PUBLIC ROADS

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APPROACH TO OBSERVATION STATION ON MAINE HIGHWAY TRANSPORTATION SURVEY

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THE MAINE HIGHWAY TRANSPORTATION SURVEY

A PRELIMINARY REPORT

BY THE DIVISION OF HIGHWAY TRANSPORT AND ECONOMICS, U. S. BUREAU OF PUBLIC ROADS

Reported by J. G. McKAY, Chief of Division, and O. M. ELVEHJEM, Highway Economist

A PRELIMINARY analysis of the evidence obtained in the Maine highway transportation survey, conducted by the United States Bureau of Public Roads in cooperation with the Maine State Highway Commission has developed a number of interesting and useful facts with regard to the traffic on the Maine highways, its growth over a period of years, present distribution over the State system, probable future density, and other matters of interest generally to all concerned with the planning and construction of highways. The evidence analyzed was recorded in the course of the field study which was begun July 1, 1924, and lasted until October 31, 1924.

The rapid increase in the demand for highway service is indicated by the increase in motor vehicle registration and in the traffic on the State highway system from 1916 to 1924. Between 1916 and 1920 the registration doubled, it doubled again from 1920 to 1924, and it is estimated that it will double again from 1924 to 1930. Parelleling this increase, the traffic doubled between 1916 and 1919, it doubled again from 1919 to 1923, and it is estimated that it will double again in the period from 1924 to 1930. But while the demand for highway service in the State, considering the transportation of passengers and commodities together, has thus apparently doubled and redoubled in the past eight years, consideration of the motor-truck and passenger-car traffic separately suggests that there is a difference, so far as the State highway system is concerned, in the demands for motor-truck and passenger-car transportation. This is evidenced by the fact that truck traffic has increased at a slower rate than truck registration, while passenger-car traffic has increased at a faster rate than passenger-car registration; but, for total vehicles, the rates of increase of highway traffic and vehicle registration have been nearly equal.

One of the most valuable results of the survey is the collection of data upon which future traffic may be forecast with reasonable accuracy. This makes possible the development of a definite program of future improvement by determining the routes to be improved, the order of their improvement, and the type of improvement required. The forecast of future traffic is of particular value in Maine since the State has reached the second critical stage in the development of its highways. Hitherto the highway commission has wisely constructed large mileages of gravel roads to make accessible the greatest possible area of the State with the funds available.

The concentration of motor-vehicle traffic around the centers of population on the principal State roads now makes necessary a definite improvement policy governing the selection of the routes to be reconstructed with surfaces of higher type, and the determination of the type of surfacing. The Maine experience indicates that a gravel road will not successfully carry over 500 vehicles per 12-hour day without resorting to surface treatment.

Application of the most reliable available information with regard to the savings in operating costs of vehicles made possible by improvement in road surfaces indicates that, on the basis of present traffic, the 300 miles of most heavily traveled roads in the State could be improved from an earth-road condition to a condition in which every mile would be surfaced with concrete, and the entire cost of the improvement, with interest at 4 per cent, would be repaid by the savings in operating costs of passenger cars only in slightly over four years.

SEVEN PER CENT OF THE ROADS SERVE MORE THAN HALF THE TRAFFIC

The survey has brought to light a number of interesting facts with regard to the traffic on the roads of the State. For example, it is shown that the primary highway system which embraces only 7.1 per cent of the total highway mileage carries 53.4 per cent of the total daily vehicle mileage. Furthermore, 18.4 per cent of the primary system carries 38.7 per cent of the total daily vehicle mileage on the system. From this it follows that, with respect to the entire highway system of the State, 1.3 per cent of the total mileage serves more than a fifth of the traffic, as measured in vehicle miles.

It is evident that the heavy concentration of traffic is confined to a relatively small percentage of the total highway mileage. For this reason it is advocated that traffic zones should be created to bring together for construction and maintenance purposes those sections of the highway system which serve approximately the same amount and type of traffic.

The traffic importance of the primary system as compared with the secondary system appears even greater when considered from the point of view of motor-truck traffic than when considered from the standpoint of passenger-car traffic. Practically all trucks using the Maine highways have capacities between one-half and 2½ tons, and the number of trucks of 5 tons capacity or over is practically negligible. Over 80 per cent of the trucks observed were equipped with pneumatic tires, and from 55 to 67 per cent were loaded. Wheel loads in excess of 2,500 pounds were found to be very exceptional on trucks weighing less than 6,000 pounds gross, and the maximum wheel load for trucks of less than 12,000 pounds gross weight (3 tons capacity) was found to be 5,000 pounds. Over 98 per cent of such trucks, however, have wheel loads less than 4,500 pounds.

On a vehicle-mileage basis it is found that a considerable portion of the cost of providing highway service on the primary system is due to its use by foreign vehicles. But these vehicles pay into the State treasury through the gasoline tax a sum which the State would not receive if there were no gasoline tax, and the amount of the tax paid is proportional to their use of the system. The use of the State's roads by foreign motor trucks is much less extensive than its use by foreign passenger cars and, except near the State line and on a few major highways, is negligible.

As a result of the survey a forecast traffic map has been prepared which shows the anticipated density of traffic on roads of the State's primary and secondary systems between July and November, 1930. Neglecting such factors as the effect of major mechanical improvements of automobiles, it is believed that the actual traffic in 1930 will closely approximate the estimated traffic as recorded on this map, and the map has therefore been used as a basis for a number of detailed suggestions with regard to the program of highway improvement up to 1930.

TRAFFIC ON PRIMARY, SECONDARY, AND THIRD-CLASS HIGHWAYS

There are 23,104 miles of highway in the State. Of this mileage 1,630 miles, constituting the State highway system, is defined as the primary system. State-aid highways, consisting of 4,049 miles not included in the State highway system but serving as feeders to it, are defined as the secondary system. Third-class roads, comprising 17,425 miles, include all highways not included in the State or State-aid systems.[1]

This classification of the roads, it was one of the purposes of the survey to check by a more exact determination of the traffic served by them. At the same time the survey methods were designed to supply the information needed to decide upon the adequacy of the types of surfaces laid on roads of the three systems with respect to present and probable future traffic, and to serve as a basis for the equitable partition of funds available for construction and maintenance.

To serve these purposes it was necessary that the survey supply four general classes of data, as follows: (1) Density of traffic on all parts of each system; (2) the size and loading of motor truck traffic; (3) vehicle-mileage per year on each of the three systems; and, (4) the probable growth of traffic over a reasonable future period.

The traffic classification of roads and the selection of the most suitable type of highway surface to serve traffic depends upon the type of traffic units as well as the number of these units. The more important considerations are: (1) Density of present and future total traffic; (2) the ratio of trucks to total vehicles; (3) the proportion of trucks of large, medium, and small capacity, and the resulting gross loads; (4) the maximum wheel loads; and, (5) the frequency of critical gross loads and wheel loads. In individual cases other factors must also be considered, but in general the more important considerations are those above mentioned. The final selection of type of highway surface depends upon certain physical considerations, such as availability and cost of materials, as well as upon traffic considerations.

Vehicle mileage involving, as it does, the factors of number of vehicles and mileage traveled serves as the basis for the equitable allocation of funds in proportion to the utilization of the three systems; and the extension of the curves of traffic and vehicle registration makes possible a forecast of the growth of traffic which will enable those in charge of highway administration to make the necessary provision for future maintenance and construction.

Density of traffic on the three systems.—The density of traffic,[2] which is one of the criteria determining the classification of roads and the types of surface needed, has been computed from the number of vehicles passing each of the survey stations during the observation periods corrected for each station to a 24-hour day.[3]

Computed in this way the average density of traffic on the three systems, as now designated, is shown in Table 1. Considering each of the systems as a whole the table indicates that the average density of traffic on the primary system is thirty-six times as great as on the third-class system and over four times as great as on the secondary system; and, as shown in Table 2, this same relation applies approximately to the truck and passenger-car traffic separately as well as to the total traffic, from which it follows, also, that the relative density of motor-truck and passenger-car traffic on the three systems is approximately the same, the ratio in each case being about 1 to 10.

TABLE 1.—*Average density of traffic on the primary, secondary, and third-class highway systems, July 1 to October 31, 1924*

Highway system	Average density of traffic	Index of relative density of traffic (third class=100 per cent)
	Vehicles per day	*Per cent*
Primary (1,630 miles)	1,044	3,600
Secondary (4,049 miles)	244	840
Third class (17,425 miles)	29	100

TABLE 2.—*Average density of motor-truck and passenger-car traffic on the primary, secondary, and third-class highway systems, July 1 to October 31, 1924*

Highway system	Average density of passenger-car traffic	Index of relative density of passenger-car traffic (third class=100 per cent)	Average density of motor-truck traffic	Index of relative density of motor-truck traffic (third class=100 per cent)	Ratio of passenger-car to motor-truck traffic
	Vehicles per day	*Per cent*	*Vehicles per day*	*Per cent*	
Primary (1,630 miles)	950	3,520	94	4,700	10.2
Secondary (4,049 miles)	221	820	23	1,150	9.6
Third class (17,425 miles)	27	100	2	100	13.5

Other things being equal, these indices describe the relative average highway requirements of the traffic on the three systems and govern the average expenditures which may justifiably be made for the improvement of each mile of each system. Thus, if the ratios of motor trucks to passenger cars is approximately the same, the fact that the average density of traffic on the primary system is thirty-six times as great as the average density on the third-class system means that the average justifiable expenditure for the improvement of each mile of the primary system is thirty-six times as great as the average expenditure which can be justified for each mile of the third-class system.

Traffic served by the three systems.—These indices also indicate the relative transportation service afforded by each mile of the three systems, but by reason of the different extent of the systems they do not describe

[1] Chap. 25, Sec. 5, Laws of Maine, 1917.

[2] In this report certain terms, frequently used, have invariably the same meaning. These terms and their definitions are as follows:

Vehicles refers only to motor vehicles (passenger cars and trucks) exclusive of horse-drawn conveyances.

Traffic is defined as the movement to and fro of vehicles over a highway.

Density of traffic is defined as the number of motor vehicles passing any given point on a highway in a unit of time. Unless a different unit of time is specifically stated it refers to the number of vehicles passing any given point on a highway during a day of 24 hours.

Daily refers to a day of 24 hours.

Vehicle-mile is defined as the movement of a vehicle 1 mile.

Vehicle-miles per mile is defined as the sum of the mileage traveled by all motor vehicles in passing over 1 mile of highway. It is numerically equivalent to the average density of traffic on the mile of highway.

[3] The accuracy of the determination of density of traffic is influenced by the distance between the survey stations. Exactness of method would require a density record for each point on the highway system where traffic varies. The cost involved in proportion to the relatively small gain in accuracy does not justify the location of recording stations at close intervals. The density computed for each station on the Maine highway system is applied to sections of the system reasonably adjacent to each station.

the relative magnitude of the service rendered by the systems or their relative total utilization considered as parts of the whole system of the State. This can only be described in terms of the total daily vehicle mileage on the three systems, which is the sum of the distances traveled in a day by all vehicles on each system.[4]

The importance of distinguishing between the total vehicle mileage on each system and the average density of traffic on each (which is numerically equivalent to the vehicle mileage per mile) is clearly indicated in Table 3. For, while the average density or vehicle mileage per mile on the primary system is thirty-six times the average density on the third-class system, Table 3 shows that the total traffic service rendered by the primary system, of 1,630 miles, as measured in vehicle-miles, is three and one-half times as great as the total traffic service rendered by the 17,425 miles of the third-class system. The latter relation should control the apportionment of available funds to the three systems; the former should control the justifiable expenditure per mile on each system.

TABLE 3.—*Relative traffic service of the primary, secondary, and third-class highway systems*

Highway system	Length of system	Portion of total highway mileage in each system	Daily traffic service by each system	Portion of total daily traffic service rendered by each system	Index of relative daily traffic service (third class=100 per cent)
	Miles	*Per cent*	*Vehicle miles*	*Per cent*	*Per cent*
Primary	1,630	7.1	1,702,000	53.4	340
Secondary	4,049	17.5	986,000	30.9	197
Third class	17,425	75.4	499,000	15.7	100

The importance of the primary system to motor-vehicle users is evident from the fact that 53.4 per cent of the total daily vehicle mileage on all highways in Maine is found on the primary system, which includes only 7.1 per cent of the total highway mileage. The slight traffic importance of the third-class system is evidenced by the fact that only 15.7 per cent of the total daily vehicle mileage is found on this system, which includes 75.4 per cent of the total highway mileage.

In these analyses of the relations between the three systems in Maine it must be borne in mind that the relations both as to density of traffic and daily vehicle mileage depend upon two elements which restrict their application more or less closely to the existing situation in Maine. These elements are the existing density of traffic on each mile of the Maine highways and the mileage of the three systems. Obviously, the expansion of the primary system by including 1,000 miles of highway now a part of the secondary system would materially change the relative daily vehicle mileage on the two systems. Similarly, a change in the mileage included in each system would also affect the average density of traffic on the three systems. The primary system, in general, now includes the more important highways of the State; the inclusion of a considerable mileage of less important highways would result in lowering the average density of traffic on the system.

It is evident, therefore, that the relationships between the three systems are true only for these systems as they exist to-day, and that any change in the systems will modify the relationships; and they are applicable in other States only in so far as the factors producing highway traffic and the proportion of highway mileage in the several systems of such States is comparable with the existing conditions in Maine.

Moreover, these relationships apply only to the three systems in Maine considered as units. Analysis of the traffic on the roads included in the sytems shows that there are material differences in the traffic importance of roads within each system.

COMPARISON OF TRAFFIC ON THREE SECTIONS OF THE PRIMARY SYSTEM

In Table 4 traffic is analyzed on three sections of the primary system. Section 1 includes route 1, from Kittery to Belfast; route 20, from Brunswick to Fairfield; route 100, from Portland to Augusta; and route 196, from Brunswick to Auburn—a total of 300 miles. Section 2 includes route 1, Ellsworth to St. Stephan; route 15, Oldtown to Houlton; route 20, Fairfield to the north State line; and route 24, from Houlton to the north State line—a total of 467 miles. All other routes of the primary system are grouped under section 3.

TABLE 4.—*Highway mileage and traffic on three sections of the primary system*

Section number	Length of section	Portion of primary system mileage in section	Average density of traffic	Daily motor-vehicle mileage on each system	Portion of total daily vehicle mileage on each system
	Miles	*Per cent*	*Vehicles per day*	*Vehicle-miles*	*Per cent*
1	300	18.4	2,197	659,000	38.7
2	467	28.7	525	245,000	14.4
3	863	52.9	924	798,000	46.9
Total	1,630	100.0	1,044	1,702,000	100.0

From this analysis it will be seen that the average density of traffic on 300 miles of the primary system (section 1) is over four times as great as the average density on section 2, which includes 467 miles and over twice as great as the average density on the 863 miles which compose section 3. The entire primary system, which includes 7.1 per cent of the total highway mileage, serves 53.4 per cent of the total daily traffic in vehicle-miles. But 300 miles, or 18.4 per cent of the primary system, serves 38.7 per cent of the total traffic served by the 1,630 miles of the primary system. With respect to the entire highway system of the State these 300 miles constitute only 1.3 per cent of the total highway mileage, but they serve 20.7 per cent of the total traffic.

[4] The daily vehicle mileage on any system is the product of the total number of vehicles operated over any part of the system during the day and the average trip mileage of those vehicles. But the total number of vehicles operated over any part of the system during the day is the sum of the densities observed at the stations on the system divided by the number of times each vehicle is counted. With any given number of stations the number of times each vehicle is counted is equal to the average trip mileage divided by the average distance between stations; e. g., if the average trip is 35 miles and the average distance between counting points is 1 mile, each vehicle will be counted on the average 35 times.

The mathematical derivation of the approximate method of computing vehicle mileage is as follows:

$$\text{Daily vehicle mileage} = \frac{(\text{Sum of densities})\ (\text{Average trip mileage})}{\text{Number of times each vehicle is counted}}$$

$$= \frac{(\text{Sum of densities})\ (\text{Average trip mileage})}{\dfrac{\text{Average trip mileage}}{\text{Average distance between stations}}}$$

$$= (\text{Sum of densities})\ (\text{Average distance between stations})$$

$$= (\text{Sum of densities})\ \frac{\text{Highway mileage}}{\text{Number of stations}}$$

$$= \frac{\text{Sum of densities}}{\text{Number of stations}}\ (\text{Highway mileage})$$

$$= (\text{Average density})\ (\text{Highway mileage})$$

The importance of section 1 is further illustrated by the comparison of the average daily gross tonnage per mile moved over each of the three sections of the primary system, which is shown in Table 5.

TABLE 5.—*Average daily gross tonnage per mile moved over three sections of the primary system*

Section No.	Average daily gross tonnage per mile		
	Passenger cars	Motor trucks	Total
	Tons	*Tons*	*Tons*
1	2, 859	305	3, 164
2	662	101	763
3	1, 159	200	1, 359

This table shows that in point of tonnage per mile, as well as density of traffic, section 1 of the primary system is over four times as important as section 2 and over twice as important as section 3.

Still another indication of the importance of the principal roads of the primary system is presented by Table 6, which shows the average maximum density of traffic on certain roads, as observed on Sundays during the period of the traffic survey, July 1 to October 31, 1924.

