ary 1, 1935, is given as an example of the variation to be encountered (Table VIII)

It seems unfair to compare directly the annual maintenance costs of these surfaces without due consideration of the average age, as well as of the many other factors affecting the costs There is much need for adoption by the State highway departments of adequate cost accounting practices which will record maintenance costs in their true light and importance

GRAPHICAL REPRESENTATION OF ANNUAL ROAD COSTS ON STATE HIGHWAYS IN WORCESTER COUNTY, MASSACHUSETTS

By A J Bone

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SYNOPSIS

This report presents the results of a graphical analysis of the annual road costs which were described by Professor Breed at the Thirteenth Annual Meeting of the Highway Research Board Annual road costs and motor vehicle tax contributions have been plotted to scale on a map similar in appearance to a traffic flow sheet This plot shows at a glance the relative amounts of the annual road costs on the many different sections of state highways within the county, and also the relationship existing between these annual road costs and the tax contributions made by the vehicles using these roads

The methods used in analyzing road costs on the state highways of Worcester County and detailed results for one highway route were presented by Professor C B Breed at the Thirteenth Annual Meeting of the Highway Research Board[1] (referred to hereafter as previous report) This report gives the final results of this analysis and emphasizes particularly the representation of these results in the form of a flow sheet of annual road cost The results of the investigation relate specifically to the roads studied, but the method of analysis and representation of results could be applied to any system of highways where the basic facts are known

The original purpose of the investigation was to extend the analysis of road cost to a system of connected highways, including trunk line roads, connecting roads and feeder roads of varying traffic densities and with different types of surface The state highways in Worcester County were chosen for this study because they are in the central part of the state and represent a fair average of Massachusetts conditions, both with respect to topography and traffic density There are a little over 300 miles of state highways in this county, including nine types of pavements ranging from surface treated waterbound macadam 15 ft wide and 30 years old to a superhighway of reinforced concrete 60 ft wide Traffic densities vary from 250 to 10,000 vehicles per day

Figure 1 shows the relative traffic importance of the different numbered routes within the county. The principal state highway routes are 2 running east and west through the northerly part of the county, 12 running north and south through the central part of the county, 9 and 20 running east and west through

[1] "Analysis of Road Cost on the State Highways of Worcester Co Mass ," by C B Breed, *Proceedings*, Highway Research Board, Vol 13 pp 79–110

the central and southern part, and 122 and 140 running southeasterly from this traffic map are not state highways, and were not analyzed in this study

