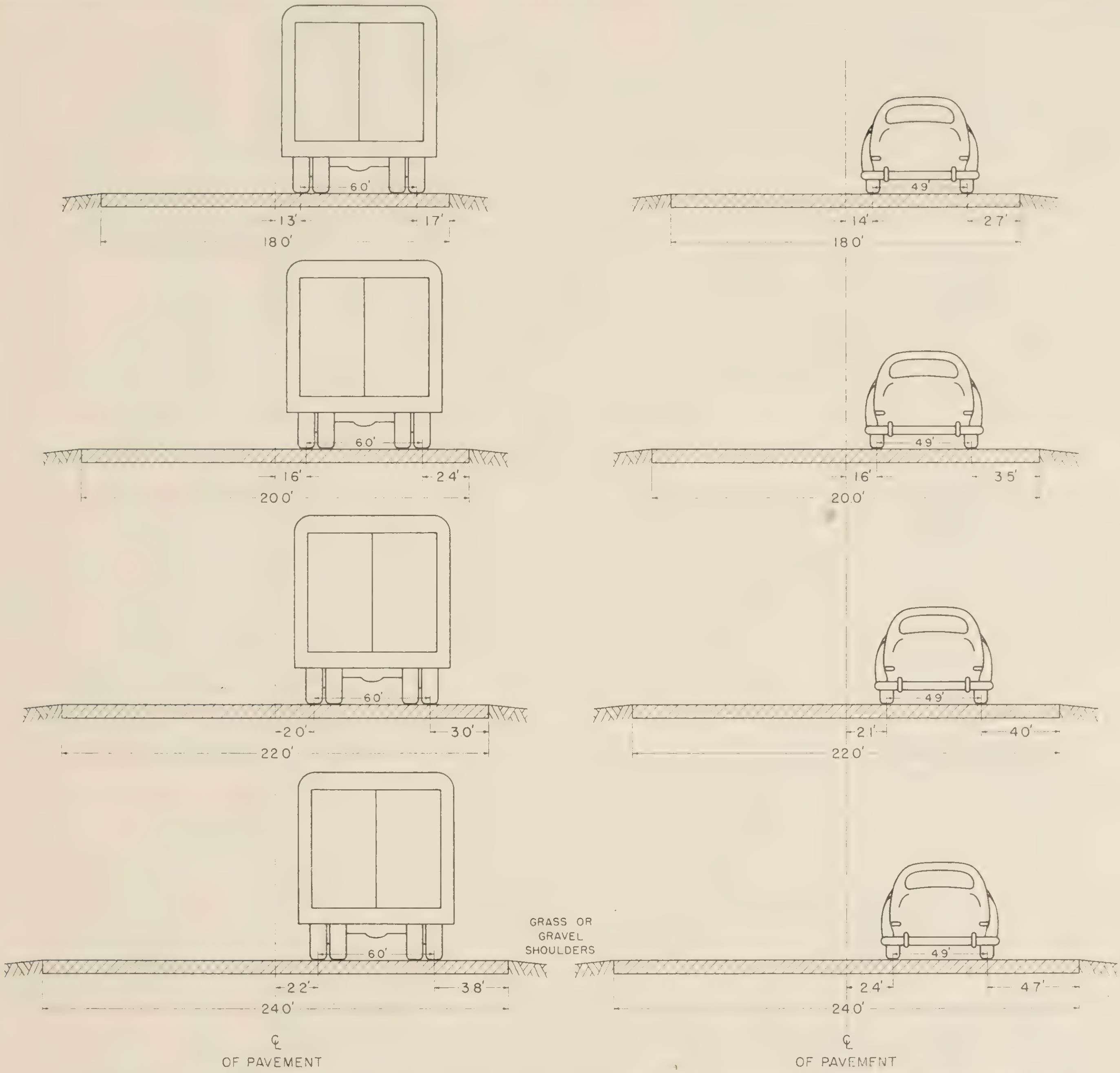


Figure 6.—Average Position of Free-Moving Vehicles on Two-Lane Concrete Pavements During the Day.

that bituminous shoulders increase the effective pavement width as much at night as during the day; and their effect on transverse positions of moving vehicles for the wider surfaces is somewhat less than for the narrower surfaces.

LIP CURBS REDUCE EFFECTIVE WIDTH

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

Table 10 shows the effect of lip curbs on the transverse positions of vehicles on 20-foot pavements with grass shoulders for day operation. Vehicles under nearly all conditions traveled closer to the center of highways with lip curbs than on sections without lip curbs. The average reduction in distance from the center due to lip curbs was two-tenths foot for passenger cars and four-tenths foot for commercial vehicles. These differences are similar but somewhat less than those found when placements on 20-foot pavements without curbs were compared with placements on 18-foot pavements without curbs.

It may be noted that under some traffic conditions, the lip curbs had an effect the same as or greater than that of a reduction of 2 feet in pavement width. On an average, however, especially for the more important conditions that govern pavement width, including meeting vehicles, the effect of lip curbs is about half as great as that of a reduction of 2 feet in

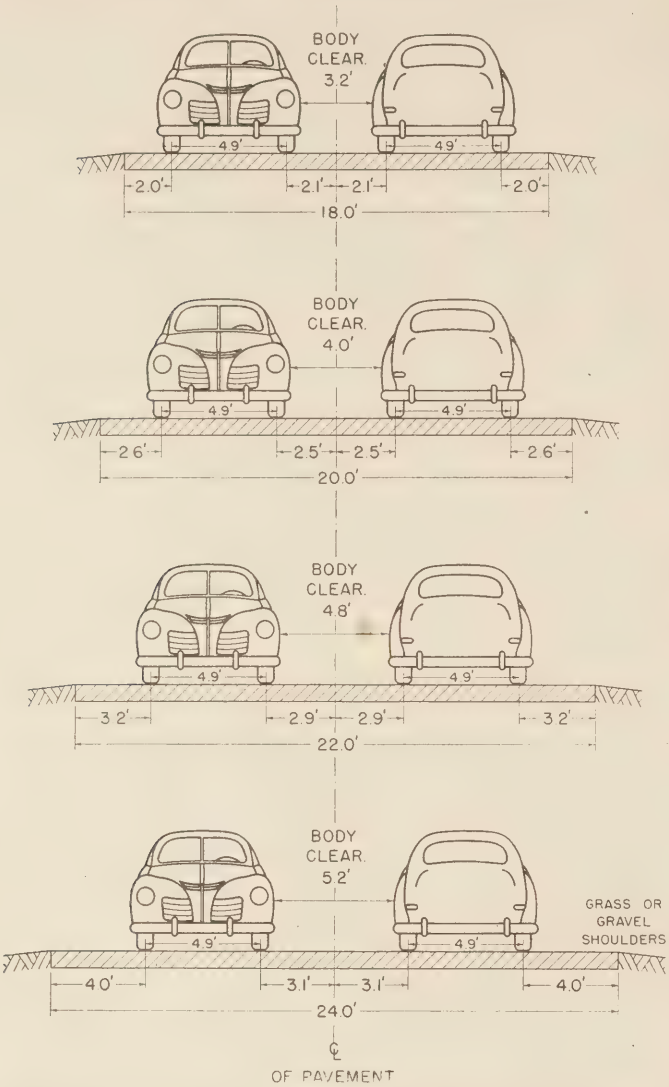


Figure 7.—Average Position of Passenger Cars Meeting Passenger Cars on Two-Lane Concrete Pavements During the Day.

surface width. During the day, lip curbs reduce the effective pavement width approximately 1 foot.

Comparative data show that curbs affect the transverse position of commercial vehicles at night as much as during the day. Lip curbs apparently do not have any appreciable effect on the transverse position of passenger cars at night.

POSITION OF VEHICLES ON SURFACES OF VARIOUS WIDTH DETERMINED

Free-moving vehicles.—Figure 6 shows the average position of free-moving vehicles on two-lane concrete pavements during the day. In figure 6 and all the succeeding figures and tables the values shown are the average vehicle placements for highway sections with grass or gravel shoulders. This procedure is possible because the previous analysis showed no measurable difference between operating on pavements with grass shoulders and those with gravel shoulders.

Figure 6 shows values for passenger cars on the right and on the left are the values for commercial vehicles. The average width of bodies of passenger cars as obtained from measurements of various makes and models of cars was found to be 6 feet. A width of 8 feet for bodies of commercial vehicles is used. The tread widths (distance between centers of wheels) of 4.9 feet for passenger cars and 6 feet for trucks and busses were determined from the wheel placements recorded in this study.

Free-moving passenger cars and commercial vehicles steadily increase their distances from the center of the pavement as width of pavement increases. The added width provided by a 20-foot over an 18-foot pavement is utilized by drivers of free-moving passenger cars almost entirely to increase their distance from the pavement edge, while the distance from the center of the pavement increases only two-tenths foot or to a value of 1.6 feet. The added widths provided by 22- and 24-foot surfaces, however, are utilized to increase the distance from the center as well as from the edge. Drivers of commercial vehicles utilize the added widths more to increase the distance from the edge than to increase their distance from the center as pavements wider than 18 feet are traveled. For each foot of added lane width, drivers of commercial vehicles, on the average, increase the distance from the edge by seven-tenths foot and from the center by three-tenths foot.

Apparently, drivers judge the position of their vehicles when uninfluenced by other traffic, by distance from the center line, since this distance is about the same for both passenger cars and commercial vehicles on pavements of the same width. The narrower tread results in greater edge clearance for passenger cars than for trucks. Drivers of passenger cars keep the centers of their vehicles approximately 1 foot to the left of the center of their lane, while drivers of commercial vehicles keep the centers of their vehicles about five-tenths foot to the left. The distance between the center of the vehicle and the center of the lane increases, however, as wider pavements are traveled.

Passenger cars meeting passenger cars.—Figure 7 shows the average position of passenger cars meeting other passenger cars during the day. These vehicles travel approximately in the center of their respective lanes on the 18- and 20-foot pavements. On 18-foot surfaces drivers allow a wheel-track distance of 2 feet from the edge and 2.1 feet from the center of the road, thus allowing a body clearance between vehicles of 3.2 feet. When 20- and 22-foot pavements are traveled, the added width is used to increase both the clearance between vehicles and the distance from the edge. However, the additional pavement width provided by a 24-foot surface is used almost entirely to increase the distance from the edge. This indicates that the desired clearance between bodies of meeting passenger cars is about 5 feet, since this clearance is nearly obtained on 22-foot surfaces and does not increase materially on 24-foot surfaces.

Passenger cars meeting commercial vehicles.—Figure 8 shows the average position of passenger cars and commercial vehicles when meeting. The fact that passenger cars on 18- and 20-foot pavements do not move to the right to allow greater clearance when meeting commercial vehicles than when meeting passenger cars is a strong indication that even 20-foot roads are entirely too narrow when there is considerable truck traffic. Average body clearances of 2.6 and 3.5 feet for passenger cars meeting commercial vehicles on 18- and 20-foot pavements, respectively, appear to be inadequate for safety. An analysis of the distribution of vehicle clearances showed that clearance was 1 foot or less for 12 percent of meetings on 18-foot pavement and for 5 per-

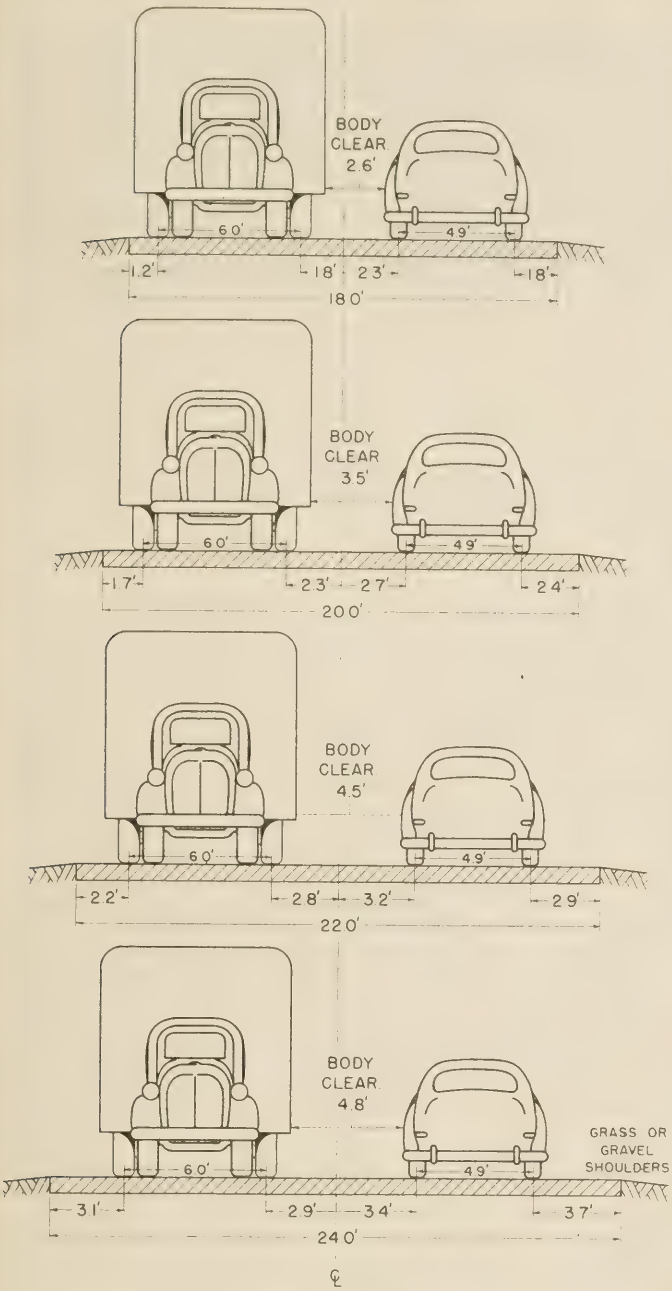


Figure 8.—Average Position of Passenger Cars and Commercial Vehicles Meeting on Two-Lane Concrete Pavements During the Day.

cent of those on 20-foot pavements. Clearances of 2 feet or less were allowed by 47 percent of the drivers on 18-foot pavements and by 11 percent on 20-foot pavements.

The influence exerted by passenger cars on the transverse position of vehicles traveling in the opposite direction is shown by figure 9. On the 18-foot pavement, when passenger cars meeting other vehicles travel 1 foot 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 feet to the right of the center line. This allows a clearance of only seven-tenths foot between the bodies of the meeting vehicles. Similarly, on a 20-foot pavement, when passenger cars that encroach on the left lane meet other vehicles, the body clearances are only about 1 foot.

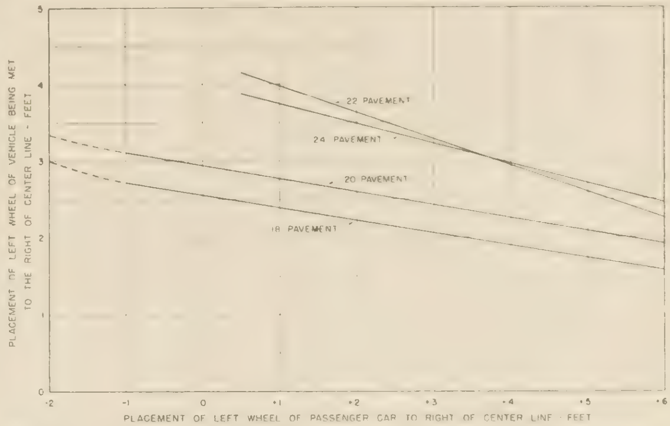


Figure 9.—Effect of Transverse Position of Passenger Cars on the Position of the Meeting Vehicles—Concrete Pavement With Grass or Gravel Shoulders.

Such clearances are entirely inadequate for safe operation.

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

Commercial vehicles meeting commercial vehicles.—Figure 10 shows the average position of commercial vehicles when meeting other commercial vehicles during the day. Eighteen-foot pavements are so inadequate for these wide vehicles that the average body clearance is only 1.6 feet.

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

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 edge and, except when traffic volumes are large, there is always a definite difference between the position of free-moving vehicles and that of meeting vehicles. The body and edge clearances for meeting vehicles or perhaps for passing vehicles are, therefore, the critical factors that determine adequate pavement width.

The relation between the position of meeting vehicles and the pavement width on straight, level sections of highway is shown in figure 11. The curve for commercial vehicles meeting other commercial vehicles shows that they travel closer to the center of the lane on 18-foot than on 20-foot pavements. The drivers have no other choice if they wish to maintain some edge clearance. On 24-foot pavements they travel in the center of the lane, apparently satisfied with both edge and center clearance.

If it is assumed that the pavement is of adequate width when meeting vehicles travel in the centers of

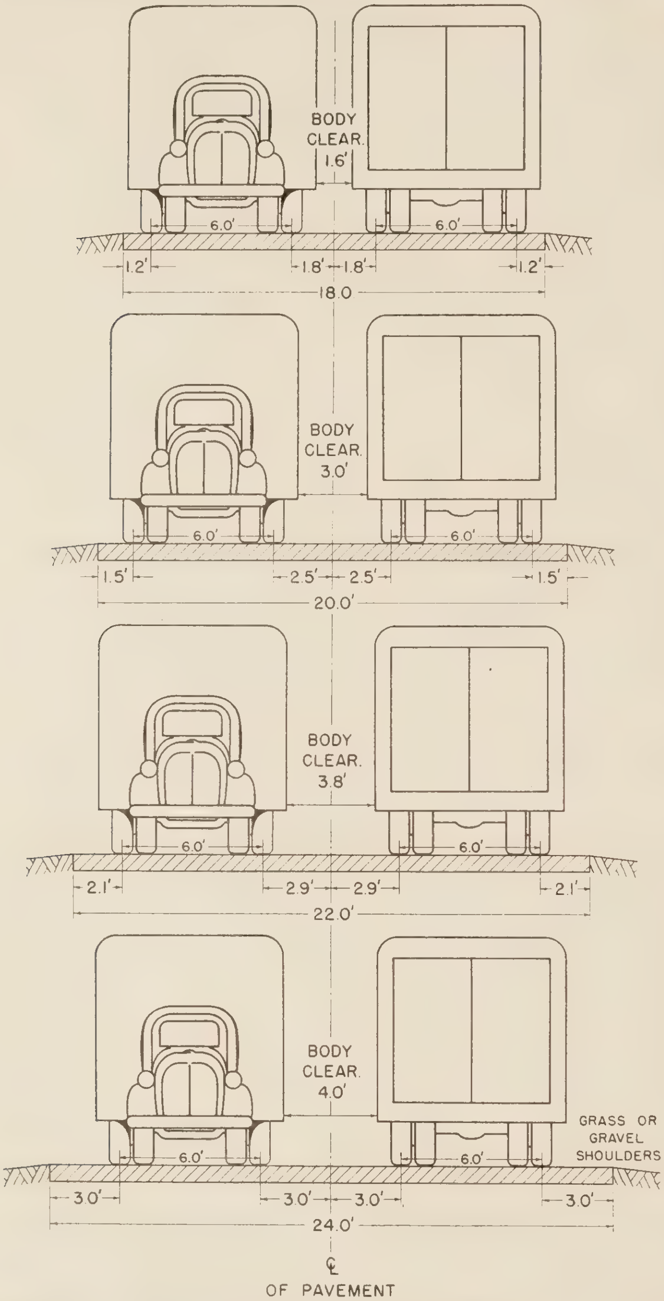


FIGURE 10.—AVERAGE POSITION OF COMMERCIAL VEHICLES WHEN MEETING COMMERCIAL VEHICLES ON TWO-LANE CONCRETE PAVEMENTS DURING THE DAY.