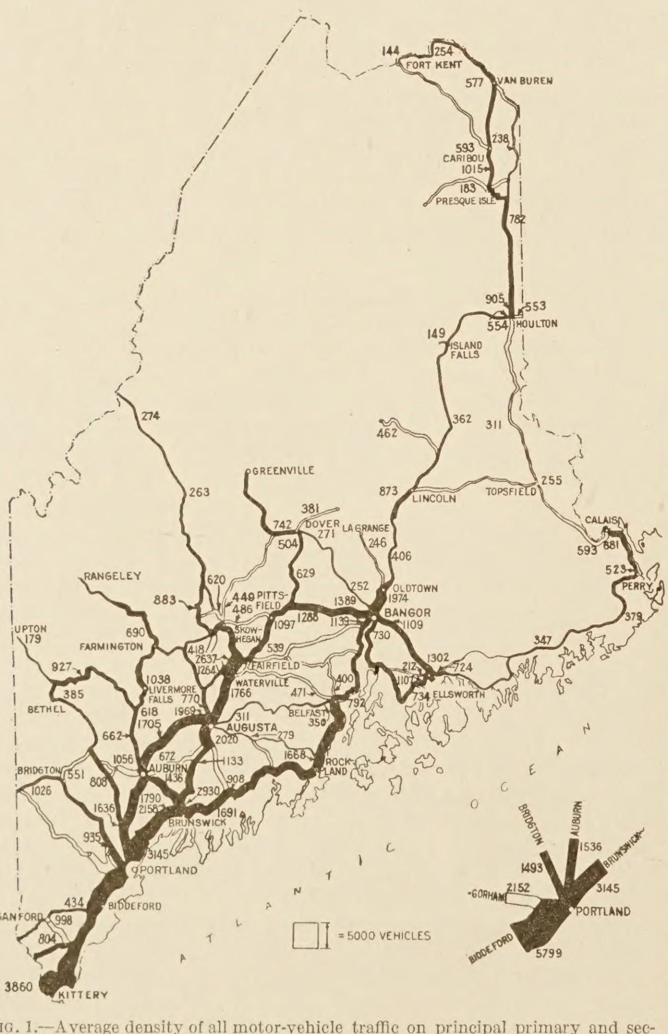


FIG. 1.—Average density of all motor-vehicle traffic on principal primary and secondary highways in Maine, July 1 to October 31, 1924

TABLE 6.—*Average maximum density of traffic on certain roads of the primary system (observed on Sundays during the period July 1 to October 31, 1924)*

Route and location of station	Average maximum density of traffic (Sunday)		
	Motor trucks	Passenger cars	Total
	Vehicles per day	*Vehicles per day*	*Vehicles per day*
Route 1:			
South of Portland	213	9, 781	9, 994
State line (south)	68	6, 780	6, 848
North of Portland	98	5, 367	5, 465
West of Brunswick	70	3, 673	3, 743
Southwest of Rockland	87	2, 695	2, 782
Route 20, north of Winslow	122	4, 357	4, 479
Route 100, west of Augusta	82	3, 285	3, 367
Route 196:			
Southeast of Auburn	77	2, 335	2, 412
North of Brunswick	55	5, 132	5, 187

A recapitulation of all data indicating the utilization of the highways of the three systems is given in Table 7.

TABLE 7.—*Motor-vehicle utilization of Maine highways, July 1 to October 31, 1924*

	All highways	Primary system	Secondary system	Third-class system
Highway mileage	23, 104	1, 630	4, 049	17, 425
Percentage of highway mileage	100. 0	7. 1	17. 5	75. 4
Daily vehicle-miles:				
All vehicles	3, 187, 000	1, 702, 000	986, 000	499, 000
Passenger cars	2, 904, 000	1, 548, 000	893, 000	463, 000
Trucks	283, 000	154, 000	93, 000	36, 000
Average density of traffic:[1]				
All vehicles	138	1, 044	244	29
Passenger cars	126	950	221	27
Trucks	12	94	23	2
Total vehicle-miles, July 1 to Oct. 31, 1924:				
All vehicles	392, 001, 000	209, 346, 000	121, 278, 000	61, 377, 000
Passenger cars	357, 192, 000	190, 404, 000	109, 839, 000	56, 949, 000
Trucks	34, 809, 000	18, 942, 000	11, 439, 000	4, 428, 000
Percentage of vehicle miles:				
All vehicles	100. 0	53. 4	30. 9	15. 7
Passenger cars	100. 0	53. 3	30. 8	15. 9
Trucks	100. 0	54. 4	32. 9	12. 7
Average daily gross tons per mile:				
All vehicles	201	1, 521	356	42
Passenger cars	176	1, 330	309	38
Trucks	25	191	47	4

[1] The average density of traffic is the weighted average density per day reduced to the nearest whole number. These average values were obtained by weighting the average daily number of vehicles at each station, or group of similar stations, by the number of miles of highway on which the daily traffic was approximately equal to this average, and therefore approximates the exact average obtained by summing the vehicles per day on each mile of highway and dividing the total by the number of miles of highway.

RELATIVE TRAFFIC IMPORTANCE OF PRINCIPAL ROADS

The relative traffic importance of the principal roads of the Maine highway system, as determined by the average density of traffic, is shown clearly in Figure 1, in which the density of traffic on roads of the primary and secondary systems is represented by the width of the lines. The chart shows at a glance which roads require the largest outlay of construction funds to provide adequate highway service.

The greatest density of traffic is found near the centers of population—Portland, Auburn, Lewiston, Augusta, Brunswick, Waterville, Bangor—and the summer-resort district. Clearly the 300 miles previously defined as section 1 of the primary system constitute the backbone of the entire system. These roads from Kittery to Belfast, from Brunswick to Fairfield, from Portland to Augusta, via Auburn, and from Brunswick to Auburn have, markedly, a greater density of traffic than any others in the State. Excluding these and the roads from Fairfield to Bangor and from Bangor to Ellsworth and Oldtown, the average density of traffic on the balance of the Maine highway system will not exceed 1,000 vehicles per day.

On a considerable mileage of the primary system and a large mileage of the secondary system the average density of traffic was less than 300 vehicles per day during the four months of the survey. It is anticipated that the density on these routes will not exceed 600 vehicles per day by 1930. No large expenditures will be required for high-type improvements on these roads for some years. They should receive only a sufficient amount of the construction and maintenance funds each year to meet their actual traffic needs, and the major portion of such funds should be devoted to the immediate improvement of the heavy-traffic roads.

Clearly, there is need for the creation of traffic zones bringing together for construction and maintenance purposes those sections of the highway system which serve approximately the same amount and type of traffic and to distinguish between those routes which require constant supervision and policing to insure satisfactory service and safety to traffic and those which do not.

In the main it is evident that the primary system includes the principal traffic arteries of the State and is therefore well selected. On the basis of their traffic density, however, some roads now included in the secondary system could more properly be included in the primary system than some that are included. The roads which could well be transferred to the primary system are those from Wells to Sanford, from Portland to Standish, from Auburn to Mechanic Falls, and from Oakland to Norridgewock.

The density of motor-truck traffic on the principal roads of the primary and secondary systems is shown in Figure 2. Obviously, the principal motor-truck routes in the State are those from Kittery to Portland, Portland to Augusta via Auburn, Portland to Brunswick, Lisbon Falls to Auburn, Auburn to Mechanic Falls, Waterville to Fairfield, Thomaston to Camden, Bangor to Ellsworth, Bangor to Oldtown, and Portland to Naples.

In general it will be recognized that these routes which have the largest daily motor-truck traffic are, with few exceptions, identical with those which have the greatest density of total traffic. The link of the primary system from Houlton to Van Buren via Easton and Presque Isle shows a relatively higher proportion of trucks to total traffic than is to be found on the primary system as a whole. So, also, does the route from Bangor to Ellsworth, a highway urgently in need of improvement. The motor-truck capacity analysis of the road from Portland to Naples, which also shows a heavy proportion of trucks to total traffic, indicates that this road carries an unusually large proportion of the heavier trucks.

The general use of motor trucks on the principal traffic routes indicates the need for highway improvement of a type adequate to provide service for truck traffic. The fact that the highway between Brunswick and Waldoboro is surfaced with gravel may be, in part, responsible for the small density of motor-truck traffic on this route. But the chart of motor-truck traffic density confirms the conclusion drawn from the discussion of the density of total traffic that high-type improvement of a considerable mileage of the primary and a large mileage of the secondary system can safely be deferred for some years.

Sections of the secondary system which have a considerable density of truck traffic are the roads from Portland to Standish and from Auburn to Mechanic Falls. These roads were shown to be eligible for transfer to the primary system by the analysis of total traffic.

STATUS OF ROAD IMPROVEMENT IN RELATION TO TRAFFIC DENSITY

The free flow of traffic on the principal sections of the primary system is hindered by gaps of unimproved highways or sections surfaced with gravel. Between Kittery and Portland, as shown in Figures 3 and 4,

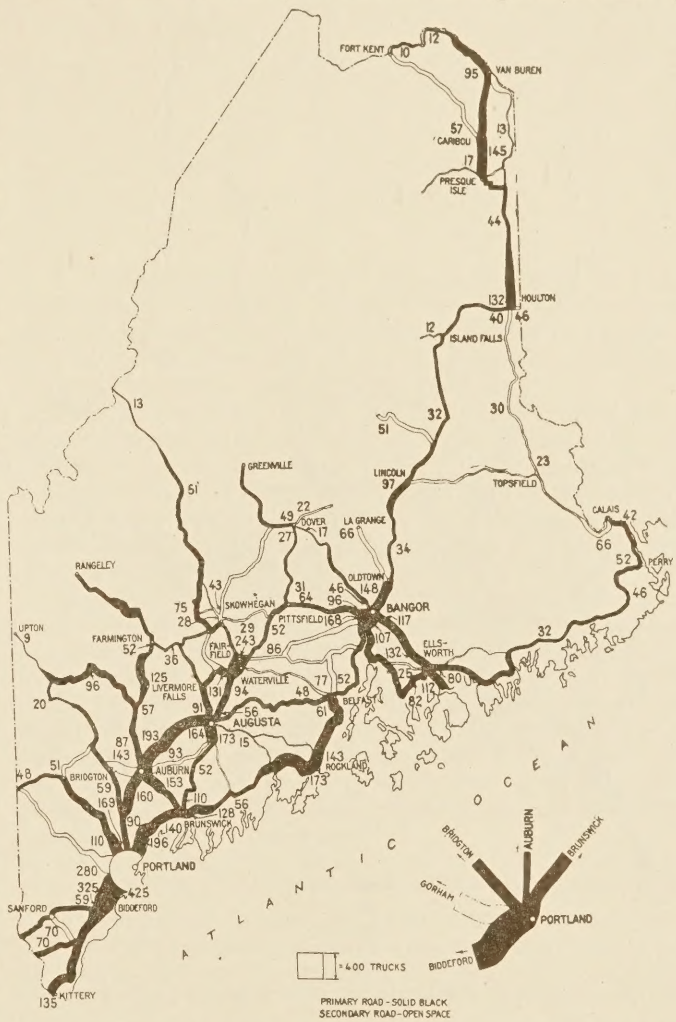


Fig. 2.—Average density of truck traffic on principal primary and secondary highways in Maine, July 1 to October 31, 1924

there are sections of concrete, macadam, and gravel. Sections of gravel road on a heavy-traffic route such as this do not provide adequate service to traffic and the yearly maintenance costs are excessive.

Between Auburn and Augusta, on one of the most heavily traveled routes in the State, approximately 16 of the 31 miles are gravel. Between Brunswick and Belfast there is a large mileage of gravel that undoubtedly does not give satisfactory service to the dense traffic. Between Brunswick and Augusta, also, there are sections of macadam, gravel, and unimproved road. After improvement the density of traffic over this route can be expected to increase materially.

The routes from Bangor to Ellsworth, one direct and the other via Orland, illustrate the need of improvement in proportion to the density of traffic. The direct route is gravel, although it is an important trucking route and is also of considerable importance as a passenger-car route. On the Bangor-Orland-Ellsworth route there is large unimproved mileage. The passenger-car movement and the surprisingly large motor-truck traffic over a large part of the route justifies at least a gravel surface.

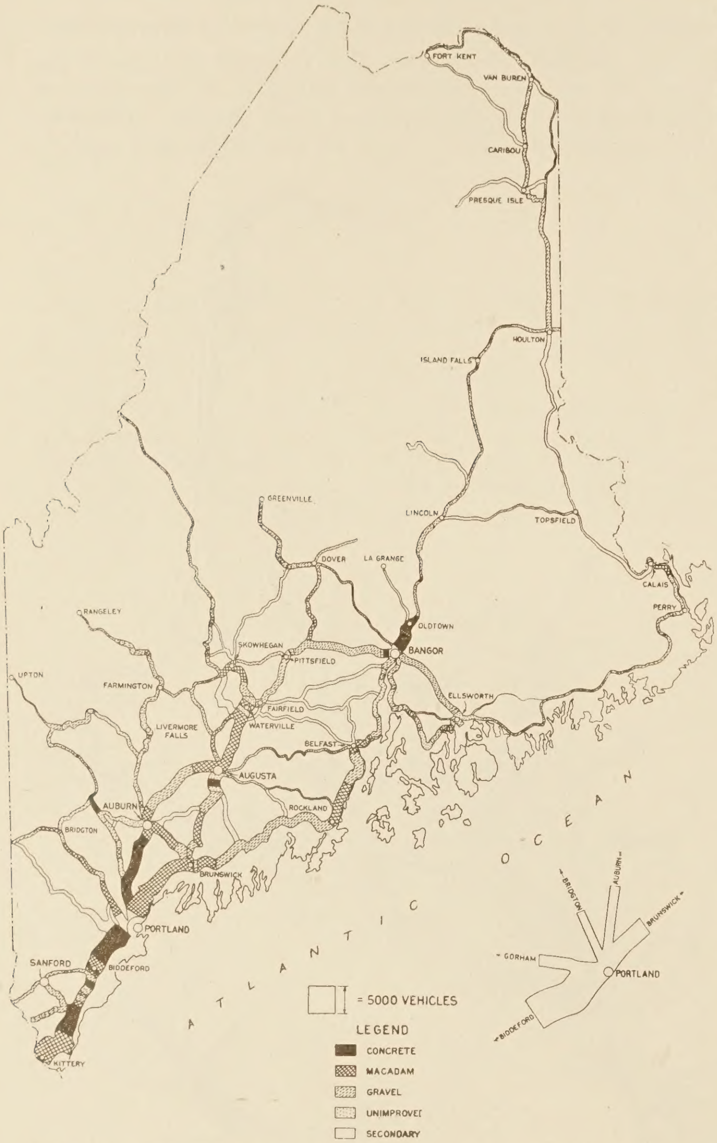


FIG. 3.—Average density of motor vehicle traffic and road types on the primary system of Maine

In the northern part of the State the heavy trucking is caused largely by the transportation of potatoes. The average density of motor-truck traffic in this part of the State exceeds that on a large mileage of the primary system in the southeastern part of the State and apparently justifies a higher type of highway.

MOTOR-BUS AND HORSE-DRAWN TRAFFIC

Motor-bus traffic was recorded at very few stations, and even on the routes on which busses were operated their number was negligible.

The daily variation in the number of horse-drawn conveyances was found to be much greater than the variation in motor vehicles. At different stations the proportion of horse-drawn traffic to total traffic varies from less than 1 to 20 per cent. In general the greatest density of horse-drawn traffic was recorded at the stations at which the motor-vehicle traffic was light, although heavy horse-drawn traffic was found at some heavy motor-vehicle traffic stations which were located near towns. Extremely light horse-drawn traffic was found at some of the outlying stations which are located in undeveloped sections of the State.

The heaviest proportion of horse-drawn traffic was observed at stations located in well-developed agricultural areas which are off the main lines of motor-vehicle travel and which therefore have little motor-vehicle traffic. The horse-drawn traffic during September and October was considerably higher at the majority of stations than it was during the months of July and August. This increase was undoubtedly due to the crop marketing movement during the early fall months.

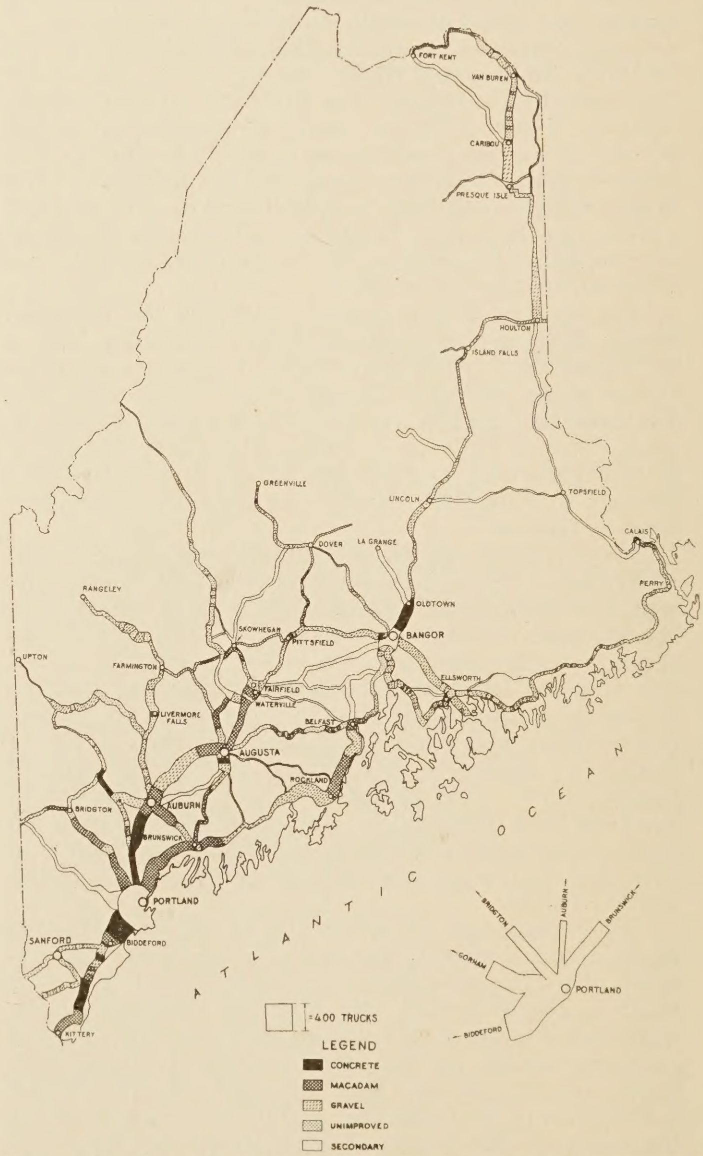


FIG. 4.—Average density of motor-truck traffic and road types on the primary system of Maine

ANALYSIS OF MOTOR-TRUCK CAPACITY AND WHEEL LOADS

Motor trucks in use on the Maine highway system are predominantly of the smaller capacities, from one-half to 1½ tons. Even on the heavily traveled sections of the primary system practically all the trucks fall within the capacity group of one-half to 2½ tons, as shown by Table 8.

TABLE 8.—*Motor-truck capacities on the primary system*

Capacity group (tons)	Section 1		Section 2	
	Number	Per cent	Number	Per cent
½ to 2½	6,681	96.7	1,064	98.1
3 to 4	207	3.0	15	1.4
5 and over	23	0.3	5	0.5

Table 9 presents a summary, in greater detail, of the percentages of trucks of the various capacities observed at each weight station.

