REPORT OF COMMITTEE ON HIGHWAY TRANSPORTATION ECONOMICS

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A GENERAL DISCUSSION OF THE COST OF HIGHWAY TRANSPORTATION AND AN ANALYSIS OF ROAD COST ON TWO MODERATE TRAFFIC STATE HIGHWAYS IN MASSACHUSETTS

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SYNOPSIS

A report of studies conducted in Massachusetts in extension of the theory of road costs presented in the Ninth Proceedings and illustrated in the Tenth Proceedings of the Highway Research Board Cost data for two sections of road are presented The report discusses the application of the cost facts and attempts to answer some of the questions which can be answered by the application of the proposed method to a limited section of a given road and also to those questions which can be only answered by a more extended application of the method to include an entire state, or at least to comprise a completed traffic pattern of considerable extent

It is suggested that cost studies of road systems can be facilitated by grouping the roads geographically into traffic patterns Since the characteristics of these patterns will vary in such respects as topography, traffic use, type of improvement, and extent of improvement comparative studies of them should be very illuminating

The report of the Committee on Highway Transportation Costs published in the Ninth Annual Report of the Board laid the groundwork for consideration of the subject. The basic formula was there proposed, explained, and its application item by item indicated

In the Tenth Annual Report the Committee applied its method to sections of two well-known roads of heavy traffic:—the Boston Post Road in Connecticut and the Des Moines-Ames Road in Iowa The annual traffic on the former was about 6,000,000 passenger vehicles and 675,000 trucks, and on the latter 1,000,000 passenger vehicles and few trucks. The Committee stated emphatically that the costs reached in these two analysis should not be used in any general way, that its report was merely an application of the general method and that, within reasonable limits, it showed only the transportation cost on these particular sections of these particular roads for the traffic then existing.

It had been the intention of the Committee to make a similar analysis of sections of several roads having traffic between 100,000 and 1,000,000 vehicles per year, and to compare these with the results obtained in the study of the two above-mentioned heavily traveled roads Time has permitted an investigation of only two of the several roads of lighter traffic which it had been the intention to study in the Massachusetts State System The two roads that have been analyzed are a seven-mile section of the Concord-Harvard Road (Route 111) and a three-mile section of the Lowell-Tyngsboro Road (Route 113). The annual vehicular traffic on the former road is 370,000 and on the latter 548,000.

The General Problem

It is almost certain that all cost data will be used by agencies impelled to find fragments of facts to support preconceived conclusions. This is almost a certain unfortunate result of the publishment of cost data, but this fact cannot be held to be sufficient reason for failing to publish such data when they are based upon reasonably dependable facts

The Committee divided transportation costs into the two divisions—road cost and vehicle cost This discussion and the following analyses deal almost wholly with road costs

In road cost data, the individual items are all open to more or less criticism, but a careful study of the most vulnerable cost items will reveal that these uncertainties really amount to little when traced through to their effects upon the final values. Unless constructed as a new route within the past twenty years, it would be hard to find any road on which all the costs to date are fully known. This is one of the discomforting facts that confronts one at the start, for one naturally begins to study the costs chronologically. The uncertain facts, however, usually relate to the cost of right-of-way and to the older parts of the road involving low cost surfaces built of local materials, and therefore do not have a large effect upon the total annual road cost as of today

The older pavements became a part of the stage construction of the existing road and are now contributing to the strength of the structure that produces the present road service. The appraisal of the capital value of the older pavements lying under the present pavement may be a subject for considerable difference of opinion Yet, if maxima and minima amounts be assigned to all of these somewhat uncertain items, the resulting cost figures will not in most instances be far apart This is true when the existing pavement is now of a high type, because its high cost masks any range in values we may assign to the underlying old pavements. It is also true in the case where the pavement is still of a low cost type, because the maintenance is so large a part of the yearly road cost as to make the effect of any difference of opinion as to the value of the past road coverings that lie under the present pavement of little importance The more recent capital expenditures on all roads

are usually greater in amount than former expenditures and are a matter of dependable records Generally speaking, there is a greater range in the prediction of yearly and periodic maintenance for the coming few years than there is in the interest on the capital value that may be set upon the older parts of the road