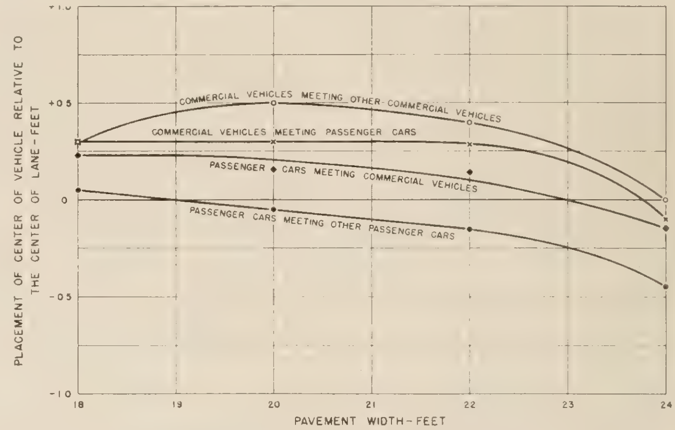


FIGURE 11.—EFFECT OF PAVEMENT WIDTH ON THE POSITION OF VEHICLES MEETING OTHER VEHICLES TRAVELING IN THE OPPOSITE DIRECTION.

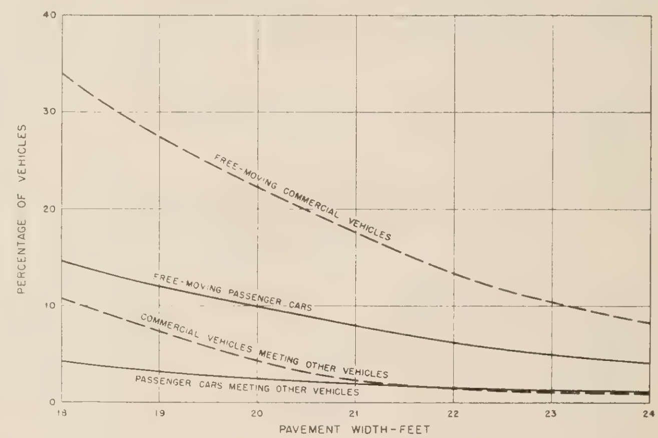


FIGURE 12.—PERCENTAGE OF VEHICLES WITH THEIR BODIES EXTENDING TO THE LEFT OF HIGHWAY CENTER LINE.

TABLE 11.—*Percentage of vehicles that travel on shoulder when meeting other vehicles during periods of light traffic*

Pavement width	Pavement with grass or gravel shoulders		Pavement with bituminous shoulders	
	Passenger cars	Commercial vehicles	Passenger cars	Commercial vehicles
	Percent	*Percent*	*Percent*	*Percent*
18 feet	0.2	5.5	4.7	17.3
20 feet	.1	1.4	1.9	6.5

their respective lanes, a 19-foot pavement is adequate during the day for traffic consisting only of passenger cars; a 23-foot pavement is adequate for the passenger cars when there is mixed traffic; and a 24-foot pavement is adequate for commercial vehicles. If provision is to be made for a majority of the drivers rather than for the average driver, wider surfaces would be needed.

From figures 7 and 8, however, it is apparent that drivers of passenger cars are not satisfied with the clearances permitted by a 19-foot pavement, when meeting other passenger cars. Instead they desire either a body clearance of about 5 feet, or a clearance between their left wheels and the center line of about 3 feet. These clearances cannot be attained until the pavement width reaches 22 feet.

If, then, it is assumed that a 22-foot pavement represents a desirable width for traffic consisting entirely of passenger cars, it can be found from figure 11 that the corresponding width for mixed traffic is 24 feet, and for traffic including a high percentage of commercial vehicles a slightly greater width is desirable.

To illustrate further driver behavior on different width surfaces, the percentages of vehicles that encroach in the lane for oncoming traffic and the vehicles that travel on the shoulder are shown by figure 12 and table 11, respectively.

On 18-foot pavements, 34 percent of the drivers of trucks and 15 percent of the drivers of passenger cars encroach on the left lane when uninfluenced by other traffic. When meeting oncoming vehicles, a surprisingly large number, 11 percent of the drivers of trucks and 5 percent of the drivers of passenger cars, fail to keep their vehicles within the proper traffic lane. These percentages decrease rapidly with an increase in pavement width. Only 1 percent of the vehicles encroach

Passenger Car Overtaking and Passing Other Passenger Car on a 22-foot Highway.

on the left lane when meeting other vehicles on 24-foot pavements.

The need of pavements wider than 20 feet 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 11).

PASSING VEHICLES DO NOT REQUIRE GREATER PAVEMENT WIDTH

Although relatively few vehicles are engaged in passing maneuvers at any one point on a two-lane highway, passing is an essential feature of two-lane highway operation. The position that the average driver of passenger cars assumes when overtaking and passing other vehicles is shown in figures 13 and 14. Included are only those passing vehicles that were definitely known to be approximately abreast of the vehicle being passed when lateral position was recorded.

Figure 13 shows the average positions of passenger cars when passing other passenger cars during the day. The average clearance between the vehicles increases from 2.3 feet on an 18-foot pavement to 4.8 feet on a 24-foot pavement. These values are from 0.7 to 1.4 feet 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 gages his transverse position by the center of the roadway. As soon as the right wheels of his vehicle are about 1.5 feet 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 five-tenths foot to the right of his free-moving position.

Figure 14 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 passed. The clearance between a passenger vehicle passing a commercial vehicle is also less than when these vehicles meet one another traveling in opposite directions on pavements of the same width.

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

VEHICLES AVOID USE OF SHOULDERS AT NIGHT

At night, free-moving passenger cars travel farther from the edge of the pavement than in the daytime

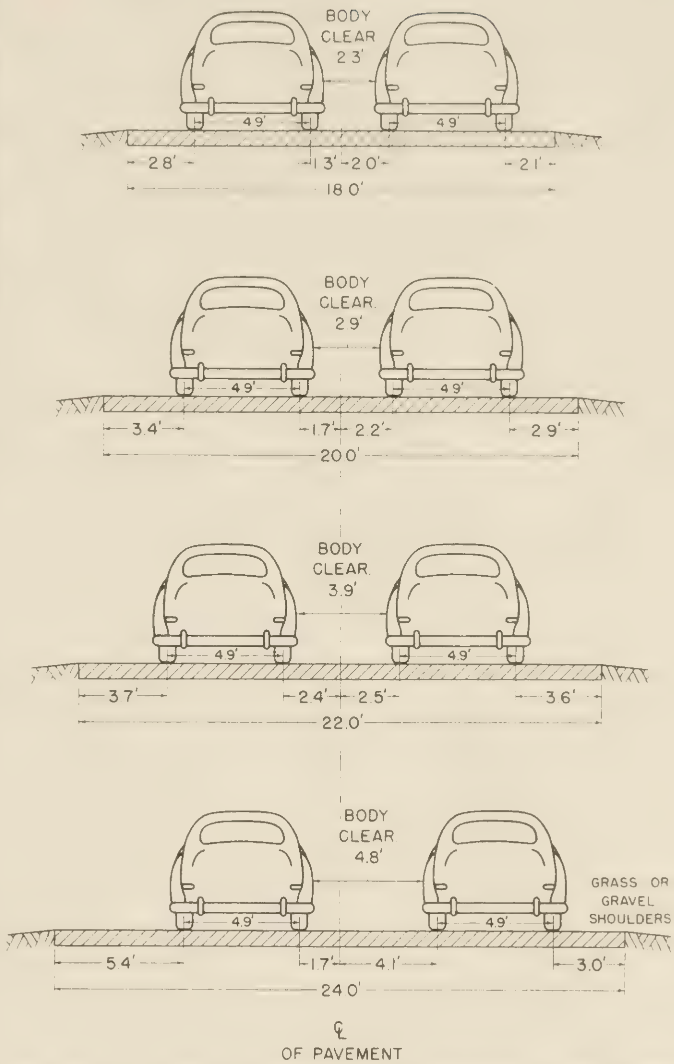


Figure 13.—Average Position of Passenger Cars When Passing Passenger Cars on Two-Lane Concrete Pavements During the Day.

(table 6). When passenger cars meet other passenger cars at night, however, their transverse positions are practically the same as during the day. Drivers of commercial vehicles 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 during the day. Also, the percentage of vehicles that encroach on 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 on the left lane when meeting other vehicles on 18-foot pavements at night as during the day.

Shoulders are used very little at night except on 18-foot pavements. On pavements of this width about 2 percent of the vehicles use the shoulders. Even bituminous shoulders are not used to a great extent at night, although they increase the effective pavement width to the same extent as during the day.

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

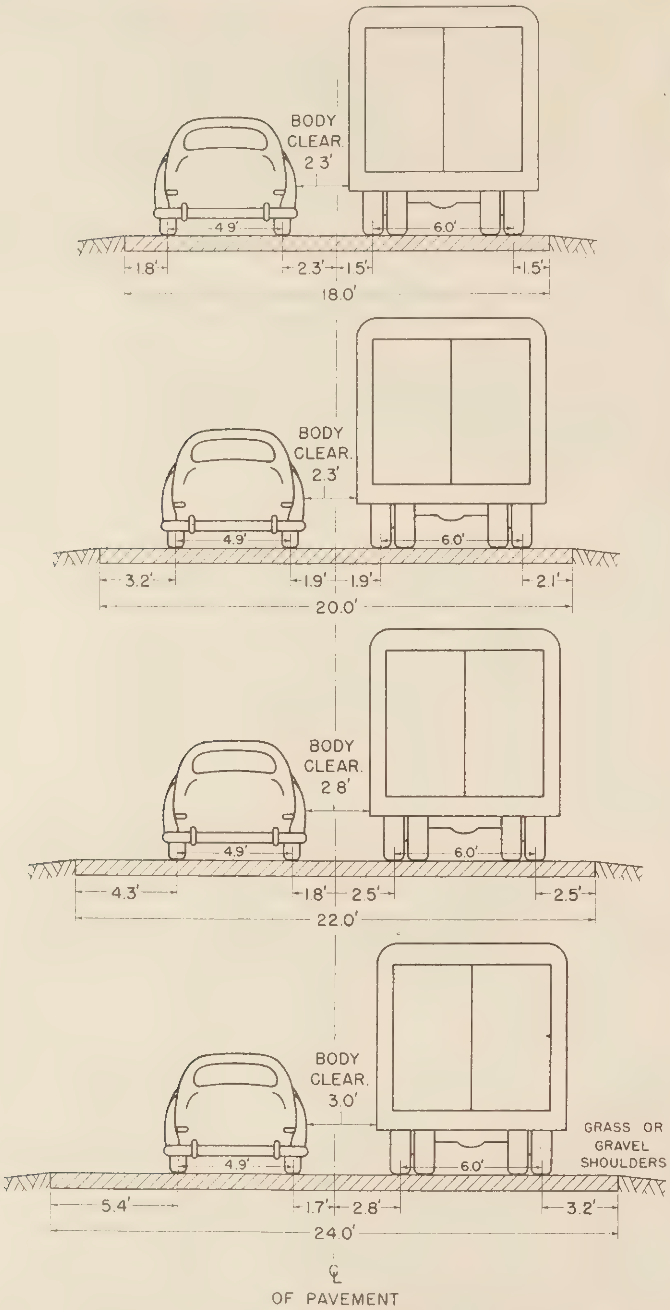


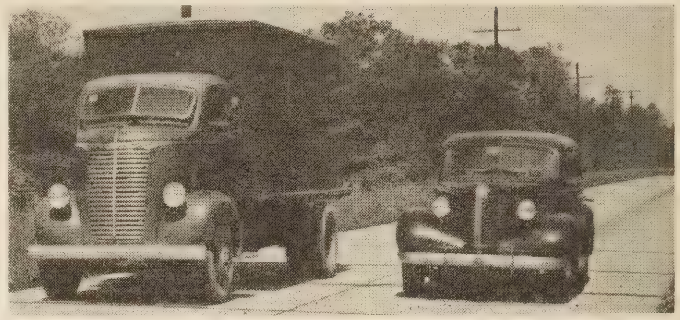
FIGURE 14.—AVERAGE POSITION OF PASSENGER CARS WHEN PASSING COMMERCIAL VEHICLES ON TWO-LANE CONCRETE PAVEMENT DURING THE DAY.

passing vehicle swerves more to the left at night. There were too few times when commercial vehicles passed at night to obtain an adequate sample (table 7).

The only definite conclusion regarding necessary surface widths for night driving is that 18-foot 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.

PATHS OF PASSING VEHICLES DETERMINED BY ANALYSIS

During 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 each vehicle, 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. In this analysis only data for those vehicles uninfluenced by oncoming traffic were used. The combined results for four locations on 20-foot pavements in California and Texas are shown in figures 15, 16, and 17.



PASSENGER CAR OVERTAKING AND PASSING TRUCK ON A 22-FOOT HIGHWAY.

Figure 15 shows time-position curves that indicate the paths of passing vehicles with respect to the passed vehicle for three speed conditions. The abscissas indicate the time spacing of the two vehicles. Plus values denote that the faster car is behind the vehicle being passed and the minus values indicate the faster vehicle is ahead and is returning to its own lane. The ordinates indicate the spacing of the left wheels of the faster passenger cars from the center of the pavement.

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 miles per hour. Drivers of these cars follow the same path as the preceding vehicle if the time spacing between vehicles exceeds 2 seconds. When the spacing falls below 2 seconds, that is, when the distance between centers of cars averages 120 feet, the drivers of the trailing cars begin to edge toward the center of the pavement. When immediately behind, the rear passenger car is about 1 foot 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 vehicle being passed are shown in curves A and B.

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

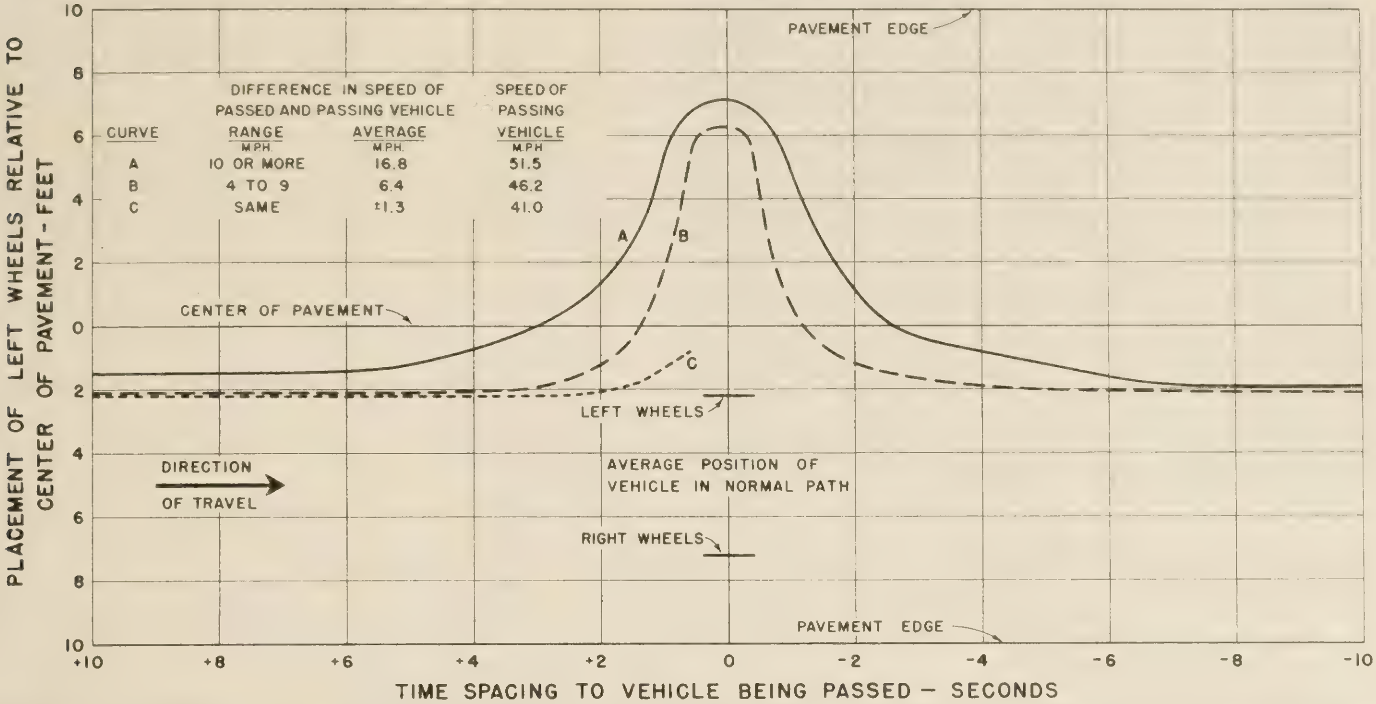


Figure 15.—Effect of Time Interval Between Successive Vehicles on the Transverse Position of Passenger Cars Traveling on 20-foot Concrete Pavement. There Was no Interference From Approaching Traffic.

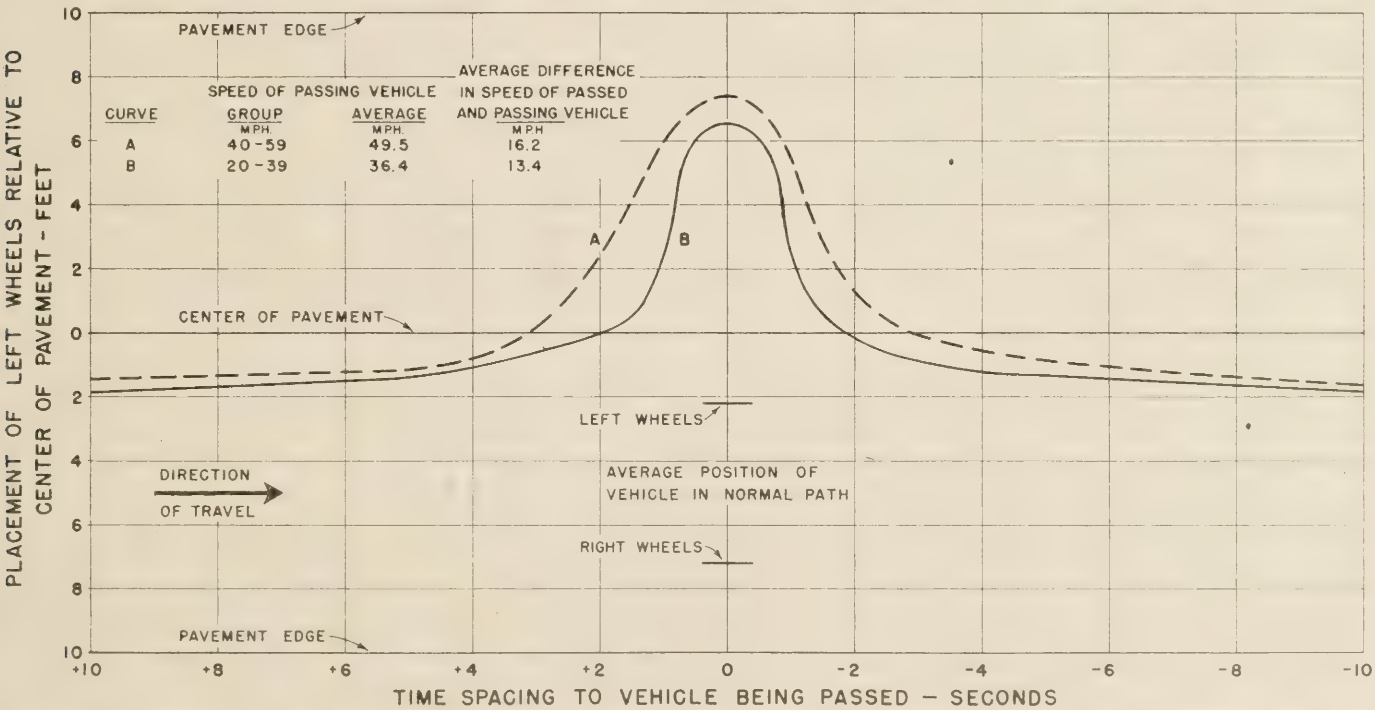


Figure 16.—Effect of Time Interval Between Successive Vehicles on Transverse Position of Passenger Cars Traveling 10 or More Miles per Hour Faster Than Vehicle Being Passed on 20-foot Concrete Pavement. There was no Interference From Approaching Traffic.