TABLE 9.—*Summary of the distribution of loaded trucks by capacity groups at weight stations*

Station	Distribution by capacity groups				
	½ to 1½ tons	2 to 2½ tons	3 to 4 tons	5 to 5½ tons	6 to 7½ tons
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
401	87.1	5.5	7.4		
402	89.7	7.6	2.7		
403	93.9	5.9	.2		
404	86.8	10.3	2.9		
405	95.0	3.7	1.1	0.2	
406	84.3	12.3	2.8	.6	
407	78.3	13.0	7.2	1.5	
408	81.6	12.7	4.9	.8	
409	86.6	10.0	3.1	.3	
410	89.3	9.4	1.3		
421	82.3	13.1	3.0	.5	1.1
422	92.1	1.4	5.8	.7	
423	93.1	6.4	.5		
424	86.6	10.8	2.5	.1	
425	100.0				
426	87.5	12.5			
427	85.9	10.0	4.1		
428	81.5	10.9	7.6		
429	92.4	4.8	2.8		
430	91.5	4.0	4.5		

At every weight station but one (station 407) more than 80 per cent of the truck traffic consists of trucks of less than 2 tons capacity. At 7 of the 20 stations over 90 per cent of the traffic is composed of trucks of less than 2 tons capacity. Five-ton trucks are found at only 8 of the 20 stations, and the highest proportion of 5-ton trucks at any station is 1.5 per cent (station 407). Trucks larger than the 5 to 5½ ton group are found at only one station (station 421), and this is undoubtedly an exceptional movement. At all stations over 90 per cent of the truck traffic is made up of trucks of less than 3 tons capacity. Station 406, although having a smaller percentage of large trucks than some of the other stations, actually has a larger number of heavy trucks per day than does any other station. For use in the control of design of pavement to meet traffic requirements these percentages should be applied to the average daily truck density.

Except at stations 407 and 408 over 90 per cent of the loaded trucks at all weight stations were under 12,000 pounds gross weight. Trucks weighing over 24,000 pounds gross were found at only two stations (stations 407 and 408), and the percentages of such trucks at these stations was very small, 0.3 per cent at station 407 and 0.1 per cent at station 408. Trucks weighing between 12,000 pounds and 18,000 pounds gross were found at 11 of the 20 stations, but the highest percentage of such trucks at any station was 3.4 per cent (station 407). The percentage of loaded trucks weighing less than 12,000 pounds gross agrees quite closely with the percentage of trucks of less than 3 tons capacity, as shown in Table 10.

TABLE 10.—*Comparison of the percentages of trucks under 3 tons capacity and under 12,000 pounds gross load by stations*

Station	Trucks under 3 tons capacity	Trucks under 12,000 pounds gross weight	Station	Trucks under 3 tons capacity	Trucks under 12,000 pounds gross weight
	Per cent	*Per cent*		*Per cent*	*Per cent*
401	92.6	93.6	421	95.4	96.5
402	97.3	95.5	422	93.5	95.0
403	99.8	98.3	423	99.5	99.5
404	97.1	96.0	424	97.4	97.2
405	98.7	98.9	425	100.0	100.0
406	96.6	95.2	426	100.0	99.6
407	91.3	87.3	427	95.9	95.8
408	94.3	89.9	428	92.4	100.0
409	96.6	95.5	429	97.2	99.5
410	98.7	95.3	430	95.5	100.0

A comparison of the percentages in Table 10 indicates that for roads in Maine where truck traffic consists exclusively of trucks of less than 3 tons capacity it is fairly safe to select a type of pavement which will carry a maximum load of 12,000 pounds.

Over 80 per cent of the trucks on Maine highways are equipped with pneumatic tires. Practically all trucks weighing less than 6,000 pounds gross are so equipped, and although the percentage of pneumatic-tired trucks weighing between 6,000 and 12,000 pounds gross varies considerably with location it will average approximately 75 per cent of the total.

The observations indicate that the maximum wheel load of trucks whose gross load is under 6,000 pounds is 3,000 pounds, that wheel loads over 2,500 pounds are very exceptional, and that 95.9 per cent of the trucks under 6,000 pounds gross weight have rear-wheel loads of less than 2,000 pounds. For gross loads of less than 12,000 pounds 5,000-pound wheel loads are the maximum, and of all gross loads less than 12,000 pounds 98.5 per cent have wheel loads of less than 4,500 pounds.

PROPORTION OF LOADED TRUCKS OVER 50 PER CENT

The ratio of loaded to total trucks varies from 54.8 to 66.6 per cent. The lowest percentage is found at station 425 and the highest at station 401. Of the four stations at which less than 60 per cent of the trucks observed were loaded three are located on outlying routes—station 425 near Columbia Falls, station 423 south of Mattawamkeag, and station 402 east of Rumford. The fourth, station 403, is on route 100 between Auburn and Augusta.

The average net weight per loaded truck varies from 760 pounds at station 405 to 2,060 pounds at station 407, and the average gross weight from 3,420 pounds at station 425 to 6,180 pounds at station 407. Only two stations, 407 and 408, have an average net weight in excess of 1,600 pounds per loaded truck. These are also the only stations that show an average gross weight in excess of 5,000 pounds per loaded truck. Several of the stations of relatively heavy traffic density show very low average net and gross weights per loaded truck because of the preponderance of one-half-ton trucks. This is especially true of station 406, which has a larger number of 3 to 4 ton trucks and also a larger number of 5-ton trucks per day than stations 407 or 408, but because of the large number of small trucks the average weights are low. The average trip mileage per vehicle depends very largely upon the location of the station. Stations 407, 410, 421, and 425 show average trip mileages in excess of 35 miles; stations 402, 403, and 429 show average trip mileages below 20 miles.

USE OF MAINE HIGHWAYS BY FOREIGN MOTOR VEHICLES

When it is considered that 21.4 per cent of all motor vehicles on the primary system are of foreign registration, that the foreign vehicles account for an average density of traffic on the primary system amounting to 223 vehicles a day, and that these vehicles travel each day 364,000 vehicle-miles, it becomes evident that the cost of providing and maintaining adequate highways in Maine is increased by the usage of the roads by foreign vehicles.

Foreign passenger cars constitute 21.2 per cent of all motor vehicles on the primary system. They produce 23.3 per cent of the total passenger car-miles on the primary system, 9.9 per cent on the secondary system, and 6.5 per cent on the third-class system.

Foreign motor trucks are of much less importance. They account for only 2.1 per cent of the motor-truck-miles on the primary system, 1.6 per cent on the secondary system, and on the third-class system their influence is negligible.

Detailed data on the use of the Maine highways by foreign vehicles are given in Tables 11, 12, and 13.

Foreign passenger cars form a very important part of the total passenger-car traffic at stations near the State line and also at points a considerable distance from the State line on the principal traffic routes. As distance from the State line increases the proportion of foreign passenger cars decreases. On route 1 near Kittery (station 407), 68.2 per cent of the passenger cars carry foreign licenses. Near Wells (station 1B) the percentage is 43.5, and south of Portland the percentage is 34.5 (Table 14). North of Portland foreign passenger cars decrease to 29.2 per cent on route 1 (station 409) and 18.1 per cent on route 18 (station 408).

On route 1 the percentage of foreign passenger cars near Bath (station 405) is 27.6 per cent and near Rockland (station 429) 18.2 per cent. On route 20, south of Augusta (station 430), foreign passenger cars are 19.1 per cent of the total traffic.

Other routes in the State do not carry as large a proportion, but some foreign passenger cars were found at every station located on the primary and secondary system.

Trucks of foreign registration are of less importance. Foreign trucks make up over 10 per cent of the total truck traffic at only four stations, and these are all located near the State line. Only three stations (stations 406, 407 and 1B) show an average of more than 10 foreign trucks a day; only seven have an average of more than five foreign trucks a day; and a large number of stations have no foreign truck traffic. The difference in importance of foreign trucks and foreign passenger cars is indicated in Table 14, which presents data for three stations on route 1, south of Portland.

The comparative use of the Maine highway system by Maine and foreign vehicles is further evidenced by the average mileage of Maine and foreign passenger cars. Maine passenger cars average 36 miles per vehicle per trip on the primary system and 26 miles per vehicle per trip on the secondary system. Foreign passenger cars average 97 miles per vehicle per trip on the primary system and 73 miles per vehicle per trip on the secondary system.

TABLE 11.—*Utilization of Maine highway systems by all Maine and foreign motor vehicles*

System	Registration	Percentage of State and foreign vehicles	Average density of traffic, State and foreign vehicles	Daily vehicle-miles by State and foreign vehicles	Total vehicle-miles by State and foreign vehicles, July 1 to Oct. 31, 1924
		Per cent	*Vehicles par day*	*Vehicle-miles*	*Vehicle-miles*
Primary	Maine	78.6	821	1,338,000	164,546,000
Do	Foreign	21.4	223	364,000	44,800,000
Total		100.0	1,044	1,702,000	209,346,000
Secondary	Maine	91.0	222	897,000	110,363,000
Do	Foreign	9.0	22	89,000	10,915,000
Total		100.0	244	986,000	121,278,000
Third class	Maine	94.3	27	471,000	57,879,000
Do	Foreign	5.7	2	28,000	3,498,000
Total		100.0	29	499,000	61,377,000

TABLE 12.—*Utilization of Maine highway systems by Maine and foreign passenger cars*

System	Registration	Percentage of State and foreign vehicles	Average density of traffic, State and foreign vehicles	Daily vehicle-miles by State and foreign vehicles	Total vehicle-miles by State and foreign vehicles, July 1 to Oct. 31, 1924
		Per cent	*Vehicles per day*	*Vehicle-miles*	*Vehicle-miles*
Primary	Maine	76.7	729	1,187,000	146,040,000
Do	Foreign	23.3	221	361,000	44,364,000
Total		100.0	950	1,548,000	190,404,000
Secondary	Maine	90.1	199	805,000	98,965,000
Do	Foreign	9.9	22	88,000	10,874,000
Total		100.0	221	893,000	109,839,000
Third class	Maine	93.5	25	433,000	53,247,000
Do	Foreign	6.5	2	30,000	3,702,000
Total		100.0	27	463,000	56,949,000

TABLE 13.—*Utilization of Maine highway systems by Maine and foreign motor trucks*

System	Registration	Percentage of State and foreign vehicles	Average density of traffic, State and foreign vehicles	Daily vehicle-miles by State and foreign vehicles	Total vehicle-miles by State and foreign vehicles, July 1 to Oct. 31, 1924
		Per cent	*Vehicles per day*	*Vehicle-miles*	*Vehicle-miles*
Primary	Maine	97.9	92	150,800	18,544,000
Do	Foreign	2.1	2	3,200	398,000
Total		100.0	94	154,000	18,942,000
Secondary	Maine	98.4	22.6	91,500	11,256,000
Do	Foreign	1.6	.4	1,500	183,000
Total		100.0	23.0	93,000	11,439,000
Third class	Maine	100.0	2	36,000	4,428,000
Do	Foreign				
Total		100.0	2	36,000	4,428,000

TABLE 14.—*Foreign passenger cars and trucks on route 1, south of Portland*

Station	Foreign passenger cars		Foreign trucks		Location
	Percentage	Average daily number	Percentage	Average daily number	
407	68.2	2,540	12.8	17.3	Near State line at Kittery.
1B	43.5	1,197	5.5	17.9	Near Wells, half way from State line to Portland.
406	34.5	1,854	2.7	11.5	Near Portland.

GASOLINE-TAX REVENUES

All motor vehicles using the Maine highways contribute toward the upkeep of these highways through the payment of a gasoline tax of 1 cent per gallon on all gasoline purchased in the State.

The total receipts from the gasoline tax during the period July 1 to October 31, 1924, were approximately $286,400. Assuming uniform consumption of gasoline per vehicle-mile and basing the calculation on the percentage of vehicle mileage as observed, the amount of revenue derived through the gasoline tax from each system would be $152,900 from the primary system, $88,500 from the secondary system, and $45,500 from the third-class system.

The total receipts from the gasoline tax for the calendar year 1924 were approximately $522,000. Assuming that the percentage of vehicle-miles on the three highway systems remains throughout the year the same as during the period of the survey (July 1 to October 31), the annual gasoline-tax revenues derived from each system are shown in Table 15, which also shows the revenue per mile on each of the three systems, as well as the revenue that could be collected from the same traffic at tax rates of 2 and 3 cents per gallon.

TABLE 15.—*Annual gasoline-tax revenues by highway systems, based on 1924 revenues and traffic from July 1 to October 31, 1924*

Highway system	Mileage	Tax of 1 cent per gallon		Tax of 2 cents per gallon		Tax of 3 cents per gallon	
		Total revenue	Revenue per mile	Total revenue	Revenue per mile	Total revenue	Revenue per mile
All highways	23,104	$522,000	$22.59	$1,044,000	$45.19	$1,566,000	$67.78
Primary	1,630	279,000	171.17	558,000	342.33	837,000	513.50
Secondary	4,049	161,000	39.76	322,000	79.53	483,000	119.29
Third class	17,425	82,000	4.71	164,000	9.41	246,000	14.12

The forecast of traffic for 1930 indicates that traffic will double during the period 1924 to 1930. Assuming that the average annual mileage per vehicle in 1930 remains the same as in 1924 and that no radical changes occur in the rate of gasoline consumption per vehicle-mile during this period, a gasoline tax of 1 cent per gallon in 1930 will produce $1,044,000, a tax of 2 cents per gallon $2,088,000, and a tax of 3 cents per gallon $3,132,000.

Foreign vehicles using Maine highways also contribute toward the upkeep of Maine highways by payment of the gasoline tax. In Table 11 the percentage of utilization by foreign vehicles is shown to be 21.4 per cent on the primary system, 9 per cent on the secondary system, and 5.7 per cent on the third-class system.

Assuming that the foreign traffic during the month of June is equal to the foreign traffic during the average month of the period July 1 to October 31 and that during the remainder of the year it is insignificant, the gasoline tax receipts from foreign vehicles during 1924 were approximately: Primary system, $40,900; secondary system, $10,000; third-class system, $3,200.

The amount of the receipts which on the same basis would be derived in a year from foreign vehicles on the three highway systems at tax rates of 1, 2, and 3 cents per gallon of gasoline are shown in Table 16.

TABLE 16.—*Annual gasoline-tax receipts from foreign vehicles by highway systems, based on 1924 traffic*

Highway system	Tax of 1 cent per gallon		Tax of 2 cents per gallon		Tax of 3 cents per gallon	
	Total revenue	Revenue per mile	Total revenue	Revenue per mile	Total revenue	Revenue per mile
Primary	$40,900	$25.09	$81,800	$50.18	$122,700	$75.28
Secondary	10,000	2.47	20,000	4.94	30,000	7.41
Third class	3,200	.18	6,400	.37	9,600	.55

IMPROVEMENT OF PRINCIPAL ROADS FULLY JUSTIFIED BY TRAFFIC SAVINGS

Whether or not the State is economically justified in improving its roads and the degree of improvement warranted—these questions depend to a considerable extent upon the amount of the savings in the operating costs of vehicles made possible by the improvement. Assuming that the operating cost is reduced 2.7 cents per passenger-car-mile by constructing a concrete road where formerly there has been an earth road,[5] and applying this difference in operating costs to the average daily traffic on the heavy-traffic routes of the Maine primary system, the change in the type of construction is shown to be fully justified.

For example, the average density of passenger-car traffic on section 1 of the primary system, involving 300 miles of the most heavily traveled roads in the State, was 2,042 cars. The total number of passenger-car-miles per mile during the period from July 1 to October 31 was, then, approximately 251,000. As gasoline-tax receipts during this period were approximately 55 per cent of the total receipts for the year, it is reasonable to assume that the traffic during this period was approximately 55 per cent of the annual traffic. On this basis, the total passenger-car mileage per mile of the heavy-traffic routes of the primary system for the year 1924 would be approximately 456,000 passenger-car-miles; and the saving of 2.7 cents per passenger-car-mile effected by changing the type of the road from earth to concrete would be approximately $12,300 per mile. As the average cost of Federal-aid concrete roads completed in Maine up to July 30, 1924, was $45,200 per mile, it will be seen that the entire cost of building the concrete road could be retired by the saving in operating costs of $12,300 per mile in a few years. With interest at 4 per cent the time required would be slightly over four years.

[5] The difference in operating cost of 2.7 cents per passenger-car-mile is based on the researches conducted by the Iowa engineering experiment station under the direction of T. R. Agg, results of which are published in Bulletin 69, Iowa State College of Agriculture and Mechanic Arts, by T. R. Agg and H. S. Carter. The costs are tentative and are applicable directly only to the surfaces and the vehicles used in the tests. They may not express the true relation of operating costs on concrete and earth roads in Maine, but they are the most reliable estimates available and seem reasonable.

It is believed that the 2.7 cents saving assumed above is a conservative estimate of the difference in operating costs on concrete and earth roads in Maine. But it will be noted that in the example cited the considerable operating savings of motor trucks, of which there were 155 a day on the heavy-traffic routes of the primary system, have been purposely ignored, as also have been savings resulting from the reduction in the cost of road maintenance. Indeed, it is highly probable that it would be impossible to maintain an earth road in satisfactory condition under the daily traffic on these

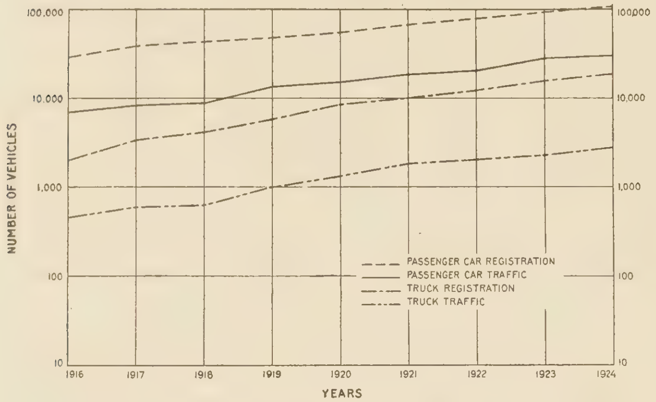


FIG. 5.—Maine highway traffic and motor vehicle registration, when plotted to a logarithmic scale, shows by the approximately equal slopes of the curves that the rates of increase of traffic and registration are nearly equal

roads which is in excess of 2,000 vehicles a day. Experience of the Maine Highway Commission with regard to maintenance costs on the more heavily traveled highways of the State indicates "that traffic is being carried on the bituminous macadam roads at a cost one-sixth as much per vehicle-mile as is the cost of carrying traffic on the gravel-surfaced highways." [6]

Maintenance costs per vehicle-mile on a concrete highway probably would not be higher than on a bituminous macadam highway. Combining this saving in maintenance costs with the saving in vehicle operating costs, the economy of the higher-type surfaces on the more heavily traveled highways of the State becomes even more apparent.

FORECASTING OF TRAFFIC MADE POSSIBLE BY SURVEY

One of the most valuable results of a highway transportation survey is the development of fundamental traffic information as a basis for estimating, with reasonable accuracy, future highway traffic. A highway traffic forecast makes possible, for the period of the forecast at least, the development of a comprehensive highway program including the designation of routes to be improved, the order of their improvement, and the types of improvement required. The selection of the improvement type should be based not only upon a forecast of vehicle density but also upon the weight of traffic units obtained by a motor-truck capacity and gross weight analysis. The forecast stabilizes the highway program. Uncertainty as to the growth of traffic is largely eliminated and the highway department is able to project a definite plan of improvement over a period of years based on the growth of traffic. By establishing a definite plan of improvement highway development is carried on in a more efficient and economical manner, and addition economy is effected by the elimination of excessive maintenance costs on unsatisfactory types of highway surfaces.

