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PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

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WEIGHING A TRUCK AT A TRAFFIC SURVEY STATION

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VOL. 10, NO. 1 — **MARCH, 1929** — **R. E. ROYALL, Editor**

TABLE OF CONTENTS

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HIGHWAY TRAFFIC ANALYSIS METHODS AND RESULTS

Reported by L. E. PEABODY, Associate Highway Economist, United States Bureau of Public Roads

IN ALL but 2 of the 48 States at least one highway traffic census of some sort has been taken. More than half the counts have been fairly complete; the others, for various reasons, have been more or less ineffectual.

Where the census has been taken only on the Fourth of July, Labor Day, and perhaps one or two additional days, the data, even if carefully gathered and studied, can be of little value except as representing maximum traffic or, when compared with similar counts taken in other years, as the basis of an estimate of traffic growth.

In at least 7 States the counts taken have been nearly valueless by reason of improper station location, failure to classify the traffic, or other faults and omissions in the methods employed.

Priority of improvement can be decided very satisfactorily upon the basis of the present observed traffic; but the development of a plan of improvement which will recognize and provide for future traffic needs must have as its basis an estimate of future traffic density as well as a knowledge of the present flow. It is in their employment of such projected data obtained by methods of forecasting developed by the bureau that the recent cooperative surveys differ from those made previously.

In addition to these uses of the census data for purposes of broad planning, there are a number of specific problems, in dealing with which an exact knowledge of traffic density and characteristics is of primary value. Some of these other uses of the data are suggested

A Truck-Recording Station with Fixed Scales

merely by stating a few of the more common highway problems: (1) The establishment of a maintenance program and expenditures thereunder; (2) whether to pave or oil a road on which the existing surface is of low type; (3) the decision as to whether a gravel surface has reached the limit of economic use; (4) the determination of the economy of snow removal; (5) the necessity for special design of highways near large cities to accommodate truck traffic of high density and great weight; (6) the determination of the amounts of foreign and tourist traffic, a factor in determining road service and fixing of gasoline tax rates; (7) the determination of pavement widths; (8) problems of traffic regulation and highway safety.

The list is not exhaustive, but it is clear that the proper solution of each of the problems mentioned is dependent upon a precise knowledge of the traffic to be served. And it is also apparent that a variety of facts concerning the traffic are required for the solution of the various problems.

For some the data required are those which will furnish an accurate idea of the flow of traffic throughout

In most cases the objects of the counts have been simply the determination of the geographical distribution of traffic; the measurement of relative use of primary, secondary, and third class highway systems; or the establishment of the fact and rate of traffic growth. These are the simpler and more obvious uses of a traffic census. The recent surveys conducted by the Bureau of Public Roads in cooperation with the highway departments of several States have gone much farther in the direction of the practical application of the census data to the planning of highway systems and the development of programs of improvement.

All States in varying degree are faced with the same situation—an insufficiency of revenue to meet the needs of increasing traffic as rapidly as they should be met. All, therefore, have in common two problems to solve: (1) The setting up of a plan of improvement, adjusted to the State's financial resources, which ultimately will meet traffic requirements; and (2) the establishment of an order of priority among the numerous improvements that must be made.

38164—29——1

the year; others require a knowledge of winter traffic; others of peak density; others of some fraction of the total traffic, such as motor trucks, or foreign vehicles, etc.

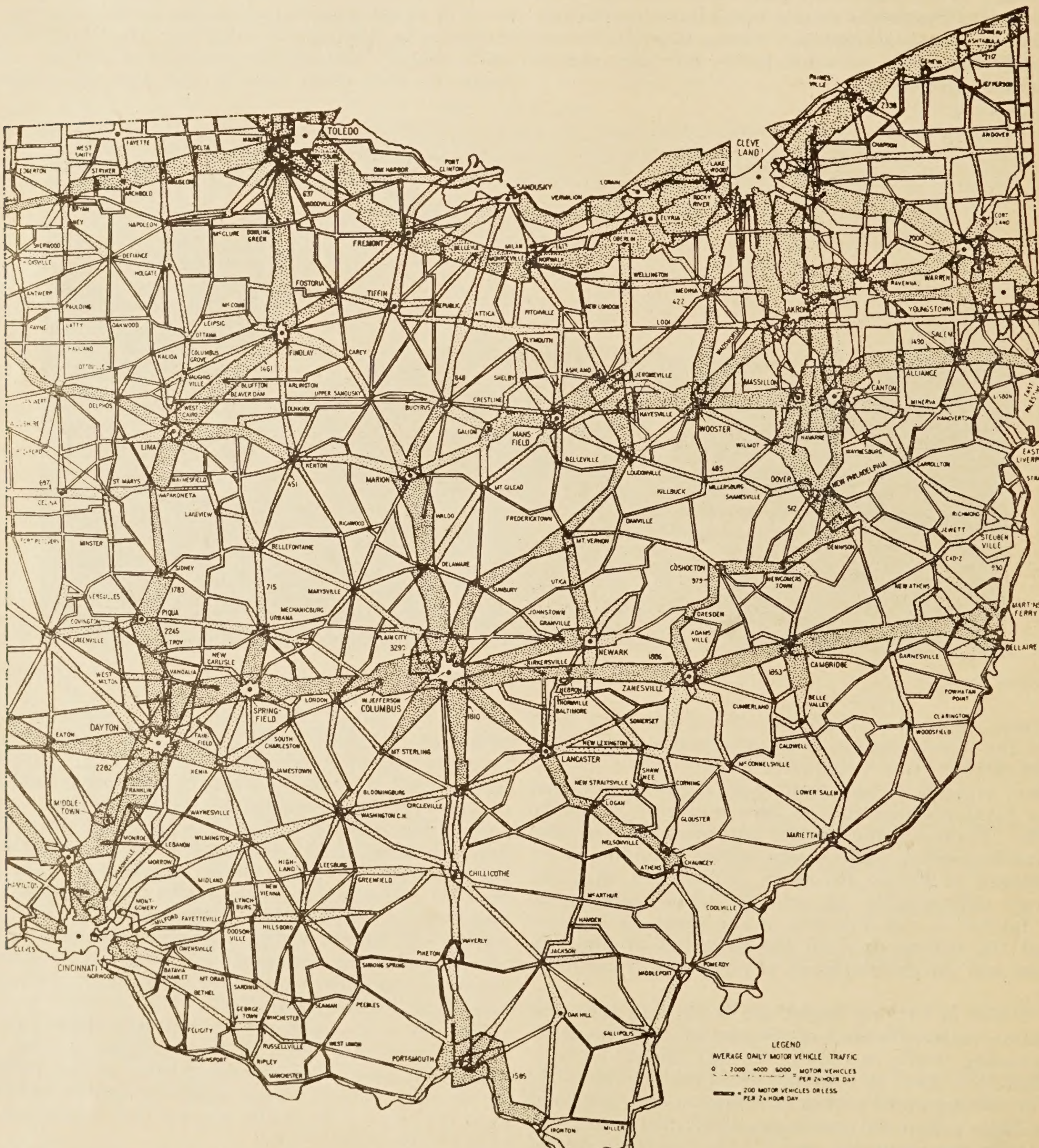
In planning a traffic survey it is essential, therefore, that there shall be a clear understanding of the methods to be employed in converting the basic data to the solution of the various problems. Otherwise essential data may not be obtained, and much gathered that is later found to be useless. The methods employed must be carefully designed to supply a maximum of information, of precisely the kind required, at a minimum of expense.

The discussion and recommendations that follow, based upon the bureau's experience with traffic surveys conducted in six States[1] and in Cook County, Ill., and the regional area of Cleveland, Ohio, in cooperation with the State and local authorities, are presented in the hope that they may prove suggestive to others who may be called upon to collect and analyze traffic data.

THE SELECTION OF STATION LOCATIONS

It is advisable to divide the territory into homogeneous areas to provide a stable basis for the computation

[1] Connecticut, Pennsylvania, Maine, Ohio, New Hampshire, and Vermont.



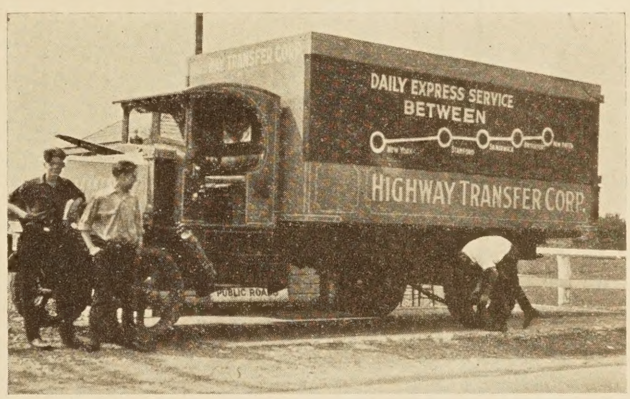
Map Showing Average Daily Density of Motor-Vehicle Traffic on the State Highway System of Ohio of various transportation averages—averages of trip mileage, weights of vehicles, weights of loads, numbers of vehicles passing a given point, etc. For example, average weights of loads in the neighborhood of the cement plants at Buffington, Ind., vary widely from average weights of loads near Washington Court House, Ohio. Passenger cars traveling over routes adjacent to Chicago during evening hours are much greater in number and in proportion to the day's travel than near Houlton, Me. At stations within the city of Chicago from 8 p. m. to midnight there pass about 22 per cent of the day's passenger cars; in Maine the corresponding percentage is a little more than 12. The average length of trip of cars passing a station between Canton and Massillon, Ohio, is much shorter than the average length of trip during the summer months at stations located in northern New Hampshire. Massillon and Canton are a short distance from each other, and much of the travel on the route connecting them originates and terminates in either city. Comparison of averages between two areas have meaning only when there is reasonable homogeneity in each. If, for example, average weights of loads are being compared for two areas, neither area should contain much admixture of industrial and agricultural sections. It is best to put all the agricultural sections into one area and all the industrial sections into another. Comparison of net loads may then be made as between agricultural and industrial regions.

The selection of station locations is affected considerably by the character of the data to be secured and the objectives of the survey. If the primary objective is that of measuring annual use of various road systems—i. e., Federal-aid routes, United States highway routes, State routes, county routes, etc.—stations must be so located as to provide a representative sample of traffic upon each. If the comparison is between sections of the State, each section must be assigned a number of stations sufficiently large to give a fair sample If it is desired to measure the average lengths of trip, stations should be located so as to get lengths of trip near large cities, in agricultural areas, and in summer-resort areas. The average trip length may vary as between interconnecting routes—viz, United States highways and county routes.

Measurement of the use of highway systems by "foreign" (out of State) cars is often an objective of the survey. In this case stations should be located so that traffic is measured both at State borders and in the interior. "Foreign" traffic near State borders is frequently more than 50 per cent of the total traffic. In States that are largely summer-resort territory, like New Hampshire and Vermont, "foreign" traffic is close to 50 per cent for the whole State.

If relocations or reconstruction are to be based upon traffic data, stations should be very carefully located and with as much preliminary knowledge of traffic conditions as possible. For example, if two alternate routes of different length between two cities exist, one in good condition and one in poor condition, stations should be placed upon each route and the origin and destination of vehicles ascertained. This will usually disclose that improvement or relocation of one of the routes will result in its exclusive use except for purely local travel. The arguments relating to the selection of homogeneous areas apply in part to the problem of station location. The variability in traffic is considerably different in urban and rural areas, and stations should be so located as to measure accurately these differences. Usually this may be done by designating as "urban" those areas within 10 miles of the larger cities, and considering all other territory as "rural." A check up as the traffic analysis proceeds will determine whether the division between urban and rural has been made correctly.

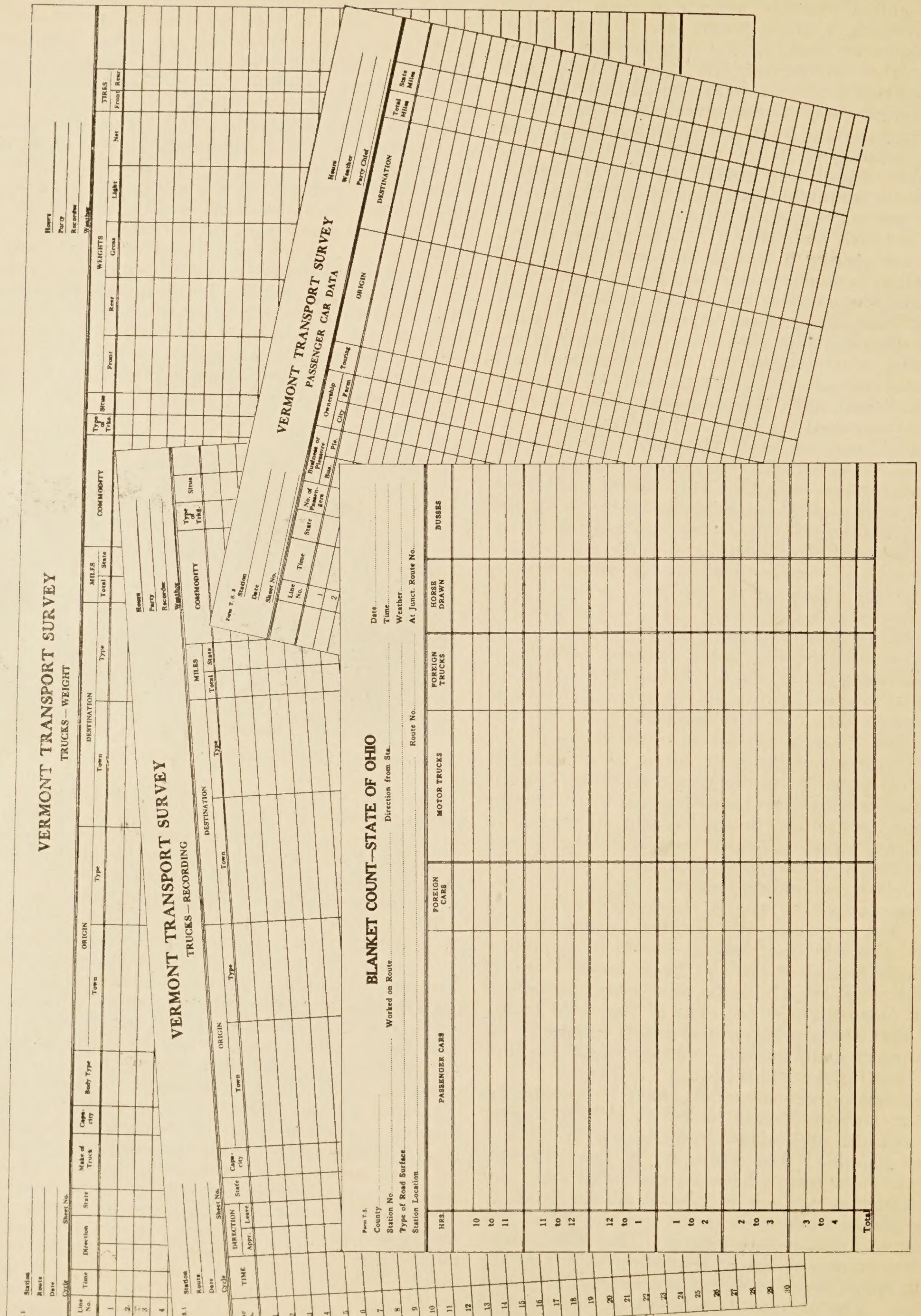
Key stations are those at which traffic information is most important. They are usually located at the intersections of all main routes, and the information obtained at them should be the most complete from the standpoint of the amount and detail of the data secured, and from the standpoint of duration of observation. Blanket-count stations are those at which only the most important data are taken (viz, number of vehicles) and which may be operated by inexperienced personnel. These stations are usually operated a smaller number of times and are located upon the relatively unimportant routes, or at intermediate points between key stations on the main routes where a closer measure of variability in traffic density is desired.