Curve A shows the path of the left wheel of cars traveling 10 or more miles per hour faster than the vehicles being overtaken. The passing cars are driven at an average speed of 51.5 miles per hour, and 16.8 miles per hour faster 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 seconds, or when about 375 feet behind the slower vehicle, they begin a gradual shift toward the left lane, encroaching on the left lane at a time spacing of 3 seconds. When abreast of the vehicle being overtaken, their left wheels travel at a distance of 2.9 feet from the left pavement edge, allowing a clearance of 3.4 feet between the bodies of the two vehicles. The passing cars return to the right lane when 2.6 seconds ahead of the slower vehicle.

The curves in figure 15 are representative of the paths of vehicles that maintain a constant speed during the entire passing maneuver. Under actual operatin

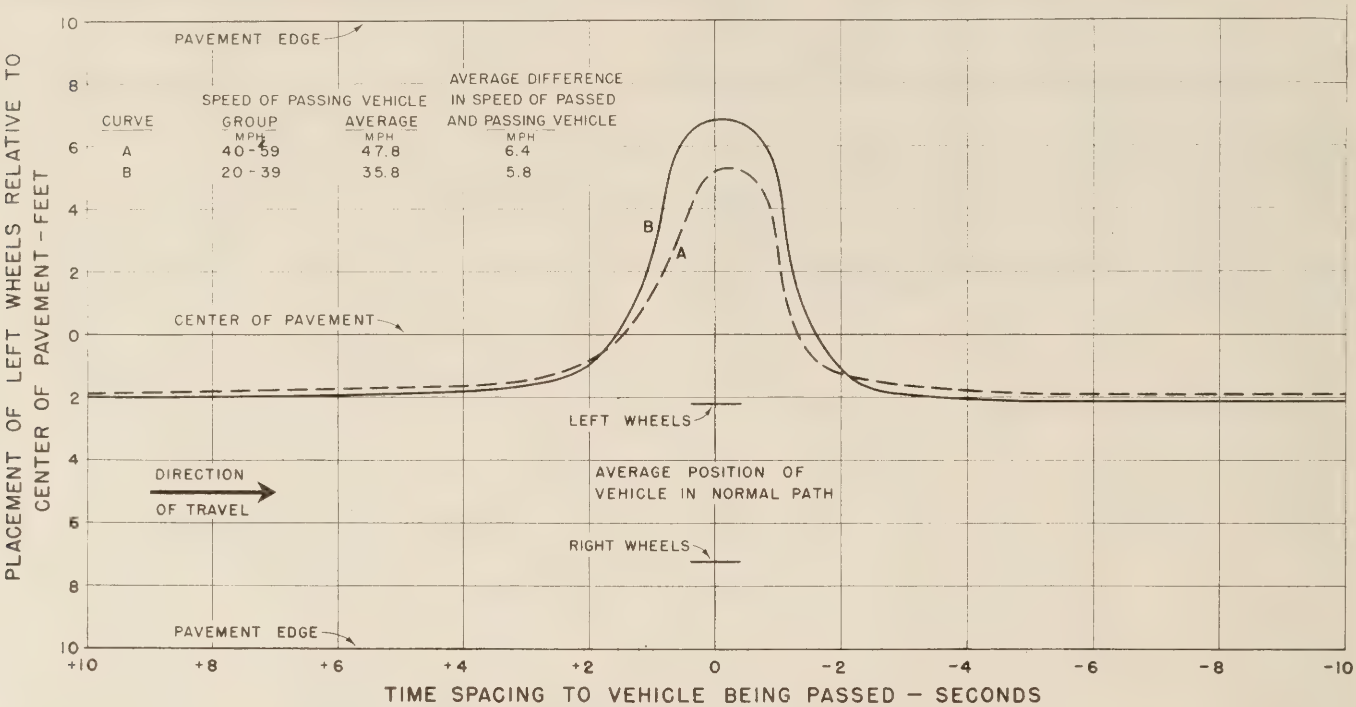


Figure 17.—Effect of Time Interval Between Successive Vehicles on Transverse Position of Passenger Cars Traveling 4 to 9 Miles per Hour Faster Than Vehicle Being Passed on 20-foot Concrete Pavement. There was no Interference From Approaching Traffic.

conditions some passing maneuvers are performed in this manner, but generally the driver of the passing vehicle accelerates as he encroaches on the left lane. The actual path of the passing vehicle that accelerates would be governed by the time spacing relative 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, its 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 15, 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 16 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 17 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 15 through 17 show the relative transverse positions of vehicles with various time spacings on the highway, they do not show the distance that the faster vehicles travel in the left lane. This distance can easily be calculated from the curves. For example, curve A of figure 15 shows that the faster car while traveling in the left lane gains 5.6 seconds on the vehicle being passed, 3 seconds 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 seconds are gained while returning to the right lane. At 51.5 miles per hour a gain of 5.6 seconds represents a gain of $5.6 \times 51.5 \times 1.47$, or 423 feet. In other words, the faster car is 227 feet behind when it enters the left lane to pass the slower moving vehicle, and 196 feet ahead 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 423 divided by 16.8×1.47, or 17.2 seconds. During this elapsed time, the faster car travels 1,299 feet in the left lane, while the slower vehicle travels 876 feet. Similarly, curve B shows that a passenger car traveling 4 to 9 miles per hour faster than the vehicle being overtaken gains 2.7 seconds and travels at an average speed of 46.2 miles per hour. The faster car travels 1,322 feet in the left lane while the slower vehicle travels 1,139 feet.

Table 12 shows the speed and transverse position of the passing vehicle and the time and distance traveled by passenger cars in the left lane while overtaking slower vehicles on two-lane concrete pavement 20 feet in width.

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

STUDIES RESULT IN SIGNIFICANT CONCLUSIONS

Based upon the results of extensive studies of vehicle operation at a large number of highway locations, the following are the more important conclusions that apply to straight, level sections of two-lane highway with concrete surfaces:

1. Shoulder width in excess of 4 feet does not influence the effective pavement width for moving vehicles

[4] Procedure Employed in Analyzing Passing Practices of Motor Vehicles, by E. H. Holmes, Public Roads, January 1939.
Progress in Study of Motor-Vehicle Passing Practices, by O. K. Normann, Public Roads, February 1940.
Passing Practices on Rural Highways, by C. W. Prisk, Highway Research Board Proceedings, 1941.

TABLE 12.—*Speed, placement, and distance traveled in left lane by passenger cars while overtaking slower vehicles on two-lane concrete pavements 20 feet wide*

Speed: Range	Speed: Average	Average difference in speed	Travel in left lane: Time	Travel in left lane: Distance	Distance gained while in left lane	Transverse[1] position when abreast of slower vehicle	Body clearance when abreast of slower vehicle
CARS TRAVELING 4 TO 9 MILES PER HOUR FASTER THAN VEHICLES BEING OVERTAKEN							
Miles per hour	*Miles per hour*	*Miles per hour*	*Seconds*	*Feet*	*Feet*	*Feet*	*Feet*
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 (total)	46.2	6.4	19.5	1,322	183	3.8	2.5
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	436	2.6	3.7
18–72 (total)	51.5	16.8	17.2	1,299	423	2.9	3.4

[1] Distance of left wheels from left edge of pavement.

when there are no vertical obstructions immediately adjacent to the shoulders. This must not be interpreted that shoulders wider than 4 feet are not necessary for other important reasons.

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 feet or more in width, adjacent to 18- and 20-foot pavements, increase the effective surface width approximately 2 feet.

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

5. Shoulder use increases rapidly with a decrease in pavement width below 22 feet. An insignificant number of moving vehicles use the shoulders on pavements of that width. On 18-foot pavements with grass or gravel shoulders, however, 5 percent of the commercial vehicles use the shoulder as they meet oncoming traffic. The corresponding value is 17 percent on highways with bituminous shoulders.

6. Hazardous traffic conditions exist on pavements less than 22 feet wide that carry even moderate volumes of mixed traffic. On 18-foot pavements with grass or gravel shoulders, 11 percent of the drivers of trucks and 5 percent of the drivers of passenger cars 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 a passenger car meets a commercial vehicle on a pavement 22 feet wide, the passenger car has the desired center and edge clearances but the commercial vehicle does not. To permit desired clearances for commercial vehicles a 24-foot pavement is required.

APPENDIX

During the analysis of the data from field studies, a large number of tables and graphs were prepared showing frequency distributions, mean and standard deviations, and other statistical measures pertaining to the variation in speeds and transverse placements of vehicles under various conditions. These tables and graphs were used in arriving at the conclusions but are omitted from the report the discussion being based primarily on average values. It is believed, however, that the frequency distributions of vehicle placements may be useful in determining slab thickness and cross section, shoulder width and type, and

TRAFFIC ON TWO-LANE HIGHWAY. NOTE THE TENDENCY OF DRIVERS TO TRAVEL CLOSER TO THE CENTER OF THE HIGHWAY WHEN TRAILING OTHER VEHICLES. THE FIRST THREE LINES ACROSS PAVEMENT ARE SPEED AND PLACEMENT DETECTORS. DETECTORS ARE CONNECTED TO INSTRUMENTS NOT SHOWN IN THE PICTURE.

other design features, in addition to their value in determining required surface width for a specific traffic condition.

Table 1 of the appendix shows frequency distributions of transverse placements for the more important vehicle classifications on two-lane concrete pavements 18, 20, 22, and 24 feet wide with grass or gravel shoulders for day operations. For night operations typical distributions are shown for 18- and 20-foot pavement widths.

Table 2 shows the frequency distribution of clearances between bodies of vehicles as they met one another traveling in opposite directions.

TABLE 1.—*Frequency distribution of transverse placements of vehicles on two-lane concrete pavements with grass or gravel shoulders at least 4 feet in width*

Placement of left wheels to the right of center line[1]: Range (feet)	Average	Passenger cars: Free moving	Passenger cars: Meeting other passenger cars	Passenger cars: Meeting commercial vehicles	Passenger cars: All, except passing vehicles	Commercial vehicles: Free moving	Commercial vehicles: Meeting passenger cars	Commercial vehicles: All, except passing vehicles
18-FOOT PAVEMENTS DURING DAY								
	Ft.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
−3.9 to 3	−3.5	0.1			(2)			
−2.9 to −2	−2.5	.2	(2)		0.2	0.7	0.7	0.5
−1.9 to −1	−1.5	1.2	0.5	0.1	.9	.8	.7	.5
−.9 to 0	−.5	4.2	.4	1.2	3.4	2.6	2.5	2.5
0 to .9	.5	21.6	5.0	3.5	16.2	29.9	6.8	24.3
1 to 1.9	1.5	49.5	32.0	24.5	45.9	48.5	54.1	49.1
2 to 2.9	2.5	21.4	53.8	52.1	29.7	16.7	27.8	21.2
3 to 3.9	3.5	1.7	8.1	18.6	3.5	.8	7.4	1.8
4 to 4.9	4.5	.1	.2		.1			0
5 to 5.9	5.5				0			.1
6 to 6.9	6.5				.1			
Total		100	100	100	100	100	100	100
Average distance, feet		1.4	2.1	2.3	1.6	1.3	1.8	1.4
20-FOOT PAVEMENTS DURING DAY								
−3.9 to −3	−3.5	0.1			0.1			
−2.9 to −2	−2.5	.3	(2)		.2	0.1	0.3	0.3
−1.9 to −1	−1.5	1.5	0.1	0.3	1.2	.6	.5	.7
−.9 to 0	−.5	4.6	1.0	.7	3.5	4.3	.4	2.7
0 to .9	.5	17.4	3.1	3.0	14.0	17.2	3.2	14.1
1 to 1.9	1.5	41.3	19.1	17.5	35.5	42.2	27.2	37.7
2 to 2.9	2.5	28.6	46.2	43.0	34.4	30.8	46.4	35.9
3 to 3.9	3.5	5.4	26.8	33.4	10.0	3.8	20.6	7.7
4 to 4.9	4.5	.6	3.7	2.1	1.0	.8	1.4	.9
5 to 5.9	5.5	.1	(2)		(2)	.2		(2)
6 to 6.9	6.5	.1	(2)		.1	(2)		(2)
Total		100	100	100	100	100	100	100
Average distance, feet		1.6	2.5	2.7	1.8	1.6	2.3	1.8

See footnotes at end of table.

TABLE 1.—*Frequency distribution of transverse placements of vehicles on two-lane concrete pavements with grass or gravel shoulders at least 4 feet in width*—Continued.

22-FOOT PAVEMENTS DURING DAY

Placement of left wheels to the right of center line[1]: Range (feet)	Average	Passenger cars: Free moving	Passenger cars: Meeting other passenger cars	Passenger cars: Meeting commercial vehicles	Passenger cars: All, except passing vehicles	Commercial vehicles: Free moving	Commercial vehicles: Meeting passenger cars	Commercial vehicles: All, except passing vehicles
	Ft.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
−2.9 to −2	−2.5	0.2			0.2			
−1.9 to −1	−1.5	1.2	0.8		.9	1.4		1.5
−.9 to 0	−.5	1.8	0		1.4	5.3		4.9
0 to .9	.5	13.5	4.0		9.9	7.9	1.4	7.5
1 to 1.9	1.5	25.4	8.9	17.4	21.6	22.8	19.0	21.1
2 to 2.9	2.5	40.6	34.9	30.5	40.1	47.7	40.1	47.3
3 to 3.9	3.5	13.9	39.1	26.1	20.5	13.5	23.8	15.4
4 to 4.9	4.5	2.8	11.0	17.4	4.7	1.4	15.7	2.3
5 to 5.9	5.5	.6	1.3	4.3	.6			
6 to 6.9	6.5			4.3	.1			
Total		100	100	100	100	100	100	100
Average distance, feet		2.1	2.9	3.2	2.3	2.0	2.8	2.1

24-FOOT PAVEMENTS DURING DAY

Range (feet)	Average	Passenger cars: Free moving	Passenger cars: Meeting other passenger cars	Passenger cars: Meeting commercial vehicles	Passenger cars: All, except passing vehicles	Commercial vehicles: Free moving	Commercial vehicles: Meeting passenger cars	Commercial vehicles: All, except passing vehicles
−2.9 to −2	−2.5	0.3			0.2	0.6		0.3
−1.9 to −1	−1.5	.2	0.3		.3	.6		.5
−.9 to 0	−.5	1.3	1.3		1.1	2.3		1.2
0 to .9	.5	9.0	2.9		5.6	4.6	1.2	3.1
1 to 1.9	1.5	24.8	7.7	4.2	18.1	33.7	21.6	27.4
2 to 2.9	2.5	33.5	31.0	35.4	33.6	37.1	37.1	39.4
3 to 3.9	3.5	24.0	34.8	33.3	27.4	17.1	21.6	20.3
4 to 4.9	4.5	5.8	19.8	25.0	12.1	3.4	17.0	6.9
5 to 5.9	5.5	1.1	2.2	2.1	1.6	.6	1.5	.9
Total		100	100	100	100	100	100	100
Average distance, feet		2.4	3.1	3.4	2.7	2.2	2.9	2.5

18-FOOT PAVEMENTS AT NIGHT

Range (feet)	Average	Passenger cars: Free moving	Passenger cars: Meeting other passenger cars	Passenger cars: Meeting commercial vehicles	Passenger cars: All, except passing vehicles	Commercial vehicles: Free moving	Commercial vehicles: Meeting passenger cars	Commercial vehicles: All, except passing vehicles
−3.9 to −3	−3.5	(2)						
−2.9 to −2	−2.5	0.1	0.2		0.2	0.2		0.2
−1.9 to −1	−1.5	.9	.8		.8	3.6		.9
−.9 to 0	−.5	6.0	.9		5.3	10.5	6.7	8.5
0 to .9	.5	21.8	5.7		18.5	41.8	20.0	34.3
1 to 1.9	1.5	45.9	31.9	16.7	44.0	32.7	53.3	40.7
2 to 2.9	2.5	22.3	48.1	66.7	26.9	9.0	13.3	14.2
3 to 3.9	3.5	1.9	12.2	16.6	3.3	2.2	6.7	1.2
4 to 4.9	4.5	.4	.2		.4			
5 to 5.9	5.5	0			0			
6 to 6.9	6.5	.7			.6			
Total		100	100	100	100	100	100	100
Average distance, feet		1.5	2.1	2.5	1.5	0.9	1.4	1.2

20-FOOT PAVEMENTS AT NIGHT

Range (feet)	Average	Passenger cars: Free moving	Passenger cars: Meeting other passenger cars	Passenger cars: Meeting commercial vehicles	Passenger cars: All, except passing vehicles	Commercial vehicles: Free moving	Commercial vehicles: Meeting passenger cars	Commercial vehicles: All, except passing vehicles
−3.9 to −3	−3.5	(2)			0.1	0.2		(2)
−2.9 to −2	−2.5	0.9	0.2		.2	.5		0.3
−1.9 to −1	−1.5	2.5	.2		1.2	.5	1.1	.7
−.9 to 0	−.5	5.8	1.2	4.5	3.5	5.0	2.0	2.7
0 to .9	.5	18.4	2.2	4.5	14.0	23.9	16.3	14.1
1 to 1.9	1.5	38.6	18.4	8.6	35.5	42.7	33.4	37.7
2 to 2.9	2.5	27.8	47.3	44.3	34.4	22.3	44.2	35.9
3 to 3.9	3.5	5.0	28.1	34.8	10.0	4.9	3.0	7.7
4 to 4.9	4.5	.8	2.4	3.3	1.0			.9
5 to 5.9	5.5	.1			(2)			
6 to 6.9	6.5	.1			.1			
Total		100	100	100	100	100	100	100
Average distance, feet		1.6	2.5	2.7	1.8	1.5	1.9	1.8

[1] A minus value indicates that left wheel is to left of center line.
[2] Less than 0.05 percent.