[6] Eleventh Annual Report of the Maine State Highway Commission, p. 17.

It is possible by means of a forecast of traffic and registration to establish the highway budget for a reasonable period of years. Revenues to be derived from motor-vehicle license fees, gasoline taxation, and other sources of revenue can be predicted with reasonable accuracy. If such revenues, together with other available highway funds, are not sufficient to carry out the necessary program, the amount of bond issues (if the use of credit is justified in carrying out the program of improvement) can be determined. By estimating some time in advance the amount of bonds to be marketed in any one year (when the bond-issue method of raising revenue is necessary) it is possible to take advantage of the most economical market for the sale of these bonds.

GROWTH OF MAINE TRAFFIC, 1916 TO 1924

Fortunately, traffic figures are available in Maine for one week each year from 1916 to 1923, inclusive. During these years vehicles were counted from 7 a. m. to 7 p. m. for an entire week, either in the latter part of August or the beginning of September. Although the total number of stations in 1923 was 58, only 26 of these stations can be used for the whole period (1916–1923), and even in the case of these 26 stations it is necessary to interpolate some figures for the years 1916 and 1917. Beginning with 1918, however, traffic records are available for all of the 26 stations. The stations are widely distributed over the highway system, and the traffic density recorded each year is representative of the change in traffic on Maine highways from 1916 to 1923.

The average daily number of trucks and passenger cars has been computed from the week's record at each of the 26 stations, and these daily station averages have been combined to yield average figures repre-

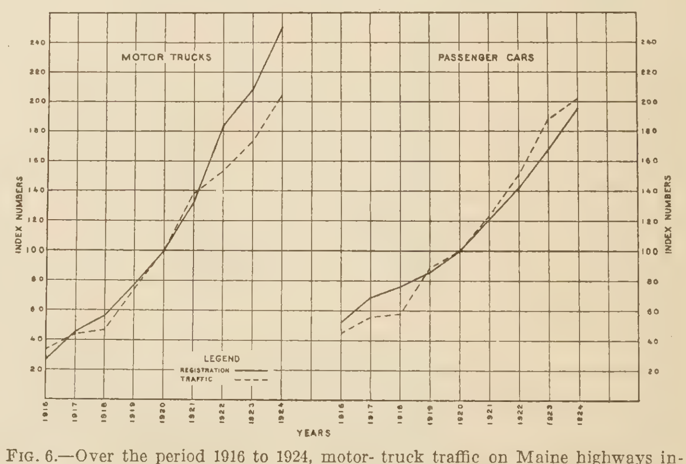


FIG. 6.—Over the period 1916 to 1924, motor- truck traffic on Maine highways increased at a slower rate than motor-truck registration; passenger-car traffic during the same period increased at a faster rate than passenger-car registration

sentative of the traffic at the 26 stations in Table 17. These figures give a reliable indication of the growth of traffic over a period of years on the principal Maine highways.

Comparing with these figures the data shown in Table 18 representative of the registration of trucks and passenger cars in the State during the same period and plotting the data from the two tables to a logarithmic scale reveals the fact that the rates of increase of

TABLE 17.—*Average daily traffic at 26 stations in Maine, 1916 to 1924*

Year	Trucks	Passenger cars	Total
1916	461	6,855	7,316
1917	584	8,392	8,976
1918	632	8,714	9,346
1919	989	13,479	14,468
1920	1,339	15,082	16,421
1921	1,848	18,484	20,232
1922	2,052	22,844	24,896
1923	2,317	28,252	30,569
1924 [1]	2,734	30,258	32,992

[1] Figures for 1924 estimated on the basis of those stations in the 1924 traffic census which were comparable with the above 26 stations.

traffic and registration are nearly equal, as shown by the approximately equal slopes of the registration and traffic curves in Figure 5. The same fact is brought out by Figures 6 and 7, in which the registration and traffic over the period are compared on the basis of index numbers derived by comparing the tabulated registration and traffic figures for each year, in one case, with the figures for 1920, and, in the other, with the average figures for the period, as a base. These charts should not be interpreted as meaning that the traffic and registration are equal throughout the series of years. They mean merely that the rates of increase of the two differ only slightly and that traffic and registration are in nearly constant ratio from year to year.

Since this is so, a forecast of registration will also predict future traffic, provided there is no important change in the average annual use per vehicle. As any change of this kind must, from the nature of the case, be gradual; such a change will not greatly affect the relation between traffic and registration during the next few years.

TABLE 18.—*Registration of motor vehicles in Maine, 1916 to 1924*

Year	Trucks	Passenger cars	Total
1916	1,991	28,991	30,972
1917	3,382	38,117	41,499
1918	4,200	42,372	46,572
1919	5,795	47,630	53,425
1920	7,512	55,395	62,907
1921	9,936	67,591	77,527
1922	13,842	78,697	92,539
1923	15,614	92,995	108,609
1924	18,779	107,933	126,712

Table 19 presents the data shown in Tables 17 and 18, as indices of the average year. The graphic presentation of these indices in Figure 7 shows clearly the close agreement in the rates of increase of traffic and registration.

TABLE 19.—*Relative growth of highway traffic and motor-vehicle registration (average of years 1916 to 1923=100)*

Year	Traffic	Registration
1916	44.2	48.3
1917	54.3	64.8
1918	56.5	69.6
1919	87.5	83.5
1920	99.3	98.3
1921	122.9	121.1
1922	150.5	144.6
1923	184.8	169.7
1924	199.5	198.0

FORECAST OF REGISTRATION AND TRAFFIC, 1924 TO 1930

This relation between the rates of increase of traffic and registration may be employed to predict traffic a reasonable number of years in advance by projection of the increase in vehicle registration. Future registration depends upon future population and car ownership per unit of population, and both of these factors can be projected on the basis of their trends over past years.

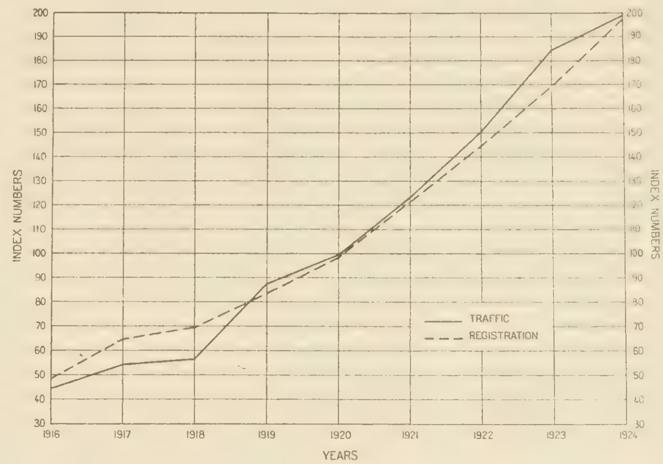


FIG. 7.—The parallel increase in the index numbers of traffic and registration indicates that, considering all vehicles, the rates of increase of traffic and registration in Maine from 1916 to 1924 were nearly equal

The registration of passenger cars and trucks per unit of population in Maine from 1916 to 1924, inclusive, is plotted as a solid line in Figures 8 and 9, respectively, and trend curves projected to 1930 from these actual figures by the method of least squares are shown by the dotted lines. The results of these projections and a comparison of the computed trend with the actual figures for the period 1916 to 1924 are shown in Table 20.

TABLE 20.—*Persons per motor vehicle, 1916 to 1930*

Year	Persons per passenger car		Persons per truck	
	Actual	Estimated	Actual	Estimated
1916	26.2	24.4	381	317
1917	20.2	21.7	225	257
1918	18.0	18.2	182	187
1919	16.1	15.4	132	137
1920	13.9	13.1	102	102
1921	11.4	11.3	77.7	78.1
1922	9.84	9.81	56.0	60.8
1923	8.36	8.62	49.8	48.1
1924	7.22	7.64	41.5	38.6
1925		6.82		31.4
1926		6.12		25.8
1927		5.53		21.4
1928		5.02		17.97
1929		4.57		15.18
1930		4.19		12.92

Applying the factors of estimated persons per passenger car and per truck (Table 20) to the expected population, the estimated registration is obtained as shown in Table 21.

The experienced and expected rates of increase in registration are shown in Table 22. The percentage increase for each of the years 1917 to 1924, inclusive, is computed from actual registrations shown in Table 18, and the percentage increase for each of the years 1925 to 1930, inclusive, is computed from predicted registration as shown in Table 21.

TABLE 21.—*Estimated motor-vehicle registration, 1925 to 1930*

Year	Population	Passenger-car registration		Motor-truck registration		Total registration	
		Number	Increase over 1924	Number	Increase over 1924	Number	Increase over 1924
			Per cent		*Per cent*		*Per cent*
1924	779, 902	[1] 107, 933	0. 0	[1] 18, 779	0. 0	[1] 126, 712	0. 0
1925	782, 544	114, 740	6. 3	24, 920	32. 6	139, 660	10. 1
1926	785, 186	128, 300	19. 0	30, 430	62. 2	158, 730	25. 2
1927	787, 828	142, 460	32. 0	36, 810	96. 0	179, 270	41. 5
1928	790, 470	157, 460	46. 0	43, 990	134. 2	201, 450	59. 0
1929	793, 112	173, 550	61. 0	52, 250	178. 1	225, 800	78. 0
1930	795, 754	189, 920	76. 0	61, 590	228. 0	251, 510	98. 5

[1] Actual 1924 registration.

From Table 21 it is apparent that motor-truck registration may be expected to increase at a faster rate than passenger-car registration. Figure 6 shows that motor truck traffic increases at a slower rate than truck registration and passenger-car traffic in-

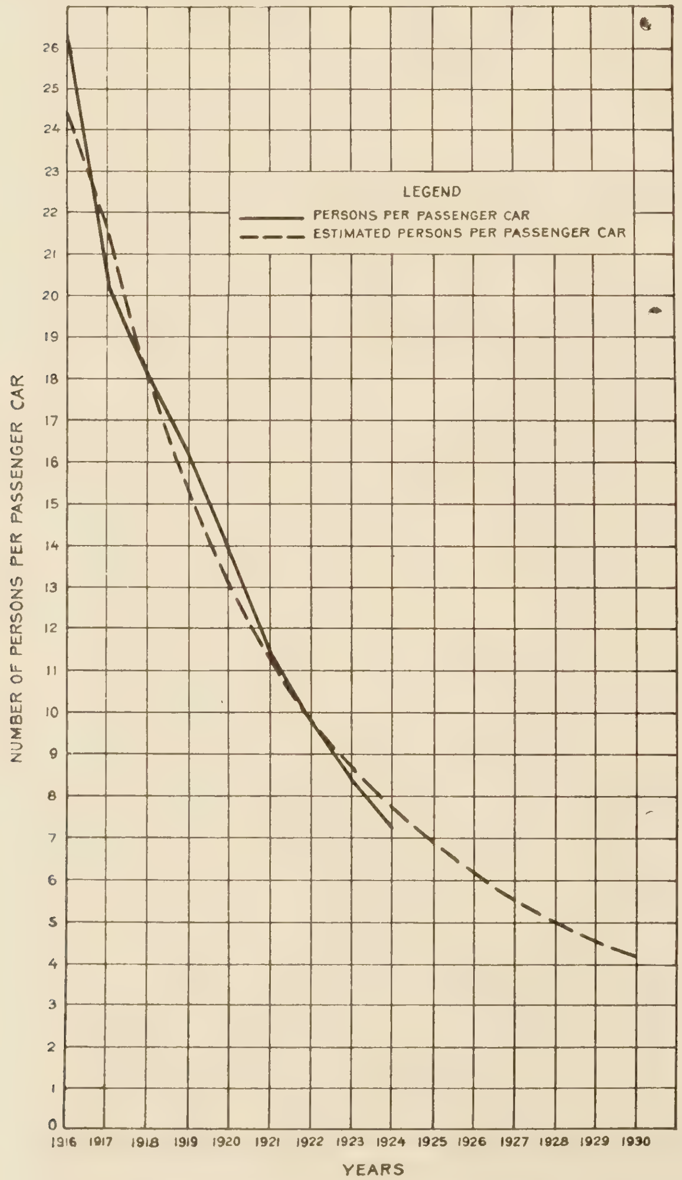


FIG. 8.—Persons per passenger car, 1916 to 1930

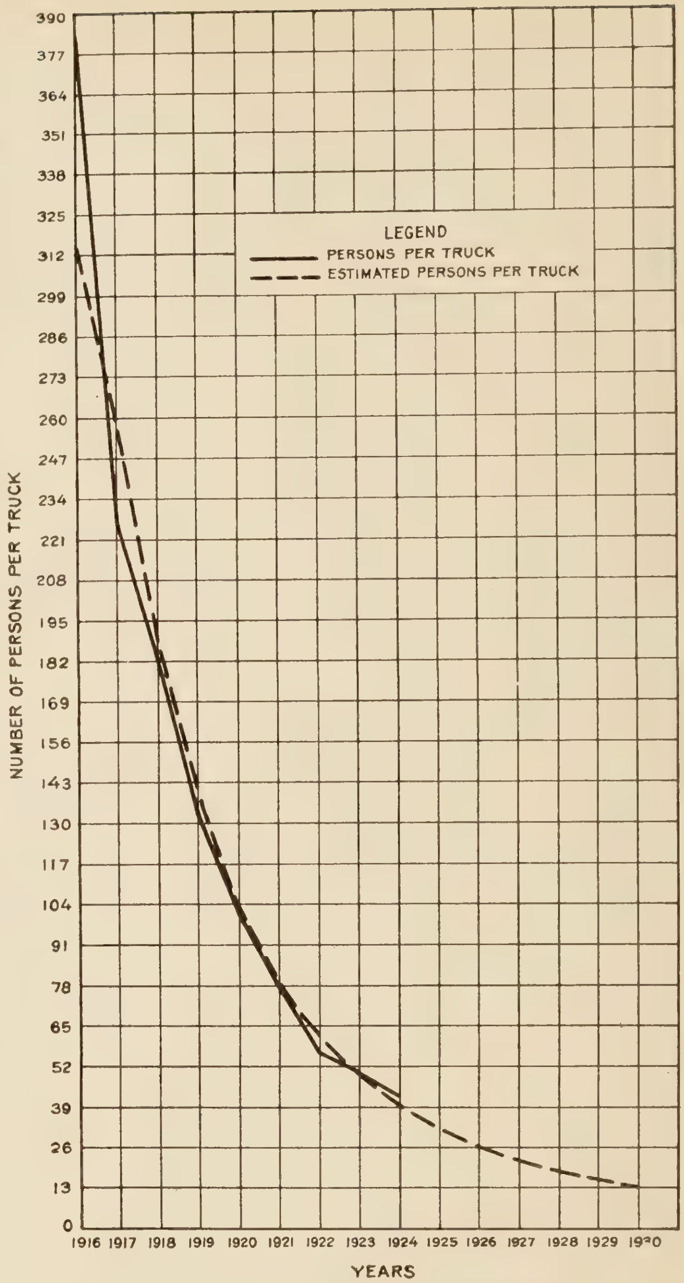


FIG. 9.—Persons per motor truck, 1916 to 1930

TABLE 22.—*Annual increase in total motor-vehicle registration, 1917 to 1930*

Year	Increase over preceding year	Year	Increase over preceding year
	Per cent		*Per cent*
1917	34. 0	1926	13. 7
1918	12. 2	1927	12. 9
1919	14. 7	1928	12. 4
1920	17. 7	1929	12. 1
1921	23. 2	1930	11. 4
1922	19. 4	Average annual increase 1917–1924	19. 4
1923	17. 4		
1924	16. 7	Average annual increase 1925–1930	12. 1
1925	10. 2		

creases a little more rapidly than passenger-car registration; but for total vehicles the rates of increase of traffic and registration have been nearly equal. The expected increase in total registration from 1924 to 1930 is 98.5 per cent, and, as shown by Figure 7, this rate of increase may be expected for the total traffic. Truck traffic will probably increase faster than passenger-car traffic but not in the ratio of the increase in registration as given in Table 21, because truck traffic on the Maine highway system has not increased as rapidly as truck registration in the State.

The expected increase in traffic of 98.5 per cent from 1924 to 1930 is applied to the 1924 traffic at all traffic stations of the 1924 survey. It is not expected that traffic at every station will increase at exactly this rate. Road improvements will modify the rate at certain stations. The opening of new routes or the development of new industries will affect the rate of increase; a new shore resort or a new route to an old resort would have considerable effect. Despite these known facts, however, a study of the traffic counts from 1916 to 1923 clearly indicates that the rate of increase at a majority of the stations varied but little from the rate of increase at all stations combined.

The expected traffic in 1930 at stations used in the 1924 traffic survey is given in Table 23. The figures are for trucks and passenger cars combined. It is anticipated that truck registration will increase at a faster rate than passenger-car registration, and the ratio of trucks to total vehicles on the road in 1930 will probably be a little greater than in 1924.

TABLE 23.—*Anticipated total traffic density in 1930 at all stations of the 1924 survey*

Station	Total anticipated traffic density, 1930	Station	Total anticipated traffic density, 1930	Station	Total anticipated traffic density, 1930
1A [1]	867	63	538	125	1,099
1B [2]	6,105	64	756	126A [1]	363
2	1,981	65	488	126B [2]	2,014
3	1,596	66	806	127	1,177
4	3,644	67	421	128	286
5	1,856	68	1,437	129	504
6	2,036	69	1,038	130	1,145
7	1,094	70	1,177	131	472
8	355	71	1,352	132	1,552
9	764	72	752	133	1,796
10	2,096	73	1,457	134	1,097
11	1,314	74	2,584	135	617
12	1,334	75	500	401	1,604
13	2,850	91	1,528	402	1,840
14	3,552	92	3,505	403	3,384
15	4,271	93	2,509	404	5,815
31	4,283	94	5,233	405	3,356
32	2,249	95	965	406	11,509
33	3,908	96	891	407	7,661
34	554	97	1,230	408	2,963
35	617	98	522	409	6,242
36	1,070	99	544	410	3,247
37	2,552	100	1,752	421	2,177
38	2,258	101	1,733	422	1,248
39	2,201	102	1,369	423	1,733
40	1,449	103	1,226	424	3,918
41	794	104	2,060	425	689
42	935	105	830	426	2,197
43	695	121	506	427	2,757
44	3,310	122	917	428	1,572
45	1,802	123	718	429	3,283
61	1,000	124	296	430	4,009
62	1,473				

[1] Before change in location; change occurred as follows: Station 1, Sept. 28, 1924; station 126, Aug. 28, 1924.
[2] After change in location.

TRAFFIC EXPECTED TO DOUBLE BETWEEN 1924 AND 1930

Summarizing the facts brought out in the foregoing discussion, it is found that Maine registration doubled in the four years from 1916 to 1920. It doubled again in the four years from 1920 to 1924, and the forecast anticipates that it will double again during the six years from 1924 to 1930, as shown in the following tabulation:

Maine motor-vehicle registration

Year	Total registration
1916	30,972
1920	62,907
1924	126,712
1930	[1] 251,510

[1] Estimated.