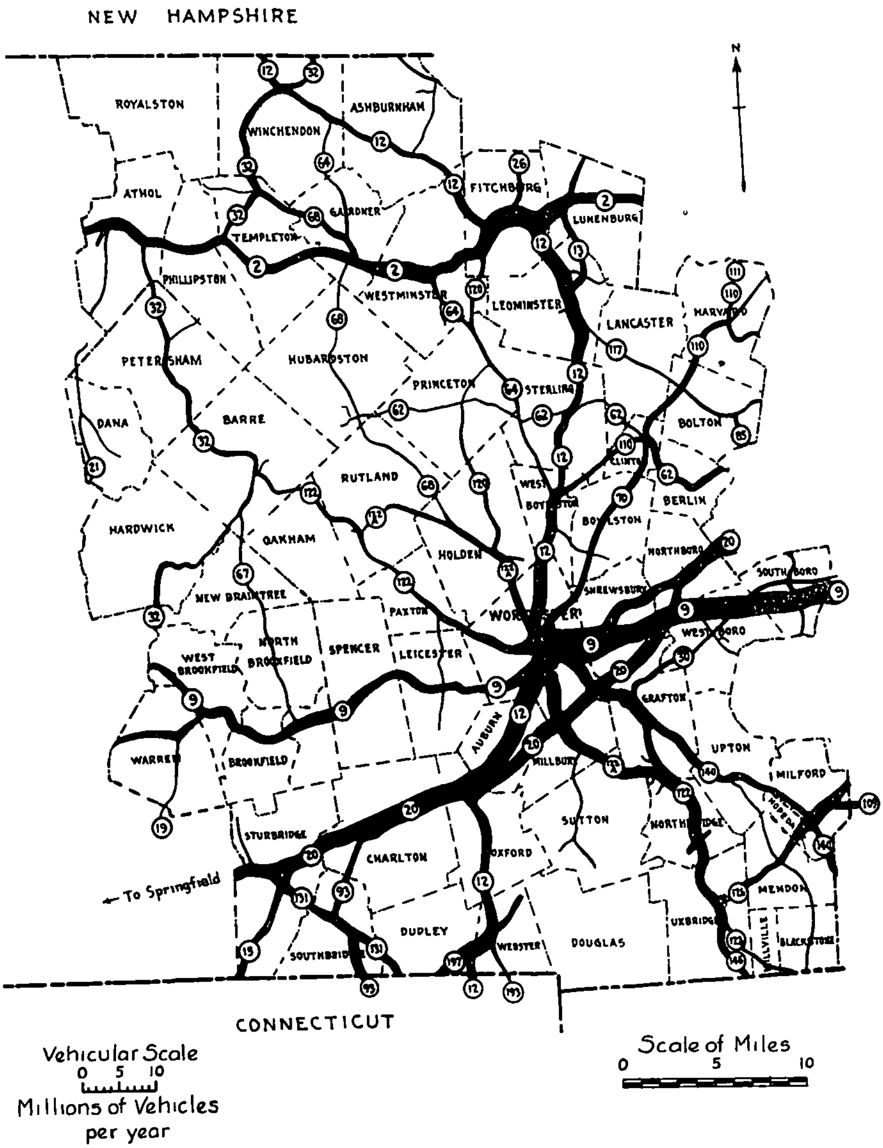

Figure 1. Highway Traffic Volume for 1933, Worcester County, Massachusetts

Worcester into Rhode Island and southeastern Massachusetts Several of the less important numbered routes shown on These routes do not appear in Figures 2 and 3 except where they connect portions of state highway

Annual road costs were computed by the following approximate formula: (See previous report, page 94)

$$R = \left(\frac{A + S}{2}\right) r + \frac{A - S}{n} + B + \frac{E}{n}$$

where R = average annual road cost, A = capital investment in highway, B = annual maintenance cost, r = rate of interest (4 per cent), n = estimated life in years of the surface before renewal is required, S = estimated salvage value of the highway at the end of n years, and E = any periodic maintenance required during life of n years.

The capital investment, A, was based on the final amount paid the contractor for the construction of the present road, plus an allowance for engineering and overhead, plus right-of-way cost, plus cost of betterments made since the last construction, plus whatever value the prior construction had to the present road In order that all costs might be on a comparable basis regardless of the year in which the work was done, a cost index was developed for Massachusetts highway construction, and used to adjust contract amounts to a common price level, arbitrarily chosen as the average of 1928–32 prices

The annual maintenance costs, B, were obtained from the records of the Maintenance Division and are in most cases an average for the five years 1928–32 The maintenance costs include surface maintenance, all other maintenance within the right-of-way, snow removal, traffic control, and engineering and overhead They are intended to include all expenses necessary to maintain the highway in a serviceable condition throughout the year.

The estimated life, n, has been varied according to the type of surface Reinforced concrete was allowed 25 years, plain concrete 20 years, modern type bituminous macadam 20 years, old type macadams and surface treated types 15–18 years In the case of old roads that had outlived their expected life, no charge was made for depreciation (second term in formula), and the investment was considered to be only the salvage value

The salvage value, S, was varied according to the type of construction For concrete pavements 40 per cent of the original investment was allowed, for bituminous types, 30 per cent was allowed

Periodic maintenance, E, was allowed for plain concrete of an early design in order to provide for a bituminous top course at the end of 10 years Provision was also made for one seal coat during the life of the modern type bituminous macadam No periodic maintenance was allowed for the other types, as their annual maintenance included all anticipated expenses