Measuring Truck Tires at a Truck-Recording Station

The key stations are divided into two classes—weight stations and recording stations. Examination of the forms accompanying this text will disclose the differences in the types of information secured at each. The main difference is that at weight stations trucks are actually weighed on loadometer or pit scales.

The number and location of weight stations are governed by many considerations, such as variations in loading practices, care to secure representative samples, the desire to measure the extent of overloading, the greater expense of operation of a weight party, the availability of scales, if pit scales are used, the interruption and delay of traffic by reason of stoppage for weighing, and the physical surroundings. Taking these in order: If a comparison of loads between industrial and agricultural areas is desired, a sufficient number of stations must be maintained in each area. If overloading is prevalent, stations should be located so as to produce the facts. The greater expense in weight-station operation results from the necessity of operating such stations with a greater number of personnel per party. At weight stations the amount of information to be gotten is great, trucks must be halted and weighed, and more experienced men are required. If pit scales are to be used in weighing trucks, the stations must be located at points where such scales have been installed. Experience indicates that the portable loadometer scales produce as good



Typical Forms Used to Record Data in the Field results, are less expensive to operate, and give the advantage of flexibility in the selection of weight station locations. Interruptions and delays to traffic are also a prime factor in locating weight stations. If the number of trucks is large, there will be a long line of waiting trucks. Truck operators become impatient and leave the station before information can be secured. Finally, it is necessary that the location will provide sufficient space at the side of the right-of-way to permit the installing of scale approaches, the maneuvering of trucks, and space for waiting vehicles.

Data secured at recording stations cover the same subjects as at weight stations, except that no trucks are weighed. Passenger-car data forms, similar to the one shown, are filled out at both weight and recording stations.

The key stations—both weight and recording—should be allocated upon primary, secondary, and third-class highway systems in accordance with the importance of these systems; and the same rule should govern the allocation of blanket-count stations. Complete and accurate descriptions of station locations should be placed in the hands of the survey parties, and copies should be filed at headquarters.

The distance between stations is governed largely by the shape of the highway network. Junctions should be covered as completely as possible, and distance between key stations should rarely exceed 20 or 25 miles, otherwise some cars will not be picked up.

SCHEDULING THE STATION COUNTS

Schedules of station operation should provide for more frequent operation at key stations and, as explained more fully later in this paper, should furnish information as to variability of traffic throughout the year. Best results will be obtained when the schedule of key-station operation is elastic enough to cover peak-traffic and minimum-traffic periods. Representative samples of traffic in urban and rural areas are required. The number of counts at a station must be great enough to provide accuracy, and night operations should be in the ratio of at least one to five day operations. Day and night counts should be of 12 hours duration, beginning and ending usually at 6 a. m. and 6 p. m. Satisfactory results are not likely to be obtained from counts on three or four days distributed throughout the year. A count taken 1 week day, 1 Saturday, and 1 Sunday at intervals of 3 months will give results accurate enough for many purposes, although a schedule providing for operation of key stations every 13 days is much to be preferred. Information at a large number of "blanket-count" stations operated but two or three days per year may be readily tied in with the more complete results of key-station operation.

Two mistakes in scheduling party operations at key stations should be guarded against: (1) Selecting for operation on successive days stations that are located too far apart (30 to 50 miles is suggested as a limit); and (2), simultaneous operation of two stations so close together that there is danger of taking data from the same vehicle twice on a single trip. The first error results in parties reaching the station later than scheduled, or reaching the station without sufficient rest. The second error is more serious on main routes and, if it occurs, tends to distort the results, particularly for average trip mileage per vehicle. Since density information only is normally recorded at blanket-count stations, the warnings just given do not apply.

THE FIELD PERSONNEL

Personnel required varies with the number of vehicles passing the stations and the amount of information taken. Weight parties may require 6 to 8 men at heaviest stations; 2 men at light stations. Blanket-count stations may usually be operated by one man, unless traffic is heavy and the station is located at an intersection, in which case one man must be assigned to each route. It is best to assign at least two men for night operations. In winter one man will occupy considerable of his time maintaining a fire, seeing that red lanterns are placed properly and are burning, etc.

Where the number of vehicles to be counted is great, a large corps of observers is required. The key stations should be operated by trained observers; volunteers may be used at the blanket-count stations. The work of volunteer observers is much less sustained, less accurate, and generally less satisfactory than that of the trained observer, although much benefit has been secured from the assistance of Boy Scout and similar organizations.

CHARACTER OF THE TRAFFIC DATA

The amount of detail in collection of the traffic data depends upon the results sought. Vehicles should certainly be separated into passenger cars, trucks, busses, and horse-drawn. Foreign vehicles should be tabulated separately, and the separation of trucks by capacity classes is very desirable. Weather conditions, date, and hours of operation should be noted.

Other less important information that may be collected includes, for passenger cars: Number of passengers, city or farm ownership, purpose of trip (whether for business or pleasure), origin and destination; for trucks: Make, capacity, body type, origin and destination, commodity, weight (loaded and empty).

Sheets containing the data secured in the field should be signed by the party chief, who is held strictly accountable for their accuracy, and forwarded daily to headquarters for analysis. At headquarters they are received by the official in charge of traffic information. This official is responsible for the operation of stations according to schedule, for the completeness of the data, and for its analysis.

The analysis is greatly facilitated by the use of punching and tabulating machines. Codes are assigned for each type of data, which is punched on tabulating cards similar to that shown. The tabulating machines provide for the rapid and economical analysis of each type of information at each station, for any area, any season of the year, any type of vehicle, etc. Analysis of data for individual stations should be so planned that the results may be properly combined with those of other stations to give homogeneous samples for any route, any section of the State, or the whole State. Failure to observe this provision frequently produces results that are incorrect, difficult to interpret, or misleading, and usually results in loss of time.

FACTORS AFFECTING TRAFFIC DENSITY

The major factors affecting the number of vehicles counted during the operation of a station are: (1) The hours, (2) the day, and (3) the month in which the count is taken; (4) weather conditions; (5) detoured traffic from a natural route due to construction or other reasons; (6) holidays, foot-ball games, fairs, or other social events attracting unusual traffic. Of the six factors enumerated, the first three are normally of greatest importance in determining average daily traffic density throughout the year.

One of the primary factors in determining the average annual density of motor vehicles at a given location is that of the variation in the number of vehicles passing during the 24 hours of the day. Accuracy of the density figures is considerably improved if most of the observations are made during the hours of heaviest traffic. The counts already made by the Bureau of Public Roads indicate roughly the general laws of traffic flow in various sections of the United States; and these will be helpful to others in planning their surveys.

Four to 5 p. m. is the peak hour for trucks in California, both in summer and winter. Ten and three-tenths per cent of the total daily number of trucks pass at that hour in summer, as compared with 8.3 per cent at the same hour in winter. At the peak hour in southeastern Pennsylvania—10 a. m. to 11 a. m. in winter—8.9 per cent of the trucks were observed; in summer the peak came from 8 a. m. to 9 a. m., when 8.8 per cent of the trucks were observed. Between 8 p. m. and 6 a. m. about as many trucks are observed as in the peak hour. In winter during these hours 7 per cent pass in Pennsylvania and 9 per cent in California. In summer 13 per cent are observed in Pennsylvania and 10 per cent in California. The greater divergence between winter and summer in Pennsylvania indicates the effect of the unfavorable winter climate upon night trucking.

In both Connecticut and Pennsylvania the peak hour for passenger cars in summer is 4 to 5 p. m., and at 5 to 6 p. m. in winter. The percentage of night travel (8 p. m. to 6 a. m.) is considerably heavier for passenger cars than for trucks. In Connecticut, night travel is about 25 per cent of the total for the day, while in Pennsylvania it is 19 per cent in winter and 21 per cent in summer. These percentages are averages for a region and will not apply for all locations.

Sunday is, probably universally, the day of heaviest passenger-car traffic. In Connecticut Sunday is 65 per cent higher in passenger-car traffic than the average day of the week; in Pennsylvania Sunday traffic is 88 per cent higher than that of the average day. Truck traffic is lightest on Sunday. It averages 17 per cent of the average day in Pennsylvania and 60 per cent in California. Trucks are approximately 10 per cent of total vehicles in California and 16 per cent in Connecticut.

ANALYSIS OF DATA ILLUSTRATED BY EXAMPLE

These examples of differences in the rate of traffic flow are not exceptional; indeed, more extreme cases might be cited. But they give a picture of the high variability in traffic fluctuation between different sections of the country. In the problem of traffic analysis it is necessary to limit the area studied to units at least as small as a State. Normally it is well to break down into much smaller units. As stated previously, homogeneous areas are to be desired; and as an example for detailed analysis, passenger car density at 112 urban stations in the State of Ohio will be taken.

Urban stations were those located within 10 miles of the limits of a city with a population of 25,000 or more. Winter operations (December to May) and summer operations (June to November) for periods of the 24-hour day are stated separately in Table 1. Figure 1 shows the data graphically for the December–May period.

The hours stated in Table 1, i. e., "6 a. m. to 10 a. m.," mean traffic observed from 6 a. m. up to, but not including, 10 a. m. The winter period includes both December and May; the summer period includes both

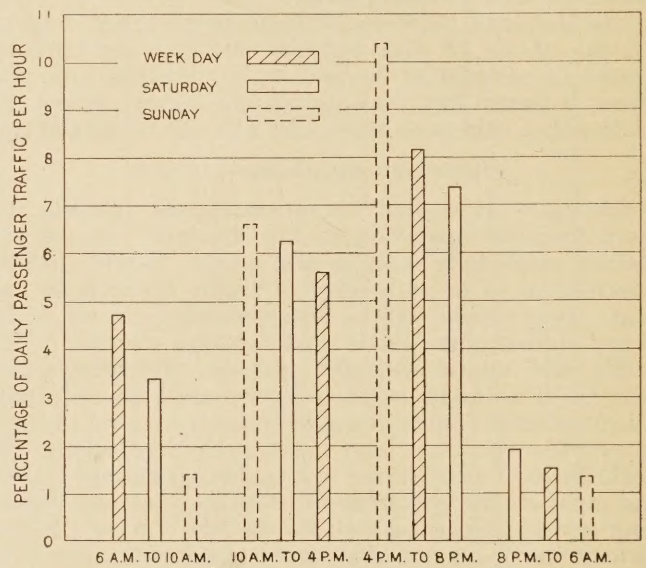
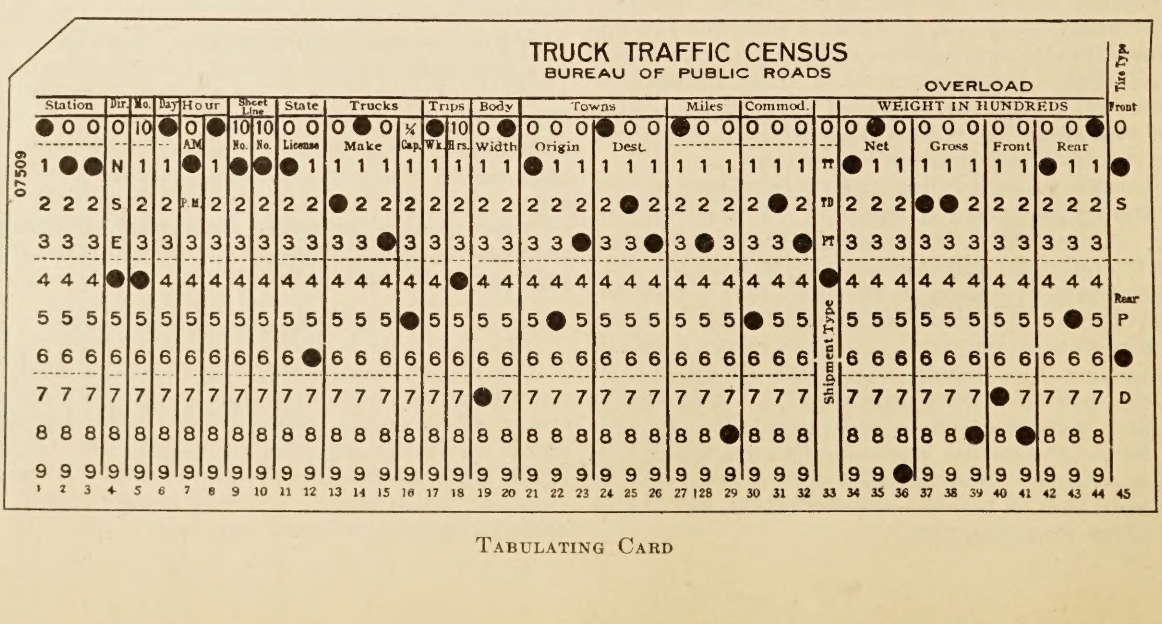


Figure 1.—Hourly Variation in Passenger-Car Traffic at Urban Stations in Ohio, December to May



Tabulating Card

June and November. Summer passenger-car traffic, as the table shows, is much greater than winter traffic. The traffic in winter is but 56 per cent of that in the summer on week days, 53 per cent on Saturdays, and 46 per cent on Sundays. The light traffic on Sunday mornings is shown by a comparison of the percentage of the total daily traffic by days of the week for the 6 a. m. to 10 a. m. period. On week days in winter 18.8 per cent of the total day's traffic moves within these hours; on Saturday, 13.6 per cent; on Sunday, but 5.5 per cent. Sunday afternoon in summer between 4 p. m. and 8 p. m. traffic is heaviest, averaging 580 cars per hour at these 112 stations, or more than 10 per cent per hour of the total Sunday traffic. Traffic in Ohio was not taken by individual hours but by the periods shown in Table 1. As a result, hourly variation can not be shown directly, but hourly variation will be taken up in detail in the discussion of results in other States.