In almost exact coincidence Maine highway traffic doubled in the three years from 1916 to 1919; it doubled again during the four years from 1919 to 1923 (this is the more significant period, since the traffic figures for 1916 and 1917 are less reliable); and the forecast anticipates that it will double again during the six years from 1924 to 1930, as shown in the following tabulation:

Total daily traffic at 26 stations

Year.	Total daily traffic
1916	7,316
1919	14,468
1923	30,569
1930	[1] 60,527

[1] Estimated.

The Eleventh Annual Report of the Maine State Highway Commission gives a tabulation of the results of past traffic surveys, which differs somewhat in respect to the rate of increase from the figures presented above. The commission's figures are given in the first three columns of Table 24, in the fourth column of which are given, for comparative purposes, the indices of total traffic at the 26 stations included in the analysis reported herein. It will be noted that the number of stations averaged in the commission's analysis differed from year to year, while the analyses made in this report are based on the same 26 stations each year from 1916 to 1923, inclusive.

TABLE 24.—*Comparison of indices of traffic taken from report of Maine Highway Commission and this report*

Year	Number of stations	Average number of vehicles per day	Index (1920=100) [1]	Index of total traffic at 26 stations (1920=100) [2]
1916				45
1917	18	428	83	55
1918	19	483	94	57
1919	38	504	98	88
1920	41	515	100	100
1921	43	715	139	123
1922	46	767	149	152
1923	49	961	187	186

[1] Eleventh Annual Report, Maine State Highway Commission.
[2] Based on 26 stations, 1916–1923.

The commission's report states: "It is seen from the above figures that traffic in 1923 was two and one-fourth times as heavy on an average as in 1917. It should be borne in mind that new stations added from year to year were not located on the heaviest traveled highways. Several of these stations were off the State highway system, the object of the commission being to secure traffic data which might indicate the location of roads which eventually should be added to the State highway system."

Despite the difference in number of stations there is a close agreement between the indices of total traffic at the 26 stations and the indices at from 41 to 49 stations from 1920 to 1923. The number of stations from 1920 to 1923 is more nearly constant in the commission's report. But the indices of traffic based on data from a number of stations varying from 18 in

FIG. 10.—Anticipated density of traffic on primary and secondary highway systems of Maine, July to November, 1930

1917 to 49 in 1923 are misleading for prediction purposes. The adding or dropping of stations from year to year makes the average number of vehicles per day (per station) incomparable in the given years. The Maine report recognizes this defect in the note quoted above.

The traffic forecast herein set forth is tentative. In all fairness it must be recalled that the Maine traffic records for the period 1916 to 1923 are for only one week per year, although that week is in the same part of each year. A second consideration, which is not so important in its effect upon the conclusions, is that data for 1916 and 1917 are missing at some of the stations, and therefore it has been necessary to interpolate some values for these years.

The location of the 26 stations used to measure the increase of traffic in Maine, 1916–1923, is a basis for confidence in the application of the increases there recorded to the 1924 traffic data, since the 26 stations are widely distributed throughout the State on the routes covered by the 1924 survey. Neglecting such factors as the effect of major mechanical improvements to automobiles, it is believed that the traffic estimates here given will closely represent traffic on Maine highways in 1930.

A definite betterment of the method of planning future highway improvements is represented by Figure 10, which shows a forecast of the average daily traffic on the principal primary and secondary routes during the period July to November, 1930. The problem of developing such a forecast in Maine was simplified by the fact that the Maine Highway Commission kept a record of traffic each year at a selected number of key stations from 1916 to 1924. As a number of State highway departments have had the foresight to preserve similar traffic records on their primary systems over a period of years, it should be possible to make similar forecasts of future traffic in these other States.

SUGGESTED PROGRAM OF HIGHWAY IMPROVEMENT

The forecast of expected registration and traffic is of particular importance at the present stage of highway development in Maine. The State has reached the second critical stage in its highway improvement program. The first stage may be called the gravel-road stage. During this first period traffic demanded highway service over a large mileage, and the highway commission wisely inaugurated the policy of stage construction based on the theory of providing highway service over a large mileage rather than a concentration of expenditures on a limited mileage. The gravel road met this demand. Traffic, however, was relatively light and, with the exception of a comparatively small mileage of heavy-traffic routes, gravel furnished a satisfactory and economical surface. The proper policy was to improve a large mileage of roads to the gravel stage and confine improvements of a higher type to a comparatively small mileage of heavy-traffic routes. The Maine Highway Commission has followed this policy in an excellent manner.

The second stage of a highway improvement program may properly be called the reconstruction and high-type improvement stage. When a State reaches this stage it is essential to set up a definite improvement policy for a period of years. Maine experience indicates that a gravel road will not carry over 500 vehicles per 12-hour day successfully unless it is surface treated.[7] The average daily density of traffic on the entire primary system for the period July 1 to October 31, 1924, was over 1,000 vehicles.

Clearly, Maine is now entering the reconstruction and high-type improvement stage. The questionable economy of attempting to maintain a gravel surface on heavy-traffic routes is demonstrated by the maintenance costs on sections of heavy-traffic gravel roads in the State.[8]

The 1923 maintenance costs per mile per vehicle on the Waterville–Bangor highway are more than double such costs during 1919 and 1920. Traffic has practically doubled during the same period. Similar maintenance costs per mile per vehicle for 1923 on the Woolwich–Bangor highway are double the costs for the years 1918 and 1919. Tables in the same report[9] indicate

(Continued on page 67)

[7] Eleventh Annual Report, Maine State Highway Commission, p. 17
[8] Ibid., p. 15.
[9] Ibid., pp. 16–17

THE WAGON AND THE ELEVATING GRADER

AN ECONOMIC STUDY OF THE WAGON—ELEVATING GRADER COMBINATION IN THREE PARTS

BY THE DIVISION OF CONTROL U. S. BUREAU OF PUBLIC ROADS

Reported by J. L. Harrison, Highway Engineer

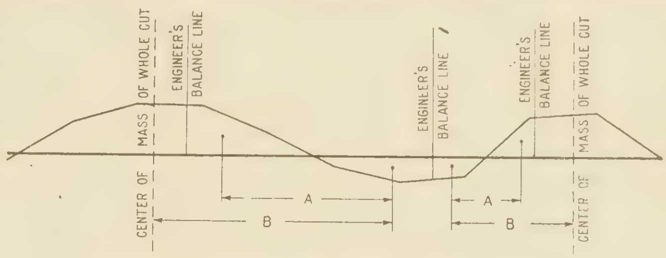
PART II.—THE INFLUENCE OF DESIGN ON ELEVATING GRADER COSTS

THE factors influencing the production of elevating grader-wagon outfits and the conditions which must obtain if a high rate of production is to be secured were discussed in Part I of this article. The proper adjustment of the size of the wagon train to the special conditions of the project in order, (1) that the number of wagons shall be sufficient to move the output of the grader as rapidly as it is produced, and (2) that their number shall not exceed the supply that can be utilized without periods of idleness by the grader, was shown to be dependent not only upon the output of the grader but also upon the distance the excavation must be moved and the rate of wagon travel. The length of haul is an especially important factor in elevating grader work, and it is peculiarly affected by the design of the road.

In all grading operations rational bidding must take account of the haul as a controlling factor. This is a comparatively simple matter when the material is moved with the simpler forms of equipment, such as the wheeler and the fresno. When these implements are used cuts can generally be taken out substantially as indicated by the balance points shown on ordinary highway plans, and the actual haul will therefore be found to be closely in agreement with the calculated haul, so that a knowledge of the average calculated haul generally suffices as a general basis for estimating.

But such data are inadequate for careful bidding on elevating grader work. In the first place the transfer of the loading function to an independent apparatus introduces an expensive operation which, whether the haul be long or short, accounts for a largerpart of the total cost than the corresponding operation on wheeler and fresno jobs. In the second place the movement of the material in the large volumes made possible by the wagons reduces the cost of movement, so that it becomes proportionately less important than on wheeler and fresno jobs. By reason of both of these differences the length of haul on elevating grader jobs is less important in its bearing on costs than on the wheeler or the fresno job, and the average haul is relatively less significant.

But, though the length of haul is less significant than with other methods of operation, the fluctuation in haul distance, which is an inseparable feature of the work, does have a most important bearing on the cost because of its effect on the relation of the moving to the loading element, i. e., the wagons supply to the grader. It is customary for the contractor to supply a fixed number of wagons with the elevating grader. The supply furnished may be in proper relation to the grader output for the aver-



A - AVERAGE HAUL AS CUSTOMARILY SHOWN BY DESIGN; APPROPRIATE FOR FRESNO WORK.
B - ACTUAL AVERAGE HAUL WITH ELEVATING GRADER.

FIG. 1.—Diagram illustrating difference in average haul on fresno and elevating-grader jobs

age haul; but from cut to cut, and even in the same cut, the haul will often vary between limits which, if the haul is short, leave the teams idle much of the time, and if the haul is long, leave the grader idle much of the time. For this reason the average haul is not a proper basis for estimating where elevating graders are to be used.

PECULIARITIES OF HAUL ON ELEVATING GRADER JOBS

Moreover, the average haul on elevating grader work differs from the average haul as calculated for fresno or wheel-scraper work. With the latter form of equipment the length of haul grows as the cut and fill are extended, and the actual haul generally agrees closely with the haul distance as shown on the plans. But the elevating grader does not open cuts as they are opened by wheelers or fresnoes. It opens the whole cut at one time, moving back and forth over such a distance as the general contour of the cut indicates to be desirable but always as long as possible up to the full length of the cut. This generates an extension of the haul distance, and the actual haul becomes the distance from the center of mass of the cut as a whole to the center of mass of the fills to

THE generally accepted idea of the usefulness of design is that of an instrument for letting contracts and a guide to be followed in construction. That with a given limiting gradient and rate of curvature, and without change in the quantity of earth moved, the cost of grading with an elevating grader outfit may be varied by as much as 20 per cent, and yet the road produced in each case will be practically the same is a fact quite generally lost sight of.

Again, variation in design may bankrupt a contractor or give him a profit, although, in each case, his contract unit price may be the same and the completed road equally useful and economical in the service of highway transport.

Fluctuations in the length of haul are primarily responsible for high unit costs on elevating-grader projects. Within the well established limits of wagon haul it matters not so much whether the haul be relatively long or relatively short; but when the contractor is put to the necessity of moving a considerable part of the material a long distance and another considerable part a short distance, unit costs for one part or the other are likely to be excessive. The reason is that the adjustment of the size of wagon train to the output of the grader which is appropriate for the long haul can not be appropriate for the short haul, yet practical considerations make difficult the changes in the size of train, which are economically necessary.

In this article the effect of length of haul is treated in detail and illustrations are presented to demonstrate the important bearing of design, involving hauls of various character, on the cost of elevating grader work.

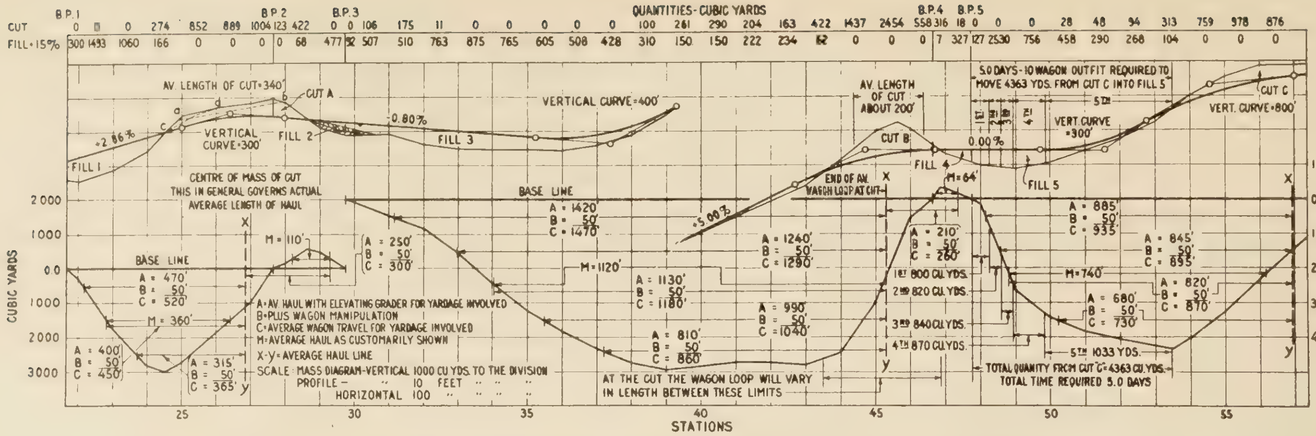


FIG. 2.—Original design of sample grading project, illustrating effect of fluctuating haul distance

which material is delivered. The difference in the two cases is illustrated in the diagram, Figure 1, and in Figure 2 which is the reproduction of the center-line profile of a part of an actual project.

Between balance points 1 and 3 in Figure 2 there is a cut A, which is divided so that part of the material is hauled to each of two fills. The mass diagram which appears below the profile shows that the average haul to fill 1, as commonly calculated, is about 360 feet and to fill 2 about 110 feet.[1] But in taking out material with an elevating grader cuts of this kind will not be divided as they would be for wheeler or fresno work. The grader will work back and forth over the whole length of the cut and the material will be hauled either to fill 1 or to fill 2, with the result that more or less material designated by the engineer as belonging to fill 1 will be placed in fill 2 and vice versa. In a symmetrical cut the result of this practice will be to lengthen the average haul so that it becomes the distance from the center of mass of the cut (line xy as shown on the mass diagram) to the center of mass of the fill. In this way the average haul to fill 1 is raised from 360 to about 400 feet and the average haul to fill 2 from 110 to about 250 feet. A study of the other cuts in Figure 2 shows the same tendency toward an increase in haul distance in all except cut D, all of which is hauled to one fill. Where this occurs no extra haul is generated by the use of the grader.

The result of increasing the haul to the center of mass of the cut as a whole in cut A is more marked in its effect on the haul to fill 2 than to fill 1. This is generally the result where the quantity to be moved in one direction is considerably larger than the quantity to be moved in the other. The haul determined in this way, however, may not be exact. Thus, if cut A had been so nonsymmetrical that the depth of excavation between stations 27 and 29 had considerably exceeded the depth of excavation between stations 25 and 27, the grader might be operated here on a short loop until the material remaining to be taken out was reasonably symmetrical over the whole cut. If this were done the material for fill 2 would be secured with a somewhat shorter haul than the method of calculation described above would indicate.

Similarly, the manner in which even a symmetrical cut is taken out may somewhat affect the length of haul. Thus, if instead of taking a first cut along line ab it is taken along line cd, the haul may be somewhat affected. But in operating elevating graders the general practice is to make the runs as long as possible. and for this reason if the cut is anything like symmetrical the tendency is to make the average haul the distance from the center of mass of the cut to the center of mass of each of the fills or fractional parts of fills into which the cuttings are placed. This should therefore be used as the basis from which to calculate haul. But it should be recognized as an approximate rather than an exact basis, as special conditions of the sort mentioned will often enter to make the actual results somewhat different from the theoretical. Lack of symmetry in the cut is responsible for most of these special considerations. It creates short grader runs, unproductive runs, nonuniform bite, etc., none of which need affect the haul distance as theoretically derived, but all of which do, more or less, because, under field conditions, there generally is less thought given to these matters than is needed to secure accurate results.

[1] There are a number of methods of calculating haul. The one here used, which is the simplest and quite accurate enough for the purpose, assumes that the average haul is the distance between the points halfway from the base to the peak of the mass curve on the cut and fill slopes.

EFFECT OF LAYER DUMPING AND WAGON MANIPULATION ON HAUL

Layer dumping also tends to affect haul. If it is required, as it should be, there is a tendency to increase haul at the fill. Thus, in Figure 2, it may be assumed that instead of placing fill 2 as shown on the plans the material secured from cut A is placed in two layers which extend well beyond balance point 3. In such a case the actual average haul instead of being 250 feet might easily reach 300 feet. There is no way of calculating such extensions in advance. They are rather to be considered as an element likely to create excess haul and therefore one which a contractor should watch and avoid. It is not at all necessary that layer dumping cause any considerable amount of extra haul.

Besides these conditions which affect haul there is another arising from the manipulation of the wagons themselves. The general operation of the wagon train, somewhat distorted for the purpose of illustration, is shown in Figure 3. As the elevating grader is moved toward the dump the empty wagon must return to a point some distance back of the loading wagon in order to reach position. Let it be assumed that wagon 10 is loading along ab and wagon 11 is the replacement wagon. Let it also be assumed that the average distance required for picking up a load is 75 feet. The distance that the load as a whole must be hauled will, of course, be calculated from the center of the distance over which the load is picked up. There is then a necessary addition of 37½ feet to the average distance over which the wagon will be moved which addition covers the distance traveled by the

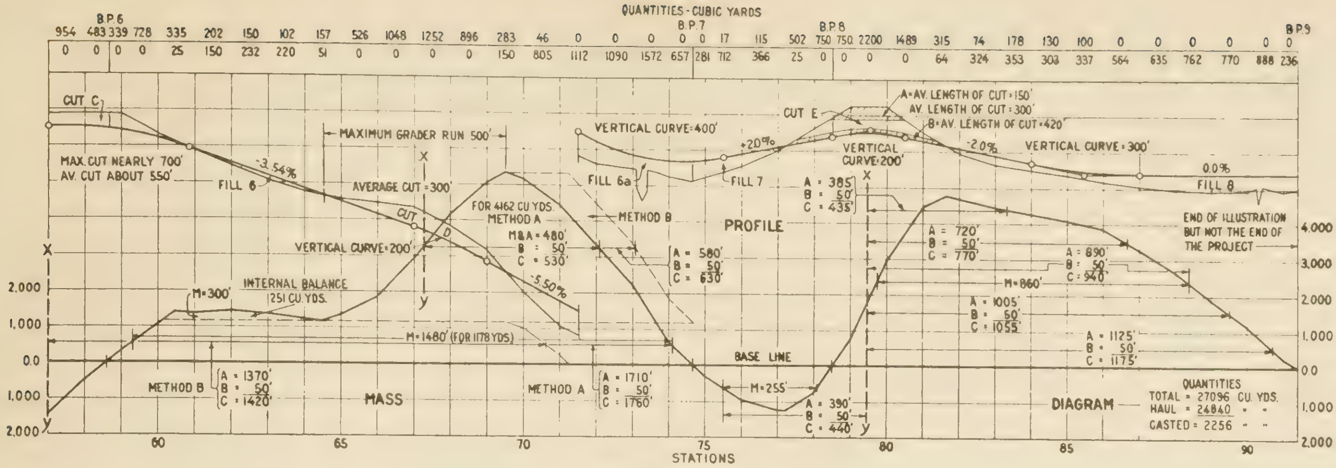


FIG. 2.—(Continued)

wagon before the beginning of the average haul distance for the total load is reached. To this must be added whatever distance was traveled after wagon 11 fell in behind wagon 10 in order to be in a position for prompt replacement Even if the wagon train is in close harmony with the output of the grader, there must still be a short distance allowed for this purpose, say from 10 to 15 feet. If the haul is to fills on both sides of the cut, this extra distance will generally be avoided; but prevailing practice is against taking out cuts in this way, because it doubles the force employed on the dumps. With wagons moving toward the dump, therefore, there is then an excess of wagon travel over the average haul, for the load as a whole, of about 50 feet.