TABLE 2.—*Frequency distribution of clearances between bodies of meeting vehicles on two lane concrete pavements with grass or gravel shoulders at least 4 feet in width*

PASSENGER CARS MEETING OTHER PASSENGER CARS

Clearance between vehicle bodies: Range (feet)	Average	Day: 18-foot pavement	Day: 20-foot pavement	Day: 22-foot pavement	Day: 24-foot pavement	Night: 18-foot pavement	Night: 20-foot pavement
	Ft.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
0 to 2	1	6.1	3.8	2.6	2.4	4.3	3.8
1 to 3	2	16.2	7.6	5.2	1.4	16.0	5.3
2 to 4	3	41.7	19.5	11.1	5.8	36.1	21.7
3 to 5	4	29.3	36.4	15.3	15.5	29.9	37.9
4 to 6	5	6.5	22.9	37.5	29.5	13.3	25.1
5 to 7	6	.2	6.6	19.4	31.8	.4	5.4
6 to 8	7		2.6	8.1	12.6		.8
7 to 9	8		.6	.8	1.0		
8 to 10	9		(1)				
Total		100	100	100	100	100	100
Average clearance, feet		3.2	4.0	4.8	5.2	3.2	4.0

PASSENGER CARS AND COMMERCIAL VEHICLES MEETING

Range (feet)	Average	Day: 18-foot pavement	Day: 20-foot pavement	Day: 22-foot pavement	Day: 24-foot pavement	Night: 18-foot pavement	Night: 20-foot pavement
0 to 1.5	0.8	7.3	2.5	2.3	1.5	6.1	13.9
0.5 to 2.5	1.5	14.8	3.8	4.5	1.7	15.1	4.0
1.5 to 3.5	2.5	50.2	24.7	6.8	9.2	57.6	20.9
2.5 to 4.5	3.5	23.6	31.6	13.6	16.6	12.1	29.4
3.5 to 5.5	4.5	3.4	26.4	38.7	24.1	6.1	29.0
4.5 to 6.5	5.5	.7	9.4	25.0	29.8	3.0	2.8
5.5 to 7.5	6.5		1.3	6.8	14.2		
6.5 to 8.5	7.5		.3	2.3	2.7		
7.5 to 9.5	8.5				.2		
Total		100	100	100	100	100	100
Average clearance, feet		2.6	3.5	4.5	4.8	2.6	3.1

[1] Less than 0.05 percent.

TRAFFIC PLANNING STUDIES IN AMERICAN CITIES

BY THE DIVISION OF HIGHWAY TRANSPORT RESEARCH, PUBLIC ROADS ADMINISTRATION

Reported by JOHN T. LYNCH, Chief of Planning Surveys Section

DURING THE PAST 2 YEARS there has been a remarkable development in city planning studies. Techniques have been greatly improved and many new studies have been begun.

The principal reason for this accelerated activity is the provision of the Federal-Aid Highway Act of 1944, which makes available $125,000,000 of Federal money in each of the first 3 years following the war for construction on the Federal-aid system in urban areas. Since this money is to be matched by State and local funds, the total sums will be about twice that amount.

NEW FEDERAL POLICY

When distributed among the States and among the cities in the States, this is not a large amount of money considering the magnitude of the problems to be solved. It does, however, mark a change in Federal policy which may result in the availability of considerable sums of money for urban construction over the next 20-year period. It was not until the emergency legislation of 1933 that Federal highway funds could legally be spent for construction through municipalities having a population of more than 2,500 where the houses average less than 200 feet apart.

Since enactment of the Hayden-Cartwright Act of 1934 regular Federal-aid funds have been available for expenditure on urban sections of the Federal-aid system and numerous improvements have been made. However pressing needs for improvements on rural portions of the system and the size of the funds provided have prevented a major attack on city highway problems. The new legislation provides $225,000,000 for either urban or rural portions of the Federal-aid system in each of the first 3 postwar years. It definitely recognizes the urban highway problem as, in part, a Federal responsibility by providing an additional $125,000,000 in each of the first 3 postwar years that is specifically assigned to urban portions of the Federal-aid system.

The legislation provides for designation and improvement of a 40,000-mile system of interstate highways with appropriate connections through cities. This system is to be made a part of the Federal-aid system and will be eligible for participation in Federal-aid system funds. No special funds have been provided for the interstate system.

Funds provided by the new legislation and general recognition of the necessity of solving the more critical city traffic problems by large scale, bold, and costly improvements assure large city programs. The concept of the scale and character of these programs is relatively new. Decisions made now as to the pattern for improvements will influence developments for many years to come. It is especially important that data be obtained and analyzed on an extensive scale in such manner as to clarify the complex urban problems and indicate the proper solutions. Recognizing that the methods used in rural-road analysis and those generally used in city planning in the past are not adequate for the solution of problems now at hand, the Public Roads Administration has made special studies of methods of accumulating the data needed for scientific planning of urban highways.

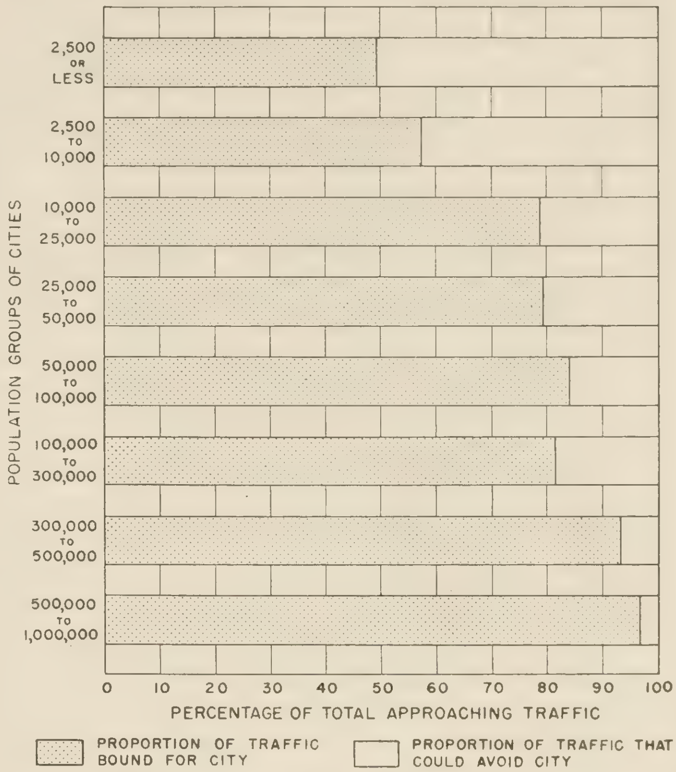


FIGURE 1.—GRAPH SHOWING TWO DIVISIONS OF THE TOTAL TRAFFIC ON ROADS APPROACHING REPRESENTATIVE CITIES OF VARIOUS POPULATION GROUPS: (1) THE AVERAGE PERCENTAGE CITY BOUND AND (2) THE AVERAGE PERCENTAGE WHICH COULD HAVE BYPASSED THE CITIES.

BYPASS STUDIES

Having thought in terms of rural roads for so many years, the inclination of the State and Federal engineers on first approaching city problems was to regard urban congestion as a hindrance to the flow of intercity and interstate traffic and to try to expedite travel by the construction of routes skirting the edge of the urban areas. In many cases such bypasses have been justified, but early studies showed that most of the traffic approaching a city wants to go into it and that a bypass solves only a small part of the problem.

Figure 1, taken from the report of the National Interregional Highway Committee which was transmitted to Congress before the passage of the Federal Highway Act of 1944, shows the percentage of the traffic approaching cities of various sizes which is bound for the city, and the percentage which could avoid the city. It must be emphasized that these are averages and that the percentages vary widely according to the conditions. It will be noted that for cities of over 500,000 population about 96 percent of the

Figure 2.—Principal Highway Routes Through Martinsville, Va.

Figure 3.—Estimated Average 24-hour Traffic Flow on Major Streets in Martinsville, Va., in 1941.

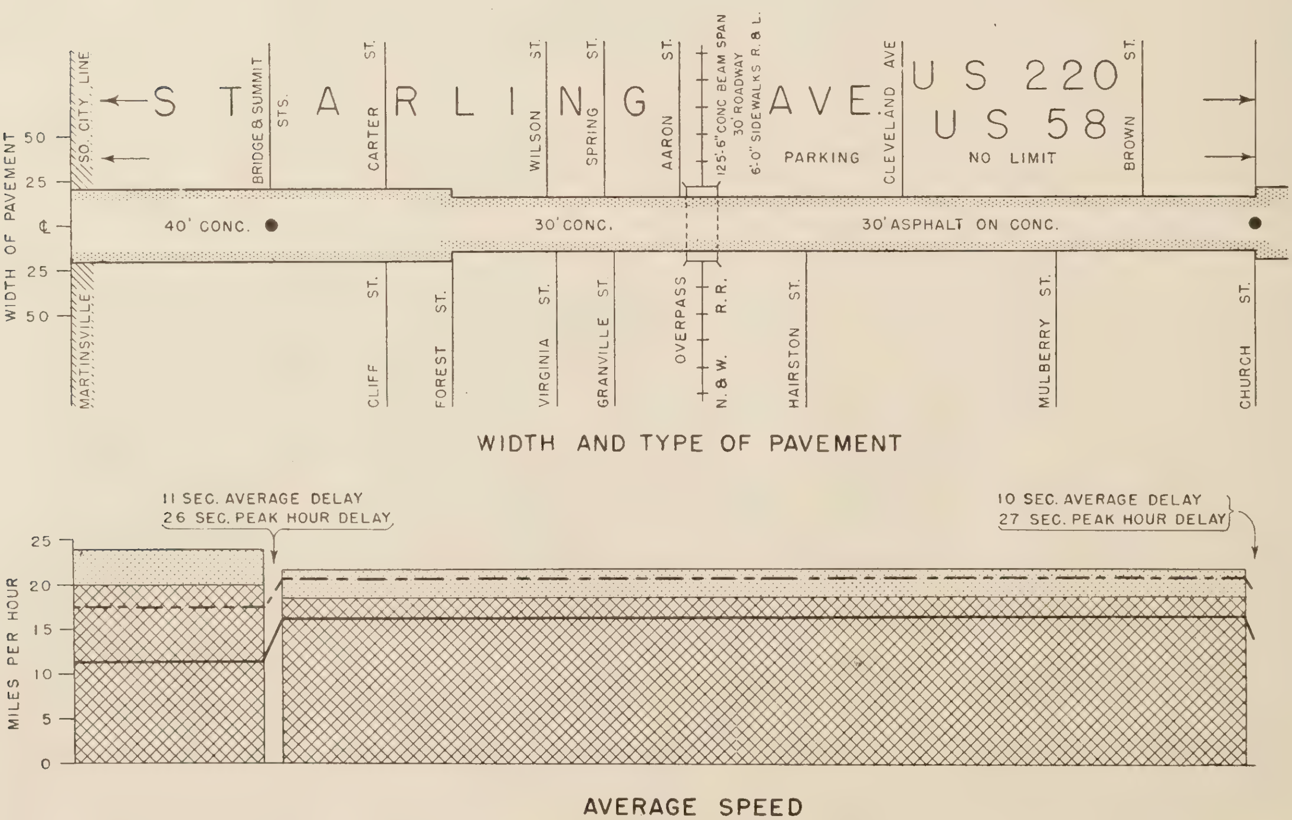


Figure 4.—Width and Type of Pavement, Average Speed, and

approaching traffic is bound for the city, whereas for cities of from 10,000 to 25,000 the corresponding figure is about 79 percent, on the average.

Smaller cities frequently need bypasses because they will contribute materially to the relief of traffic congestion within the city. To illustrate the kind of studies being made to determine the need for bypasses, a survey made in Martinsville, Va., by the State highway department in cooperation with the Public Roads Administration will be briefly described and some of the results will be given.

MARTINSVILLE STUDY USED AS ILLUSTRATION

Martinsville, a city of about 10,000 population, is located in southwest Virginia in the foothills of the Blue Ridge Mountains. It has an average elevation of above 1,000 feet and the surrounding topography is comparatively rough. As is usual in cities so situated, the streets have steep grades and are rather narrow. The chief industry is the manufacture of furniture, but there is diversified manufacturing including textile and other products.

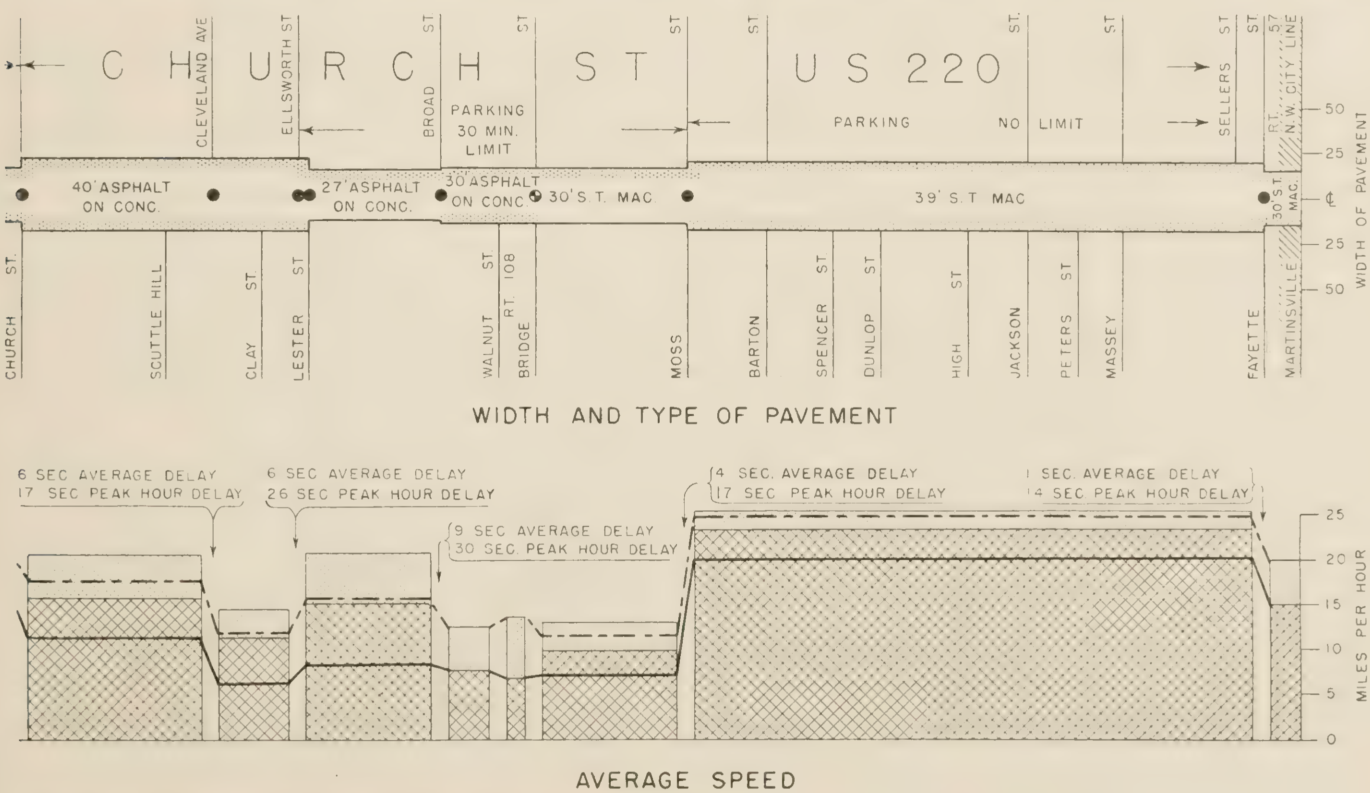
Figure 2 shows the principal highway routes through the city. U S 58 comes in from the southwest from Bristol, Va., follows Starling Avenue to Church Street, turns right on Church Street and goes out in an easterly direction to Danville, Va. U S 220 from Greensboro, N. C., joins U S 58 south of the corporate limits and is coincident with it along Starling Avenue to Church Street. At this point, however, U S 220 turns left and follows Church Street through the retail business district, and leaves the city in a westerly direction to Roanoke, Va. State route 57 coming in from the west from Bassetts, Va., joins with U S 220 near the west city limit and follows Church Street all the way through the city, coinciding with U S 58 from Starling Avenue to the east city limit, and thence turns and goes in a northerly direction to Chatham, Va. Two of the three principal routes through the city follow Church Street through the congested downtown section. A fourth route, State route 108, which is of less importance, comes in from the north and terminates in the business section at Church Street.

Figure 3 shows the traffic volumes on these routes and on other major streets in Martinsville. The greatest traffic volume on any portion of the transcity connections amounts to 5,167 vehicles per day and occurs on Church Street between Starling Avenue and Lester Street. At Lester Street this traffic divides and part of it follows Main Street.

A portion of the 4,344 vehicles coming in each day from the south leave Starling Avenue at Broad Street and another portion turns off on Cleveland Street. Both Broad and Cleveland Streets offer shorter routes to the downtown section and would be used by a much larger portion of the traffic were they equal in physical characteristics to Starling Avenue.

Figure 4 shows conditions through the city along U S 220. At the south city limit there is a 40-foot concrete pavement which narrows to 30 feet at Forest Street and the pavement continues at this width to the point where the route turns to the left from Starling Avenue on to Church Street. The first section on Church Street is 40 feet wide, but from Lester to Moss Streets, through the congested downtown section, the width is only 27 to 30 feet. Except for a very short section of 30-foot width near the west city limit, the remainder of the route is 39 feet in width.

There are numerous grades on this route, some of them rather steep. From the south corporate limit to Church Street the maximum is 5.2 percent, and on Church Street through the business section, the range is from 2.6 percent to 4.6 percent. For the half mile between Moss Street and Jackson Street there are



Delay on Route 220 Through Martinsville, Va., as of July 1944.

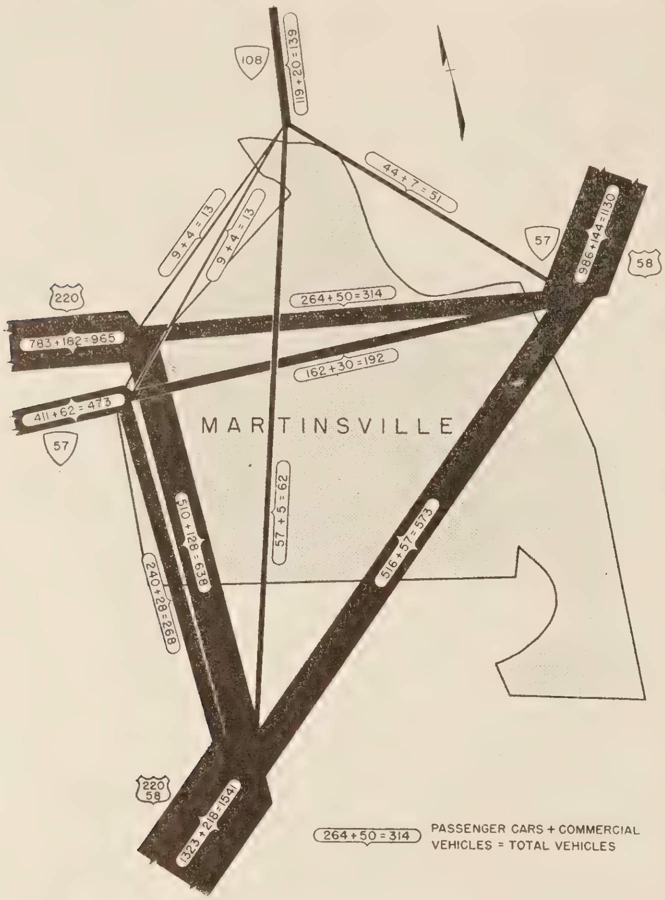


Figure 5.—Origin and Destination of Daily Through Traffic at Martinsville, Va., in 1941.

continuous grades, ranging from 4 percent to 6.6 percent, and from Jackson Street to the west city limits the grades range from 4 percent up to 8 percent.