Traffic variation at urban stations by days of the week is presented in Table 2 and Figure 2. The data are given as the number of passenger cars per day and as a ratio to the average day of the week.

TABLE 1.—*Hourly variation in passenger-car traffic, 112 urban stations, Ohio*

NUMBER OF CARS

	December-May					June-November				
	6 a. m. to 10 a. m.	10 a. m. to 4 p. m.	4 p. m. to 8 p. m.	8 p. m. to 6 a. m.	Total 24 hours	6 a. m. to 10 a. m.	10 a. m. to 4 p. m.	4 p. m. to 8 p. m.	8 p. m. to 6 a. m.	Total 24 hours
Week day	251	447	433	204	1,335	406	681	744	561	2,392
Saturday	241	670	530	337	1,778	491	1,137	914	804	3,346
Sunday	144	1,027	1,089	348	2,608	449	1,898	2,318	1,005	5,670
PER CENT OF 24-HOUR DAY										
Week day	18.8	33.5	32.4	15.3	100.0	17.0	28.5	31.1	23.4	100.0
Saturday	13.6	37.7	29.8	18.9	100.0	14.7	34.0	27.3	24.0	100.0
Sunday	5.5	39.4	41.8	13.3	100.0	7.9	33.5	40.9	17.7	100.0

TABLE 2.—*Daily variation in passenger-car traffic, 112 urban stations, Ohio*

[Average day=100 per cent]

Day	Number of cars	Index
		Per cent
Monday	43,554	84.6
Tuesday	41,673	81.0
Wednesday	41,764	81.2
Thursday	42,151	81.9
Friday	42,230	82.1
Saturday	56,459	109.7
Sunday	92,328	179.4

The days from Monday to Friday show little variation, traffic for all being a little above 80 per cent of that of the average day. Saturday traffic is about 10 per cent higher than that of the average day, while Sunday traffic is nearly 80 per cent greater than that of the average day. The reason for relating the day's traffic to that of the average day will be apparent as the analysis proceeds. One obvious advantage in so stating traffic is that it permits easy comparison of rates of traffic flow in areas with widely differing numbers of vehicles.

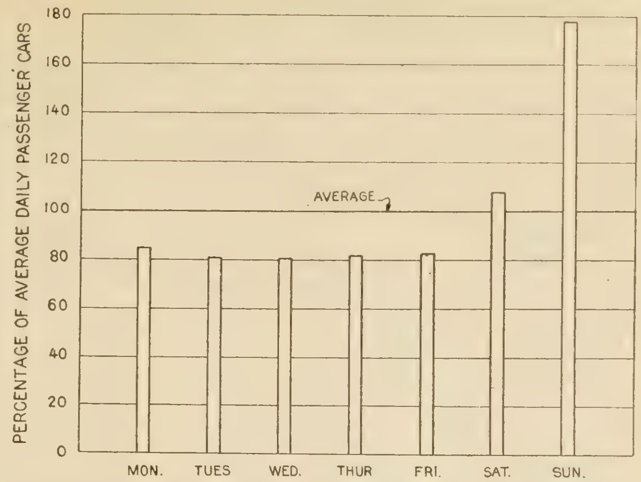


FIGURE 2.—DAILY VARIATION IN PASSENGER-CAR TRAFFIC AT URBAN STATIONS IN OHIO

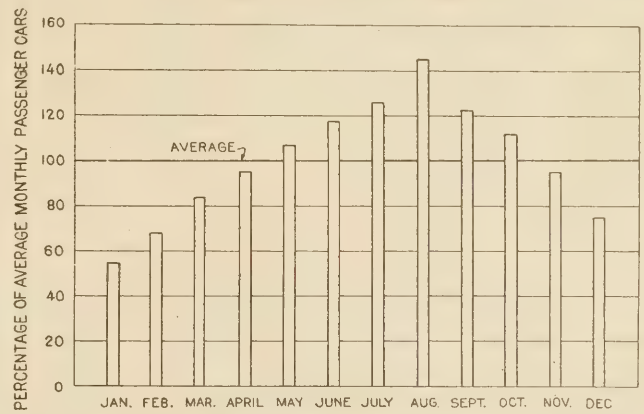


FIGURE 3.—SEASONAL VARIATION IN PASSENGER-CAR TRAFFIC AT URBAN STATIONS IN OHIO

TABLE 3.—*Seasonal variation in passenger-car traffic, 112 urban stations, Ohio*

[Average month=100 per cent]

Month	Number of cars	Index
		Per cent
January	17,100	55.5
February	21,176	68.7
March	25,338	82.4
April	29,355	95.3
May	32,866	106.7
June	36,325	117.9
July	38,829	126.1
August	44,551	144.6
September	37,458	121.6
October	34,547	112.1
November	29,138	94.6
December	22,940	74.5

Seasonal variation in passenger-car traffic at urban stations in terms of passenger cars per month and as a ratio to the average month is shown in Table 3 and Figure 3.

As shown by this table, traffic increases from a low of 56 per cent of the average month in January to a maximum of 145 per cent of the average month in August. These figures differ from measurements in rural areas, and this phase of the analysis will be discussed later.

HOW STATION AVERAGES ARE OBTAINED

Having obtained measures of the principal factors affecting passenger car traffic flow in urban areas, we are in position to apply these factors to traffic observed at individual stations. Passenger-car traffic observed at station 313 and the corrections for hourly, daily, and seasonal variation are tabulated in Table 4. This station is between Mansfield and Lexington, Ohio, on United States Route 42. The date, day, and hours of observation are stated in the first three columns; the number of passenger cars observed in the fourth column.

TABLE 4.—*Passenger-car density, station 313, Ohio*

Date	Day	Hours	Observed	Corrected to— 24-hour	Average week day	Average month
Dec. 15	Monday	6–4	455	870	1,028	1,380
Jan. 16	Friday	10–8	533	809	985	1,775
Feb. 14	Saturday	6–4	544	1,062	969	1,411
Mar. 17	Tuesday	10–8	542	822	1,015	1,232
Apr. 15	Wednesday	6–4	514	983	1,212	1,271
May 17	Sunday	10–8	1,619	2,178	1,213	1,137
June 13	Saturday	6–4	1,119	2,300	2,098	1,779
July 14	Tuesday	10–8	863	1,448	1,788	1,418
Aug. 13	Thursday	6–4	783	1,723	2,104	1,456
Sept. 14	Monday	10–8	971	1,629	1,925	1,582
Oct. 15	Thursday	6–4	630	1,387	1,694	1,511
Nov. 11	Wednesday	10–8	994	1,508	1,859	1,965
Total						17,917
Average for year						1,493

In the fifth column the observed passenger cars are raised to a 24-hour basis. From Table 1 the percentage of the 24-hour day from 6 a. m. to 4 p. m. on week days is 18.8+33.5, or 52.3. The observed passenger cars on December 15 are 455, and dividing by 0.523, the 24-hour figure of 870 is obtained. On February 14 the observed passenger cars totaled 544. The percentage of 24-hour traffic from Table 1 for Saturdays, 6 a. m. to 4 p. m., is 13.6+37.7, or 51.3. Dividing by 0.513 the 24-hour figure of 1,062 is obtained. The number of decimal points actually carried in the analysis was beyond that shown in Table 1, with resulting differences of one or two vehicles.

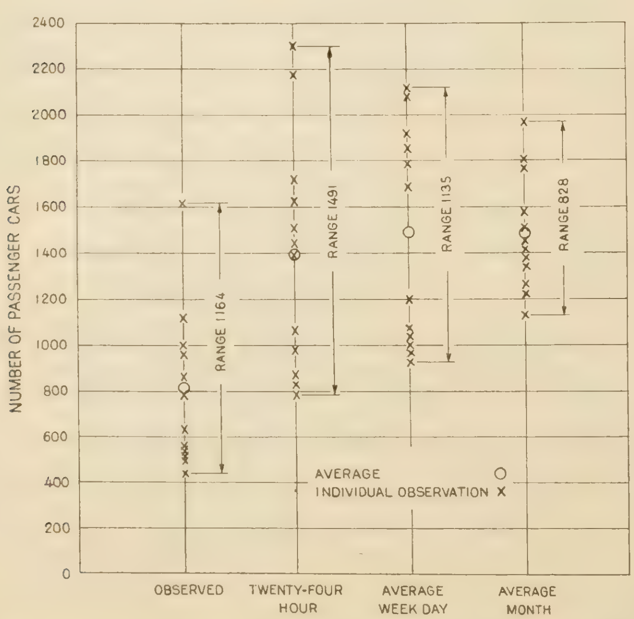


FIGURE 4.—GRAPHICAL REPRESENTATION OF DATA SHOWN IN TABLE 5

In column six the 24-hour figures are corrected for daily variation. (Table 2.) The 24-hour figure of 870 for Monday, December 15, obtained as explained in the preceding paragraph, is divided by 0.846, the ratio of Monday to an average day, with a resultant figure of 1,028 passenger cars. The 24-hour figure of 1,062 for Saturday, February 14, is divided by 1.097, the ratio of Saturday to an average day, with a resultant figure of 969 passenger cars.

Finally, the figures obtained as explained in the preceding paragraph are divided by their seasonal factors (Table 3); $1,028 \div 0.745 = 1,380$; $969 \div 0.687 = 1,411$. Thus, 1,380 and 1,411 are each a measure of the probable number of passenger cars passing station 313 during 24 hours of an average day of the year. Each observation establishes such a figure. There remains a certain amount of variation due to factors unmeasured or not completely measured in the analysis. The mean of these "probable densities" is 1,493, the best measure of the number of passenger cars passing station 313 during 24 hours of an average day of the year.

ACCURACY IMPROVED BY ANALYSIS

The improvement in accuracy resulting from the analysis can be measured in several ways. As an example, take the two Monday operations at station 313. On the first Monday, December 15, the station was operated from 6 a. m. to 4 p. m., with 455 passenger cars observed. On the second Monday, September 14, 971 cars were observed from 10 a. m. to 8 p. m. The number of cars observed on the second Monday was 113 per cent greater than the number observed on the first Monday. The final densities for these two Mondays are 1,380 and 1,582, a variation of less than 15 per cent. The results are much the same when the two Saturday observations, February 14 and June 13, are compared. A complete comparison of results is given in Table 5. Figure 4 shows the same data graphically. In this table are computed the range in observed and corrected traffic and the range in percentage of the mean.

TABLE 5.—*Analysis of passenger-car data, station 313, Ohio*

Type of data	Range	Number of vehicles in range	Mean	Range in percentage of mean
				Per cent
Observed	455–1,619	1,164	797	146
Computed 24 hour	809–2,300	1,491	1,393	107
Average week day	969–2,104	1,135	1,491	76
Average month [1]	1,137–1,965	828	1,493	55

[1] If the Nov. 11 observation be omitted, the range in percentage of the mean for the final correction is but 44.

TABLE 6.—*Comparison of the results of operation by density party and by traffic survey party in Vermont*

Station No.	Average motor-vehicle density: Density-party operation	Average motor-vehicle density: Staggered-count operation	Station No.	Average motor-vehicle density: Density-party operation	Average motor-vehicle density: Staggered-count operation
1 s	2,319	1,898	55 ne	369	299
1 e	861	729	55 se	84	84
1 w	3,039	2,576	55 sw	444	389
5 n	1,347	1,277	60 w	1,151	1,089
5 s	1,832	1,755	60 e	725	613
5 ne	538	524	60 s	1,064	991
15 s	2,826	2,294	72 n	376	335
15 n	1,541	1,134	72 s	179	144
15 nw	1,462	1,284	72 e	201	207
17	1,121	1,203	72 w	150	155

Broadly stated, the results of the analysis are to raise the mean from 797 to 1,493 and to decrease the dispersion from 146 per cent to 55 per cent, with a final density that is much more stable and less affected by chance variation. Such chance variations are caused by poor weather conditions during an observation period, the occurrence of fairs and foot ball games, abnormal traffic because of detours, high truck density due to near-by construction projects, even a big funeral at stations where traffic is normally light. Detection of chance variation in the observed data is virtually impossible because such variation is smothered by the normal hourly, daily, and seasonal variations. Detection of chance variation in the corrected data is not difficult when local conditions are known. In computing final densities, clearly abnormal traffic observations should be rejected.

Another check upon the accuracy of the results is obtained by computing from the data of Tables 2 and 3 the maximum daily traffic at the 105 stations that were operated on Sunday in either July, August, or September. The computed density for an August Sunday at these stations totaled 242,028 vehicles. Reference to the observed traffic showed that 281,594 vehicles were actually recorded on the maximum days. Thus, the computed figures are conservative, being exceeded by the observed maximum vehicles by about 16 per cent. The measurement of traffic variation permits the computation of maximum traffic at stations where no observation was scheduled during the period of maximum traffic. Obviously not all stations could be operated at their periods of maximum traffic except at great expense.