A similar situation prevails when the grader is moving away from the dump. In this case each wagon must move an average of 37½ feet beyond the average haul for the load in order to secure its full load. Moreover, in driving to a clearance for the replacement wagon the loaded wagon must move ahead far enough to permit the replacement wagon to reach the loading position before a turn is made. This will require at least 15 feet and often more. Whether the grader is moving to or from the dump, therefore, the wagons actually travel about 50 feet further than the average haul for the load, the additional travel being necessary in the interest of manipulating the wagons at the grader. Applied to the cut which has been used as an illustration, this results in an average wagon travel of 450 feet to fill 1 and 300 feet to fill 2, with the possibility that when layer dumping is required the haul to fills as short as fill 2 will be somewhat further increased.

WORKING THE WHOLE CUT GENERALLY ADVISABLE DESPITE LONGER HAULS

Ordinarily the contractor will not find it to his interest to avoid the extra wagon travel that arises from the failure to follow the engineer's balance points. With normal efficiency in the operation of the grader and an adequate wagon supply, a cut such as A, which averages about 340 feet in length, permits of working the grader about 50 per cent of the time, but if such a cut were divided into two parts and taken out in accordance with the engineer's balance points the shortened run would permit the grader to work only about 34 per cent of the time in the shorter cut. The resulting loss in output would generally outweigh any advantage that might be obtained from the shortened haul, since it is probable that the wagon time saved by reducing the haul would be wasted in waiting for loads, for it must be remembered that the wagon train generally consists of a fixed number of wagons; therefore, unless the grader output is correspondingly increased, shortening the haul merely tends to cause a piling of the wagons. This is invariably the result when the haul is within the capacity of the wagon train. If the haul is beyond the capacity of the train, the reduction in haul by splitting the cut may overbalance the reduction in grader output, but cases of this sort are comparatively rare, and to take advantage of them the contractor must have at his disposal the accurate data supplied by the mass diagram.

AVERAGE OUTPUT 1,000 CUBIC YARDS A DAY

An analysis of the average wagon travel when combined with an analysis of the average length of each cut, by which the possible output of the grader is indicated, will serve to avoid many of the speculative risks contractors encounter in elevating grader work. To be really effective, however, the analysis should be extended to include a study of the haul cut by cut, and

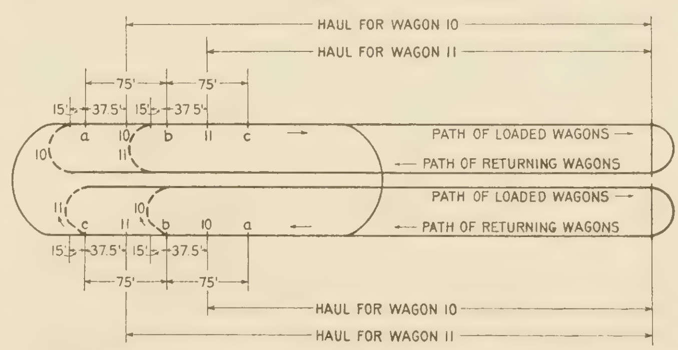


FIG. 3.—Operation of wagon train on each side of grader loop

the results of this analysis developed on the basis of some standard unit of production. For this purpose, in the description of the method which follows, an output of 1,000 cubic yards per day has been used.

The bureau's studies of elevating grader projects indicate that the average length of cut is about 450 feet. The studies also indicate that, when the wagon supply is adequate, ordinarily efficient operation results in an exchange of wagons in about 11 seconds. The time required to load a wagon averages about 23 seconds. With due allowance for breakdowns, clean outs, rests, etc., these conditions permit of securing

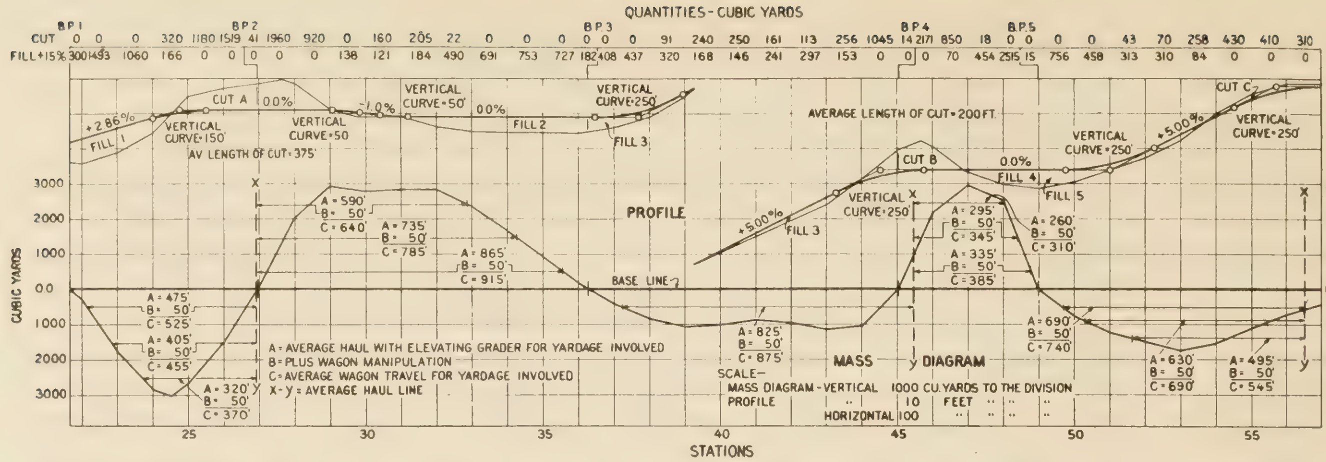


FIG. 4. · First re-design of sample grading project, illustrating the possibility of equalizing haul distances. In this design it is assumed that fills will be built entirely from the cuts. This assumption limits the reduction of haul to about half the distance center to center of cuts

an output somewhat over 100 cubic yards an hour with only average efficiency in operation. Allowing, then, for the losses in working time which, on practically all jobs, result in reducing the working day to something under 10 hours, it is still possible for the average contractor, with no change in managerial policies and no improvement in general efficiency, to secure an output of 1,000 yards a day if his wagon supply is adequate and his cuts are of standard length. This output has therefore been used as a basis from which to work in showing how the length of cut and the length of haul are likely to affect output and why contractors often lose money on work of this character through a failure properly to gauge the effect of those elements.

CORRECT BIDDING IMPOSSIBLE WITHOUT STUDY OF HAUL

It will be seen, in cuts A and B, Figure 2, that a knowledge of the average wagon travel does not cover the situation. Thus cut A can be taken out with an average wagon travel of 450 feet for the material moved to fill 1. The mass diagram shows that there are approximately 3,000 cubic yards of material to be moved into this fill. But of this amount 1,000 cubic yards calls for an average wagon haul of about 520 feet, 1,000 cubic yards an average haul of about 450 feet, and 1,000 cubic yards an average haul of 365 feet. In comparison with this the mass diagram for cut B shows about 5,000 cubic yards of material to be placed in fill 3. Of this material 1,000 cubic yards must be moved 1,470 feet, the second 1,000 cubic yards 1,290 feet, the third 1,000 cubic yards 1,180 feet, the fourth 1,040 feet, and the fifth 1,000 cubic yards 860 feet. What is perhaps the most serious problem the contractor has to meet in this sort of work is brought out clearly by the study of these two cuts. An output of 1,000 cubic yards has been set up as the standard day's work, assuming normal efficiency. But if the eight standard days' work in these two cuts are tabulated it will be apparent that the work can not be performed in eight days with any ordinarily constituted outfit, because the range in haul distance is too great. Such a tabulation, in which the effect of length of cut has been purposely omitted, is shown in Table 1.

Table 1 illustrates clearly the dependence of production on the proper adjustment of the wagon train to the length of haul and the danger of depending on the average wagon travel in analyzing elevating grader projects.

TABLE 1.—*Effect of length of wagon haul on elevating grader production and time required for grading*

(Based on cuts A and B, Figure 2)

Material moved to fill	Amount of material	Wagon haul	Number of wagons required for full output of grader	Using 8-wagon outfit: Team time wasted	Using 8-wagon outfit: Grader time wasted	Probable daily output	Time required to move each 1,000 cubic yards	Equivalent yardage[1]
	Cubic yards	*Feet*		*Per cent*	*Per cent*	*Cubic yards*	*Days*	*Cubic yards*
1	1,000	520	8	0.0	0.0	1,000	1.0	1,000
1	1,000	450	7	12.5	0.0	1,000	1.0	1,000
1	1,000	365	6	25.0	0.0	1,000	1.0	1,000
3	1,000	1,470	16	--------	50.0	500	2.0	2,000
3	1,000	1,290	15	--------	47.0	530	1.9	1,887
3	1,000	1,180	13	--------	38.0	620	1.6	1,613
3	1,000	1,040	12	--------	33.0	670	1.5	1,500
3	1,000	860	10	--------	20.0	800	1.2	1,250

[1] Based on standard daily production of 1,000 cubic yards.

Time required for movement of 8,000 cubic yards, 11.2 days; probable average output per day with 8-wagon outfit, 720 cubic yards.

Cuts A and B are on one project and only a short distance apart. The average wagon travel from cut A to fill 1 is 450 feet, and from cut B to fill 3 it is 1,180 feet. These averages would indicate that trains of 7 and 13 wagons, respectively, would be required for 100 per cent production at the grader as against the range of from 6 to 16 wagons shown by the detailed analysis actually to be required if full production is to be secured. If an 8-wagon outfit were used, 100 per cent grader production could be obtained in cut A, but the longer hauls of cut B would reduce the average daily output for both cuts by 28 per cent. Even if the long wagon train indicated by the average travel to fill 3 were provided, full production at the grader still could not be maintained at all times. The point to be stressed here is that haul varies over such a wide range that no contractor is in a position to make other than a random guess as to what the work on any project will cost without a careful analysis of this element.

THE MASS DIAGRAM AS A MEANS OF CONTROLLING FIELD OPERATIONS

The analysis of elevating grader work through study of the mass diagram can be made an effective means of controlling field operations. Thus, cut E is a symmetrical cut from which approximately 6,000 cubic yards of material are secured. Wagon haul per 1,000

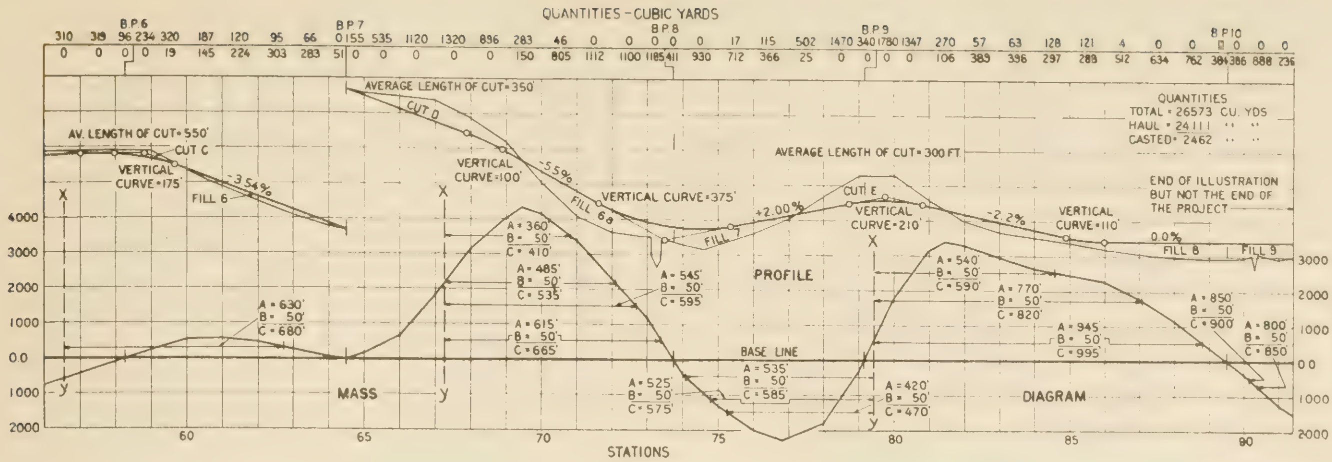


FIG. 4.—(Continued)

cubic-yard unit to fill 8 varies from 435 to 1,175 feet. But this cut offers a grader loop varying in average length from 150 feet for the top three feet to over 420 feet at the bottom. At the top the grader loop will be short and the production low. If the top of this cut is placed at the far end of the fill, the low output at the grader and the long haul tend to offset each other, with the result that only 12 wagons will be required in order to maintain an adequate supply at the grader. If this is done, the bottom of the cut will fall at the near end of the fill, and for placing it here 7 wagons will be required. If this process is reversed, the top of the cut being placed at the near end of the fill, only 6 wagons can be used, while in placing the material from the bottom of the cut at the far end of the fill 16 wagons could be utilized. If the wagon train consists of, say, 10 wagons, 30 per cent of the wagon time would be lost in placing the close-in material, and the grader would be idle about 17 per cent of the time in placing material at the far end of the fill under the first scheme of operation. If the second scheme of operation were adopted, 40 per cent of the wagons would be idle while the material close in was being placed, and the grader would be idle about 37 per cent of the time while material was being placed at the far end of the fill. The advantage of the first arrangement is clear. There is no way of determining points of this kind by rule of thumb. Therefore the field superintendent often overlooks them. They are clear enough, however, when the mass diagram and the profile are thoughtfully scrutinized.

This is only one of the many illustrations which could be given to show that the mass diagram on work of this kind offers a logical means of controlling field operations, just as it offers the proper basis on which to study a project prior to selecting the outfit best suited to economical work on it. Another illustration of the usefulness of the mass diagram in controlling elevating grader work is found in fills 6 and 6a (Fig. 2), which are built from cuts C and D. In this case the mass diagram indicates the movement of approximately 5,300 cubic yards of material between balance points 6 and 7. There is a considerable excess of material—about 1,200 cubic yards—originating in cut C which must be hauled to some point beyond cut D. There are approximately 250 cubic yards in a small fill between cuts C and D, which for the purpose in hand is of no consequence, and some 4,100 cubic yards originating in cut D which must be placed in fill 6a. The mass diagram indicates an average haul of 480 feet for this latter material. If to this is added 50 feet for wagon manipulation, the average wagon travel becomes 530 feet. As against this the average wagon travel for the 1,178 cubic yards originating in cut C is 1,760 feet, if this material is hauled to the far end of fill 6a. If, however, this material is placed at the near end of fill 6a the wagon haul is reduced to 1,420 feet, and by so doing the average wagon travel on the material taken from cut D is extended to 630 feet. This illustration shows that contractors can often improve output by studies of the details of the work. At current bid prices on this sort of work (about 25 cents per cubic yard) the gain in daily production with a 10-wagon outfit would be worth nearly $16, as shown by Table 2, which is a saving well worth while.

TABLE 2.—*Comparison of production under two methods of working cuts C and D (Fig. 2) with a 10-wagon outfit (average management)*

Material from cut	Quantity	Scheme A				Scheme B			
		Haul	Wagons required for 100 per cent production	Production with 10 wagons	Days work required	Haul	Wagons required for 100 per cent production	Production with 10 wagons	Days work required
	Cubic yards	*Feet*	*Number*	*Per cent*	*Number*	*Feet*	*Number*	*Per cent*	*Number*
C	1,178	1,760	23	44	2.7	1,410	19	53	2.2
D	822	660	9	100	0.8	755	10	100	0.8
D	1,000	600	9	100	1.0	685	9	100	1.0
D	1,000	500	8	100	1.0	620	9	100	1.0
D	1,000	415	7	100	1.0	525	8	100	1.0
D	350	325	6	100	0.3	470	7	100	0.3
Total	5,350				6.8				6.3

Average daily production:	Cubic yards
Scheme B	850
Scheme A	787
Gain	63

At 25 cents per cubic yard, value of increased daily output—63×.25=$15.75.

A wide-awake superintendent can sometimes save team time by using a double dump. This is of advantage only when a fill contains yardage that is within the haul limit of his outfit and other yardage that is outside of this limit. A 10-team outfit, with average management, can keep the grader busy up to a wagon-travel distance varying from 600 to 850 feet, depending on the length of cut from which the loads are being secured. As an illustration, suppose the mass diagram

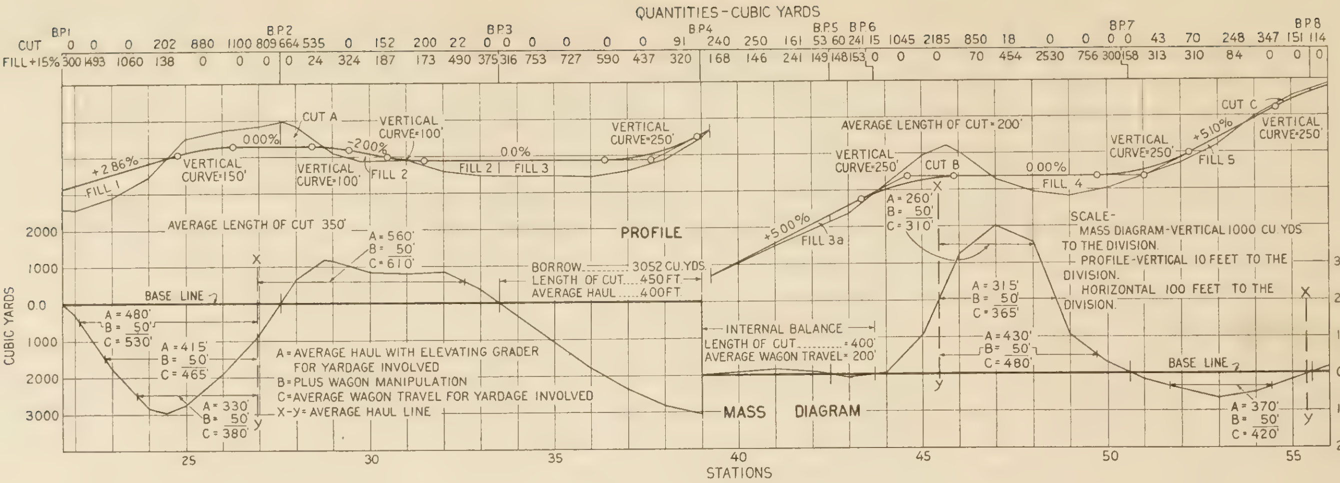


FIG. 5.—Second re-design of sample grading project, illustrating how hauls may be further reduced by use of borrow pits

indicates that the current day's work involves an average wagon travel of 350 feet. Six wagons are required to keep the grader busy, and if eight are sent out the time of two will be wasted. If under such conditions enough wagons are diverted to a longer haul, so that the proper rate of wagon supply is maintained, the time of the two wagons can be saved. A study of the time-distance graph for wagons (the time-distance graph will be discussed in the third part of this article) will show how many wagons must be diverted if this method of operation is to be successful. When this is done, however, the superintendent must use considerable care to insure that the long-haul wagons do not become bunched, as bunching will largely obliterate the benefit to be derived. The dumping at the long-haul dump need not be given much supervision as it may be so handled that subsequent operations will cover work of this kind and correct any careless placement of material.