A computation of annual road cost has been made for each contract section and for each different type of pavement within a contract section, all results have been converted into costs per mile of road so that they would be readily comparable They might have been expressed in costs per square yard, but it was felt that the cost per mile was a more significant unit of comparison Costs per mile have one decided disadvantage, because they fail to show the relationship between road cost and width of pavement provided This relationship could be introduced by expressing road costs in dollars per mile per foot of width In the detailed analysis supporting the flow map of road costs, the annual road costs have been expressed in several different units. An illustration of these supporting data is given in the previous report, pages 98 and 99

In Figure 2 the annual road cost per mile for each contract section is plotted of $28,000 per mile and the narrowest band about $1000 per mile

The general appearance of the map is much like the traffic map shown in Fig-

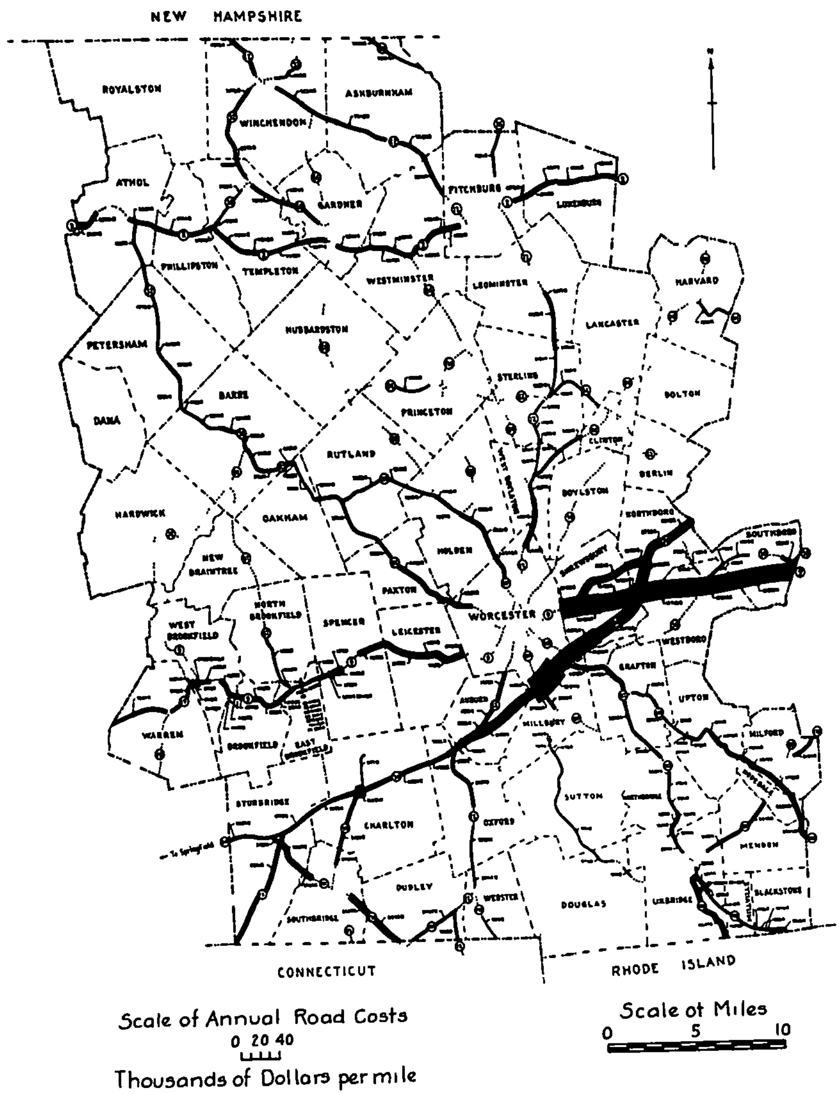

Figure 2. Flow Sheet of Annual Road Costs for State Highways in Worcester County, Massachusetts. Compiled as of November 30, 1932

to scale at its proper location on a road map of the county. The widest band on the plot represents an annual road cost ure 1, however, if the two figures were placed side by side it would be seen that the variations in road cost do not closely follow the variations in traffic density. If the highway system is built to fit traffic needs, one might expect the bands on the flow sheet of road cost to be roughly proportional to those on the traffic flow sheet Where this is not the case, the reasons for the variation should be investigated