The cost data that have already been published in the Committee's reports have been prepared for the purpose of illustrating the method of approach to the problem But these facts, nevertheless, serve to aid one's judgment relative to certain limited economic problems pertaining to the particular parts of the roads investigated, and to the problems of other sections of road where the conditions are similar Clearly these few results cannot be applied to highway economic problems of a general character The danger of doing so was well brought out in the discussions of the Committee's report at the Tenth Annual Meeting of the Board This discussion as well as the report itself was focussed upon the fact that the report referred only to a limited portion of two roads of heavy traffic It was stated in the discussion that such a survey of transportation costs should cover an entire state So extended an investigation would obviously be an expensive undertaking Yet, if it could be performed with the thoroughness that has been exercised in the transportation surveys which have been made in many of the states, it would be of great value in the study of the larger economic questions

It is believed that the method of analysis suggested by the Committee is as applicable to an entire road system as to a small section of road The more extended such an economic survey is made the more general will be the questions it can answer All of the criticisms of the Committee's studies have so far been focussed upon the danger of an improper application of the results and upon the fear that the publishing of data relating to a short section of road will be used in answering general economic questions These criticisms indicate what has been clear to the Committee, namely, that the type of question the analysis is to attempt to answer or to aid in answering should determine the scope of the investigation An economic survey might include an entire state or group of states, and such an extensive survey should give facts that would aid in showing, for example, whether or not the present gasoline tax and registration fees are reasonable in the district surveyed, it would give a valuable comparison of road and vehicle transportation costs, it might give some indication of the appropriate economic field of motor transport as related to railroad transportation within the area studied

In the extended investigations by the Interstate Commerce Commission of motor truck and bus operation which was reported last spring, the Commission indicated that the evidence pertaining to transportation costs on the highways presented by the railroads was so fragmentary

and incomplete as to give no basis for formulating proposed legislative action The Commission pointed out the desirability, both from the standpoint of the federal and the state governments, of learning the facts of highway transportation costs

A more limited investigation than a full state survey might include a complete traffic pattern which would aid in answering questions of a more regional character than those just enumerated The limits of such a traffic pattern would be a line drawn around a large traffic center (such as a large city) connecting the points where the traffic is the lowest on the radiating roads, and assigning the rest of the radiating roads to some other pattern, and thus dividing the state into a number of adjacent patterns, or traffic areas The patterns at the state border would extend into the adjacent states A traffic pattern study of this sort would give an economic picture of many of the present-day problems of extensive road improvements such as high speed trunk highways, circumferential highways, and grade separations Such improvements usually draw traffic from other roads in the same traffic pattern or affect distribution of traffic in adjacent patterns An economic analysis of the patterns affected is obviously required in studying the justifiableness of the improvement Of course the bare transportation cost figures will not show the value of such improvements The value of time saved, freedom from liability of accidents, commercial and industrial values, and many other intangibles must be given proper weight in justifying the expenditures

The transportation costs of several dissimilar patterns may be used as a basis for cutting short the work of investigating larger areas, for some of the patterns that make up the large system may be so similar in physical character and in amount of traffic as to be closely comparable from an economic standpoint These same patterns, however, may be wholly dissimilar in their capital expenditure program One group may have experienced great improvement, and had much money expended upon improvements in alignment and on high types of pavements The other group may have been composed mostly of roads of no higher type than penetration macadam with the ordinary gravel road predominating (surface treated every other year with a little oil and sand) The total cost of transportation per vehicle mile in these two patterns, therefore, may be quite different One pattern may be in mountainous country, the other over flat terrain, and the vehicle operating cost on these two patterns will then differ It may be possible by intelligent selection of patterns of different topographical conditions, traffic densities, or economic history to develop transportation cost facts that can safely be applied to other similar traffic areas without the necessity of a complete economic survey of an entire state

In all these studies of transportation costs, one must make a clear distinction between the *cost* and the *value* of transportation

Transportation road cost is the cost to the public of the service provided by the given road or system of roads The *value* as well as the *cost* of this same road must be appraised to properly answer the question as to whether or not the public expenditure is justified. Its value may be almost wholly commercial, or it may serve for school transportation and fire protection It may be impossible to express these values in money, yet they may be so obvious as to carry unanimous public approval of a policy involving a road cost well above any saving that can be computed in dollars and cents. The justification, then, of most large highway improvements will not be found wholly in their effect upon transportation cost but rather in their influence on transportation values, of which cost is an element.