OTHER METHODS OF CHECKING ANALYSIS

Still another check resulted from the manner of scheduling party operations in Vermont In that State the survey was for a period of but three months. Two observations per month were made at each station. In addition to these observations a "density party" counted vehicles for an entire week at certain stations. The final densities computed in once case from the 'density-party" counts and in the second case from the usual staggered operation extending throughout the three months are tabulated by stations in Table 6. Taking into account the relatively light traffic at most of these stations, with consequent high variation during short periods of observation, the agreement in final density is good.

A check may be made upon the method of securing hourly variation by the use of complete 24-hour counts—i. e., by combining night and day observations in all cases where a day operation is followed or preceded by a night operation. Table 7 compares the results of the two methods used in Pennsylvania, where traffic was recorded by hours instead of by totals for parts of the day. In column two, Table 7, the variation in hourly flow of traffic is taken from the staggered operation, while in column three the results of over 100 complete 24-hour cycles are tabulated. The results are shown graphically in Figure 5, in which the close correspondence in results may readily be seen.

There were 12 observation periods of 10 hours each at Ohio station 313, but the foregoing checks upon the method indicate that it may be used in cases where the time of the period of observation is much shorter. For instance, at station 388, located on United States route 20 in North Kingsville, Ohio, at the intersection with

TABLE 7.—*Hourly variation in truck traffic, division 1, Pennsylvania*

[Average hour in each case=100 per cent]

Hour	Staggered-count operation	24-hour cycle operation	Hour	Staggered-count operation	24-hour cycle operation
	Per cent	*Per cent*		*Per cent*	*Per cent*
1-2 a. m	12	12	1-2 p. m	186	197
2-3 a. m	14	14	2-3 p. m	185	182
3-4 a. m	22	21	3-4 p. m	189	186
4-5 a. m	31	32	4-5 p. m	157	168
5-6 a. m	60	56	5-6 p. m	111	121
6-7 a. m	119	125	6-7 p. m	70	65
7-8 a. m	174	170	7-8 p. m	45	45
8-9 a. m	180	189	8-9 p. m	20	20
9-10 a. m	196	186	9-10 p. m	24	23
10-11 a. m	204	195	10-11 p. m	15	16
11-12 a. m	188	173	11-12 p. m	13	15
12-1 p. m	175	179	12-1 a. m	11	12

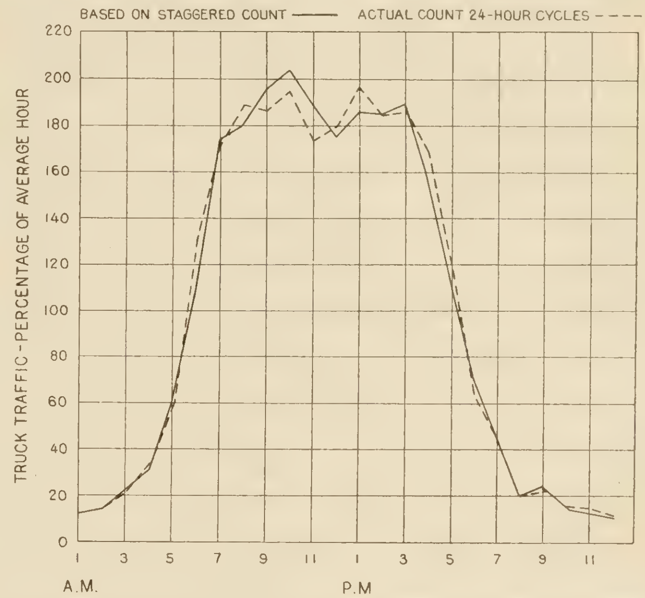


FIGURE 5.—HOURLY VARIATION IN TRUCK TRAFFIC, DIVISION 1, PENNSYLVANIA

a county road, the observation period was for but six hours, 10 a. m. to 4 p. m. on Monday, April 13. This station was operated by Boy Scouts as a blanket-count station and was supposed to have been operated on April 13, July 18, and October 17. For some reason the latter two operations were not made. During the six hours on April 13 there passed 620 passenger cars and 94 trucks traveling west on United States route 20. If the factors explained in the foregoing analysis are applied, the average annual density at station 388 (west) becomes 2,213 passenger cars and 180 trucks, a total of 2,393 motor vehicles. Station 4 was operated for twelve 10-hour periods throughout the year and is located about 3 miles west of station 388 on United States route 20. There are no important intersections between the two stations. The final density at station 4 (east) was 1,969 passenger cars and 148 trucks, a total of 2,117 motor vehicles.

Thus, the final density at station 388, operated for but six hours, is but 13 per cent greater than the density at station 4, which was operated twelve 10-hour periods throughout the year. Such agreement in density between blanket-count and key stations occurs frequently; in fact it is the usual thing, although there is always the danger of picking up abnormal traffic during so short an observation period as six hours. Traffic at blanket-count stations should be observed at least four times, preferably at intervals of three months.

COMPARISON OF TRAFFIC AT URBAN AND RURAL STATIONS

Passenger-car traffic at 112 urban stations, as tabulated in Table 1, and at 242 rural stations in Ohio are compared graphically in Figure 6. Since the hourly periods into which the day is divided are of different length, the results in Figure 6 are presented in terms of the percentage per hour of the total daily traffic by days of the week. The differences between urban and rural traffic flow are marked. For instance, on Sunday morning the rate of traffic flow during the 6 a. m. to 10 a. m. period is about 30 per cent higher in the rural areas. On Sunday afternoon the situation is reversed, urban traffic flow being about 11 per cent higher than that in rural areas between 4 p. m. and 8 p. m. In fact, on all days of the week traffic flow in urban areas is at a higher rate than in rural areas between 4 p. m. and 8 p. m.

The comparison between urban and rural areas in traffic flow by days of the week shows the great similarity in truck movement, but there is relatively a much greater movement of passenger cars on Saturdays and a smaller movement on Sundays in rural areas. The figures are tabulated in Table 8. Sunday, as will be seen, is the day of heaviest passenger-car traffic and lightest truck traffic in both urban and rural areas.

Seasonal variation does not differ sharply between urban and rural areas. The maximum month for passenger-car traffic flow is August; for truck traffic, September. The relation of maximum to average month is higher in the rural areas, about 10 per cent for passenger cars and 7 per cent for trucks. There is a tendency in urban areas for both passenger-car and truck traffic to hold up better during the winter months. The results are given in detail in Table 9. Passenger-car traffic in both urban and rural areas, as will be noted, varies within a much wider range from January to December than truck traffic.

SOME USES OF TRAFFIC DATA NOTED

Since maintenance costs are so large a factor in total highway costs over a period of years, the economic selec-

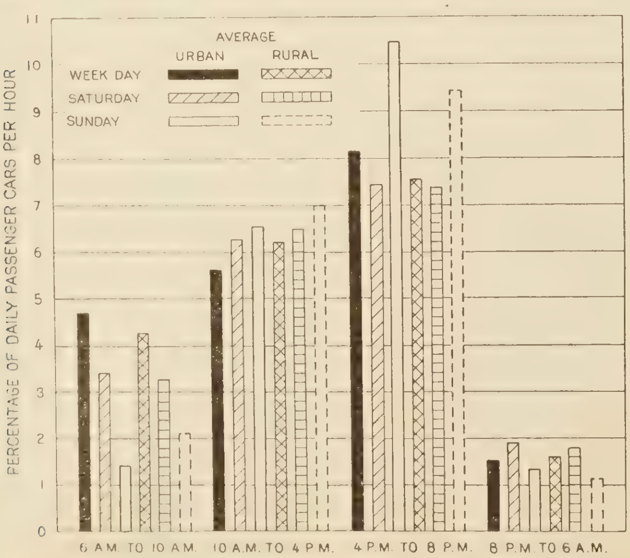


FIGURE 6.—HOURLY VARIATION IN PASSENGER-CAR TRAFFIC AT URBAN AND RURAL STATIONS IN OHIO

TABLE 8.—*Daily motor traffic variation, Ohio*

[Average day=100 per cent]

Day	Traffic in percentage of average day			
	Trucks		Passenger cars	
	Urban	Rural	Urban	Rural
	Per cent	*Per cent*	*Per cent*	*Per cent*
Monday	113	113	85	83
Tuesday	117	118	81	79
Wednesday	115	120	81	80
Thursday	111	110	82	81
Friday	115	113	82	88
Saturday	102	101	110	128
Sunday	26	25	179	162

TABLE 9.—*Seasonal motor traffic variation, Ohio*

[Average month=100 per cent]

Month	Traffic in percentage of average month			
	Trucks		Passenger cars	
	Urban	Rural	Urban	Rural
	Per cent	*Per cent*	*Per cent*	*Per cent*
January	84	77	56	59
February	80	79	69	67
March	88	85	82	81
April	93	91	95	92
May	101	92	107	96
June	100	101	118	116
July	102	108	126	128
August	114	116	145	158
September	118	126	122	122
October	113	118	112	109
November	107	113	95	94
December	100	93	74	78

tion of a suitable type of highway depends to a large extent upon variation in maintenance costs under varying traffic densities. Climatic conditions, soil types, drainage conditions, and many other factors so complicate maintenance-cost analysis that unless accurate traffic data are available, misleading conclusions may easily be reached.

The usefulness of accurate traffic data in problems of design is obvious. The variation in traffic during different periods of the year and the density of large-capacity truck traffic should not be overlooked in this connection, especially in the selection of proper highway widths and design near large cities.

The validity of many conclusions resulting from the study of highway problems depends vitally upon the accuracy of the traffic data underlying such conclusions. Haphazard methods and fragmentary traffic data lead to economic and engineering errors. Reliable data result from careful planning and complete understanding of the objectives of the traffic survey. Many of the highway problems are extremely complicated; one factor, traffic, may be accurately obtained without tremendous expenditure. In the sea of evidence affecting the solution of a difficult problem the traffic factor may be used with some assurance of reliability. An error of a few vehicles in the traffic evidence has no engineering significance, and the accuracy resulting from continuous observation at a great number of stations is not worth the cost. On the other hand, traffic evidence obtained by going out on the highway for a few hours at any time of the year is worth very little to the serious investigator.

THE EFFECT OF INCREASED SPEED OF VEHICLES ON THE DESIGN OF HIGHWAYS

Reported by A. G. BRUCE, Senior Highway Engineer, Division of Design, United States Bureau of Public Roads

A STUDY of the speed limits now imposed by the various States shows a decided increase over those imposed 10 years ago. In 1918, three States had speed limits of 35 to 45 miles an hour, and eight States had no limitation. In 1928, 36 States permitted speeds up to 35 to 45 miles per hour and 3 had no limitation. The speed limitation predominating in 1918 was 25 miles per hour, and in 1928 it was 35 miles per hour.

A great many users of the highway travel at speeds much higher than the legal limit, especially in those States with the lower limitations. The models of motor cars produced in recent years are all capable of relatively high speeds, and the general trend toward increased braking capacity and greater riding comfort has given drivers a sense of greater security at high speeds. Taking into account the more liberal legal speeds, the difficulty in rigidly enforcing a speed limitation, and the greater possible speed due to improved roads and improved cars, it appears safe to estimate that the average speed on the open road to-day is fully 20 miles per hour greater than it was 10 years ago.

Studies made in connection with the Cleveland survey [1] show that passenger vehicles on the open road where traffic is far below full capacity generally travel at a speed varying from 30 to 40 miles per hour. (Figures 1 and 2.)

This increased volume and speed of motor-vehicle traffic require smoother and wider road surfaces, easier curves, wider shoulders, shallower ditches, greater superelevation of curves, more extensive use of vertical curves, longer vertical curves at the top of hills, greater sight distance on both horizontal and vertical curves, the avoidance of compound curves, more adequate guard rails, more adequate protection at railroad grade crossings, and special treatment of intersections of heavy-traffic highways.

WIDTH OF SURFACE

The safe passing of rapidly moving automobiles and busses requires a surfaced width of at least 20 feet for a 2-lane rural highway, but because of limited funds the 18-foot width still predominates on State and Federal-aid improvements. The mileage of 20-foot pavement, however, is increasing each year, and during the past year 20 per cent of the mileage of hard pavements on Federal-aid projects was of this width and 70 per cent was 18 feet wide. The free flow of traffic on highways through villages and built-up sections requires a pavement width of at least 36 feet where parallel parking is permitted and 50 feet where diagonal and right-angle parking is permitted.

Figure 1 gives some indication as to the effect of width on speed on a highway carrying considerable traffic. The 18-foot width appears to have a retarding effect under the conditions illustrated, but so many factors are involved that this can be taken only as an indication.

[1] Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio.

The most recent studies of transverse distribution of traffic on highways of various widths are those made in connection with the Cleveland survey. The distribution of passenger-car, truck, and bus traffic was

A WIDENED AND SUPERELEVATED CURVE

TABLE 1.—*Maximum legal speed limits in open country for 1918 and 1928*

State	Speed limit, 1918	Speed limit, 1928	State	Speed limit, 1918	Speed limit, 1928
	Miles per hour	*Miles per hour*		*Miles per hour*	*Miles per hour*
Alabama	30	45	Nebraska	25	35
Arizona	30	35	Nevada	(1)	45
Arkansas	20	35	New Hampshire	25	35
California	30	35	New Jersey	30	30
Colorado	(1)	35	New Mexico	(1)	35
Connecticut	30	(1)	New York	30	30
Delaware	25	35	North Carolina	25	45
Florida	25	45	North Dakota	30	35
Georgia	30	40	Ohio	25	35
Idaho	30	35	Oklahoma	(1)	35
Illinois	25	35	Oregon	25	40
Indiana	25	40	Pennsylvania	25	35
Iowa	25	40	Rhode Island	25	35
Kansas	40	40	South Carolina	15	40
Kentucky	20	40	South Dakota	25	25
Louisiana	(1)	35	Tennessee	20	30
Maine	25	35	Texas	25	35
Maryland	35	40	Utah	(1)	30
Massachusetts	20	20	Vermont	25	30
Michigan	25	(1)	Virginia	20	35
Minnesota	25	35	West Virginia	35	35
Mississippi	30	30	Washington	30	40
Missouri	25	25	Wisconsin	25	40
Montana	(1)	(1)	Wyoming	(1)	35

SUMMARY OF SPEED LIMITATIONS

Legal speed (per hour)	Number of States, 1918	Number of States, 1928	Legal speed (per hour)	Number of States, 1918	Number of States, 1928
15 miles	1	0	40 miles	1	10
20 miles	5	1	45 miles	0	4
25 miles	20	2	50 miles	0	0
30 miles	11	6	No limit	8	3
35 miles	2	22			

[1] No limit.