In looking at this plot, one is struck with the excessive costs of two highways, one, Route 9, the Boston-Worcester Turnpike running from Worcester in the middle of the map towards Boston at the right, and the other, Route 20, by-passing Worcester to the southeast These highways are paved with concrete 30 to 60 feet wide and have several expensive grade separations, which accounts for their high road cost

In this plot no attempt has been made to distribute road costs outside the contract section to which they refer, hence the bands of road cost often break sharply at the limits of these sections In many cases the cost should be distributed, particularly where an expensive bridge is included within a short contract section Where all costs are plotted on one chart, such as this, a rough distribution of these concentrated costs may be made by eye For example, the annual road cost for Route 20 between Routes 9 and 12 (bypassing Worcester) varies from $10,097 to $28,270 per mile As this route performs about the same traffic service throughout this stretch, the costs should be distributed When this is done, the average annual cost is about $16,000 per mile

Road costs alone are useful for comparing one road with another, but their full significance is not brought out unless they are compared with the road service that they provide and the tax revenue that they earn Road service is measured by the width, type and condition of the surface and the volume of traffic using the road The tax revenue is measured by motor vehicle tax contributions to the state highway fund originating from the road, assuming these contributions to be accumulated or earned on a vehicle mile basis

In Massachusetts motor vehicles pay to the State a registration fee plus a 3-cent gasoline tax The gasoline tax is essentially a vehicle mile tax, and the registration and license fees can be prorated on a vehicle mile basis by assuming average annual mileages for the different classes of vehicles The sum of the gasoline tax per vehicle mile and the registration fees so distributed on a vehicle mile basis times the annual traffic using a given mile of road equals the annual contributions (or annual toll, if you like) paid by motor vehicles using that mile of road In this study road costs are compared with motor vehicle contributions The details of the method used in estimating contributions will be found in the previous report page 102 In employing this method of comparison, no account is taken of what is actually done with the motor vehicle contributions—they are merely used as a measuring stick for the justification of the annual road costs

Figure 3 shows road costs to the same scale as Figure 2, but with the motor vehicle tax contributions superimposed upon them Where the bands have a white center the road costs exceed contributions, and the width of the black band outside this white center is a measure of how much the road costs exceed contributions Where the bands have a black center, the contributions exceed road cost The black center band is a measure of the road cost and the width between the fine lines outside a measure of the contributions.

on Route 20, the Worcester by-pass, road costs exceed contributions five fold in the