There are eight stop lights and one caution light on this route and at several other points there are interferences by cross traffic which cause considerable delay. The diagram at the bottom of the chart shows the average speeds on U S 220 through the city for all hours of the day and at the peak hour. This information was determined by cruising with the traffic. From the southern limit to Church Street conditions are fairly satisfactory, and automobiles maintain an average speed of 22 miles or more for the day, and 18 miles or more during the peak hour. After turning on to Church Street there are numerous stop lights and other interferences and average speeds decline. In the most congested section between Broad and Moss Streets the average speed for the day was from 12 to 13 miles per hour and during the rush period was from 7 to 9 miles per hour. From Moss Street to the west city limit fairly satisfactory speeds are maintained.

ORIGIN AND DESTINATION SURVEY MADE

In order to determine the improvements needed to serve through traffic, and the relation between the benefits which would accrue to the traveling public, and the cost of the improvements, "origin and destination stations" were operated on each main highway where it enters the city. Each station was manned for a full 24-hour period by interviewers who stopped all vehicles leaving the city and asked the drivers their origins and destinations and if stops were made in the city that required them to follow the route traveled even though a more attractive and more direct route were provided.

About 80 percent of the traffic had origin or destination within the city or made essential stops there, and only about 20 percent could have used a bypass, had one been available. However, conditions in this city are such that the construction of a bypass may be justified for even this small portion of the total traffic. Further analysis was made of the origins and destinations of the through traffic to determine how much of it would use the various segments of a circumferential route.

Figure 5 shows the interchange of the bypassable traffic between the major highways entering the city. The largest single through movement consists of 510 passenger cars and 128 trucks, or a total of 638 vehicles, which travel between U S 220 to the west and the coincident routes U S 220 and U S 58 to the south. The only movement of comparable magnitude is that between U S 58 and U S 220, combined, at the south and U S 58 and State route 57, combined, at the northeast.

The various types of improvements that might relieve existing conditions were considered. If existing streets could be improved in such a manner as to permit the free flow of traffic, or if other parallel facilities could be provided within the city itself, the greatest benefits could be expected because so much of the traffic has its origin or destination within the city. However, this was found to be impracticable for several reasons; Church Street is narrow and closely built up and there are no parallel streets except Main, which is already seriously congested. There is much interference by cross traffic and the total volume of traffic to be served does not justify the cost of a controlled-access highway. Even a new street at grade would require an enormous expenditure for right-of-way and would not give full relief because of the cross traffic.

POSSIBLE SOLUTIONS CONSIDERED

It was decided then to study each of the segments of a circumferential or bypass route to determine what benefits could be expected from each. A route bordering the northern part of the city would serve 506 vehicles for its entire length, and 51 additional on its eastern half, and 26 additional on its western half, the additional traffic being contributed by State route 108. At most, this would relieve Church Street of only about 10 percent of its present traffic. It is not practicable to locate the bypass so as to save distance for any except a few vehicles from State route 108, and it is probable that the route would be longer than the existing route for most of the traffic. It would be possible to save 3½ minutes in travel time for east-west traffic, but this small benefit would hardly justify the cost of construction. It is fairly obvious, without further analysis, that such a route would not be justified.

A bypass skirting the city on the east would serve 573 vehicles for its entire length, but would be as long or longer than the existing route. It would save little travel time because the existing route is fairly adequate and delays are not comparable to those encountered on the routes traversing the business section. On the whole, such a bypass would be even less justifiable than one around the northern edge of the city.

A road bypassing the city on the southwest and connecting U S 220 and U S 58 from the south with U S 220 and State route 57 to the west would obviously save considerable distance over existing routes and, in addition, would serve the largest single movement of through traffic; namely, that which enters and leaves by U S 220. The benefits that would accrue from the construction of such a route will be analyzed in some detail. This analysis is presented for purposes of illustration and varies in some particulars from the analysis presented in a report on this project.

SOUTHWEST BYPASS ANALYZED

The approximate location of the bypass under consideration is labeled "assumed bypass" in figure 2. This location would save approximately 2 miles for through traffic on U S 220, the distances being 4.5 miles by the present route and 2.5 miles by the bypass. For traffic between U S 220 and U S 58 to the south and State route 57 to the west the saving would be 2.2 miles. Assuming that traffic will increase 60 percent during the life of the improvement and will average 30 percent higher during that period than at present, the average daily vehicle-miles saved would be as follows:

Passenger cars	2, 012
Trucks	413

The benefits per vehicle-mile of travel saved can be computed by taking into consideration cost of gasoline, oil, tires, maintenance, and that portion of depreciation which is chargeable to driving as distinguished from fixed expenses which must be incurred regardless of the distance traveled. For passenger cars the saving was computed by the Oregon State Highway Commission as 3.21 cents and by the Connecticut State Highway Department as 2.83 cents per vehicle-mile. In this analysis 3 cents is used. The saving to trucks depends upon the type and weight of truck. Figures developed by Oregon are 6.30 cents for light trucks, 8.84 cents for medium trucks, and 14.61 cents for heavy trucks. Connecticut figures are 6.30 cents for light and medium trucks and 13.87 cents for heavy trucks and combinations. In the present analysis the value of distance saved to trucks of all classes combined was assumed to be 8 cents. The daily benefits to automobile users for saving distance would then be as follows:

Passenger cars	2, 012 × 0. 03 = $60. 36
Trucks	413 × 0. 08 = $33. 04
Total	$93. 40

The value of time saved is much more controversial and cannot be computed with a high degree of certainty. However, benefits from time saving are real and are sometimes actually paid for in cash, as in the case of a toll facility. The State highway departments of both Oregon and Connecticut have used a figure of 60 cents per hour as the value of saving time for passenger cars. This figure has had quite general usage and appears to be reasonable on the basis of the meager information available. It is used, therefore, in the analysis of the Martinsville southwest bypass.

The saving for trucks is more definite than that for passenger cars, because there is frequently a money return and the driver is paid. Figures developed by Oregon are $0.86, $1.17, and $1.47 per hour for light, medium, and heavy trucks, respectively, and figures developed by Connecticut are $0.87 for light and medium trucks combined, and $1.46 for heavy trucks and combinations. In this analysis $1.20 per hour, or 2 cents per minute, is used for trucks without classification by size.

Assuming an average speed of 45 miles per hour on the bypass, time saved would be approximately 8 minutes and 45 seconds for all through vehicles which use it. The average daily vehicle-minutes saved during the life of the improvement would be as follows:

Passenger cars	8, 525
Trucks	1, 775

The total daily benefits from the saving would, therefore, be as follows:

Passenger cars	8, 525 × . 01 = $85. 25
Trucks	1, 775 × . 02 = $35. 50
Total	$120. 75

There are numerous other benefits that are not evaluated. Among them are the savings of wear on brakes and tires in eliminating stops, relief from the strain of driving in congested traffic, and benefits to other traffic, particularly that on Church Street, brought about by the lessening of traffic volume by almost 20 percent.

Considering only the distance saving and time saving, the values are as follows:

Distance saving per day	$93. 40
Time saving per day	120. 78
Total	214. 18
Annual saving	$78, 176

Thus, an annual cost of $78,176 in the construction and maintenance of a new facility would be offset by the benefit to the users. The relation of first construction cost to annual cost varies in accordance with local conditions and the type of improvement, but, as a rough general figure for improvements of this kind, the annual cost can be considered to be approximately 7 percent of the construction cost, being made up of 3 percent amortization, 2 percent maintenance, and 2 percent average interest figured on the basis of 4 percent each year on the unpaid balance. On this basis an initial construction cost of about $1,120,000 would be justified by annual benefits of $78,176.

It may be that a particular improvement is fully justified on the basis of such a calculation, yet should be deferred because other improvements show a higher ratio of benefits to cost. In this case, construction cost estimates have not been made, but, assuming that the route could be constructed for $100,000, the ratio of benefits to cost would be 11.2. Such a figure derived from an actual estimate could be used as a priority index to be compared with similar indices for other projects.

In the case of Martinsville, the situation is especially favorable for a bypass because of the large saving in distance. Considered on its own merits, such a bypass is well worth constructing and, as has been shown, the benefits would probably be much in excess of the cost. However, it does not solve the Martinsville traffic problem as a whole, nor, in fact, the major part of it. Church Street would be relieved of only 20 percent of its traffic and, while this would afford relief, it would not be many years before increase in traffic volume would make Church Street as congested as it was before the construction of the bypass. Other and more radical measures will have to be taken before the problem is permanently solved.

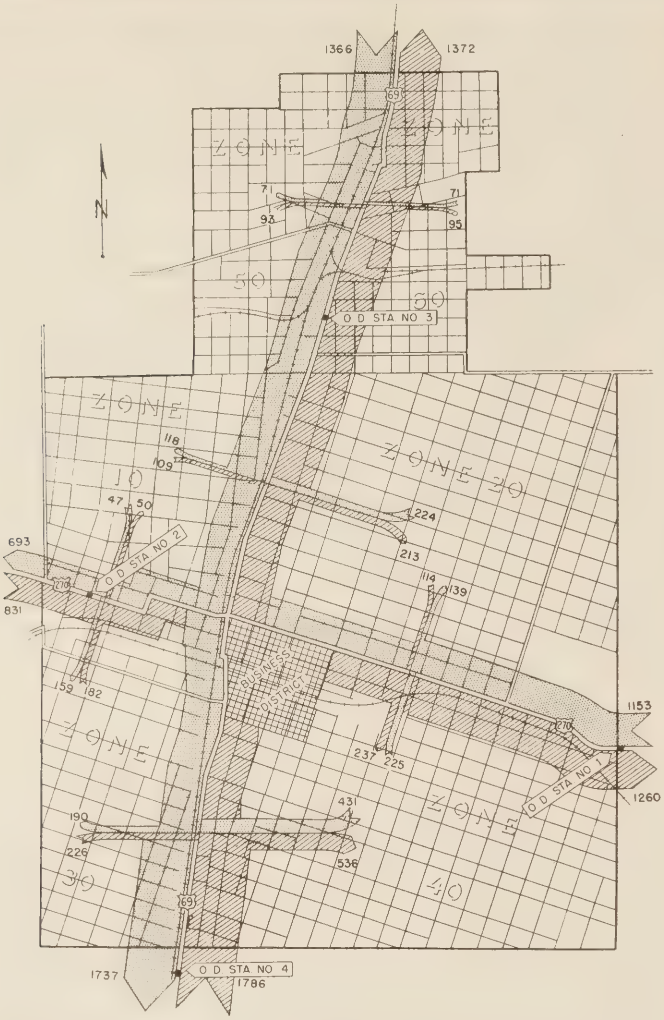


Figure 6.—Volume of Traffic on State Highways Within McAlester. Okla., Having Origin or Destination or Both Outside the City.

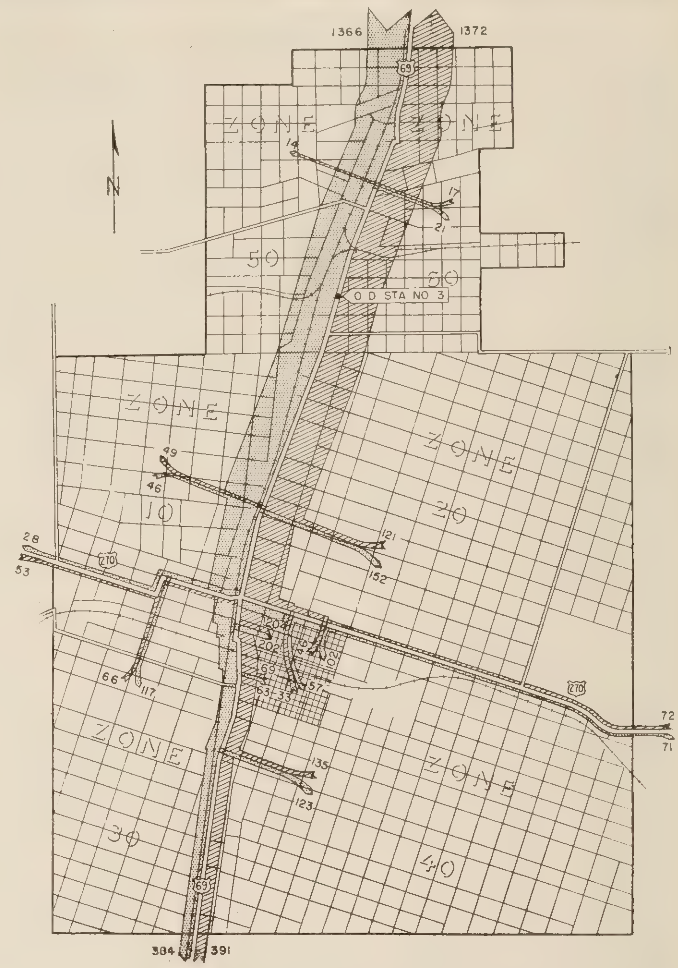


Figure 7.—Distribution Within and Through McAlester, Okla., of In-Bound and Out-Bound Traffic Passing the North City Limit on US 69.

McALESTER STUDY SHOWS IMPORTANCE OF LOCAL ORIGINS AND DESTINATIONS

A study made in McAlester, Okla., illustrates a more typical situation. McAlester is a town of about 12,000 population, just about the size of Martinsville. A survey very similar to the one made in Martinsville was made there. Interview stations were operated at four points where the State highways enter the city, and questions were asked of motorists concerning origins and destinations.

Figure 6 shows the amount of traffic, with either origin or destination outside the city, which uses different portions of the highways within the city limits. Examination of this chart alone, indicates that a circumferential route would serve a useful purpose and would carry considerable volumes of traffic. However, this is an incorrect conclusion.

Figure 7 shows the distribution of traffic entering and leaving over US 69 at the northern limits of the city. As can be seen, most of this traffic has origin or destination near the center of the city and only a small portion of it goes on through.

Similarly, figure 8 shows the distribution of the traffic entering and leaving the city at its southern boundary on the same highway. Most of this traffic also terminates near the center of the city and the comparatively uniform band which was shown in figure 6 was made up of these two tapering traffic streams superimposed upon each other. A similar situation exists on US 270 running east and west the through traffic being an even smaller portion of the total.

A further analysis of the traffic on US 69 within McAlester is given in figure 9. The narrow ribbon at the bottom shows the through traffic, the jog near the center of the chart being caused by traffic turning off to US 270. The wedge just above this ribbon represents traffic coming in from the north and feeding out into the city, mostly in the central business district. The opposing wedge just above this one represents traffic coming in from the south and feeding into the city in a similar manner. The mound at the top of the chart is the local traffic with origin and destination entirely in the city.

It is evident that, even in a city as small as McAlester, the local traffic constitutes a large portion of the total traffic on the main through routes. For cities of a larger size the local traffic is relatively of much greater importance and the through traffic of correspondingly less importance. Figure 10 shows the traffic on US 66 through St. Louis, Mo. The traffic at the city limits is small compared to that nearer the center of the city, and the large mound represents internal trips almost entirely. Of course, many of the vehicles observed at the city limits are moving locally from a point near the city to a point within the city.

It is clear that the traffic problems of the Federal, State, and local governments merge and cannot be

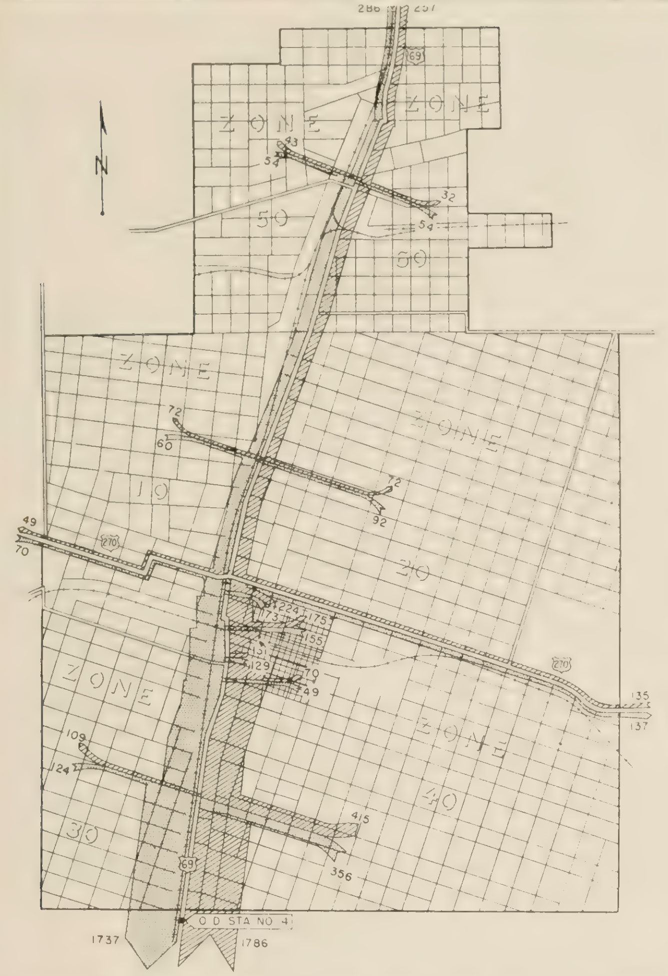


FIGURE 8.—DISTRIBUTION WITHIN AND THROUGH MCALESTER, OKLA., OF IN-BOUND AND OUT-BOUND TRAFFIC PASSING THE SOUTH CITY LIMIT ON US 69.

separated from each other on any rational basis. When vehicles come into a city from other parts of the State or from other States, they merge with the local traffic, and any facilities built to accommodate them will produce a greater total benefit to the traffic which circulates within the area itself. It is for this reason that State and Federal engineers are having to interest themselves in urban traffic problems which appear to be local in character.

URBAN TRAFFIC COMPLEX

Traffic within an urban area is much more complex than that on rural roads. Traffic volumes are larger, and traffic arteries are much more numerous. Parallel streets offer many alternate routes of travel, and it is not possible to tell from observing traffic volumes alone where the drivers really want to go. Drivers often travel considerable distances out of their way to use exceptionally attractive routes, or to avoid congested and unattractive routes. Examples of this have been noted in numerous cities and origin and destination surveys have shown that the facts were sometimes quite different from assumptions made by traffic experts with long familiarity with the local situation.