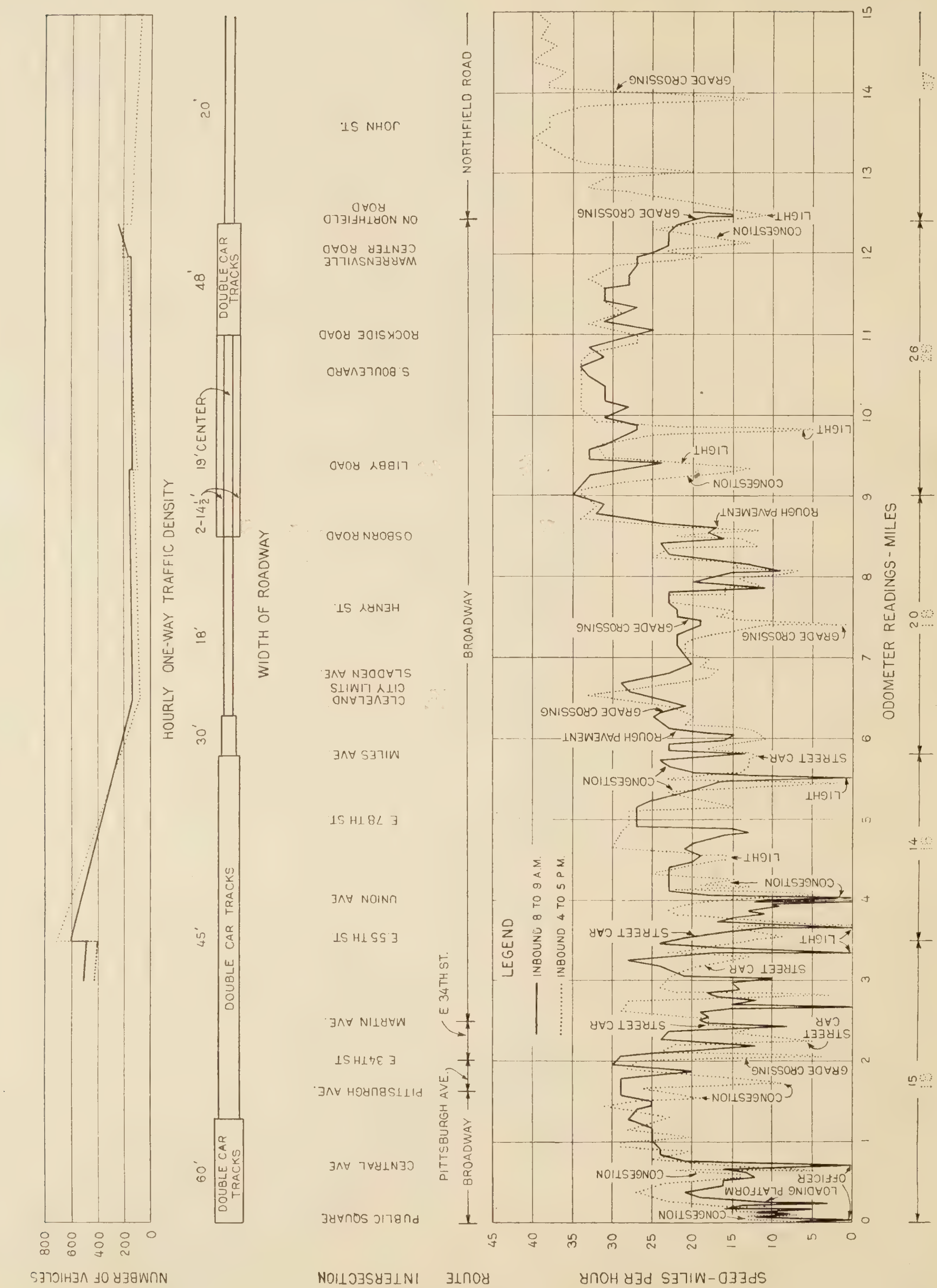


Figure 1.—Hourly Passenger-Car Traffic, Traffic Speed, and Roadway Width on Broadway and Northfield Road from the Public Square to Akron (Cleveland Survey)

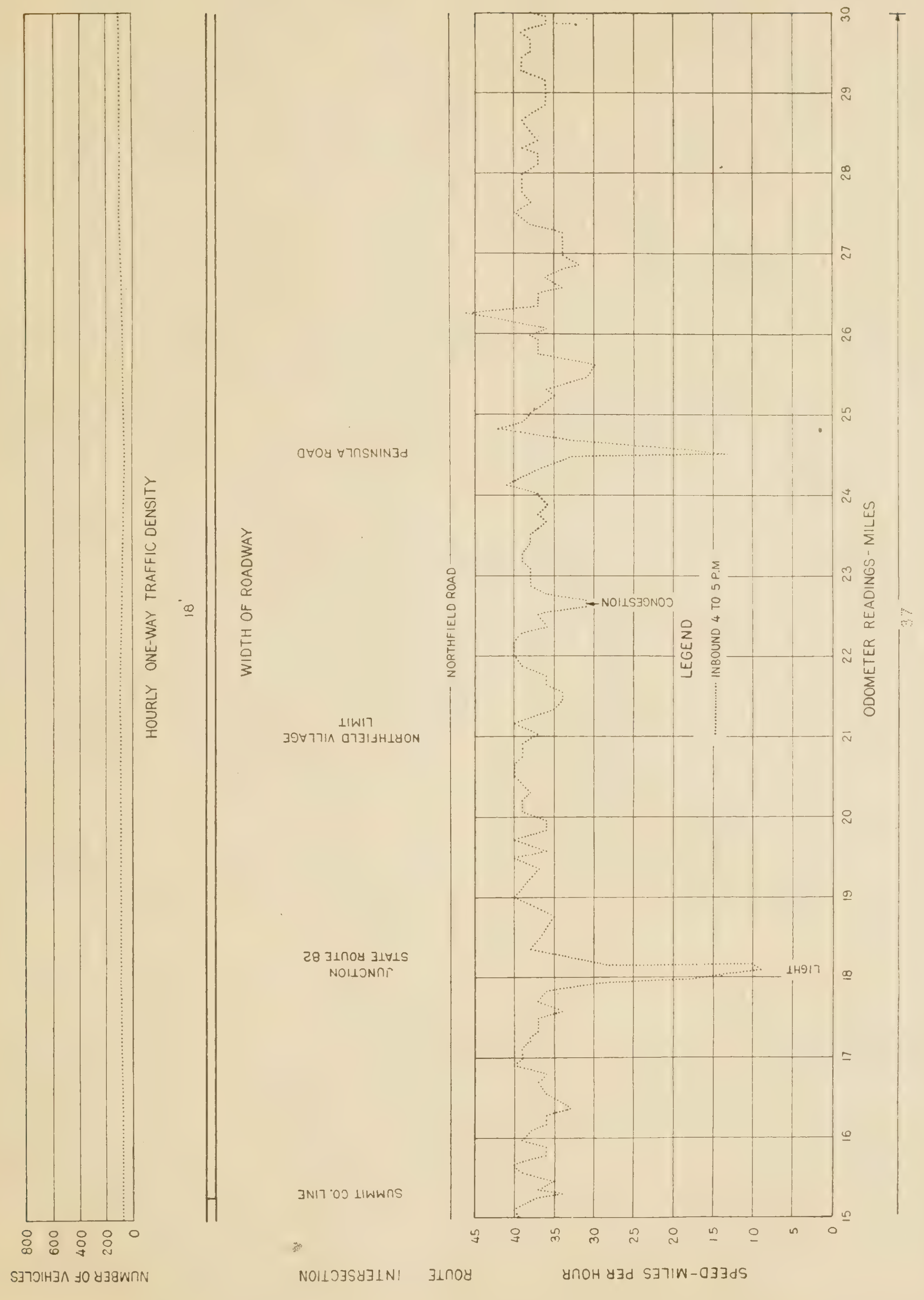


Figure 2.—Hourly Passenger-Car Traffic, Traffic Speed, and Roadway Width on Broadway and Northfield Road from the Public Square to Akron (Cleveland Survey)

recorded for pavements, the width of which ranged from 18 to 40 feet. The total pavement width, where observations were recorded, was divided into 1-foot lanes, with painted identification markings. With the passage of each vehicle the 1-foot lane within which its right rear wheel passed was recorded. These data form the basis of the studies of transverse distribution of motor-vehicle traffic on straight and level highway pavements in the various width classes made during the month of November, 1927.

Figures 3, 4, and 5, and Table 2, are typical of the results obtained outside of the urban area. There was found to be a marked difference between the transverse distribution of the right rear wheel passages of passenger cars on pavements 18 and 20 feet in width and similar data on pavements in excess of 20 feet in width but not wide enough for four lanes of traffic. On the 18 and 20 foot surfaces over 80 per cent of the passenger-car traffic traveled 6 feet or less from the edge of the pavement. For surfaces in excess of 20 feet the highest percentage of utilization of the section within 6 feet of the edge of the pavement was 46.3.

On pavements over 20 feet in width, truck and bus traffic fail to utilize to any extent the 3 feet nearest the edge on each side of the pavement. With an increase in width there is an increasing tendency for motor-vehicle traffic to operate more toward the center of the pavement.

Passenger cars on an 18-foot highway when passing vehicles moving in the opposite direction travel approximately 1 foot nearer the edge of the pavement than when they are not passing other vehicles.

The average clearance between passing cars on an 18-foot pavement is approximately 1 foot, while on a 20-foot pavement the average clearance ranges from 1.9 to 2.4 feet. On both 18 and 20 foot pavements, drivers of passenger cars apparently prefer to sacrifice clearance rather than drive close to the edge of the pavement.

The average distance of rear-wheel passages of passenger cars from the edge of the pavement on 32, 38, and 40 foot highways is over 8 feet. The average clearance of passenger cars passing in opposite directions ranges from 6.7 feet on the 32-foot pavement to 11.7 feet on the 40-foot road.

The following conclusions as to width of highway were presented in the report on the plan of improvement for the Cleveland regional area:

1. The roadway surface for all 2-lane roadways should be 20 feet, exclusive of space for parked vehicles. Roadways of 18-foot width in good condition are classed as satisfactory, but these should be widened to a minimum of 20 feet when reconstruction is necessary. Surfaces less than 18 feet in width should be widened to a minimum of 20 feet as rapidly as conditions permit except in the case of extremely light traffic routes where the widening is less urgent.

2. Normal distribution of traffic requires an even number of traffic lanes. When the volume of traffic exceeds the capacity of a 2-lane roadway a 4-lane roadway (approximately 40 feet), exclusive of space for parked vehicles, is recommended. The 3-lane roadway is found satisfactory in a few cases where there are very pronounced peak periods of traffic in alternate directions at different periods of the day and particularly when the acquisition of right of way for a 4-lane roadway is extremely difficult or prohibitive in cost. The 3-lane roadway, when used, requires lane marking and careful traffic control.

3. All roadways designed for more than two lanes of traffic should have complete lane marking, and provision should be made for regulation of traffic in conformity with the lane marking.

4. Assuming that the roadway is designed for the accommodation of moving traffic, the choice of any width between 20 and approximately 40 feet, except in the relatively few cases where the 3-lane roadway is satisfactory, is normally uneconomical, as the excess of width above 20 feet adds but little to the traffic capacity of the roadway. If the additional width is intended to provide space for parking, such widths as 22, 24, and 27 do not permit parking without obstruction of the normal traffic lanes.

TABLE 2.—*Transverse distribution of passenger-car traffic on highway pavements in the Cleveland regional area*

Highway	Surface width	Direction of traffic	Total passenger cars observed	Distance from edge of surface (feet) — Right rear wheel passages, percentage of total number: 1	2	3	4	5	6	Total
Cedar Road, east of Warrensville Center Road	18	East	1,069	1.5	12.0	21.3	25.3	13.6	8.9	82.6
		West	931	1.5	15.7	31.9	26.1	14.1	4.0	93.3
West Lake Road, west of Wagar Road	20	East	1,304	.5	[1] 3.8	17.2	33.5	23.4	8.6	87.0
		West	1,042	2.5	19.5	41.9	23.6	4.8	1.3	93.6
Northfield Road, south of Forbes Road	20	North	620	1.9	13.9	32.7	27.7	13.9	3.4	93.5
		South	806		[2] 2.1	13.9	27.2	21.6	16.1	80.9
Euclid Avenue,[3] east of Chardon Road	18.7	East	1,403		.8	2.1	3.7	6.5	8.3	21.4
		West	1,376		.6	3.5	6.7	9.7	13.5	34.0
Euclid Avenue,[3] west of Chardon Road	18.7	East	2,328		.6	.7	4.3	11.0	9.0	25.6
		West	2,354		.7	4.8	10.7	10.7	9.1	36.0
Detroit Avenue, east of Clague Road	32	East	2,000	.1		.3	1.4	6.0	16.6	24.4
		West	1,668	.1	.2	.3	1.9	8.1	11.0	21.6
Franklin Avenue,[4] east of West Sixty-fifth Street	32	East	2,948	.1	.3	2.1	6.0	12.1	16.3	36.9
		West	2,095		.3	1.7	4.6	10.6	16.5	33.7
Lake Shore Boulevard, east of Harland Avenue	38	East	1,334	.0	.7	2.4	8.0	9.6	11.0	31.7
		West	1,803	.1	.1	.9	3.1	4.3	6.6	15.1
United States route 20, east of Wickliffe	40	East	1,081	.0	.0	.0	.5	.7	4.0	5.2
		West	1,094	.0	.0	.8	.6	4.1	7.4	12.9
Bulkley Boulevard,[5] east of Center Parkway Section	40	East	8,183	.2	1.1	7.3	18.2	13.0	6.5	46.3
		West	4,702	.0	.1	1.4	5.5	12.7	15.7	35.4

[1] A letter box located close to the edge of pavement accounts for the low percentage in the second foot lane, east direction of traffic.
[2] A 6-inch raised curb accounts for the low percentage in the second foot lane, south direction of traffic.
[3] Each direction is used for 2-way traffic and is separated by a gravel strip 18.5 feet in width.
[4] Used as a 3-lane road during peak-hour traffic; the inbound, or outbound peak traffic, uses 2 lanes during peak hours. Lanes are not separated by markings.
[5] Roadway width separated into 4 marked lanes, each 10 feet in width. Inbound or outbound peak traffic uses 3 lanes during peak hours.