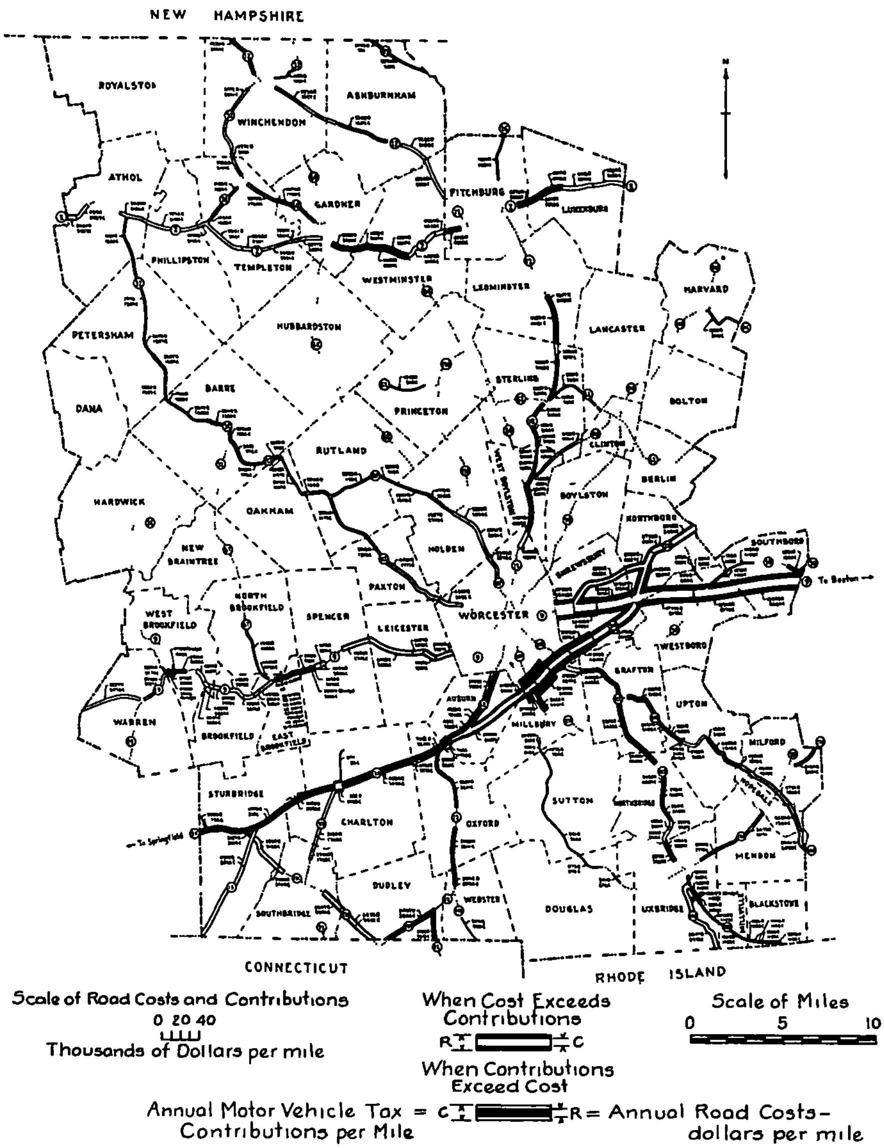

Figure 3. Flow Sheet of Annual Road Costs and Motor Vehicle Tax Contributions for State Highways in Worcester County, Massachusetts. Compiled as of November 30, 1932

In general, the road costs exceed contributions, but the relationship between the two is quite variable For example, section lying between Millbury and Worcester, whereas in Charlton (to the west) the contributions exceed road costs by 50 per cent There are reasons for these variations For example, the Worcester by-pass which was built in 1932 saved 2 2 miles of distance and 7 minutes of time for all vehicles which would otherwise have had to go into the city of Worcester and out again Assuming that the saving for a mile of distance is 2 cents per vehicle mile, the annual saving for the average annual traffic of 1,500,000 vehicles is 0 02 × 2 2 × 1,500,000 = $66,000 or $5,550 per mile when distributed over the length of the by-pass (11 9 miles) Other less tangible benefits are the saving of 175,000 vehicle hours per year, and the relief of traffic congestion in the business district of Worcester, likewise there is a saving in vehicle operating cost, because the old route through Worcester is much rougher than the by-pass, and frequent stopping and starting is required on account of the congestion at the principal intersections

Another effect of the by-pass has been to shift traffic from Route 9 to Route 20 west of Worcester Both routes lead to Springfield, but since the by-pass was built, Route 20 has become the more direct route for through traffic Note that the portion of Route 20 west of Worcester shows an excess of contributions over road cost whereas on Route 9 the contributions are much less than the road costs At the time of this study, November 30, 1932, both routes were of about the same type and width Since this time Route 20 has been extensively widened to accommodate the increase in traffic and its road cost now is much greater than shown in Figure 3