Because of the complexity of urban traffic, it is difficult or impossible to collect needed data by methods used at external origin and destination stations. The multiple lanes and the large numbers of vehicles make it difficult and sometimes hazardous to stop traffic and conduct interviews at the roadside. The numerous routes of travel over the grid of streets necessitate operation of a large number of interview stations if all or a large part of the traffic is to be intercepted. Parallel streets invite bypassing survey stations and where roadside interviewing has been attempted at points that could be readily bypassed, there has invariably been bypassing as soon as lines of standing vehicles began to accumulate.

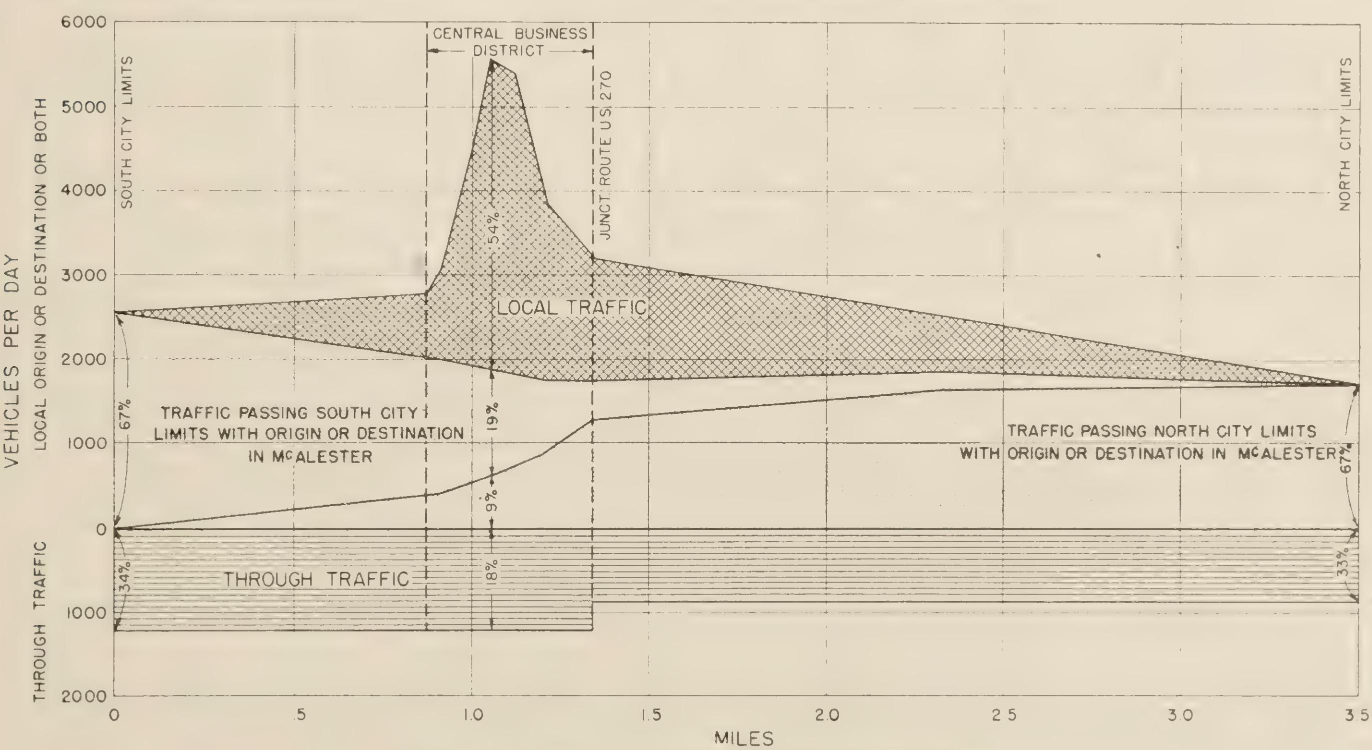


FIGURE 9.—TRAFFIC ON US 69 IN MCALESTER, OKLA.

Figure 10.—Traffic Profile Along US 66 Through St. Louis, Mo.

For the solution of special problems under especially favorable conditions, it is sometimes possible to collect needed data at traffic-interview stations within a city. In Columbia, S. C., there are a number of points of traffic concentration just outside of the downtown business section, including a bridge across a river. It was possible to operate a cordon of stations around this section in much the same manner as external stations around a city are operated. Some difficulties were encountered, but the work was satisfactorily done even though the traffic volume was as high as 15,000 vehicles per day at one of the stations. The results obtained were limited in some respects, but were sufficient for the solution of the problems under consideration.

Similarly, interviews were conducted at a bridge between Shelton and Derby in Connecticut, and information was obtained which has been quite useful in the solution of highway problems in the Shelton-Derby-Ansonia area.

NEW SURVEY METHODS TRIED

For several years the need for new methods of determining origins and destinations of traffic within urban areas has been apparent and effort has been made to develop improved methods in numerous cities. In Chicago, Ill., the movement of vehicles throughout the city on a typical weekday was determined by observing license numbers as the vehicles passed different survey stations. Several thousand Boy Scouts were used to man the stations and several hundred supervisors were required to direct the work. The results of this survey have been extremely useful in pointing out the location and kind of highway improvements most needed and in assigning priorities to these improvements. One difficulty inherent in the method is that the zones used in traffic observation are necessarily large, and it is not always possible to fix the desired routes of travel with an accuracy as great as is needed.

In Detroit, Mich., questionnaires were given to war workers to determine the daily number of workers traveling between their homes and places of work. The questionnaires were distributed in all major industrial plants through the employers, and the answers showed the location of the employees' homes, how they went to work, participation in group riding, and at what time. To these data were added the origins of downtown employees obtained by the street railway department through a questionnaire distributed in cooperation with building managers, and information concerning shoppers obtained through the department stores. From the combined data the daily number of workers and shoppers going into and out of each of 10 industrial areas and the downtown retail district were determined. The movement to and from each of these 11 areas was portrayed on a map by traffic flow bands, or rays. These were studied and combined in such a manner as to indicate the major routes of travel. This chart was superimposed on a map of existing streets and from it a network of proposed expressways was developed.

In Cleveland, Ohio, a traffic study, very similar to that in Detroit, was made. Data from worker questionnaires were used in determining expressway location. This survey was made before the Detroit survey and was completed before the war. As a result of experience in Cleveland, the Ohio Highway Department decided that it would be better to interview persons in their homes rather than to seek information at their places of employment. In Toledo, Ohio, home interviews were obtained by having school children bring in reports on the daily travel to and from work by all the workers in their families.

All of the methods described have been extremely useful and have met the needs for which they were made. None of them, however, are sufficiently comprehensive to serve as a desirable basis for long-range highway planning envisioning the expenditure of large amounts of Federal, State, and local funds. When it became apparent that urban construction would play an important part in the postwar program, a study was made of all methods of urban traffic studies that have been used, and a new method was developed based on this experience.

HOME INTERVIEW METHOD DEVELOPED

The work which had been done indicated that the best line of approach was to interview occupants of dwellings according to a standardized method of sampling, and to determine the travel by automobile or by public conveyance by each resident of the dwelling unit on a representative weekday. Since the Bureau of the Census has had a large amount of experience with home interviews on a sample basis, conferences were held with officials of that bureau. In surveys made by the Bureau of the Census, and participated in by numerous nationally known public opinion experts, it was determined that a sample would be representative if it were uniformly distributed as to area. A consumer requirement survey, for example, showed that in a sample selected on the basis of place of residence alone, the relations between age groups, family size, sex, race, and occupational groups were essentially the same as determined in the full census. It was decided, therefore, to distribute the sample uniformly as regards place of residence and to ignore all other factors, such as occupation. To be representative the sample must be preselected and rigidly followed. The interviewer should have no option as to whom he will interview.

Following the conferences with the Bureau of the Census, conferences were held with State and city highway officials in Little Rock, Ark.; Tulsa, Okla.; New Orleans, La.; and other cities. A manual of procedure was developed and work was started in the cities mentioned in February or March of 1944. Interest has spread rapidly and surveys of this type are now being made, or have recently been completed in

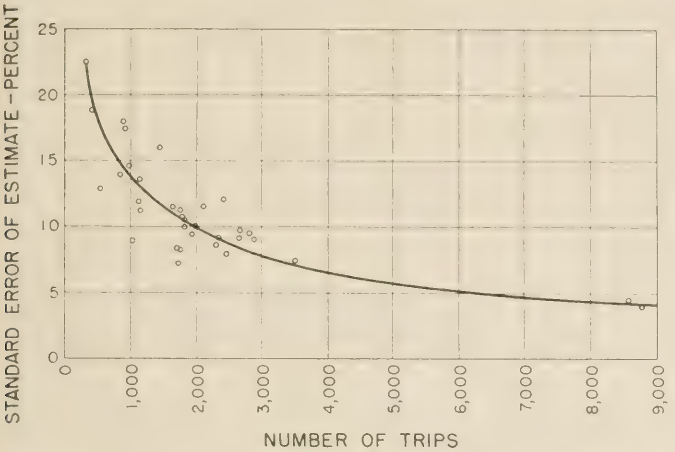


FIGURE 11.—STANDARD ERROR OF ESTIMATE OF TRIPS DESTINED TO DIFFERENT ZONES IN SAVANNAH, GA.

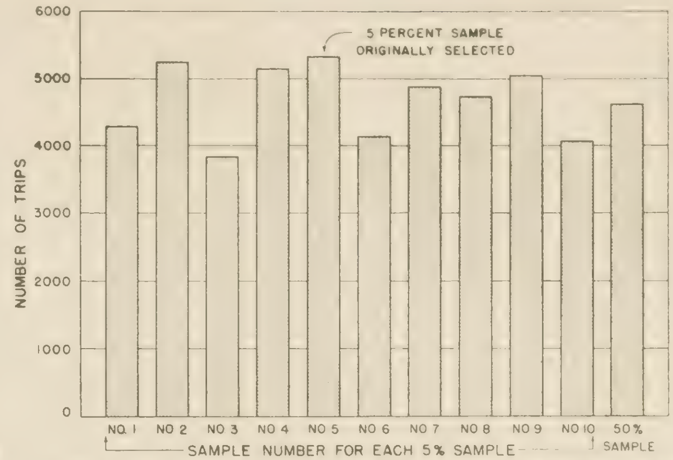


FIGURE 12.—COMPARISON OF THE NUMBER OF TRIPS IN TEN EXPANDED 5-PERCENT SAMPLES IN TRACT 97, MILWAUKEE, WIS.

the metropolitan areas of 35 cities.[1] The manual of procedure is being constantly revised on the basis of experiences gained, but the basic methods remain unchanged.

Information concerning traffic entering and leaving an area is determined at a cordon of external stations located on the principal highways at the boundary of the area. The method used is to conduct roadside interviews in the manner described for Martinsville and McAlester.

Information concerning trips made wholly within the area by persons residing there is determined from home interviews conducted in dwellings selected to form a representative sample. The size of the sample as a percentage of the total varies in accordance with the size of the urban area. In cities of 100,000 to 300,000 population a 10-percent sample has generally been used. In the smaller cities the sample has generally been larger, while in the very large cities samples of 5, 4, and 3⅓ percent are used. As data from the surveys become available, analyses are made to aid in determining the size of sample best suited to give the desired balance between accuracy and cost.

The basis for the sample selection is a map showing the streets and all of the residences. If the sample is 1 in 10 in a zone of one-family houses, every tenth house is selected proceeding clockwise around a block. If there are apartment houses, each apartment is treated as though it were a separate dwelling unit and the counting proceeds through the apartment house, selecting every tenth apartment.

Each interviewer is given a list of the dwelling units in his territory selected for inclusion in the sample, and he is instructed to obtain interviews in these dwelling units and no others. He obtains information concerning all trips made by automobile or by public conveyance on the preceding day, including the means of travel, the origin and destination, the purpose of the trip, the times of starting and arrival, and other information which varies somewhat from city to city. There have been refusals to give the information in only a negligible number of cases.

In the home interviews no information is obtained concerning truck travel, but a special sample of trucks is selected from the registration list. The owners of the trucks selected are called on by an interviewer and information concerning all of the trips made by each truck on the day preceding the interview is recorded. If there is no record of the trips made by the selected truck on that day, the owner is asked to have the driver keep a record on the day following and this information is used instead. The data concerning truck trips generally consists only of the type of commodity carried, the origin and destination, a list of the stops made, and the time of starting and ending the trip. Taxicabs are sampled and data obtained concerning their movements in the same manner as for trucks.

SURVEY ACCURACY TESTED

In several cities checks have been made to test the adequacy of home-interview samples. The method used was based on recommendations of the Bureau of the Census and involves sampling the sample to derive factors indicating probability of error. Figure 11 shows for Savannah, Ga., the amount which estimates of the number of trips made to different zones, based on a 10-percent sample, would be expected to vary from the values which would have been obtained if interviews had been made in every household. The abscissas of the curve represent the number of trips with destination in a given zone and the ordinates represent the standard error of estimate, which is the percentage variation which would not be exceeded oftener than about one-third of the time. Naturally the larger the number of trips being estimated, the more accurate the estimate can be expected to be. For a group of about 6,000 trips the standard error is only about 5 percent, whereas for a group of about 1,000 trips it is about 14 percent. On the whole, the curve indicates that a sample of 10-percent is adequate for a city the size of Savannah because it is not probable that there will be need to estimate traffic volumes (or trip groups) less than several thousand vehicles per day with a very small percentage of error.

In Milwaukee, Wis., the sample for the city as a whole was 5 percent. Ten 5-percent samples were selected in one of the zones and variations between these different 5-percent samples were determined. Figure 12 shows the number of trips made by residents of the zone as determined from each of the samples. The extreme variation is from about 3,900 (sample 3) to about 5,300 (sample 5). The probability of obtain-

[1] Boston, Providence, Newark, Baltimore, Richmond (Va.), Charlotte (N. C.), Greenville (S. C.), Spartanburg (S. C.), Atlanta, Savannah, Waycross (Ga.), New Orleans, Baton Rouge, Shreveport, Memphis, Nashville, Chattanooga, Cincinnati, Indianapolis, Fort Wayne, South Bend, Port Huron (Mich.), Milwaukee, Ottumwa (Iowa), Mason City (Iowa), Omaha, Lincoln (Nebr.), St. Louis, St. Joseph, Springfield (Mo.), Kansas City, Little Rock, Oklahoma City, Tulsa, and Denver.

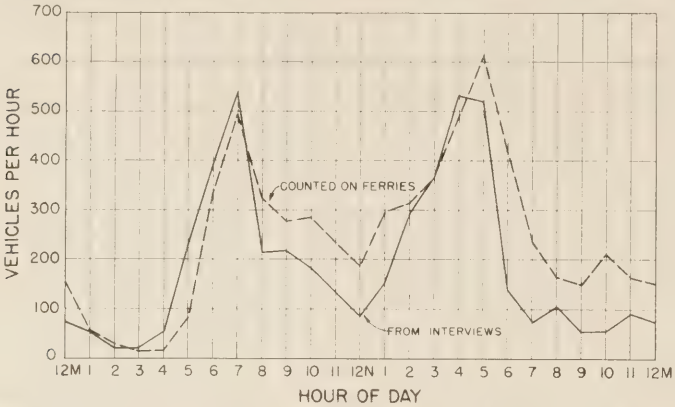


FIGURE 13.—COMPARISON OF THE ACTUAL NUMBER OF PASSENGER CARS CROSSING THE MISSISSIPPI RIVER ON THE FERRIES AT NEW ORLEANS, LA., WITH THE NUMBER ESTIMATED FROM INTERVIEWS TO HAVE DONE SO.

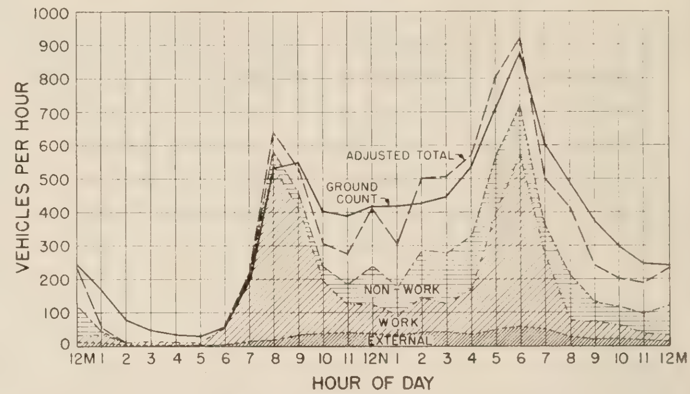


FIGURE 14.—NUMBER OF PASSENGER CARS COUNTED AT FIVE CONTROL POINTS IN DENVER, COLO., COMPARED WITH THE NUMBER ESTIMATED FROM INTERVIEWS TO HAVE PASSED THESE POINTS.

ing a sample that deviates from the mean as much as No. 3 is only about 5 percent, and the probability of obtaining one that deviates from the mean as much as No. 5, at the other extreme, is only 7 percent. The test for Milwaukee seems to indicate that a 5-percent sample is in keeping with the over-all requirements as to cost and accuracy.

In order to test the completeness with which trips are reported, certain well-known points through which traffic funnels are designated as control points and, in the interviews, information is obtained concerning the vehicles passing them. Counts are made at these points and the expanded interview data are compared with the actual ground counts. A bridge or an important artery carrying a large amount of intracity traffic is ideal for a control point. In some cases there are no points of traffic concentration that are well enough known to make them suitable control points. It is then necessary to determine from origins and destinations alone those trips crossing a so-called "screen line" drawn across the area and also to count all of the trips on all of the streets crossing this line, making as many counts as there are streets crossing the line. A river makes an excellent screen line and, in some cases, this method of checking is preferable to the control point method. One objection to it is that it is sometimes possible for a trip to cross the line twice, even though the origin and destination are both on the same side of the line, and the line has to be selected with considerable care to minimize occurrences of this kind.

Figure 13 shows for New Orleans, La., expanded interview data by hours and compares these results with counts on all ferries crossing the Mississippi River, the river being used as a screen line. The morning and afternoon peaks check very closely, but a considerable portion of the midday and night travel appears to have been missed in the interviews. Since much of the travel in the morning and afternoon peaks is to and from work, and much of that in the midday and night periods is for shopping and recreational purposes, this chart suggests that work travel was more fully reported in the interviews than nonwork travel. This was expected in view of the restrictions on driving in effect when the survey was made. As a test of this conclusion a zone was selected in an industrial area containing only manufacturing plants for which employment figures could be obtained. This zone was census tract No. 17 containing the Delta, Higgins, and Pendleton shipbuilding plants and five smaller plants. According to the manufacturers, the total number of daily workers was 26,149, some of whom may have walked to work. According to actual counts made by the New Orleans Public Service Commission, the number of people riding to work daily by automobile, streetcar, or bus was 23,531. The expanded home-interview data indicated work trips into this zone amounted to 21,904 per day. The percentage relation between those driving by automobile and those riding by streetcar or bus was almost the same in the Public Service Commission data as it was in the survey data. This confirms the implication of figure 13 that trips to work were almost completely reported and that the trips not reported were those for recreation and other nonwork purposes.