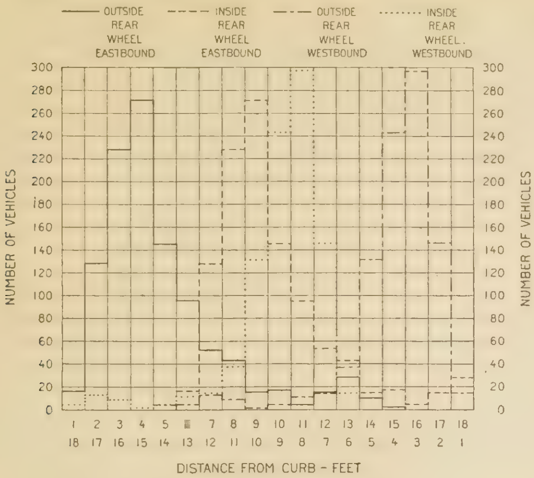


FIGURE 3.—TRANSVERSE DISTRIBUTION OF PASSENGER-CAR TRAFFIC ON AN 18-FOOT PAVEMENT (CEDAR ROAD, CLEVELAND), BASED ON TOTAL PASSENGER-CAR TRAFFIC NOVEMBER 23, 1927, FROM 7.15 A. M. TO 12 M. AND 1 P. M. TO 5 P. M.

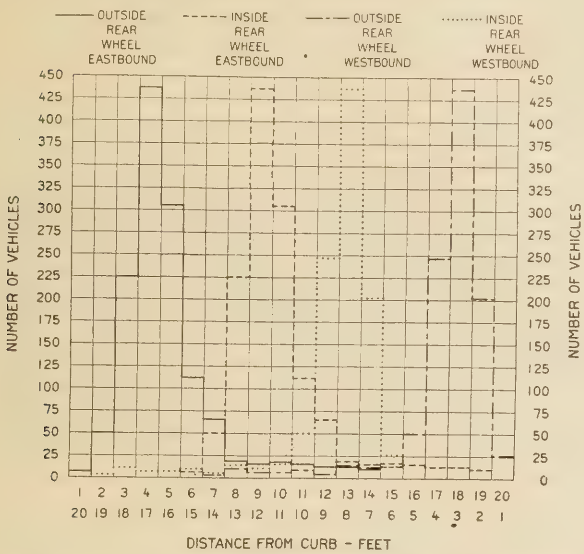


FIGURE 4.—TRANSVERSE DISTRIBUTION OF PASSENGER-CAR TRAFFIC ON A 20-FOOT PAVEMENT (WEST LAKE ROAD, CLEVELAND), BASED ON TOTAL PASSENGER-CAR TRAFFIC NOVEMBER 26, 1927, FROM 7.15 A. M. TO 12 M. AND 1 P. M. TO 5 P. M.

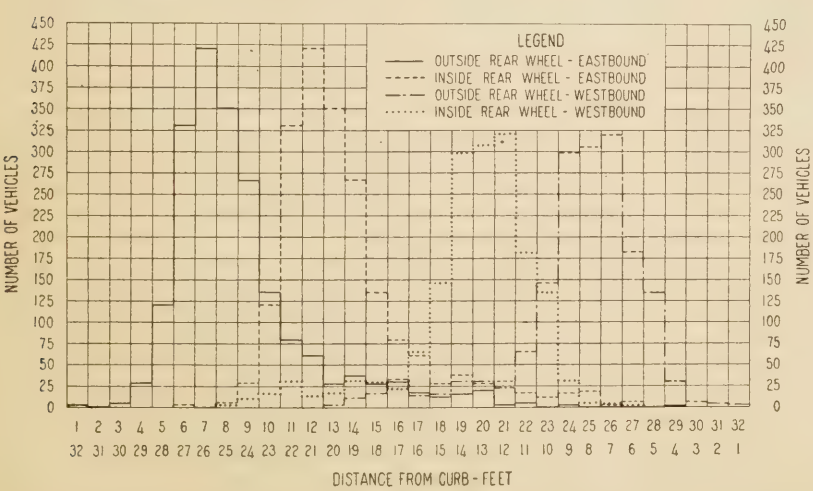


FIGURE 5.—TRANSVERSE DISTRIBUTION OF PASSENGER-CAR TRAFFIC ON A 32-FOOT PAVEMENT (DETROIT ROAD, CLEVELAND), BASED ON TOTAL PASSENGER-CAR TRAFFIC NOVEMBER 25, 1927, FROM 7.55 A. M. TO 12 M. AND 1 P. M. TO 5 P. M.

5. Under open-road conditions—i. e., through areas outside of suburban development—with little local traffic and relatively infrequent cross routes, the normal traffic capacity of a 2-lane roadway, at a traffic speed of 25 miles per hour, is approximately 10,000 vehicles per day. In suburban sections, with parking adjacent to the roadway surface and a larger volume of cross traffic and local traffic, the capacity of a 2-lane roadway is reduced to approximately 8,000 vehicles per day. An abnormally high proportion of large-capacity trucks, busses, or other slow-moving vehicles will decrease these limits.

SHOULDERS

With the improvement in motor cars and equipment, emergency roadside repairs are less frequent than formerly, but one such obstruction in a mile of heavily traveled road creates a serious danger, and shoulders of 6 or 8 feet should be provided for parking and repairs. In mountainous country the cost of wide shoulders is extremely heavy, and in many cases shoulders 3 or 4 feet wide are being built, while in other sections of the country shoulders 10 feet wide are the rule, but the predominating practice appears to be 6 feet.

RIGHT OF WAY

During the past few years there has been a noticeable trend toward the acquisition of wider right of way, especially at intersections of important highways. Rights of way 100 and 200 feet wide are not uncommon, although the majority of States are still acquiring less than 100 feet. The acquisition of right of way at intersections prevents the obstruction of view by private construction, such as filling stations, lunch stands, and roadside markets.

SIGHT DISTANCE

The increase in volume and speed of traffic has made necessary greater sight distances on both horizontal and vertical curves. It is desirable to maintain a sight distance of at least 500 feet, but this is not always feasible on mountain roads. A traffic line should be marked along the center of the road at all convex vertical curves.

A few years ago it was the rule to use a vertical curve only where the algebraic difference in grade was 2 per cent or more. Vertical curves are now used at almost every change in grade, although some engineers use them only at changes of five-tenths or more.

CURVES

No general rule can be given for determining the minimum radius of horizontal curvature. In mountain location curves of 100-foot radius are sometimes necessary, whereas in the flatter sections of the country curves of 1,000-foot radius are the prevailing practice. During the past year the predominating minimum radius of curvature on Federal-aid projects has been about 500 feet. Figures 6 and 7 are diagrams for determining sight distances on vertical and horizontal curves which should be useful in design.

GRADES

On main-line highways it is customary to adopt a maximum grade of 5 per cent in gently rolling country and 7 per cent in rough country, but it is no longer

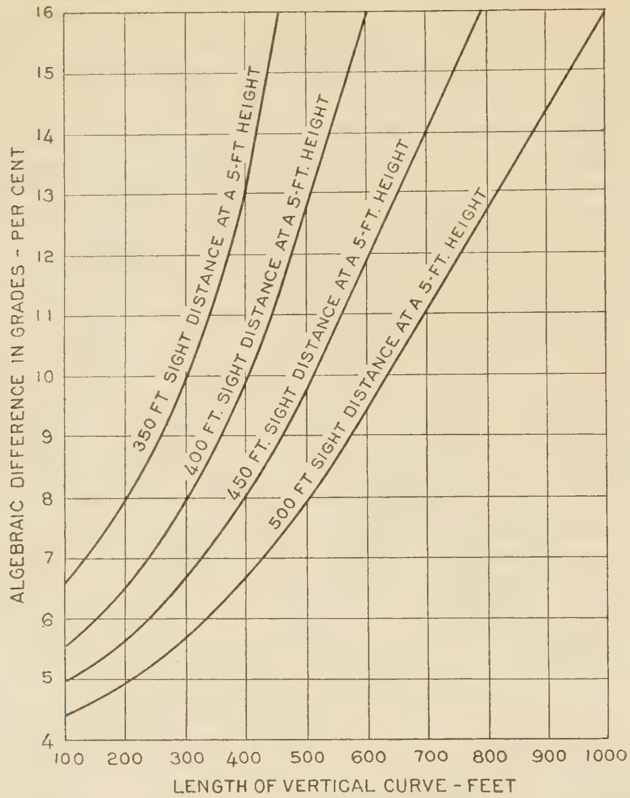


FIGURE 6.—DIAGRAM FOR DETERMINING LENGTH OF VERTICAL CURVE FOR A REQUIRED SIGHT DISTANCE

considered good practice to resort to sharp curvature in order to avoid grades somewhat steeper than 7 per cent. If local conditions permit either a 7 per cent grade with a sharp curve or a short 9 per cent grade with a wider curve, the latter design is thought to be the better practice because it is safer for modern motor traffic.

There is a difference of opinion among engineers as to whether, in gently rolling country, the grades should follow the general topography with very little cutting and filling or whether railroad practice should be followed with long easy grades involving cutting at every hill and filling every valley. A few years ago, when the cost of grading was a large part of the total cost of the improvement, the use of railroad grades made a considerable difference in the cost, but at the present time it is a smaller percentage of the total cost, and there is, therefore, not as much tendency to cheapen the design in this direction. There is a lack of agreement among authorities as to the relative economy of operating motor vehicles on the two kinds of grades, and the subject is one which warrants further investigation. Studies made at Iowa State College [2] are somewhat favorable to rolling grades.

The top or weathered zone in many soil types is more stable than certain of the unweathered zones. Under these conditions, and when the weathered zone has appreciable thickness, subgrades located close to the original ground surface are apt to be more stable than those located in deep cuts and fills. Usually, however, it is not advisable to lay a grade line so as to consistently take advantage of this fact.

[2] Agg, T. R. Economics of Highway Grades, Bul. 65, Engineering Experiment Station, Ames, Iowa.

COMPENSATION OF GRADES FOR CURVATURE

It is customary to compensate grades over 5 per cent on curves of less than 500-foot radius to permit unretarded ascending speed on curves. The amount of compensation depends on local conditions, but a general rule followed by many engineers is to reduce the grade one-half of 1 per cent for each 50 feet of reduction in radius below 500 feet.

SUPERELEVATION AND WIDENING

When highway curves were first superelevated there was considerable opposition from the users of horse-drawn vehicles, because they felt that superelevation was primarily for the purpose of converting the highways into automobile speedways. Now, that superelevation has become general there is little opposition to a conservative practice, but in some cases a degree of superelevation is used which is excessive for slow-moving vehicles. A maximum superelevation of 2 inches per foot of width as called for on some plans is questionable, and the standard recommended by the American Association of State Highway Officials with a maximum of 1 inch per foot of width appears to agree with the consensus of opinion among highway engineers.

BRIDGE BUILT ON A CURVE WITH SUPERELEVATED ROADWAY

Various experiments have been tried in superelevating for mixed traffic, using a compound cross section instead of the usual straight section, and it is possible that a solution of the problem will be worked out along this line. The formula recommended by the American Associations of State Highway Officials is:

$$E=0.067\frac{V^2}{R}$$

where E = maximum elevation in feet per foot of width,
V = the velocity in miles per hour (35 recommended), and
R = radius of curve in feet.

Figure 8 presents a graphic solution of this formula with the limits indicated.

In eight States curves of 1° or more are superelevated, but in the majority of States superelevation is used only on curves of 3° or more. There is no standard practice for developing the superelevation, but the majority of States start the banking from 100 to 200 feet ahead of the point of curvature and reach full superelevation at the same distance inside the curve. There are several States, however, that reach full superelevation at the point of curvature.