The above remarks illustrate but two of many such facts that are brought to light by a plot of this kind

A flow sheet of road cost, like a flow sheet of traffic, applies only to the year for which it is made It must be prepared periodically to reflect the changes brought about by new construction and varying traffic density Figure 3 was prepared as of November 30, 1932 A revised flow sheet as of December, 1935 would be quite different in many respects, particularly with reference to those routes which have been extensively widened and reconstructed during the past three years Unlike a traffic flow sheet, however, a complete set of new data is not required for each revision The original construction cost of the highway, which is the basis for estimating the capital investment, remains the same over a long period of years This information need be assembled only once during the life of the road Maintenance costs are kept as a matter of routine by the Maintenance Department and can be kept in such a way that they are at all times available for a road cost analysis In Massachusetts, state wide traffic counts are made every three years An economic map of road costs might well be prepared every three years immediately following the traffic survey

Table I shows weighted averages for age, width, traffic, motor vehicle contributions and annual road cost for each of the nine types of roads included in this analysis The reinforced concrete roads have been divided into three classes, as the Boston-Worcester Turnpike, Route 9, and the Worcester By-pass, Route 20, are of the nature of super-highways and should be kept in a class by themselves The dual type is similar to concrete, as most of the traffic drives on the concrete, using the bituminous center strip for passing Bituminous macadam employing asphalt comprises over one-half of the total mileage This is the most common type of pavement in Massachusetts It

TABLE I

AVERAGE ANNUAL ROAD COST—MOTOR VEHICLE TAX CONTRIBUTIONS—ESTIMATED COST OF TRANSPORTATION FOR EACH ROAD TYPE ON STATE HIGHWAYS IN WORCESTER COUNTY, MASSACHUSETTS

	Type of Road	Length Averaged Miles	Average Age of Surface Years	Average Width of Surface Feet	Average Annual Traffic (all Veh)	Average Speed of Vehicles M P H	Average Motor Vehicle Tax Contributions to State H'w'y Fund		Average Annual Road Cost		Average Cost of Motor Vehicle Operation		Motor Veh Taxes Used for State H'w'ys Per Veh Mi 14/23 × (8)	Average Cost of Transportation Per Veh Mi (10) + (12) − (13)
							Per Mile	Per Veh Mile	Per Mile	Per Veh Mile	Ratio	Per Veh Mile		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Modern Types	Reinf Conc (Wor Pike)	13 64	1 0	41 3	2,730,000	42	$9210	$0 00337	$18,800	$0 00688	1 01	$0 0748	$0 00205	$0 0796
	Reinf Conc (Wor By-Pass)	15 22	0 5	33 0	1,475,000	45	5030	0 00341	16,000	0 01086	1 01	0 0751	0 00207	0 0839
	Reinf Concrete	16 37	4 8	23 9	1,292,000	38	4340	0 00336	5,680	0 00440	1 00	0 0741	0 00205	0 0764
	Dual Type*	2 56	1 0	30 0	1,666,000	38	5600	0 00336	8,698	0 00522	1 00	0 0741	0 00205	0 0773
	Plain Concrete	19 49	10 4	19 1	1,016,000	36	3450	0 00339	3,897	0 00384	1 02	0 0757	0 00207	0 0775
	Bit Mac Asphalt	153 12	5 2	22 8	938,000	37	3220	0 00343	4,030	0 00429	1 05	0 0778	0 00209	0 0800
	Bit Conc -Cold Mix	3 47	0 5	22 0	523,000	37	1794	0 00343	3,110	0 00594	1 05	0 0778	0 00209	0 0816
Old Types	Bit Mac -Tar	21 15	16 0	20 1	1,059,000	35	3740	0 00353	2,583	0 00244	1 10	0 0815	0 00215	0 0818
	Bit Conc Asphalt	9 90	15 1	17 7	853,000	30	3080	0 00361	2,185	0 00257	1 15	0 0853	0 00220	0 0857
	Surf Treat W B Mac	38 41	23 4	16 0	314,000	30	1133	0 00361	1,466	0 00467	1 15	0 0853	0 00220	0 0878
	Surf Treat Gravel	11 06	18 5	17 0	357,000	30	1313	0 00368	1,687	0 00473	1 18	0 0874	0 00225	0 0899
All Types		304 39	8 9	22 6	977,000	36 2	3370	0 00346	4,834	0 00483	1 07	0 0790	0 00211	0 0817