Figure 14 shows a comparison between ground counts of passenger cars and expanded interview data for five control points combined in Denver, Colo. Here again the ground counts and expanded interview data are in agreement for the morning peak and the difference between them is not great in the afternoon peak. Apparently, trips were missed in the interviews for the midday and night periods, and presumably, these were trips other than to and from work. If the figures for nonwork travel were adjusted by a factor of 2.5, the interview data would be in fairly close agreement with the ground counts as indicated by the line on the chart labeled "adjusted total."

Fortunately, from the point of view of design requirements, traffic during peak hours is being determined rather closely from the expanded interview data and the trips missed are generally those occurring in off-peak hours. However, an effort is being made to improve techniques to obtain more complete information concerning trips throughout the day. That such efforts are bearing fruit is indicated by figure 15 showing combined data for three control stations in Milwaukee, where the survey was made later. This check indicates that the data are sufficiently accurate to be used without adjustment.

Another indication that more complete information is being obtained is that the number of trips per dwelling unit averages much higher in the later than in the earlier surveys. In Milwaukee and Richmond, for instance, about five trips per dwelling unit were obtained compared to about three trips per dwelling unit in New Orleans and Denver. Improvements are being brought about by more careful training of the interviewers, insistence that the information be obtained

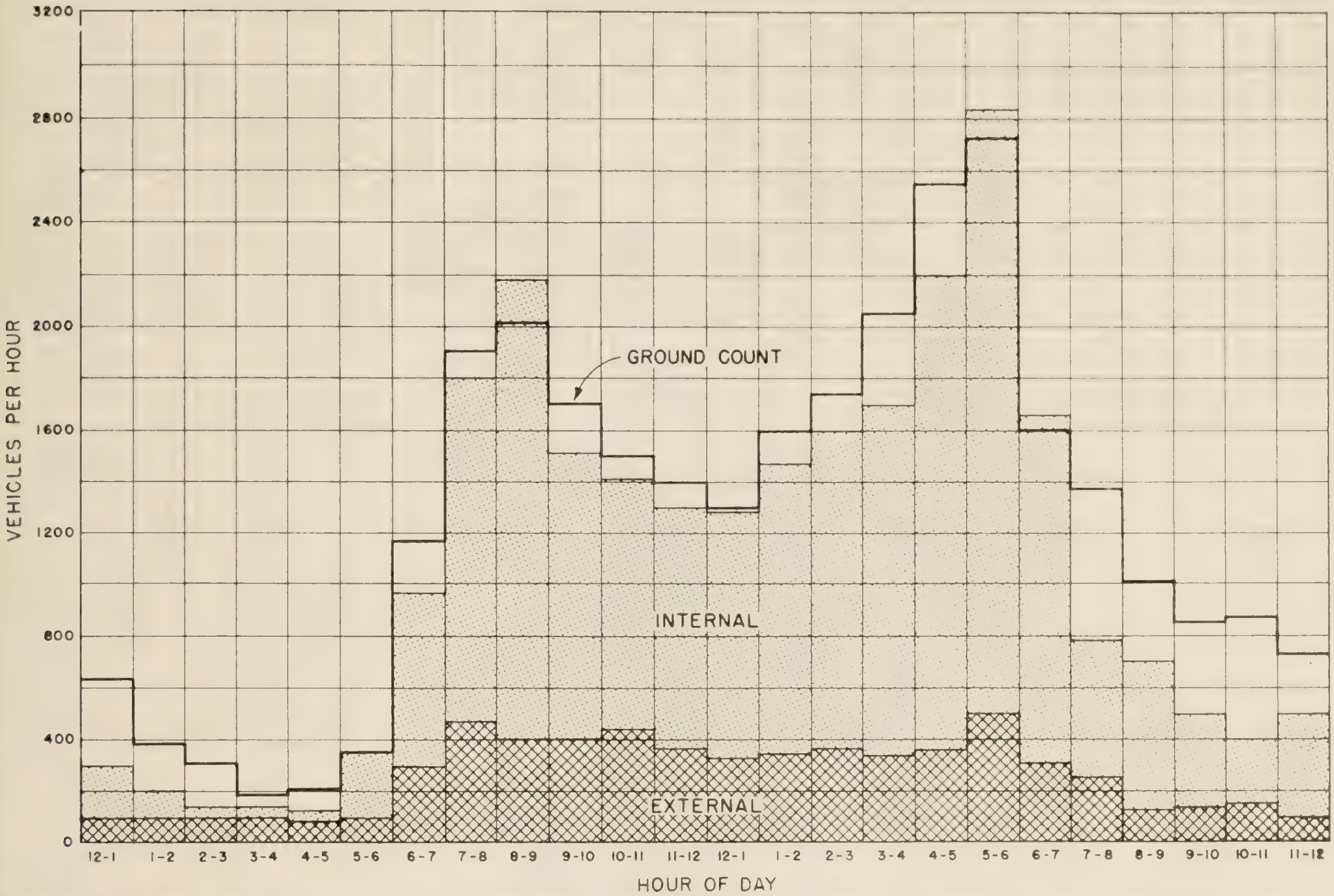


FIGURE 15.—COMPARISON OF THE NUMBER OF PASSENGER CARS AND TRUCKS COUNTED AT THREE CONTROL POINTS IN MILWAUKEE, WIS., WITH THE NUMBER ESTIMATED FROM INTERVIEWS TO HAVE PASSED THESE POINTS.

first hand from the person who did the traveling, even at the expense of more repeat calls, and, in some cases, by a shortening and simplification of the form.

It was necessary to undertake the surveys under war conditions in order to develop information that would be of value in the immediate postwar program. Because of manpower shortages, particularly in supervisory capacities, it was necessary to limit the work to procurement of information concerning the most important problems. In all cases, field work was conducted for only a few months and there is a lack of seasonal coverage. Because of war restrictions, Sunday and holiday travel was curtailed and data were obtained for weekdays only. It will be necessary to make allowances for these conditions in interpreting the data. As regards the shift from automobile to public transportation because of gasoline rationing, the basis for adjustment is contained in the reports of interviews. Full information was obtained concerning trips by all means and the desired method of travel under normal conditions.

Now that the war is over it will undoubtedly be practicable to use a well-trained party and to extend the work over a full year, obtaining information concerning Sunday and holiday travel, as well as weekday travel. If this can be done, a degree of accuracy much greater than any yet obtained should be possible.

USES OF THE DATA

The most useful tabulations made from survey data show the number of trips daily from one zone to another by automobiles, trucks and passengers in automobiles and public transit vehicles. From these tabulations determination can be made of routes that will best serve traffic needs, and the traffic volumes to be expected on new facilities which may be constructed. Such data for the greater Kansas City area are depicted graphically in figures 16 to 20, inclusive.

Figure 16 shows the interzone movements of passenger cars occurring wholly within the area which amount to 300 or more trips per day; figure 17 shows those which consist of 150 to 299 trips per day, and figure 18 shows those of 75 to 149 trips per day. The major movements depicted in figure 16 follow a well-defined pattern, while the minor movements are shown by figure 18 to be widely dispersed. It is obvious that movements of less than 75 trips per day are so widely scattered that no pattern or trend can be shown. No matter where improvements are located the minor traffic movements will be served in about equal proportions, and it is the larger movements shown in figures 16 and 17 that should govern in route selection.

Figures 19 and 20 give similar information for passenger-car trips passing external stations and extending beyond the limits of the area. From the data depicted in figures 16 to 20, inclusive, figure 21 was constructed to show major desire lines of travel for passenger automobiles. If it were possible to establish adequate routes along these lines, they would attract approximately the volumes of passenger-car travel indicated by the band widths. This and a chart showing the desired lines of travel for trucks, similarly constructed, form the basis

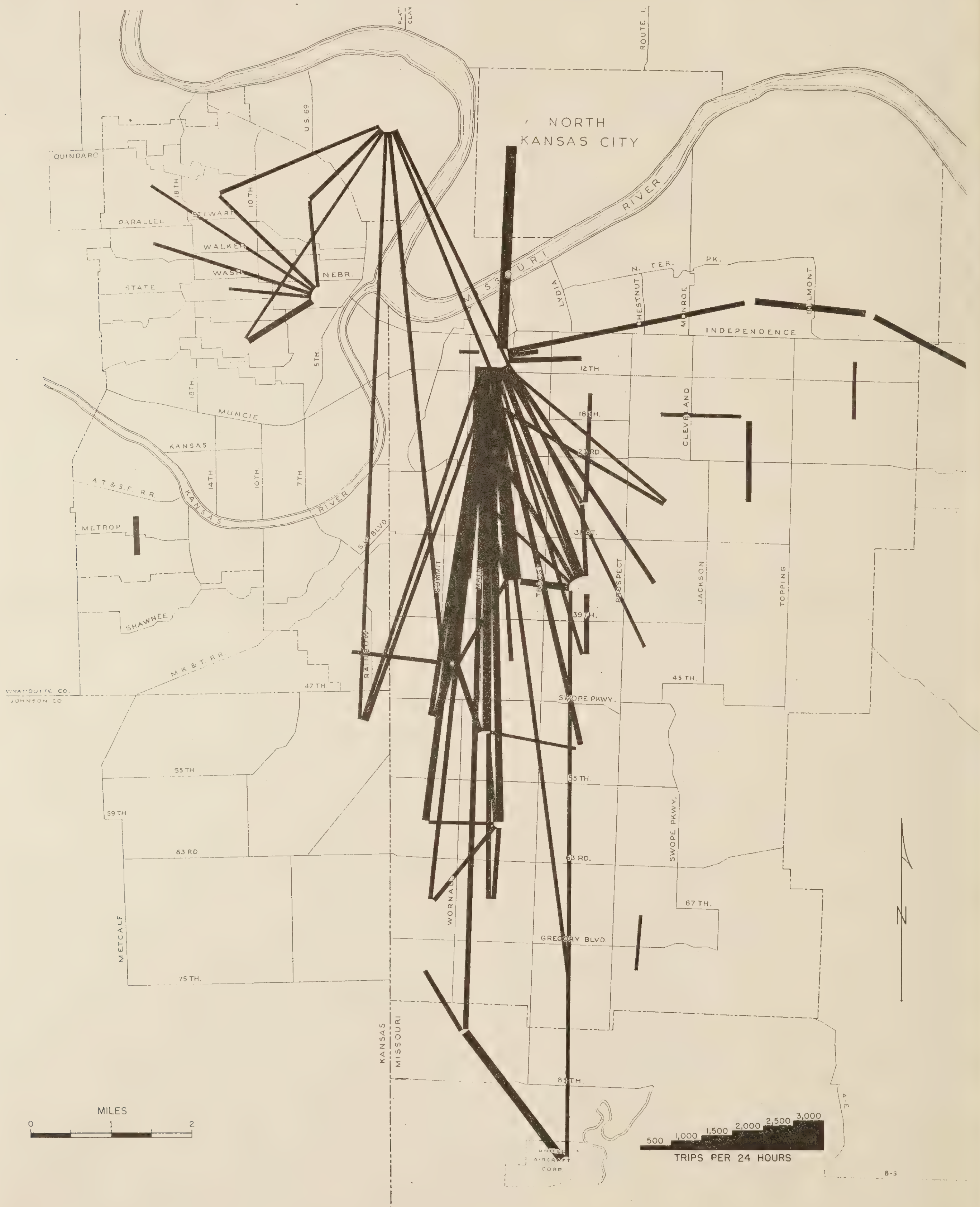


Figure 16.—Desired Lines of Automobile Travel Between Zones in Kansas City Having a Volume of 300 or More Trips per Day.

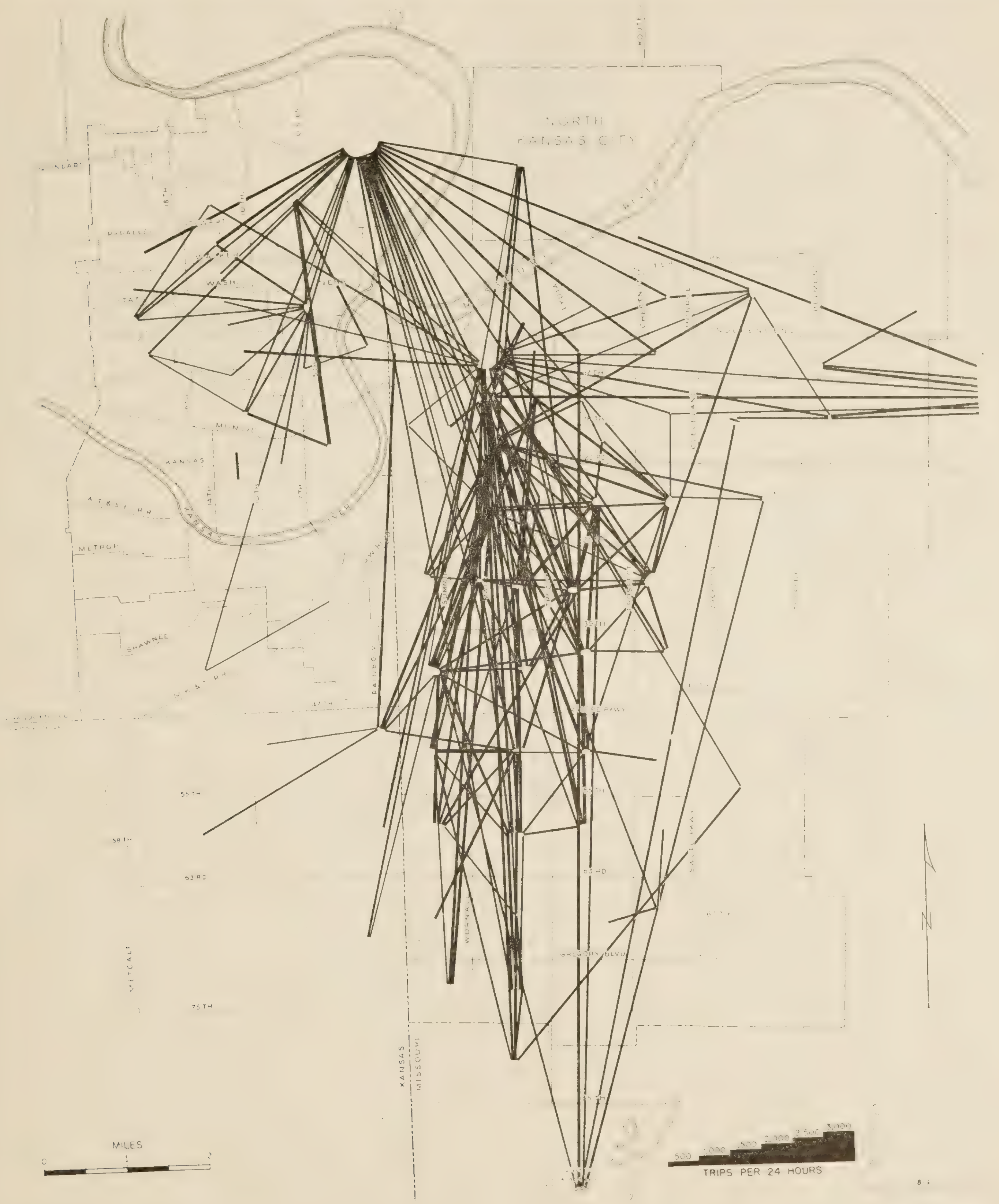


Figure 17.—Desired Lines of Automobile Travel Between Zones in Kansas City Having a Volume of 150 to 299 Trips per Day.

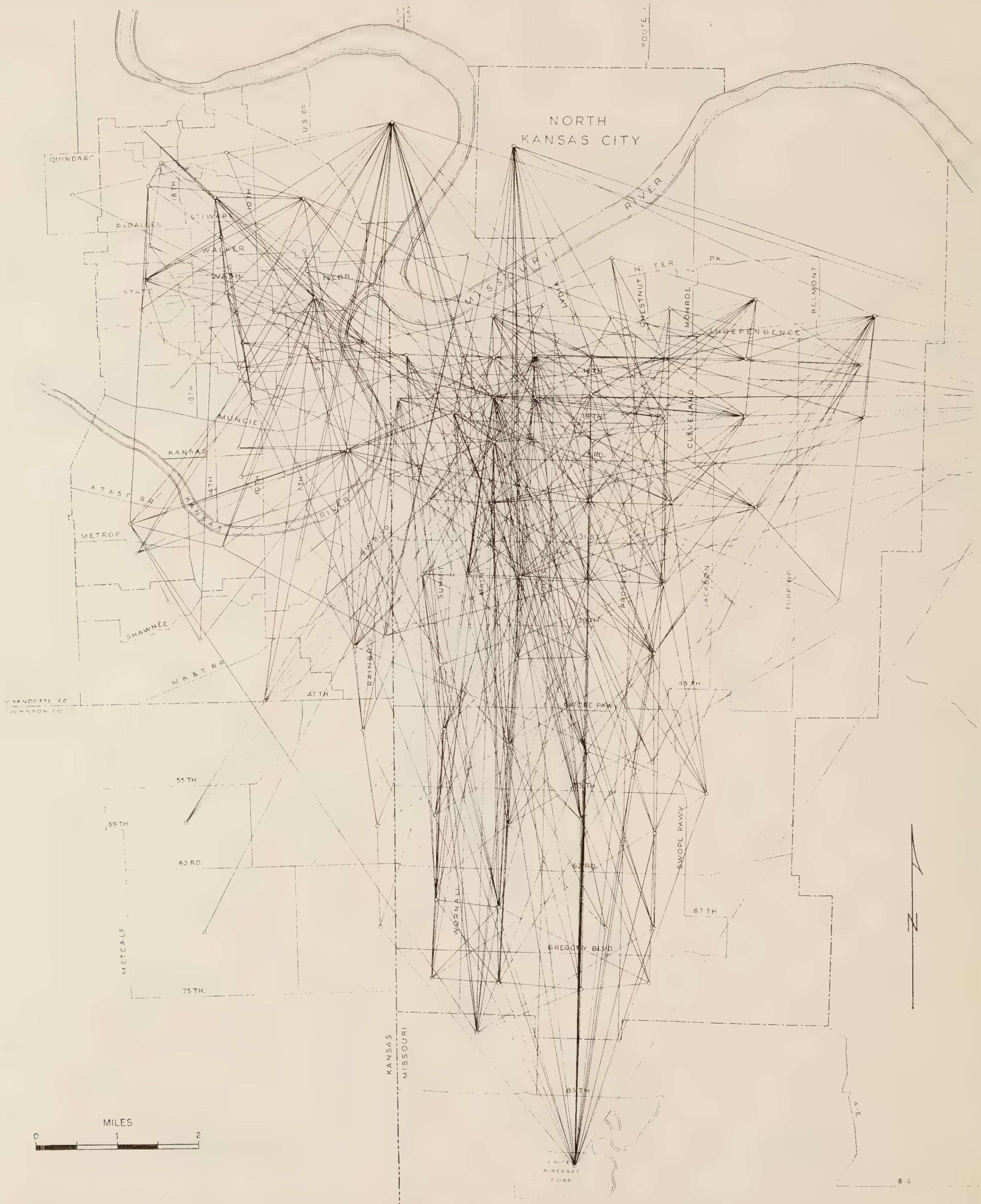


FIGURE 18.—DESIRED LINES OF AUTOMOBILE TRAVEL BETWEEN ZONES IN KANSAS CITY HAVING A VOLUME OF 75 TO 149 TRIPS PER DAY.