The mass diagram may also be made to give a picture of each day's work and so to assist the contractor by showing how much material he has placed. How this can be done is shown in the mass diagram for fill 5 (Fig. 2). Once the mass diagram is in hand all that the contractor needs to know is the distance completed in order to determine the yardage he has placed with considerable accuracy. This is a valuable control and one that should not be overlooked.

POOR DESIGN REDUCES ELEVATING GRADER OUTPUT

The foregoing illustrations indicate some of the problems a contractor faces in his effort to operate an elevating grader outfit with maximum efficiency. They show that the mass diagram is a valuable guide to proper bidding and also in the conduct of the work. But they also show clearly that the highest degree of economy may be impossible unless the road is designed with that end in view. The profile shown in Figure 2 represents a decidedly poor design for elevating grader construction. The essence of economical design for this type of equipment is that the cuts and fills shall be so related in yardage and in the distance between them that a reasonable wagon train can keep the elevating grader operating at or near full capacity all the time. This means that variations in haul should be kept within a reasonable range. A design which produces a succession of long and short hauls, such as are found in fills 1, 2, 3, and 4 of Figure 2, violates the first principle of economical elevating grader operation: First, because the short cuts reduce the rate of output of the grader; second, because some of the hauls are so long that no reasonable wagon train can handle the full output of the grader; and third, because other hauls are so short that the wagon train can work but a fraction of the time with the grader working at full speed. More nearly correct treatments of this section of highway are illustrated in the redesigns shown in Figures 4 and 5.

In preparing these modified designs it has been assumed that local conditions govern the height of the fills. These have, therefore, been left approximately at the same height as in the original design, and the modification in the grade line has been limited to a readjustment of the cuts in order to secure more nearly uniform hauls. Cut depths have been freely altered and vertical curves have been standardized by the adoption of a uniform radius of curvature of approximately 5,000 feet. No particular effort has been made to keep the yardage the same as in the original design, although it is approximately the same. The purpose is to illustrate certain principles of design, the employment of which is not in any way dependent upon the yardage.

The object in presenting the redesign shown in Figure 4 is to lay emphasis on the manner in which by careful design the haul on elevating grader projects can be so adjusted as to improve output and reduce production cost. In this first redesign it has been assumed that the fills will be built entirely from the cuts. Obviously this assumption limits the reduction of the maximum haul to about half the distance from center to center of cuts, yet even with this limitation it is possible materially to reduce the wagon travel. Under the original design only 42 per cent of the material could be moved with a wagon travel of less than 600 feet, and 35 per cent involved a travel of over 900 feet. Under the first redesign (Fig. 4) 59 per cent of the material can be handled with a wagon travel of less than 600 feet and only 8 per cent requires a travel of over 900 feet. The haul of this latter material is imposed by the distance between cuts, and as already stated it can not be reduced under the system of design in use.

PRODUCTION COST REDUCED 11 PER CENT BY FIRST REDESIGN

That the first redesign is an improvement from the standpoint of the contractor will be apparent without much explanation. Under the redesign economical operation requires nearly as many wagons as under the

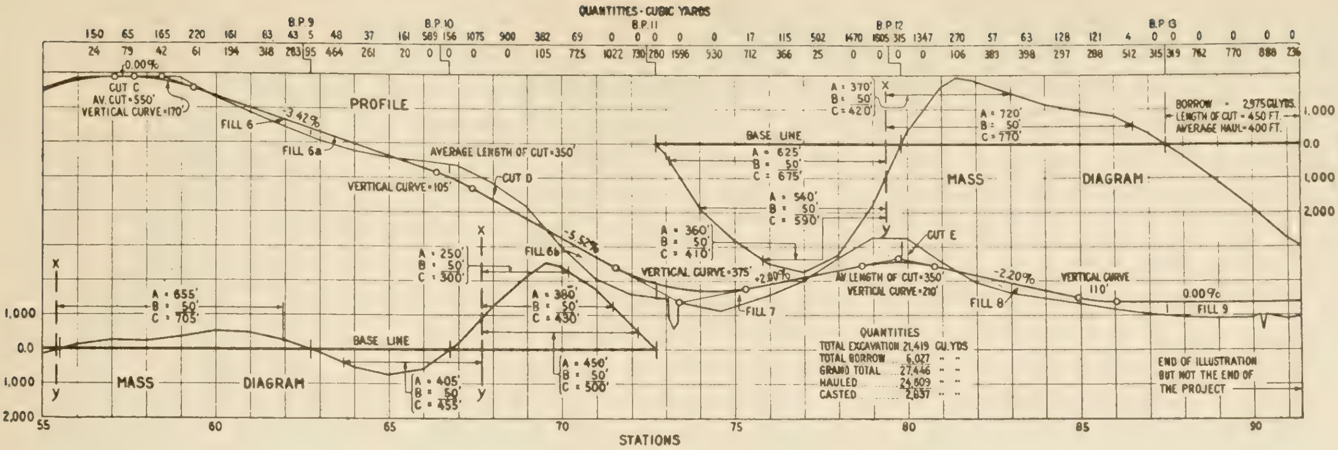


FIG. 5.—(Continued)

original design, but because much less work has to be done over the long wagon travel distances the cost of production is reduced about 11 per cent. At the prevailing bid price for work of this kind (25 cents per cubic yard) this difference, if obtainable on projects generally, should in the long run mean a reduction of from 2 to 2½ cents per cubic yard in the price paid by the State for elevating grader work. Whether on any large percentage of projects a similar saving could be made by redesign has not been fully investigated. This is, however, of less importance to the designer than the fact that it can be made on some projects.

To the contractor such a saving is of vital concern for his money is at stake. To him the original design and the redesign present a concrete example of how design often affects his profit by introducing a wide range of wagon travel; and the comparison of the two designs should explain why two jobs in which topographic conditions are similar may return different percentages of profit or loss. The writer has more than once been told by distracted contractors that it has been impossible to obtain proper production on the job in hand though jobs in similar territory had on other occasions yielded a fair profit; but never has there appeared to be any appreciation of the fact that the fault might lie in the design rather than in the way in which the job had been handled or that the size of the outfit might have affected the cost of handling the work.

BORROW PITS REDUCE COST BY ELIMINATING LONGER HAULS

Figure 5 shows a second redesign. Under this design long haul has been further reduced by the use of borrow pits. In the Mississippi Valley it is often possible to obtain stripping rights, i. e., the right to take material to a certain depth, generally a foot or two, from abutting property. The advantage of this practice lies in the fact that the grader run can readily be made such as to yield 100 per cent production at the grader, while at the same time the haul can be kept within the capacity of a normal wagon train.

Whether to use the method or not, from the standpoint of the State, depends on the saving likely to result and the cost of the rights. From the standpoint of the contractor its desirability is apparent as its use reduces the longer hauls imposed in the first redesign by the distance between cuts. Under this design only seven wagons would be required for the most economical prosecution of the work, 87 per cent of the material would be hauled less than 600 feet, no material would require wagon travel in excess of 900 feet, and the production cost would be 20 per cent less than under the original design. A condensed comparison of the three designs is given in Table 3; the methods used in deriving the results shown will be explained in Part 3 of this series of articles.

TABLE 3.—*Comparison of cost of three designs using various wagon trains*

Design	Figure No.	Total actual yardage	6-wagon outfit: Equivalent yardage [1]	6-wagon outfit: Production cost	7-wagon outfit: Equivalent yardage [1]	7-wagon outfit: Production cost	8-wagon outfit: Equivalent yardage [1]	8-wagon outfit: Production cost
		Cubic yards	*Cubic yards*	*Cents*	*Cubic yards*	*Cents*	*Cubic yards*	*Cents*
Original	2	27, 096	--------	--------	--------	--------	--------	--------
First redesign	4	26, 573	--------	--------	--------	--------	31, 480	14. 3
Second redesign	5	27, 446	33, 663	13. 5	30, 445	12. 7	29, 419	12. 9

Design	9-wagon outfit: Equivalent yardage [1]	9-wagon outfit: Production cost	10-wagon outfit: Equivalent yardage [1]	10-wagon outfit: Production cost	11-wagon outfit: Equivalent yardage [1]	11-wagon outfit: Production cost	12-wagon outfit: Equivalent yardage [1]	12-wagon outfit: Production cost
	Cubic yards	*Cents*	*Cubic yards*	*Cents*	*Cubic yards*	*Cents*	*Cubic yards*	*Cents*
Original	--------	--------	33, 177	15. 9	31, 612	15. 8	30, 644	15. 9
First redesign	29, 887	14. 1	28, 947	14. 2	--------	--------	--------	--------

[1] Based on standard daily production of 1,000 cubic yards.

Minimum production cost:
Original design, 15.8 cents with 11 wagons.
First redesign, 14.1 cents with 9 wagons.
Second redesign, 12.7 cents with 7 wagons.
Difference in production cost=3.1 cents, or about 20 per cent.

PRODUCTION COST IN RELATION TO HAUL

The relation of haul to cost may be further illustrated by a very general production cost statement. Under the wage scales prevailing in the Mississippi Valley and contiguous territory the fixed costs of operating an elevating grader are not far from $80 a day. The cost of hauling is about $5 per team per day. These costs cover field pay roll, feed for the teams, cookhouse losses, and minor repairs only and, for the purposes in hand, will be referred to as the production cost. The contractor has many other costs to meet, such as the costs of office overhead, bond, financing, getting onto the job, depreciation, etc., all of which are presumably included in the bid price, but these are largely independent of production cost and should not be included, since it is only the factors affecting production cost that are under consideration.

Accepting the above production costs as a basis of comparison and assuming the condition of an elevating grader working in a 450-foot cut and the wagon supply necessary for standard production of 1,000 cubic yards a day at the various lengths of wagon travel, the costs of production per cubic yard will be as shown in Table 4.

TABLE 4.—*Unit costs of production for standard production from a 450-foot cut with various hauls*

Average wagon travel to fill	Wagons required	Daily production cost per outfit	Production cost per cubic yard
Feet	*Number*	*Dollars*	*Cents*
325	6	110	11
500	8	120	12
675	10	130	13
850	12	140	14
1,025	14	150	15

Average rate of increase, 0.6 cent per station.

The table presents, of course, a highly generalized statement of the costs, but it will serve to show, for example, that if the wagon travel can be kept down to a point where an 8-wagon outfit can be appropriately used, production cost will be about a cent a yard less (bid prices should average about 2 cents less) than where the wagon travel is such that a 10-wagon outfit is required. If, with any given wagon supply, the length of cut is shortened the effect will be to lower production so that the saving resulting from a shortening of the haul may in this way be offset by the reduced output obtainable.

If, on the other hand, the wagon supply is not adequate, the cost will mount rapidly. Thus, if an 8-wagon outfit (basic cost of production 12 cents) is working where the wagon travel is 1,025 feet, it will supply only eight-fourteenths of the necessary number of wagons; the production will fall, therefore, to eight-fourteenths of normal, and the cost of production will rise to 21 cents.

Two important points should be somewhat clarified by this analysis. The first of these is that the contractor who undertakes a project with less than the proper wagon supply will generally find that his production cost is higher than the haul distances prevailing would normally generate; and the second, that the injection of occasional long hauls has relatively a more important effect on production cost than a general increase in the haul for which provision can be made in the selecting of the outfit.

To the contractor this latter point is of special importance in that it shows that bids on overhaul must be carefully scrutinized. It is customary to take overhaul on work of this sort at about 2 cents per station yard. If the station yardage of overhaul is large, the contractor will be justified in providing a wagon supply sufficient to care for it properly, and the price of 2 cents may be sufficient or even excessive, but more often the overhaul is generated by a few cuts from which long hauls are required. In such cases it is not practicable to increase the wagon supply and the output may be so reduced, when operating on this long-haul work, that the production cost alone may about equal the price received. In such cases the contractor loses on his overhaul.

SUPPLEMENTARY USE OF FRESNO MAY SAVE MONEY

In the foregoing discussion it has been assumed that contractors use an outfit of fixed size. This, in fact, is the all-but-universal practice. Under this system team time is lost in considerable amounts whenever the wagon travel is short, and grader time is lost whenever a long travel distance is encountered. There is, however, another method of handling such work that deserves more consideration than it is now receiving.

It is well known that the fresno can move dirt on short-haul jobs about as cheaply as it can be moved by an elevating grader outfit. This being the case, there seems to be no good reason why the fresno and the elevating grader can not be combined with profit when the conditions warrant. There are a good many angles to this question, and it is quite impossible to treat all of them in the short space here available. Briefly, however, the situation is substantially this: The elevating grader is a wonderfully effective loading mechanism; the wagon is perhaps the most efficient hauling mechanism available for work within its proper field. As long as these can be kept in balance and efficiently operated, the cost of producing yardage in place is probably as low as it can be made with any type of earth-moving equipment, particularly if the haul is of any considerable length. However, as the haul approaches zero there is a short distance, probably not exceeding 200 feet, in which the fresno can produce yardage in place about as cheaply as the elevating grader. For such short hauls the wagon supply of the elevating grader must be excessive, since it is properly designed for the longer hauls. On the average project there is always a certain amount of work to do which is well within the field of the fresno, and there are hauls which, while clearly within the field of the elevating grader, are shorter than the average for the project and are capable of handling with less than the full outfit of teams. If, whenever this condition obtains, the teams not needed by the grader are shifted to fresnoes, whatever yardage is moved by the latter will represent a clear gain in production.

The field of competition again turns against the fresno when the distance becomes so short that the elevating grader can cast the material into place, assuming, of course, that no wagons are kept idle during the casting operation and that the ditches are not so deep that the output of the grader will be sharply reduced by the tilting of the machine. But the fact that is apt to be overlooked in considering the relative cost of short haul and casting is that so long as the contractor must maintain his teams (including drivers) he can gain nothing by casting unless he thereby increases his output per hour. The possibility of increasing output by casting lies in the fact that the time lost in wagon exchange is saved, but this saving is not always a net gain, because a certain amount of time must always be lost in resting the grader stock. As a matter of fact, when the grader is drawn by a tractor or by 20 horses the output generally is somewhat increased when casting, but if only 16 horses are used the aggregate of the rest periods is generally about as great as the time lost in wagon exchange, and no particular advantage accrues.

Under these general conditions if a contractor, desiring a high average rate of output at the lowest possible cost, instead of selecting a wagon train on the basis of the average haul would select it on the basis of the longer hauls and then plan to send out with the wagons each day only those teams which can be worked to capacity, using the balance in taking out ditches and short-haul cuts with fresnoes, he would find that under practically all circumstances his grader could be worked to capacity, and his extra teams, instead of spending much of the time waiting to be loaded, would be producing yardage at a profitable margin. In discussing this scheme of operation with contractors two objections to it have been raised: First, that teamsters operating wagons do not like to transfer to fresnoes and, second, that the standard 1½-yard wagon requires only two horses while the 4-foot fresno requires three.

There is a valid answer to both objections. To the first there is the answer that employers generally find no difficulty in enforcing conditions which are clearly set forth when men are employed. The other may be met with the blunt statement that the 1½-yard wagon has no place on elevating grader work and should be replaced by the more efficient 2-yard wagon. The 2-yard wagon requires three horses, but day in and day out it will haul 50 per cent more than the 1½-yard wagon. Where it is used there will be no difficulty in shifting the 3-horse teams to 4-foot fresnoes.

TWO-YARD VERSUS ONE AND ONE-HALF YARD WAGONS

The desirability of using 2-yard instead of 1½-yard wagons needs no very extended defense. In the first place, as noted above, 50 per cent more yardage is secured per load at the expense of only one extra horse. At the present time it costs about 70 cents each per day to maintain stock. With drivers at $3.50 the cost to a contractor of maintaining a 2-horse team on the job is in the neighborhood of $4.90 a day. As compared with this, the cost of maintaining a 3-horse team is about $5.60. Thus, with a 14 per cent increase in cost a 50 per cent larger load can be moved, and this is an advantage that no contractor can afford to overlook. Moreover, the actual load per horse is slightly less when three horses are used on a 2-yard wagon than when two horses are used on a 1½-yard wagon, because while the pay load per horse is about the same, there is no important difference in the internal frictional resistance of the two sizes of wagons.

In addition to this saving in the hauling cost, which is a relatively large one, the larger normal grader output must also be considered. This larger output is due to the smaller number of wagon-exchange periods for a given yardage. As by its use only about two-thirds as many waits between loads are required, the 2-yard wagon, used with normal efficiency should produce at least 10 per cent more output than the 1½-yard wagon.

The one valid objection which has been raised to the use of the larger wagon is that in soft ground it tends to mire down a little more than the 1½-yard wagon. This can be avoided by supplying the larger wagon with a tire of proper width.

It is impossible to recommend the use of wagons larger than the 2-yard size, because when more than three horses are used there is difficulty in getting under the belt quickly. There is also some difficulty in maneuvering at the dump. These problems are not, however, of any consequence where three horses are used, and the evident success of those outfits now using 2-yard wagons offers concrete evidence that the advantages here noted are being secured by at least a few progressive contractors.

The natural deduction from these facts is that if the contractor desires to operate as profitably as possible, and at the same time to reduce the element of risk in his elevating grader work to a minimum, he will study the various elements of his job with care and will provide enough wagons that he can keep his grader working at capacity. There are industries which to-day make all of their profit out of the use of materials formerly wasted. The situation of the elevating grader contractor is somewhat analagous in that as his work is now conducted team time is wasted in large amounts. One way of utilizing waste team time has been mentioned. Others could, no doubt, be suggested. The point is that every time a team stands idle when it could be made to produce something value is lost. Salvaging this value will prove profitable to any contractor who will undertake it seriously and methodically. If, to his efforts to salvage lost time he will add a serious study of those elements in this sort of work which are responsible for its present speculative aspects, particularly the element of haul, he should have little trouble in avoiding the financial troubles so often encountered by those operating in this field.