Investigation of the cost of vehicle operation on different road conditions needs much extension At present we are obliged to use only general values These costs are rapidly changing year by year, due to many such causes, as commodity prices, more efficient motor vehicles, improvement in riding qualities, and improvement in smoothness of road surface Commodity prices also affect yearly road costs A survey of transportation cost should, therefore, be continued by a yearly program if it is to be of value.

No revision has here been made of vehicle transportation costs used in the Committee's 1930 report merely because of lack of more recent data Obviously the data desired should relate to the particular character of traffic using the particular section of road under investigation and all data should be as of the date of the analysis As the scope of the investigation is broadened geographically, average values for vehicular transportation costs become more nearly applicable

In the four sections of roads investigated by the Committee, the total road cost per vehicle mile ranged from 0 11 cents for passenger cars on the Boston Post Road (Connecticut) to 0 50 cents for passenger cars on the Concord-Harvard Road (Massachusetts) It is interesting to note the fact that in Bulletin No 91 of the Iowa State College Engineering Experiment Station, Professor Agg found considerable variation in the cost of operating on low, intermediate, and high type road surfaces In fact, the variation between the types ran as high as a cent per vehicle mile, an amount greater than the total road cost on roads carrying heavy traffic. The effect of evenness and hardness of pavement surface on savings in vehicle operating costs appears to be so great as to indicate that where the traffic is above, say, 300,000 vehicles per year, there is no excuse (from the standpoint of economics) for permitting a pavement to have any other than a uniform hard pavement surface. This is an example of one of the questions that even the limited investigation the Committee has already made should assist in answering

Another fact shown by the investigations so far made is that the vehicular cost is so much greater than the road cost on roads carrying

over 300,000 vehicles per year that improvements in vehicle design may in any year develop an annual saving in vehicle transportation costs as great as or greater than the annual road transportation cost

There is little doubt but that economies in vehicular operating cost as great as the annual road costs on any of the four roads so far investigated have occurred since 1928 when the Iowa Bulletin No 91 was published It leads one to suspect that the total cost of highway transportation will be reduced much more through perfection of the motor vehicle and its engine than through economies due to improved pavements and maintenance Yet, as vehicle operating costs are lowered, road costs have a greater proportional effect upon the total annual cost These are all added reasons why such cost studies should be carried on from year to year

Transportation costs are needed for the study of intimate problems on limited sections of roads, for the solution of regional problems and for the study of many of the major economic questions of highway transportation and taxation The survey of large geographical scope may be shortened materially by making use of the economic analysis of a traffic pattern which may have been made originally for the study of problems lying wholly within the pattern These cost data should be extended from year to year Such yearly records should uncover some of the mistakes of the past and develop better vision to guide future action They should present a better insight than we now possess into the relative amounts the vehicle owner pays or should pay toward the total transportation cost

Investigations of transportation costs on typical sections of typical roads are of considerable value as the first step toward a comprehensive study of a traffic pattern or of a state system. These isolated studies develop the method to apply to the larger study, and discussion of them should develop the proper course to pursue in making the more extended studies. Approximate road cost of transportation for a given type of road, or for a number of different types forming a traffic pattern can be readily estimated without a detailed analysis by using a chart similar to that prepared by Mr Paustian in his paper presented at the Twelfth Annual Meeting of the Highway Research Board [1] All that needs to be known to use this chart is the type of surface of the road or roads being investigated and the volume of traffic on them A comparison of the road costs as given by the Paustian chart with those obtained in the intimate analysis made on the Des Moines, Tyngsboro, and Concord-Harvard roads shows that they differ only 10 to 15 per cent No comparison could be made for the Boston Post Road because the traffic of 6,750,000 vehicles per year on that road is above the range of the chart Any state may prepare such a chart based upon its own road costs.