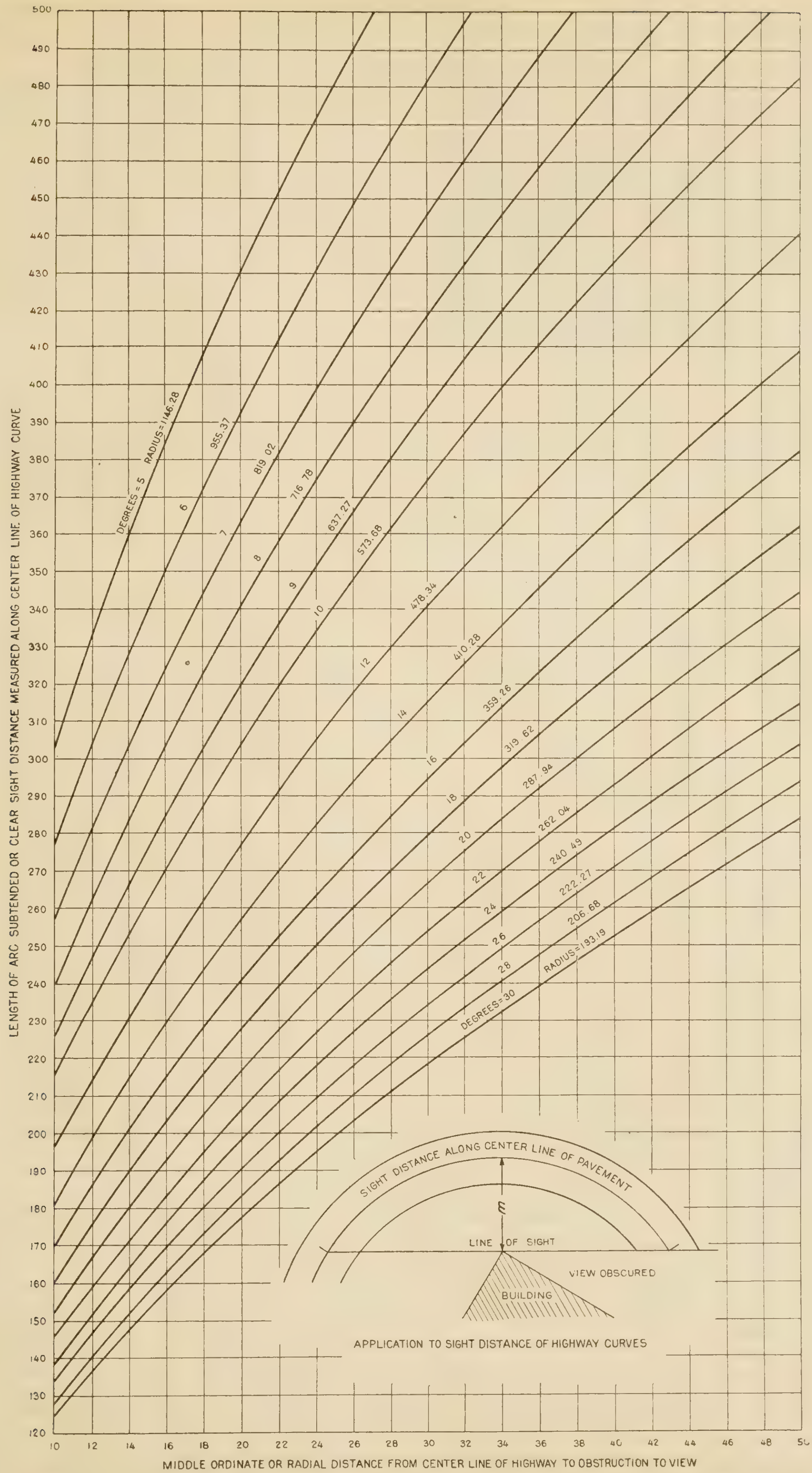


FIGURE 7.—DIAGRAM FOR DETERMINING LENGTH OF UNOBSTRUCTED VIEW ALONG CENTER LINE OF HIGHWAY FOR VARIOUS DEGREES OF CURVATURE AND RADIAL DISTANCES FROM CENTER LINE TO OBSTRUCTIONS TO LINE OF SIGHT

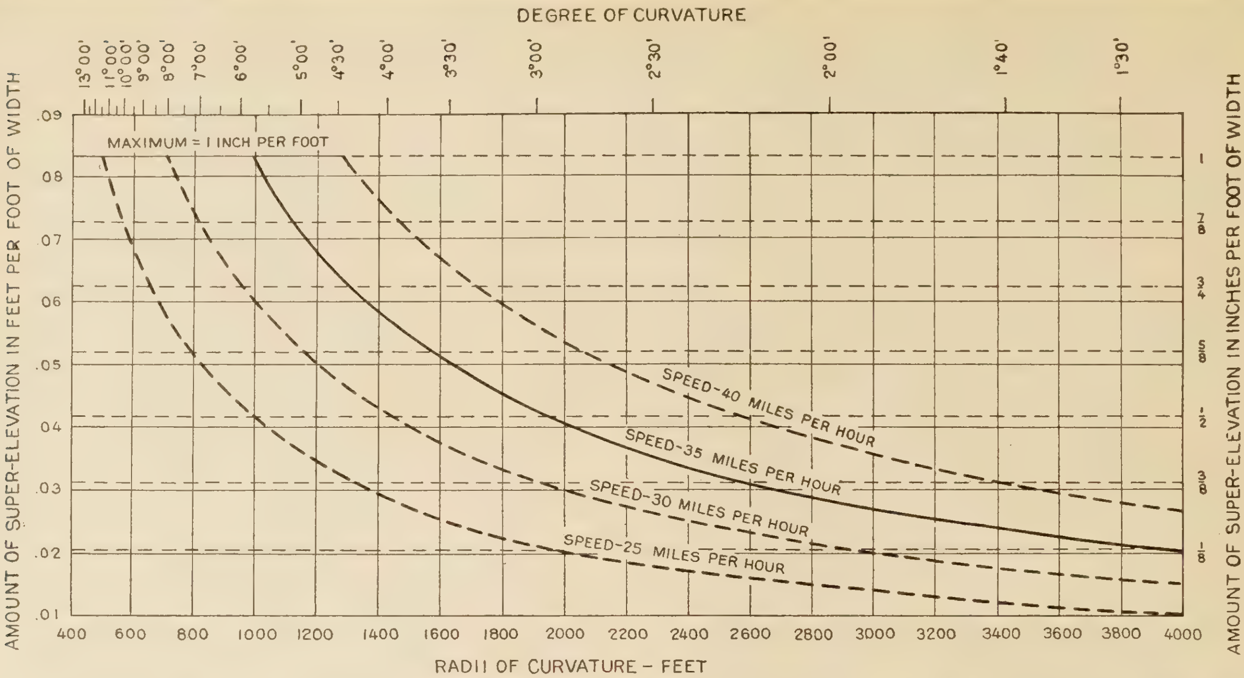


FIGURE 8.—SUPERELEVATION OF CURVES REQUIRED ACCORDING TO FORMULA RECOMMENDED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS

Curves are usually widened where the curvature is 8° or more. The Voshell formula for widening, recommended by the American Association of State Highway Officials is as follows:

$$W=2(R-\sqrt{R^2-L^2})+\frac{35}{\sqrt{R}}$$

where W = the widening in feet,
R = the radius of curve in feet, and
L = the wheel base of the vehicle in feet (20 recommended).

The majority of States start the widening 50 to 100 feet ahead of the point of curvature and reach the full widening at the same distance inside the curve. A few States reach full widening at the point of curvature. Most States use the parabolic spiral transition, although a few States use a straight-line transition. Widening of the pavement has become less important where sharp curves are not used, and one State has abandoned widening of the pavement as standard practice.

COMPOUND AND REVERSE CURVES

Compound curves were frequently used up to the past few years, but it is now recognized that they are dangerous for fast-moving traffic if there is considerable difference in the radii. When a vehicle passes from a slow to a rapid rate of curvature, a change in steering and often a change in speed are required immediately. Failure to sense the changed condition, which is most likely to happen at night, may result in an accident. Usually a tangent section can be used between the curves of different radii; or better still, a simple curve can be used throughout.

Reverse curves were considered objectionable with the speed limits in force in 1918 and are now considered very dangerous. The danger is due not only to the sudden change in direction of curvature, but also to the fact that superelevation can not be provided at the transition point. A tangent section 200 feet long between the curves will permit proper transition with superelevation and widening.

CROWN AND SMOOTHNESS OF SURFACE

Smoothness of road surface is now emphasized much more than formerly, and most specifications require a surface finish with a maximum tolerance of one-fourth inch under a 10-foot straight edge. With such surface trueness it has been possible to reduce the crown to a very small amount, and at the present time one-eighth to one-tenth inch per foot is the prevailing practice.

It is noticeable that some States are more successful than others in building smooth riding pavements, even where the specifications as to finish are the same, and it is obvious that only the greatest care in finishing will produce the results desired. During the past year the machine finisher has been tried on bituminous pavement construction, and apparently greater trueness of surface is produced than by the usualy hand-raking methods.

GUARD RAIL

The light wooden guard rail commonly used 10 years ago was intended as a fence to keep the horse-drawn vehicle from going over the edge of the embankment at night. It has been superseded in most States by some type that offers more resistance to the impact of a rapidly moving motor vehicle.

Where lumber is plentiful, several types of low, heavy, wooden guard rail are used, but woven-wire and steel-cable guard rail on wooden or concrete posts are the predominating types. As at present developed, the cable guard rail with wooden posts affords the greatest safety to heavy vehicles. In mountainous country where large stones are available a bowlder guard rail is attractive and effective. A few States are experimenting with earth banks in place of guard rail. These banks are usually about 8 feet wide at the bottom, 4 feet wide at the top, and are built to a height of about 4 feet. It appears that this type is satisfactory on tangents, but is not so effective on sharp curves, because a rapidly moving car striking the bank at an angle will sometimes climb over it. Many plans specify guard

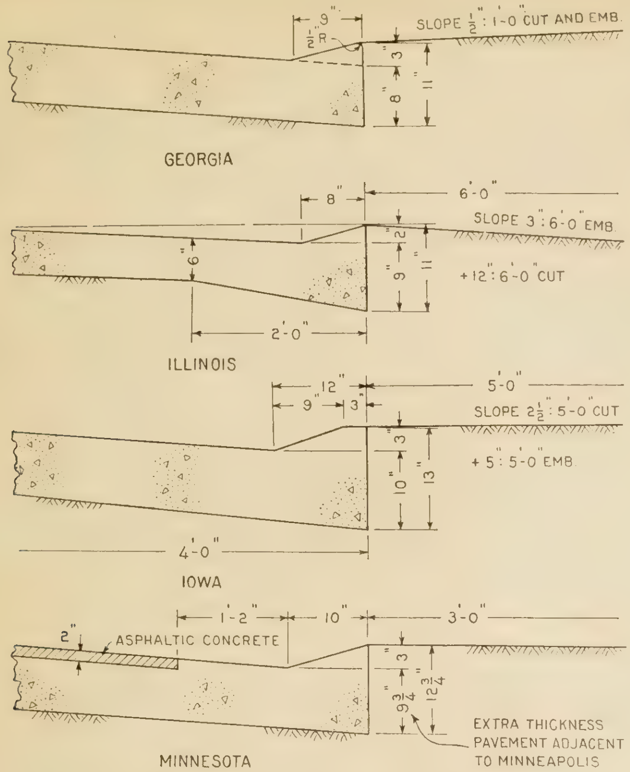


FIGURE 9.—DESIGNS OF LIP CURBS FOR CONCRETE PAVEMENTS SUBMITTED BY GEORGIA, ILLINOIS, IOWA, AND MINNESOTA

rail on low embankments which could easily be graded to a 1 to 4 slope and sodded.

CURBS

The use of curbs with a vertical face is necessary in built-up areas for drainage and the proper protection of life and property, but on rural roads they are a source of danger to motor traffic and their use has resulted in numerous serious accidents. On the other hand, it is very desirable to carry storm water along the edge of concrete surfaces where the shoulder and ditch material erodes easily or it is difficult to keep the ditches clean. Several States are now using concrete edging or some form of lip curb for this purpose, which is so designed as to permit the use of shoulders for emergency repairs and parking. Typical designs are shown in Figure 9.

RAILROAD CROSSINGS

Railroad crossings at grade not only constitute an accident hazard, but also reduce the traffic capacity of a route. This reduction in traffic capacity is due (1) to the actual stopping of vehicles to permit passing of trains, and (2) to the general decrease in speed of all traffic in order to determine the safety of the crossing. Considerable progress is being made in eliminating railroad crossings, but there are so many of them and the cost of eliminations is so heavy that the program each year must be relatively small. Better progress would be made if a uniform survey of the grade-crossing situation could be made in each State and a program of elimination prepared. It is difficult to evaluate the relative danger of factors such as volume and speed of motor traffic, volume and speed of train traffic, sight distance, and approach conditions, but if these are to be used at least an approximate weight could be assigned to each in order to determine the proper place

RAILROAD GRADE CROSSING ELIMINATION

of a crossing in the order of elimination. Protection at crossings other than by means of grade separation is being given serious consideration, and various signal and warning devices are being tried out with varying degrees of success but with a general improvement in conditions.

It has been suggested that the order of grade-crossing eliminations be according to a definite classification of crossings based on the relative value to the traveling public of their elimination. To determine the relative value of specific eliminations, a purely economic study would be made on the basis of time lost at crossings under assumed conditions of entirely safe operation. From the railroad point of view this must be acceptable, because the expense of stopping is the reason why trains may not be stopped at all such crossings. The expense of stopping a motor vehicle is only a small fraction of that incident to stopping a train, but the number of units involved in highway traffic is so great that in the aggregate the loss is considerable.

If the railroads protest the stopping of their own traffic as expensive and destructive of efficiency, they must recognize it as having a similar disadvantage to highway traffic. Some studies of such losses have been made and several cases which indicate what these may amount to are shown in Table 3.

It is clear that there are crossings where there is considerable loss of time to the public. On such crossings the time which is lost may be stated in terms of the efficiency of the highway, as follows:

In the first case shown in Table 3 the highway is 86 per cent efficient (crossing closed 14 per cent of the time), and in the following cases the efficiencies are 79, 95, 90, 90, and 92 per cent.

This measure of efficiency does not, however, indicate the total loss to traffic due to the grade crossings. In some States, notably North Carolina, Louisiana, Mississippi, Florida, and Nebraska, there are crossing stop laws requiring all approaching automobiles to come to a full stop before entering the intersection. In some cases the law requires a reduction of speed to a rate at which the automobile will be completely controllable within a few feet. The speed fixed in Nebraska on secondary crossings is 12 miles per hour. These laws apply to all traffic and represent, if observed, another source of lost time. If such methods are adopted in all States the total losses in highway service will be enormous.