(Continued from p. 58)

that maintenance costs on macadam roads are approximately one-sixth as much per mile per vehicle as those on gravel roads, and in individual cases much less than this amount.

Even estimating 1,000 vehicles per day instead of 500 as the capacity of a gravel road, reference to the 1930 forecast map (Fig. 10) will indicate that a considerable mileage of gravel roads on the Maine primary system should be reconstructed with more durable surfaces within the next six years.

On the basis of a maximum capacity of 1,000 vehicles per day for gravel-surfaced highways, the following program for the improvement of Maine highways is suggested for the period 1925 to 1930:

1. Construction of high-type pavements on the heavy-traffic routes.

2. The heavy-traffic routes included in the suggested improvement program, listed below, are divided into three groups based on density of traffic, the type of traffic on each highway, and the urgency of the need for immediate improvement.

3. It is suggested that the routes in Group 1 be improved first, those in Group II second, and those in Group III last.

4. Because of the greater total traffic as well as the larger number of motor trucks per day on the highways in Group I, high-type pavements are suggested for this group.

5. On the basis of Maine construction and maintenance experience it is believed that bituminous macadam, of the type now being constructed in the State will adequately serve the present and future traffic on

the highways included in Groups II and III for the expected life of the bituminous-macadam type of construction.

6. In the selection of the surface type for highways in Groups II and III consideration should be given to the present type of surface on sections of the highways included in these groups.

7. Following is a description of the highways included in each group:

Primary system

Group I:
- Kittery—Portland—Brunswick.
- Portland—Auburn—Augusta.
- Augusta—Gardiner.
- Waterville—Fairfield.
- Bangor—Oldtown.

Group II:
- Brunswick—Gardiner.
- Brunswick—Belfast.
- Brunswick—Auburn.
- Augusta—Waterville.
- Fairfield—Bangor via Newport.
- Bangor—Ellsworth.
- Waterville—Oakland.

Group III:
- Belfast—Bangor.
- Bangor—Ellsworth via Orland.
- Ellsworth—Bar Harbor.
- Fairfield—Skowhegan.
- Wells—Berwick.
- Portland—Bridgton—State line.
- Gray—Norway.
- Auburn—Farmington—Strong.
- Newport—Dover.
- Perry—Calais.
- Houlton—Presque Isle—Van Buren.

Secondary system

Group I:
- Portland—Westbrook.

Group II:
- Auburn—Mechanic Falls.
- Wells—Sanford.

Budget requirements for this period can be established by computing the mileage of each type to be constructed (total mileage of designated routes less improvements already made) and estimating the costs of such construction. If estimated available revenues over the period are not sufficient to meet such expenditures, the possibility of a bond issue to be retired from funds derived from an increased gasoline tax is suggested.

It is estimated that a gasoline tax of 1 cent per gallon will yield approximately $4,500,000 during the six-year period 1925 to 1930, inclusive. An increase of this tax from 1 to 3 cents per gallon would provide approximately $9,000,000 in additional revenue.

During this same six-year period license fees, assuming no change in fees, may be expected to yield approximately $17,000,000, making a total of $21,500,000 from license fees and a gasoline tax of 1 cent per gallon, or a total of approximately $30,000,000 from license fees and a gasoline tax of 3 cents per gallon.

NEW TESTING DEVICES DEVELOPED

Three new testing devices for the use of the highway engineer have been developed by the Division of Tests of the Bureau of Public Roads.

A test for the consistency of concrete in the field has been devised as a substitute for the slump test, which is not particularly reliable under all conditions. The method is particularly adapted for concrete paving and other work in which a relatively dry consistency can be employed. It is based upon the principle that, within working limits, the consistency of freshly mixed concrete is proportional to the weight which will be retained upon a plate of given diameter when the concrete is deposited on it in a standard manner. The device consists of a truncated cone large enough to hold about 75 pounds of wet concrete, supported by an angle-iron frame above a circular plate 15 inches in diameter, which in turn rests upon a spring balance.

The method of testing is as follows: The apparatus is placed upon the subgrade and the cone is filled with concrete immediately after the batch has been deposited by the bucket. Immediately after filling the cone a removable slide at the bottom is withdrawn and the concrete flows out upon the plate. If the mix is either very dry or very wet, a larger quantity will roll or flow over the edges of the plate than if it is moderately dry. The plate is supported above the spring balance by two cams which take the weight of the concrete off the spring until it has all been deposited. By turning a handle which revolves the supporting cams the concrete upon the plate can then be weighed. It has been found that for a 15-inch plate the usual variations in the amount of water in a 1 : 2 : 3 paving mix will cause a difference in weight of from 20 to 50 pounds. Experiments have indicated that for machine-finished work the proper consistency to use is one which will give the greatest weight of concrete retained upon the plate. For hand-finished work a mix slightly wetter than this would probably have to be used. This device has been tried on actual construction and it appears to be of practical value. A more complete description of the process, together with test data illustrating the use of the apparatus, will appear in an early issue of Public Roads.

Work has also been carried forward on a device designed to register the intensity of pressure used during the molding of Portland cement mortar briquettes. Considerable latitude has always been allowed operators in regard to this detail of cement testing, resulting in quite appreciable variations in manipulation, which undoubtedly affect test results. The device consists of a small weighing platform approximately 15 inches long and 4 inches wide, large enough to hold a glass plate and a three-gang briquette mold. The device is so arranged that an electric contact is made when a certain pressure is exerted on the briquette by the operator, lighting a white light in the front of the apparatus. Another contact, which when made shows a red light, may be set for a pressure beyond which the operator should not go. In determining whether an operator is using the proper pressure it is only necessary for him to mold a set of briquettes on the weighing platform and to note whether the pressure he exerts is sufficient to light the white light but not the red light. Both of the contact points are adjustable so that any pressure within working limits may be recorded.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORT

Report of the Chief of the Bureau of Public Roads, 1924.

DEPARTMENT BULLETINS

No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370. The Results of Physical Tests of Road-Building Rock. 15c.
386. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
390. Public Road Mileage in the United States, 1914. A Summary.
*393. Economic Surveys of County Highway Improvement. 35c.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463. Earth, Sand-Clay, and Gravel Roads. 15c.
*532. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583. Report on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916. 10c.
*660. Highway Cost Keeping. 10c.
*670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917. 5c.
*691. Typical Specifications for Bituminous Road Materials. 10c.
*704. Typical Specifications for Nonbituminous Road Materials. 5c.
*724. Drainage Methods and Foundations for County Roads. 20c.
*1077. Portland Cement Concrete Roads. 15c.
*1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
No. 1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1259. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1279. Rural Highway Mileage, Incomes and Expenditures, 1921 and 1922.

DEPARTMENT CIRCULAR

No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS

No. *338. Macadam Roads. 5c.
*505. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *727. Design of Public Roads. 5c.
*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.

OFFICE OF PUBLIC ROADS BULLETIN

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS

No. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D–2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 20, D–4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D–6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 7, D–13. Toughness of Bituminous Aggregates.
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

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

APRIL 30,1925

GOVERNMENT PRINTING OFFICE

STATES	FISCAL YEARS 1917-1925: PROJECTS COMPLETED PRIOR TO JULY 1, 1924			FISCAL YEAR 1925: PROJECTS COMPLETED SINCE JUNE 30, 1924			FISCAL YEAR 1925: *PROJECTS UNDER CONSTRUCTION			FISCAL YEAR 1925: PROJECTS APPROVED FOR CONSTRUCTION			BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 4,598,721.63	$ 2,186,247.54	464.1	$ 1,211,826.12	$ 597,175.34	132.2	$ 15,535,183.95	$ 7,536,992.14	819.8	$ 83,897.90	$ 41,948.95	0.5	$ 2,432,469.03	Alabama
Arizona	8,338,365.41	4,287,683.88	527.8	954,635.99	553,824.61	77.5	2,003,875.73	1,214,965.20	141.4	751,503.67	478,400.86	55.6	2,016,997.45	Arizona
Arkansas	11,094,751.31	4,424,345.63	944.4	2,027,459.11	861,846.28	89.2	6,696,583.84	2,882,172.11	362.3	582,116.38	247,945.55	33.4	1,910,264.43	Arkansas
California	12,999,075.03	5,647,148.17	533.7	8,111,073.28	4,377,480.41	320.1	9,468,989.20	4,491,514.94	231.9	235,597.25	137,985.74	11.1	4,911,812.74	California
Colorado	8,108,070.31	4,029,898.97	502.6	2,485,167.72	1,327,686.59	108.3	4,681,519.97	2,484,092.77	193.1	434,324.88	156,517.34	9.9	2,934,922.33	Colorado
Connecticut	3,062,872.02	1,269,558.60	73.6	344,021.87	163,383.00	8.2	3,144,249.93	995,572.55	50.8				1,427,481.85	Connecticut
Delaware	3,056,832.22	1,007,714.83	72.5	1,089,734.63	431,625.92	30.8	638,530.64	270,431.10	16.1	30,647.50	15,323.75		380,059.50	Delaware
Florida	961,134.07	461,470.92	48.8	1,998,139.65	944,017.05	47.5	8,633,082.35	4,202,091.68	236.9	116,547.09	91,547.09	0.1	1,480,638.26	Florida
Georgia	17,167,373.32	7,955,805.20	1,214.2	2,826,450.71	1,370,881.74	260.9	10,768,861.15	5,310,312.75	720.1	649,058.00	287,629.36	25.1	1,508,356.95	Georgia
Idaho	8,181,697.92	4,092,395.52	506.8	1,048,443.42	597,683.81	70.2	1,982,767.55	1,238,144.41	136.9	647,468.63	430,955.79	53.4	1,255,458.47	Idaho
Illinois	26,964,706.06	12,279,546.33	804.7	12,087,130.27	5,902,126.18	397.1	5,987,993.79	2,873,742.27	202.4	2,519,871.45	1,255,092.37	90.0	4,317,463.85	Illinois
Indiana	7,577,444.16	3,655,540.97	225.7	4,844,133.70	2,334,801.41	159.2	12,317,347.83	6,010,171.02	399.9	594,281.83	297,140.96	20.3	3,953,430.64	Indiana
Iowa	23,195,778.19	9,237,031.86	1,682.9	4,020,893.35	1,842,654.30	290.3	5,030,879.18	2,307,655.17	376.8	2,920,333.58	1,231,126.05	99.9	2,788,065.62	Iowa
Kansas	17,084,136.48	6,043,176.80	502.7	8,526,612.68	3,347,336.40	294.2	12,963,047.64	5,585,975.49	604.9	1,220,170.43	353,734.05	42.8	2,043,426.26	Kansas
Kentucky	10,822,980.31	4,613,947.28	429.4	3,068,981.16	1,238,955.61	119.5	7,974,588.37	3,625,924.83	298.2	448,259.93	161,246.58	4.7	2,143,271.70	Kentucky
Louisiana	8,488,463.18	3,636,143.36	661.2	2,506,645.04	1,216,178.85	218.8	4,141,634.04	2,023,616.02	199.9	120,174.25	60,087.12	10.0	1,326,678.65	Louisiana
Maine	6,911,058.78	3,299,935.38	230.7	1,263,222.53	607,934.95	50.7	749,878.17	350,363.39	24.2				1,516,878.28	Maine
Maryland	8,760,044.42	3,213,321.78	243.2	1,267,148.78	590,561.24	48.1	1,784,838.61	768,190.52	53.7	919,150.96	357,131.89	28.2	355,527.57	Maryland
Massachusetts	10,191,202.02	4,105,727.22	232.8	3,138,337.19	1,132,910.86	56.6	4,195,527.34	1,232,855.80	67.6	945,862.58	244,699.88	13.9	2,293,704.24	Massachusetts
Michigan	13,434,135.07	6,060,612.23	494.5	2,165,559.55	994,055.92	101.6	14,965,650.26	7,044,686.58	479.5	163,170.00	81,585.00	5.4	3,924,069.27	Michigan
Minnesota	24,037,561.24	9,885,843.07	2,292.0	6,378,124.65	2,852,798.97	429.2	6,325,341.84	2,928,600.00	667.0	647,775.08	41,300.00	63.3	1,734,027.96	Minnesota
Mississippi	7,888,193.89	3,828,941.39	655.0	2,122,301.02	1,021,625.74	148.2	8,350,578.28	4,167,448.04	482.6	14,353.65	7,176.82		1,798,041.01	Mississippi
Missouri	11,352,027.70	5,245,899.18	803.5	5,266,914.59	2,601,319.53	264.6	24,189,720.35	9,774,930.05	807.7	3,663,762.32	1,204,095.22	119.3	1,531,671.02	Missouri
Montana	8,867,279.16	4,384,335.12	791.4	1,289,321.25	933,188.03	130.2	1,861,844.92	1,367,818.50	158.6	1,062,089.80	603,378.69	119.9	5,226,169.66	Montana
Nebraska	7,876,337.16	3,714,691.59	1,440.4	1,138,077.45	534,606.07	66.0	7,933,588.33	3,929,316.09	887.4	491,629.53	245,725.94	40.7	4,608,575.31	Nebraska
Nevada	3,460,245.52	1,853,624.98	225.6	1,446,557.71	1,228,225.07	131.4	4,431,686.34	3,731,975.54	366.6	245,675.33	209,952.34	33.8	814,619.07	Nevada
New Hampshire	3,076,750.19	1,487,867.58	171.3	1,088,937.67	498,359.29	36.8	760,383.53	366,326.09	25.0	63,256.58	30,502.65	1.7	417,533.39	New Hampshire
New Jersey	7,623,795.12	2,661,531.49	148.7	3,925,528.07	1,048,793.50	63.0	7,922,198.08	2,406,081.64	49.1	136,173.65	44,160.00	2.9	1,363,762.37	New Jersey
New Mexico	5,306,286.45	2,758,849.68	714.3	2,682,242.02	1,712,033.39	300.2	5,125,836.15	3,350,646.06	461.4	250,993.39	154,354.77	16.7	1,798,614.10	New Mexico
New York	18,862,742.49	8,257,844.44	572.7	6,200,578.11	2,506,693.04	165.3	27,131,862.84	10,002,819.38	593.0	7,289,400.00	2,000,967.50	131.8	7,596,919.64	New York
North Carolina	12,567,732.97	5,676,757.66	884.7	6,093,681.22	2,189,158.07	169.8	8,154,431.12	3,350,984.58	219.3	2,354,066.81	1,052,808.73	56.2	1,723,709.96	North Carolina
North Dakota	9,088,973.11	4,418,505.42	1,587.9	1,707,265.90	833,931.18	325.6	2,528,753.74	1,269,985.04	355.3	706,957.94	339,035.59	79.9	2,622,896.77	North Dakota
Ohio	33,122,751.43	11,879,917.99	962.5	7,996,678.33	3,212,875.94	216.0	8,617,837.99	3,021,034.95	258.3	2,649,183.76	1,132,091.70	75.7	3,683,831.42	Ohio
Oklahoma	12,986,865.26	5,888,852.03	497.3	6,891,839.01	3,351,322.64	303.1	5,647,061.76	2,606,096.78	244.7	2,013,951.44	883,639.88	95.0	1,561,896.67	Oklahoma
Oregon	12,082,873.17	5,819,093.79	655.6	2,162,545.40	1,274,243.08	140.2	2,464,973.77	1,419,566.88	105.7	196,470.25	119,432.94	15.6	1,053,490.31	Oregon
Pennsylvania	36,825,248.98	14,114,694.79	729.7	4,110,864.64	1,505,005.07	84.5	20,659,418.64	5,410,193.75	336.0	17,649,575.35	4,978,197.18	347.3	1,953,648.21	Pennsylvania
Rhode Island	1,774,397.25	779,227.96	46.0	854,098.95	340,460.13	18.8	1,411,044.89	406,599.59	18.9	475,198.35	132,090.00	8.8	640,288.32	Rhode Island
South Carolina	9,016,476.73	4,124,045.22	924.4	1,822,999.07	846,189.44	280.6	6,299,660.52	2,372,182.32	396.6	725,276.32	282,968.56	14.8	1,114,709.46	South Carolina
South Dakota	8,674,597.86	4,244,636.27	989.8	3,367,308.41	1,720,478.53	447.8	5,733,499.27	2,808,687.34	791.9	979,062.92	458,497.57	135.8	701,400.29	South Dakota
Tennessee	6,805,683.35	3,313,936.07	259.6	5,808,932.39	2,830,881.08	198.0	12,803,570.05	5,794,277.31	453.1	208,868.55	104,434.27	9.5	1,604,093.27	Tennessee
Texas	42,341,998.56	16,190,624.91	3,122.8	10,675,000.47	4,381,946.83	683.4	23,868,278.36	10,004,592.83	1,470.3	3,631,658.94	1,430,267.76	205.8	4,132,495.67	Texas
Utah	3,304,423.75	1,895,805.92	219.0	1,787,404.63	1,156,002.09	158.6	3,901,513.02	2,572,253.79	230.4	474,143.39	336,183.74	50.7	1,002,694.46	Utah
Vermont	1,922,114.16	942,769.12	74.4	809,908.56	384,869.27	23.8	1,461,197.20	698,908.78	35.4	10,699.53	5,349.76		867,707.07	Vermont
Virginia	10,035,301.48	4,801,782.43	562.5	2,609,879.62	1,253,191.20	99.7	9,678,136.61	4,392,276.66	336.9	1,633,065.17	735,085.81	53.4	860,329.90	Virginia
Washington	11,384,615.67	5,290,895.45	457.0	1,759,239.46	739,794.59	66.2	2,855,248.30	1,371,400.00	120.6	296,296.71	134,000.00	9.0	1,469,574.96	Washington
West Virginia	5,489,747.96	2,366,041.53	255.6	1,853,452.91	865,251.80	71.1	4,166,291.65	1,791,537.78	127.8	2,458,182.33	900,745.56	63.9	628,850.33	West Virginia
Wisconsin	18,753,903.15	7,441,033.57	1,325.3	3,001,359.02	1,452,667.68	121.0	2,317,433.76	1,096,311.36	109.7	878,417.25	462,708.00	40.7	5,099,038.39	Wisconsin
Wyoming	6,127,625.61	3,078,098.70	687.6	2,629,027.49	1,626,626.97	290.5	2,736,020.87	1,702,074.25	122.2	310,152.08	199,661.00	14.0	1,015,840.08	Wyoming
Hawaii										342,377.22	97,440.00	6.5	633,810.00	Hawaii
TOTALS	549,655,391.27	237,852,399.82	32,452.9	162,465,684.77	75,335,658.59	8,314.6	353,002,451.62	156,564,394.12	15,847.9	65,240,138.95	24,316,350.31	2,317.0	104,181,197.16	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 91,290,453.71 Federal aid $ 40,220,630.47 Miles 3,616.7