[1] See Figure 2, page 57.

The Computation of the Annual Road Cost of that Portion of Massachusetts State Highway No 111 (Concord to Harvard) Lying Within the Towns of Boxboro and Acton

DESCRIPTION OF ROAD

Route No 111 is a secondary or connecting road linking the towns through which it passes with the principal through route of the district which is Massachusetts Route No 2 The length of road studied is 7 28 miles It was constructed in nine sections between the years 1897 and 1913 Table I shows the types of surfaces and dates constructed These original surfaces are all in use today, although their character has been changed by repeated bituminous surface treatments and the width of surfaced road has been increased to about 16 ft by encroachment on the shoulders

The road has an undulating profile The maximum grade is about 6 per cent and grades of 4 or 5 per cent are common The alignment in general is straight with flat curves

COST INDEX

The two portions of Massachusetts State Highways studied in this report were constructed between 1896 and 1913 The Engineering News-Record Cost Index goes back to 1903 only, and could not, therefore, be used to bring costs prior to 1903 down to date It was, therefore, decided to adopt an average of the U S Department of Labor average curves for "Building Materials" and "U S Hourly Wage Scale" for those years prior to 1903, and to use the Engineering News-Record Index for 1903 and subsequent years (See Figure 1)

The reason for using an average of the two curves was twofold first, an inspection of the curves indicated that for the years 1925 to 1932 (which omit the abnormal price variations of the War period) the Engineering News-Record Index lies nearly midway between the two curves, and in the ten years previous to the war it lies sometimes a little above and sometimes a little below these curves, and, second, highway costs are made up of two general items, materials and labor, and both of these should be given prominence in an index to apply to highway costs It is recognized that building materials are not highway materials, and also that labor was probably a much larger factor in highway costs in the '90s than it is today These curves, however, do show the general cost trend and in the absence of any index applicable directly to highway costs, an average of the two is probably as reliable for the period prior to 1903 as the use of the Engineering News-Record Index is for the subsequent period

ROAD COSTS

The road costs were computed in the same order and by the same general method outlined in the Ninth and illustrated in the Tenth Annual Proceedings of the Highway Research Board

Construction Costs

1 Right-of-Way Cost and Property Damage The right-of-way was acquired by the State when the road became a State Highway The dates of acquisition are given in Table I no property damages were paid The financial history of the road previous to these dates is not considered in this report, a town road of local material existed in about the same location before the state highway was built

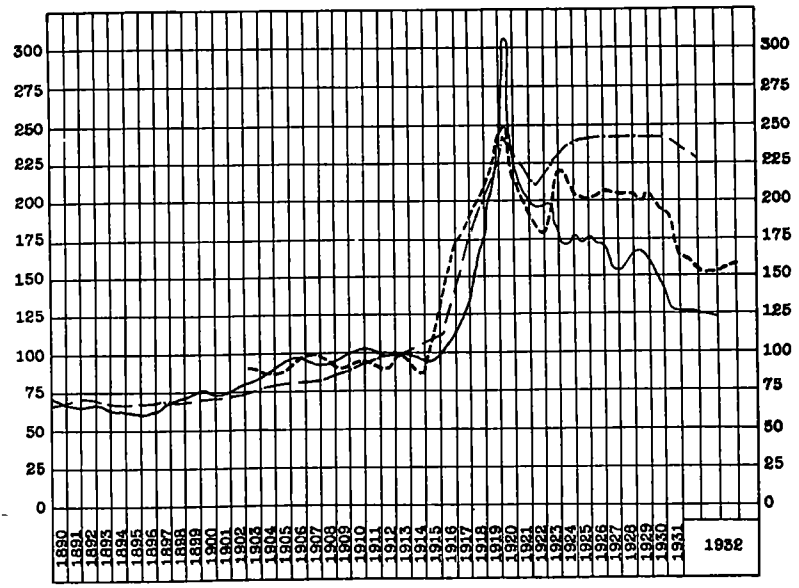

Figure 1. Cost Indices

Building Materials (U S Dept. of Labor)————
U. S. Hourly Wage Scale— — —
Engineering News-Record Const Cost Index----------