* Two lanes of concrete separated by one lane of bituminous macadam-asphalt

consists, in general, of a 12-in gravel foundation, a 4 5-in base course of broken stone, and a 2 5-in top course of broken stone penetrated with $2\frac{3}{8}$ gallons per square yard of hot asphalt cement The reinforced concrete pavements are of 8-in uniform thickness, reinforced with from 7 to 10 lb of steel per square yard. The plain concrete pavements are about 6 in thick without reinforcing The old types of pavement, shown below the heavy horizontal line in Table I, consist of about 5 in of surface material on a gravel or stone base of variable depth Although these pavements were originally constructed as different types, they have received so many surface treatments that they now have much the same appearance The modern types have an average age of about 5 years, and the old types an average age of about 20 years

The different road types are arranged in Table I in the order of decreasing importance The highest type is at the top and lowest at the bottom The annual road costs in column (9) also decrease in about the same order from a maximum of $18,800 per mile for the Worcester Turnpike to a minimum of $1466 per mile for the surface treated waterbound macadam type The annual road costs per *vehicle* mile in column (10) do not vary through nearly so wide a range As pointed out above, if a highway system is well adjusted to traffic needs, the road costs will be roughly proportional to traffic, and the road cost per vehicle mile should be nearly the same for all types The values in column (10) indicate that for Massachusetts conditions the normal annual road cost per vehicle mile is about 0 48 cents The road types that vary greatly from this amount are the Worcester By-pass which has a much higher cost, and the old tar macadam and asphaltic concrete types, which have much lower than average costs. The high cost for the by-pass is justified in part by the special service it renders in saving time and distance over the optional route through the city of Worcester Consideration should also be given to the fact that both the by-pass and the Worcester Turnpike are designed for much greater traffic than they now carry. As traffic increases on these roads, the cost per vehicle mile will decrease and approach the average for other types The low costs for the tar macadam and asphaltic concrete do not indicate economical road types, but rather they indicate that these roads do not adequately serve their traffic They should be replaced with a higher type Since this study was started in 1933, several sections of these old types have been rebuilt and paved with a much higher type of surface A report by Professor C B Breed[2] analyzes the changes in road costs resulting from the reconstruction of several miles of these old types on Route 12

The average speeds recorded in column (6) are based upon observations made by the Massachusetts Accident Survey in 1933 and 1934.

The motor vehicle tax contributions per mile are shown in column (7) and per vehicle mile in column (8) The latter were computed for average conditions in the previous report, page 102 They have been modified in Table I to take account of variations in the rate of gasoline consumption which directly affect the amount of gasoline tax contributed per vehicle mile On high type pavements the average speed is high, and tax

[2] Road Costs as Affected by Reconstruction on State Highway Route No 12, Worcester Co Mass ," by C B Breed, *Proceedings* Highway Research Board, Vol 14, p 60

contributions are increased on that account, because more gasoline is requirde to travel a milc at high speed than at moderate speed On the lower types more gasoline is required per mile because of the wavy and rough character of the surface The increase in tax contributions from this cause usually outbalances the slight saving due to lower average speed of operation on these lower types