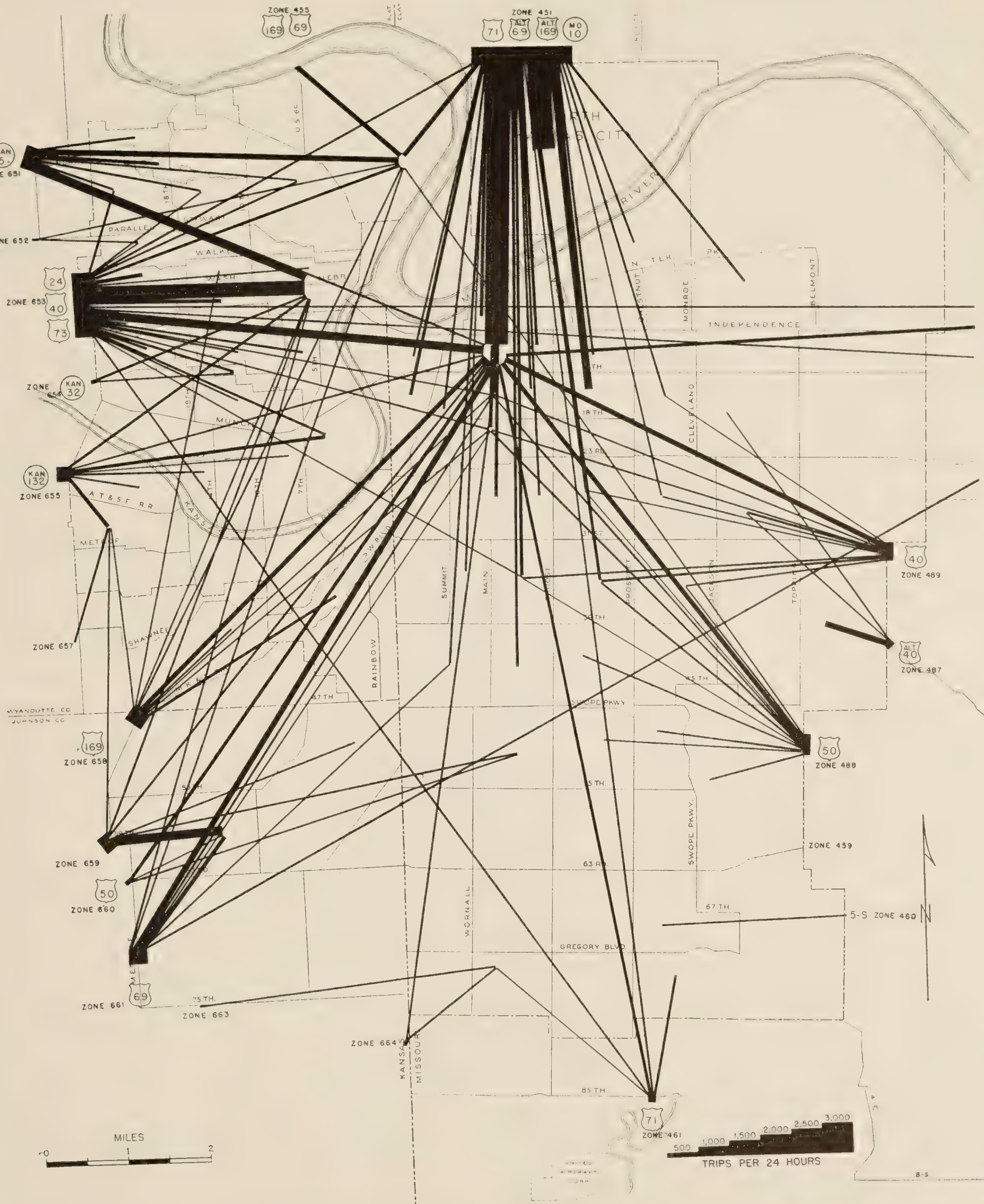


Figure 19.—Desired Lines of Automobile Travel From Zones in Kansas City to Points of Exit From the City Having a Volume of 100 or More Trips per Day.

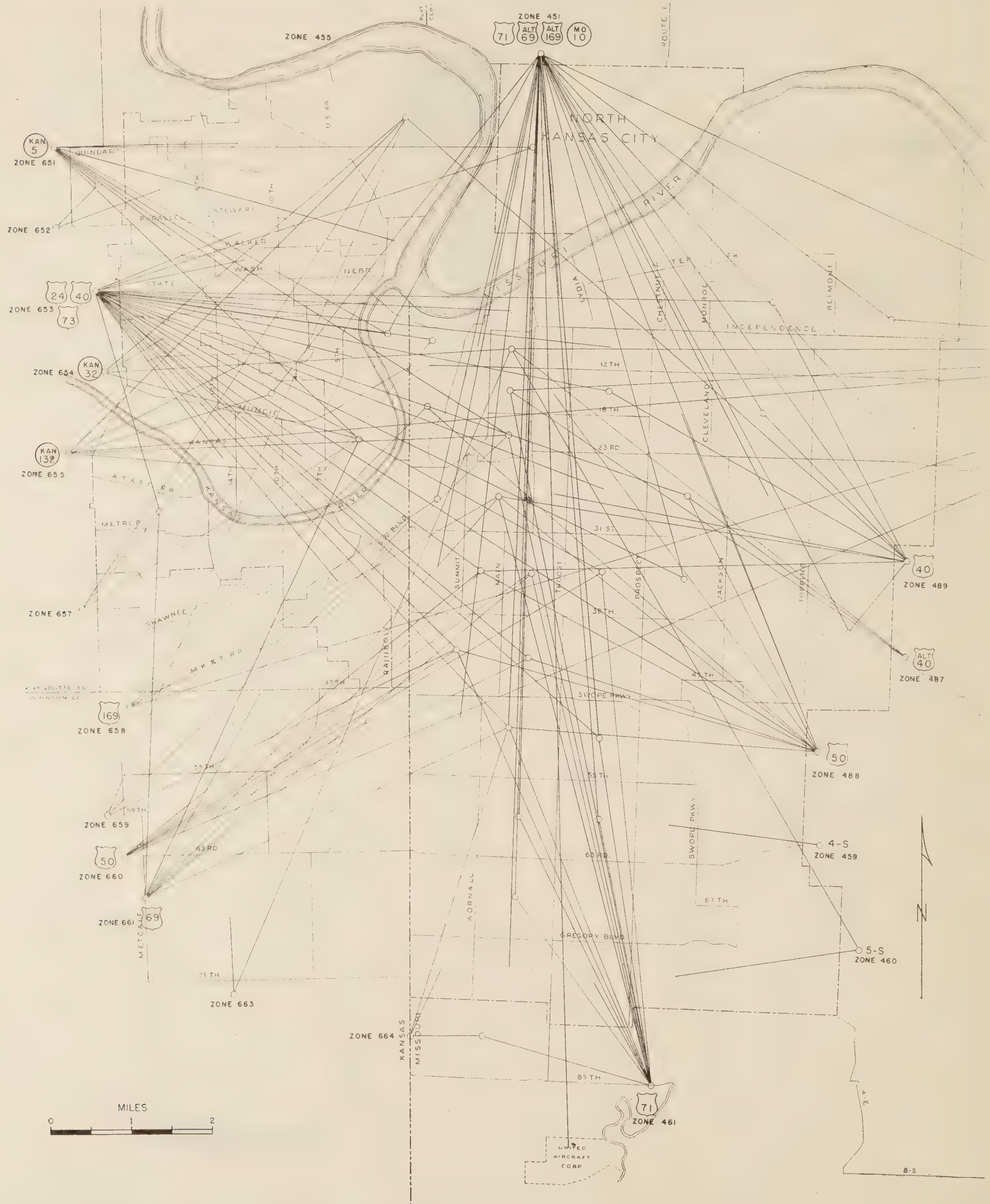


FIGURE 20.—DESIRED LINES OF AUTOMOBILE TRAVEL FROM ZONES IN KANSAS CITY TO POINTS OF EXIT FROM THE CITY HAVING A VOLUME OF 50 TO 99 TRIPS PER DAY.

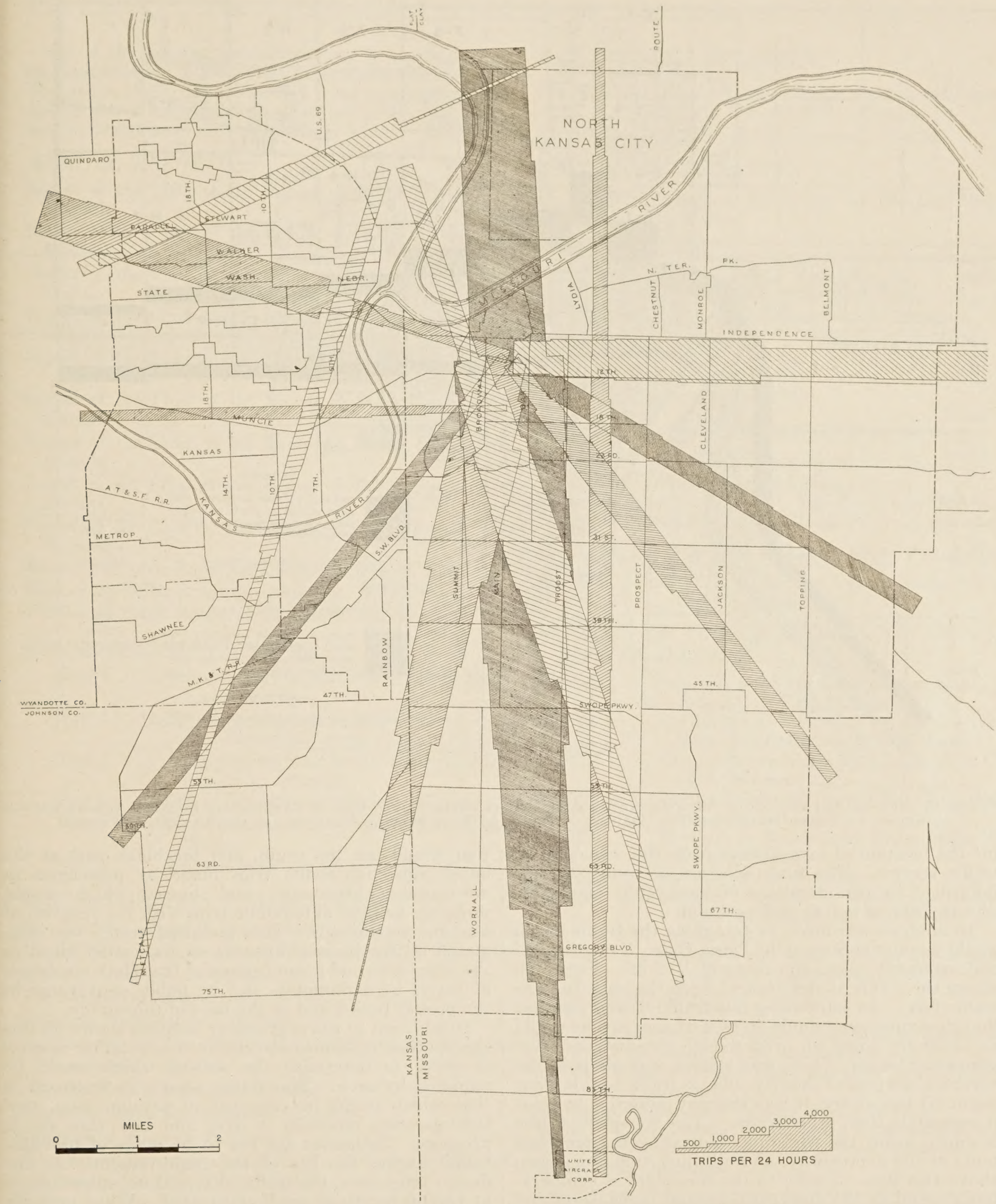


FIGURE 21.—MAJOR DESIRED LINES OF AUTOMOBILE TRAVEL IN KANSAS CITY.

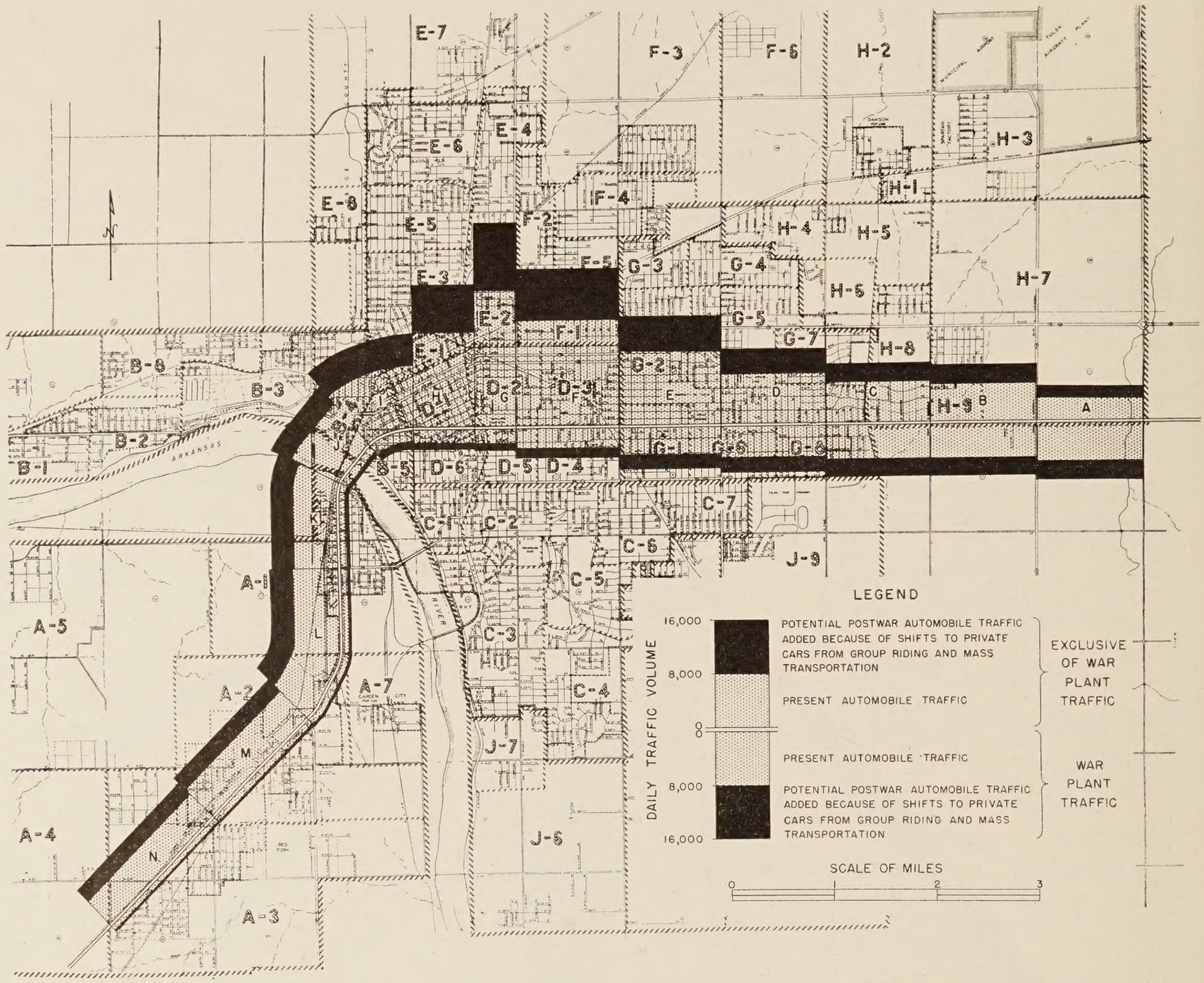


FIGURE 22.—ESTIMATED VOLUME OF EXISTING AUTOMOBILE TRAFFIC THAT WOULD USE AN EXPRESSWAY LOCATED APPROXIMATELY AS SHOWN IN TULSA, OKLA., AND THE AMOUNT OF INCREASE THAT MAY BE EXPECTED IN THE IMMEDIATE FUTURE.

for the location of expressways from the viewpoint of traffic service. The final selection of routes will be influenced by considerations of topography and right-of-way costs, as well as traffic criteria.

An analysis was made to determine the traffic which would use an expressway in Tulsa, Okla., if constructed approximately along the route of U S 66. Figure 22 shows the result as determined from the zone to zone traffic flow. In estimating this traffic it was assumed that the expressway would be used whenever time would be saved by doing so, even though the distance were somewhat longer. There was a large war plant in the northeastern part of the city, and, as traffic to this plant might be temporary, it was thought advisable to treat it separately from other traffic. This war-plant traffic is shown below the white line indicating the proposed route of the expressway, and all other traffic is shown above this line. Traffic to the war plant is comparatively small in the downtown section (zone D–1) and becomes relatively large at the edge of the city, whereas the other traffic is relatively small at the edge of the city and increases as the downtown section is approached. The lighter portion of the band adjacent to the white line represents existing automobile travel that would use the route, and the black part at the outer edges represents trips made by passengers in automobiles, streetcars, and busses which would probably become automobile trips with the removal of wartime restrictions. This potential traffic was estimated on the basis of answers to a question asked in the interviews and a comparison of the relative volumes of travel by automobile and by public conveyance in the prewar period and at the time of the survey.

In addition to the expressway location shown on this chart, other locations were analyzed in a similar manner in order to determine the service which would be rendered by each. The traffic shown in figure 22 is that which might be expected to develop soon, now that gasoline rationing is over and new cars are in prospect. Estimates are yet to be made of probable traffic during the life of the improvement. As the design progresses, the traffic that will use interchanges at various locations can be estimated. When properly analyzed and interpreted, the survey data give all of the information needed to compare a route with any other route as regards traffic service, to determine the design volumes for different sections, and to determine the needed locations and capacities of the interchanges.

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Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

ANNUAL REPORT

Public Roads Administration, 1943.

Public Roads Administration, 1944.

MISCELLANEOUS PUBLICATIONS

No. 279MP. . Bibliography on Highway Lighting.

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 15 and 17–23, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

REPORTS IN COOPERATION WITH UNIVERSITY OF ILLINOIS

No. 303 . . . Solutions for Certain Rectangular Slabs Continuous Over Flexible Support.

No. 304 . . . A Distribution Procedure for the Analysis of Slabs Continuous Over Flexible Beams.

No. 313 . . . Tests of Plaster-Model Slabs Subjected to Concentrated Loads.

No. 314 . . . Tests of Reinforced Concrete Slabs Subjected to Concentrated Loads.

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No. 345 . . . Ultimate Strength of Reinforced Concrete Beams as Related to the Plasticity Ratio of Concrete.

No. 346 . . . Highway Slab-Bridges with Curbs: Laboratory Tests and Proposed Design Method.

UNIFORM VEHICLE CODE

Act I.—Uniform Motor-Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor-Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor-Vehicle Civil Liability Act.

Act IV.—Uniform Motor-Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Federal Works Bldg., Washington 25, D. C.