The width of the present right-of-way is 60 feet with the exception of 447 feet in Acton which is 50 feet The total area is 52 85 acres

The present value of the right-of-way has been estimated at $100 per acre, which is a fair valuation of land for agricultural and other purposes

Total cost of right-of-way upon this basis is $5,285, or $726 per mile

2 Drainage Structures There are no structures which could be classified as major stream crossings, and there are no bridges

The culverts are all of durable types, such as clay pipe, iron pipe, stone box and concrete box The expenditures for drainage structures

TABLE I

DETAILS OF SURFACES—STATE HIGHWAY ROUTE NO 111—BOXBORO AND ACTON, MASS

Type of surface	Town of Boxboro				Town of Acton				
	Gravel		Water bound macadam		Water bound macadam		Bituminous macadam penetration		
Length of Section, Ft	4529 5	5754	3200	4000	3800	5028 5	3401 5	6000	2716 8
Width, Ft	15	15	15	15	15	15	15	18	18
Year Constructed	1907	1905	1899	1897	1901	1907	1912	1913	1913
Depth of Bottom Course, Inches									
Center			4	4	4	4	4	4	4
Side			2 5	2 5	3	2 5	3	2	2
Depth of Top Course, Inches									
Center			2	2	2	2	2	2	2
Side			1 5	2	2	1 5	2	2	2
Total Depth, Inches									
Center	6	6	6	6	6	6	6	6	6
Side			4	4	5	4	5	4	4
Total Cost, Dollars	3942 84	5672 55	4495 83	6279 17	8794 17	9351 16	7555 69	15,526 36	5498 44

by years is given in Table II which was compiled from records of the Highway Division of the Department of Public Works Each of these items was brought to date (October 1932) by the method described under "Cost Index"

Total Cost of Drainage Structures as of October, 1932, is $14,192, or $1,949 per mile

3 Earthwork and Prior Surfaces Since none of the prior surfaces have become an integral part of the existing wearing surface, no salvage value has been given them

The total cost of earthwork as of October, 1932, was $35,934, or $4,936 per mile (See Table II)

4 Road Surface The total cost of road surfaces as of October, 1932, was $58,728 or $8,067 per mile (See Table II)

TABLE II

ROUTE NO 111—BOXBORO-ACTON

Construction expenditures

Year	Drainage structures	Earthwork	Surface	Miscellaneous	Engineering, administration and inspection	Total
1897	$600 00	$1,608 34	$3,300 00	$200 00	$570 83	$6,279 17
1899	332 00	1,353 22	2,292 50	109 40	408 71	4,495 83
1901	1,536 80	2,069 50	4,305 40	83 00	799 47	8,794 17
1905	482 81	3,001 75	1,275 30	397 00	515 69	5,672 55
1907	2,451 70	4,015 10	4,879 75	738 90	1,208 55	13,294 00*
1912	1,183 59	1,547 40	4,062 82	75 00	686 88	7,555 69
1913	861 80	5,912 00	11,685 71	653 95	1,911 34	21,024 80†
Totals	$7,448 70	$19,507 31	$31,801 48	$2,257 25	$6,101 47	$67,116 21

* The costs for 1907 include two projects (see Table I) These two projects had different type of surface

† The costs for 1913 included two projects (see Table I), both of which had same type of surface

5 Miscellaneous Construction Costs These include such items as fences, stone bounds, and paving in gutters Bringing the costs in Table II to date gives total cost of miscellaneous expenses as of October, 1932, as $4,102, or $563 per mile

6 Engineering and Administration Engineering administration and inspection has been taken as 10 per cent of the cost in each year, since this is the amount that had to be added to the actual construction costs to give the total expenditure The costs for Engineering, Administration and Inspection given in Table II were obtained by adding the costs for drainage, earthwork, surface and miscellaneous and taking 10 per cent of the sum