Annual road costs in columns (9) and (10) for the most part exceed annual contributions in columns (7) and (8) In this connection it should be pointed out that the annual road costs were assembled primarily for comparing one road with another, and therefore include all elements of cost, interest, depreciation and maintenance of all kinds Had this study been undertaken as a tax study to determine whether or not the highways were paying their way, the interest item probably should be omitted, because nearly all of the highways included in this study were built on the pay-as-you-go plan and financed directly from motor vehicle funds The motor vehicle owner provided the original investment, and should not, therefore, be charged interest on his own money In the computation of annual road cost supporting Table I the interest item amounted to about 30 per cent of the total road cost Should the road costs in Table I be reduced by 30 per cent, they would be slightly less than the tax contributions, considering the county as a whole

In order to evaluate and compare every type of road completely, an economic analysis should be extended to include not only road costs but also vehicle operating costs The sum of these less duplications is the cost of transportation In Table I in columns (11) to (14), the cost of transportation for each type of road has been estimated These results are for the purpose of illustration only and not the result of an original research They are based upon a study of published data relating to the vehicle operating costs supplemented by a field examination of the surface condition of the different road types The reliability of the values shown in Table I is dependent upon the accuracy of the ratios adopted in column (11) Before an analysis of this kind can be extended to include the actual measurement of the cost of transportation, some simpler method than any so far devised must be developed for evaluating the cost of motor vehicle operation over an extensive mileage of pavements of different types If a definite relationship exists between road roughness and vehicle operating cost, roughness tests might be made and used to determine indirectly the vehicle operating cost Most states are equipped to make roughness tests, and already have roughness records for many of their roads

The values adopted in column (12) are based upon a compilation of motor vehicle operating costs prepared by J A Johnston, District Highway Engineer for the Worcester District These costs are for average traffic, which is assumed to be made up of 87 3 per cent passenger cars and 12 7 per cent trucks Mr Johnston's figures for high type pavements were applied to reinforced concrete and given a ratio of 1 00 in column (11) The costs for the other types were obtained by applying their adopted ratios to the cost for concrete

The cost of motor vehicle operation includes taxes, a part of which are spent on state highways and therefore appear again in their road cost In order to eliminate this duplication, a deduction has been made in combining road costs and vehicle costs This deduction is shown in column (13), and amounts to about 14/23 of the total motor vehicle tax contributions

The costs of transportation in column (14) vary in nearly the reverse order from the road costs in column (10) That is, although the road costs for the modern types are much higher than those for the lower types, the cost of transportation for these modern types is less than for the old types This is further evidence that the old types should be replaced by modern types In fact, the road costs for these old types could be doubled in order to provide a modern pavement, and still the resulting cost of transportation would be lower than at present due to the saving effected in vehicle operating cost

In conclusion, the purpose of this study was to illustrate the application of an economic analysis to a system of connected highways, and to point out the value and use of the information obtained from such a study In this paper the results are presented graphically in a flow sheet of road costs and contributions This chart shows at a glance the economic relationship between all parts of the highway system studied It points out those roads which appear to have more than their share of development and those which have less It suggests the need of further study to determine the justification for the road costs on those roads which are high in cost and to determine the advisability of improving those roads which are low in cost It serves as a basis for planning highway improvement and studying the effects of such improvement on the system as a whole With certain modifications it can be used to estimate the amount of motor vehicle revenue required for the system, and the proper distribution of expenditures of this revenue among the different highways in the system

The next step in an analysis of this kind would be to prepare a flow sheet of transportation costs, including both road costs and vehicle operating costs This will require the development of a simple method for measuring vehicle operating costs over a considerable mileage of pavements of different type and condition

AIR RESISTANCE OF MOTOR VEHICLES

By L E Conrad

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SYNOPSIS

Tests were made on 54 automobiles in the wind tunnel at Kansas State College in 1932 and 1933 Check tests were made on two cars by coasting down hills

The 54 cars represent 14 makes, 7 yearly models, and 4 body types A succession of yearly models of the same make were secured whenever possible Duplicate wind tunnel tests were made on three cars at a later date and under different atmospheric conditions The greatest individual difference in the duplicate tests was 4 per cent

The authors conclude that

1 A wind tunnel capable of testing full-size automobiles offers a practical