The ratio of night traffic (7 p. m. to 7 a. m.) to day traffic indicates that the vehicle-hours loss shown in Table 3 may be increased by 50 per cent to arrive at the

Table 3.—*Vehicle time lost at selected grade crossings in Cleveland regional traffic survey*

Road	Railroad	Location	Highway traffic, 7 a. m. to 7 p. m.	Rail traffic 7 a. m. to 7 p. m.			Time blocked, 7 a. m. to 7 p. m. (hours)	Vehicles stopped	Per cent of time blocked	Per cent of vehicles stopped	Ratio of clearance time to time crossing is blocked	Total vehicle time loss (vehicle-hours)
				Passenger trains	Freight trains	Switch trains						
East Seventy-second Street.	New York Central	West end, Gordon Park	7,752	27	17	31	1.69	1,078	14.1	14.0	1.24	23.6
Lorain Avenue	do	Near West One Hundred and Forty-third Street.	5,955	44	4	36	2.48	1,867	20.6	31.4	1.22	46.0
Broadway	Wheeling & Lake Erie	At Union Avenue	14,220	6		27	.62	600	5.2	4.2	1.38	12.1
East Ninety-third Street	Erie	Near Meech Avenue [1]	4,372	13	7	22	1.20	709	10.0	16.2	1.31	30.6
Do	Wheeling & Lake Erie	do	4,372	6	11	18	1.18	650	9.8	14.9	1.24	23.7
United States Route 20	Nickel plate	West of Painesville	4,799	2	12	4	.89	319	7.4	6.6	1.18	16.4

[1] Crossings approximately 300 feet apart; blocking of 1 crossing impedes traffic at other.

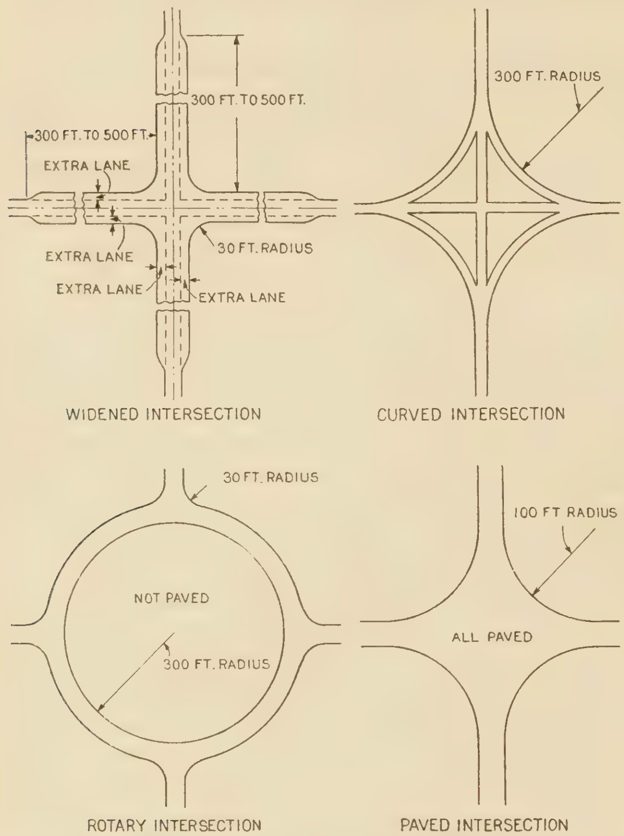


Figure 10.—Types of Intersections

24-hour loss. In the cases cited these full-day losses in vehicle-hours would be, respectively, 35.4, 69, 18.1, 45.9, 35.5, and 24.6. If we assume that the use of an automobile is as valuable as its operating costs, we are conservative in assigning $1 an hour as the cost of the lost time. The above losses, so charged and capitalized at 6 per cent, would justify expenditures of $215,350, $419,750, $110,412, $279,225, $216,262, and $149,650.

These facts are convincing that priority based on the value of time lost is a rational procedure. This applies whether the crossing is protected by gates, watchmen, or is wholly unprotected. In general, the method may be applied by taking a traffic census and computing the losses which would result from motor-vehicle operation in such a manner as to produce complete absence of accidents at the crossing. At the present time only meager data are available.

It should be noted that this plan assumes that the value of eliminating a crossing varies directly with the amount of rail and highway traffic, and no attempt is made to evaluate the hazard of the crossing. The value of elimination is referred directly to a measurable economic loss.

HIGHWAY INTERSECTIONS AND GRADE SEPARATION

The separation of highway grades at important intersections is a new problem in highway engineering but one that will undoubtedly receive considerable attention in the future. Already grades have been separated in cities and in parks, but the expense is so great that it has not been done on rural roads, and it is probably not justified at the present time except on heavy-traffic roads near large cities. In the congested areas where unhampered flow of traffic on multi-lane arteries is essential the separation of grades may be justified because the increased capacity of the highway in cars per hour will afford the same relief as an additional traffic lane which would otherwise be required.

Most highway intersections, even within congested areas, will remain at grade for many years, and their proper treatment has become an important problem in many instances. The two methods most generally used are widened pavements with nearly right-angle intersections and the more common combination of right-angle intersection with wide curves connecting the intersecting routes. In the widened-pavement design, two additional traffic lanes are added for 500 feet on each side of the intersection, and the curves at the intersection are of about 30-foot radius. Traffic about to make either a right or left turn enters the extra lane and makes the turn at slow speed. Figure 10 shows four types of intersections.

The wide-curved intersection with radii of 300 to 500 feet requires considerably more right of way and costs more to construct than the widened roadway intersection. Whether the additional expense is justified appears to be questionable.

SIGNS

The improvement in character and number of directional and warning signs has been a great aid to more rapid automobile transportation. This is especially noticeable where standard United States route markers have been erected. Thirty-eight States have now completed the marking of the United States routes within their borders, and many other States have the marking of these routes well along toward completion.

U.S. GOVERNMENT PRINTING OFFICE : 1929

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ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.
Report of the Chief of the Bureau of Public Roads, 1928.

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Report of a Survey of Transportation on the State Highways of Vermont.
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Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio.
Report of a Survey of Transportation on the State Highways of Pennsylvania.

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Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
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Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL AID ROAD CONSTRUCTION

AS OF

FEBRUARY 28,1929

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE			Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
Alabama	1,926.9	$ 3,648,339.26	$ 1,822,143.18	246.4	12.3	258.7	$ 328,539.28	$ 164,269.63	6.4	21.1	27.5	$ 2,549,298.33	Alabama
Arizona	895.6	1,470,444.69	1,168,019.08	49.7	12.4	62.1	215,690.65	162,393.47		23.5	23.5	3,570,427.47	Arizona
Arkansas	1,757.9	3,121,460.42	1,346,226.15	91.7	6.6	98.3						3,054,379.01	Arkansas
California	1,550.4	10,979,562.72	5,029,902.68	277.1	16.6	293.7	393,207.47	193,662.16	4.4	5.8	10.2	2,551,103.73	California
Colorado	1,084.0	2,818,986.74	1,595,838.01	146.7	15.8	162.5	279,679.17	157,053.50	16.7		16.7	2,948,124.20	Colorado
Connecticut	228.8	900,832.42	272,216.34	13.0		13.0	673,564.46	272,075.09	3.6		3.6	844,972.54	Connecticut
Delaware	213.0	295,099.10	147,549.55	8.0		8.0	509,338.50	154,379.50	7.7		7.7	306,511.22	Delaware
Florida	429.5	2,991,248.90	1,263,593.92	110.7	5.5	116.2						2,047,979.85	Florida
Georgia	2,504.0	4,593,856.16	2,091,623.65	202.5	46.6	249.1	259,439.89	124,002.22	13.4	4.6	18.0	2,008,031.43	Georgia
Idaho	1,100.9	1,399,396.55	834,332.77	112.7	3.0	115.7	49,186.67	29,816.95	3.7		3.7	1,009,127.91	Idaho
Illinois	1,815.6	20,015,962.78	8,930,212.36	603.9		603.9	1,051,302.52	523,777.59	39.3		39.3	2,943,226.56	Illinois
Indiana	1,255.8	5,805,538.55	2,780,546.70	174.1	3.5	177.6	2,320,192.32	1,112,929.89	77.0		77.0	1,147,987.72	Indiana
Iowa	2,988.5	2,509,794.53	995,769.49	41.8	90.8	132.6	501,599.17	229,607.06	14.7	13.5	28.2	2,080,799.99	Iowa
Kansas	2,376.6	5,745,504.27	2,298,087.63	364.2	11.2	375.4	252,913.89	87,353.30	12.1		12.1	2,176,408.98	Kansas
Kentucky	1,289.5	4,532,649.66	2,162,110.02	227.7		227.7	729,981.29	364,990.63	54.3		54.3	926,267.45	Kentucky
Louisiana	1,307.3	4,264,192.30	2,124,337.52	167.1		167.1	103,055.30	25,000.00	.1		.1	1,209,402.36	Louisiana
Maine	480.5	1,779,653.03	596,458.57	40.9		40.9	192,121.39	93,601.55	8.9		8.9	1,439,377.47	Maine
Maryland	621.4	459,798.80	194,190.00	13.7		13.7						665,255.03	Maryland
Massachusetts	568.4	3,115,502.75	989,072.70	58.1		58.1	1,031,876.39	294,525.63	14.7		14.7	2,166,467.10	Massachusetts
Michigan	1,446.6	10,935,667.95	4,659,725.11	264.5		264.5	691,320.00	273,541.86	14.5	6.5	21.0	2,187,878.01	Michigan
Minnesota	4,089.8	1,249,220.75	350,618.27	96.1	11.2	107.3						2,147,297.96	Minnesota
Mississippi	1,616.8	5,006,153.34	2,286,032.19	228.0	22.0	250.0	275,179.91	137,590.43	24.9		24.9	1,422,774.43	Mississippi
Missouri	2,257.1	8,312,927.69	3,080,308.65	187.7	48.7	236.4	1,194,075.97	503,103.88	39.3	8.0	47.3	1,813,877.96	Missouri
Montana	1,540.4	3,702,351.54	2,407,327.59	232.7	7.4	240.1	729,437.65	384,068.64	79.6	.2	79.8	4,955,676.36	Montana
Nebraska	3,511.6	2,999,356.72	1,493,375.79	290.7	106.0	396.7	629,707.98	314,853.94	26.1	49.7	75.8	3,258,307.38	Nebraska
Nevada	1,017.6	1,213,690.52	1,060,738.92	138.3	77.5	215.8	151,190.60	134,332.83	14.5	26.9	41.4	979,108.31	Nevada
New Hampshire	331.7	279,253.01	108,613.31	7.5		7.5						403,276.47	New Hampshire
New Jersey	451.8	4,663,566.44	786,255.00	52.4		52.4	228,694.37	53,565.00	3.6		3.6	892,185.94	New Jersey
New Mexico	1,801.1	2,828,600.79	1,787,202.93	199.3	5.1	204.4	370,507.18	236,198.30	13.0		13.0	1,087,154.11	New Mexico
New York	2,132.0	22,493,431.43	4,968,700.55	331.8		331.8	3,103,860.33	677,805.00	45.3		45.3	6,574,580.12	New York
North Carolina	1,680.4	1,794,731.15	912,526.89	73.1	11.2	84.3	569,862.63	281,041.21	23.4	7.1	30.5	1,825,745.06	North Carolina
North Dakota	3,670.7	2,839,946.84	1,226,174.00	418.2	106.0	524.2	991,373.38	325,765.42	184.9	107.3	292.2	1,266,712.40	North Dakota
Ohio	1,979.6	10,974,910.39	3,806,553.15	229.1	.1	229.2	3,061,680.00	859,335.00	38.8	9.8	48.6	3,723,624.61	Ohio
Oklahoma	1,724.7	3,209,885.44	1,387,482.50	96.0	45.7	141.7	1,106,741.26	513,908.12	47.5	7.1	54.6	1,264,496.13	Oklahoma
Oregon	1,132.4	658,409.07	389,806.71	32.1		32.1	124,960.00	77,092.56	20.5		20.5	2,266,946.36	Oregon
Pennsylvania	2,016.9	12,246,385.83	3,288,753.63	197.3	14.1	211.4	1,523,036.22	451,759.91	27.4		27.4	3,642,841.85	Pennsylvania
Rhode Island	165.2	396,745.71	89,340.00	6.0		6.0	274,697.74	108,825.00	7.2		7.2	776,149.23	Rhode Island
South Carolina	1,754.4	5,514,349.21	1,272,452.17	146.2	64.7	210.9						1,084,844.55	South Carolina
South Dakota	3,266.9	2,569,708.86	1,403,920.28	419.3	39.4	458.7	270,778.01	148,927.87	50.6	3.0	53.6	1,152,192.89	South Dakota
Tennessee	1,095.9	3,800,755.06	1,725,895.88	99.7	44.5	144.2	878,003.66	375,220.28	4.1	30.1	34.2	1,888,556.37	Tennessee
Texas	6,102.6	12,211,000.33	5,108,701.85	482.1	177.9	660.0	4,880,948.42	2,188,258.50	187.2	85.8	273.0	3,924,239.07	Texas
Utah	907.9	1,481,671.90	984,186.31	66.9		66.9	148,000.00	110,000.00	5.4		5.4	717,211.43	Utah
Vermont	229.0	965,465.68	288,777.15	20.5		20.5						415,745.06	Vermont
Virginia	1,327.7	2,303,173.74	997,146.17	56.4	15.2	71.6	189,903.81	90,217.75	5.7		5.7	1,313,379.12	Virginia
Washington	833.2	4,087,895.39	1,418,875.25	90.4	18.1	108.5	57,177.61	30,800.00	5.3		5.3	1,390,737.83	Washington
West Virginia	688.8	977,449.44	453,397.42	39.7	12.4	52.1	341,958.11	145,997.43	11.2		11.2	1,058,307.58	West Virginia
Wisconsin	2,100.4	4,322,767.28	1,854,839.96	124.3	8.9	133.2	53,392.29	26,690.00	5.8		5.8	3,133,250.30	Wisconsin
Wyoming	1,679.0	971,120.20	620,793.85	100.9		100.9						985,027.22	Wyoming
Hawaii	39.4	175,931.99	57,501.20	1.8		1.8						1,432,123.59	Hawaii
TOTALS	76,986.2	215,634,347.32	86,918,253.10	7,679.0	1,060.4	8,739.4	30,738,175.49	12,438,337.10	1,162.8	410.0	1,572.8	94,679,396.05	TOTALS

[1] The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.