The Engineering and Administration costs thus obtained were brought to date in the same manner as other costs in Table II, giving a total as of October, 1932, of $11,295, or $1,551 per mile

Summary of Construction Costs as of October, 1932

Item 1.	Right-of-Way	$5,285
2	Drainage Structures	14,192
3	Earthwork	35,934
4	Road Surface	58,728
5	Miscellaneous Construction Costs	4,102
6	Engineering and Administration	11,295
	Total Construction	$129,536
	Total Construction per Mile	17,793

Maintenance Costs

Since the maintenance costs of a road of this general type are so great a part of the total road cost, it has seemed advisable to analyze them more in detail than was done in the case of the two roads treated in the Tenth Proceedings

Furthermore, the items making up the total yearly maintenance have been grouped hereunder in a manner somewhat different from the classification used in Figure 1, page 362, of the Ninth Proceedings

TABLE III

SURFACE MAINTENANCE COSTS

Towns of Boxboro and Acton

Year	1927	1928	1929	1930	1931	Average 1927–1931	Average cost per mile 1927-1931
Repairs	$575 90	$1888 23	$2203 35	$1142 59	$525 96	$1267 20	$174 11
Treatment	1798 58	1937 21	1893 21	3305 72	2236 13	2234 18	306 98
Road Bed	1058 12	990 04	199 81	322 27	434 00	600 84	82 55
Total	$3432 60	$4815 48	$4296 37	$4770 58	$3196 09	$4102 22	$563 64

Annual maintenance has been divided into three general classes as follows.

(1) surface maintenance
(2) right-of-way maintenance
(3) operation maintenance

Surface and right-of-way maintenance costs are compiled annually by the Maintenance Department of the Highway Division Similar records are kept for certain, although not all, of the items that go to make up Operating Maintenance Costs

1 Surface Maintenance has been further subdivided into three kinds· "repairs," "treatment," and "road bed" (See Table III)

"Repairs" includes cost of repairs to the surface such as patching

"Treatment" includes cost of surface treatments of tar or asphaltic oil and sand

"Road Bed" includes cost of repairs to foundation or base course.

An average for the five years, 1927–31, has been assumed in this analysis as representing the yearly maintenance cost

Some portion of this section of road is treated every year, so that the surface treatment is an annual rather than a periodic maintenance

2 Right-of-Way Maintenance has likewise been subdivided into "drainage," "right-of-way," and "trees" See Table IV

"Drainage" includes repairing and cleaning drainage structures and cleaning out ditches

"Right-of-way" includes the care of shoulders and roadside structures, such as fences

"Trees" includes cost of clearing out brush and trimming trees within the right-of-way to improve visibility and beauty of roadside Planting trees is included in this item

An average for the five years, 1927–31, has been used in this analysis

TABLE IV

RIGHT-OF-WAY MAINTENANCE Cost

Route No 111—Towns of Boxboro and Acton Length 7 278 miles

Year	1927	1928	1929	1930	1931	Average 1927–1931	Average cost per mile 1927–1931
Drainage	$323 03	$69 15	$152 35	$100 40	$215 75	$172 14	$23 65
Right-of-Way	653 84	715 04	478 29	104 56	1243 65	639 08	87 81
Trees	96 96	1 25	123 44		22 95	48 92	6 72
Totals	$1073 83	$785 44	$754 08	$204 96	$1482 35	$860 14	$118 18

3 Operating Maintenance includes the expenses incurred for such items as, traffic signs, lines, signals, and traffic counts, snow removal, policing, registration cost, and gas tax collection

Expenditures for traffic lines on the Boxboro-Acton road average $61 for the years 1927–1931 Cost of traffic engineering, signs, and traffic counts for the State was $165,600 for the year ending November, 1931 Proportioning this cost on the basis of vehicle miles gives $74 per year for the section of road analyzed The sum of these two items is $135, or $18 50 per mile

Costs of snow removal were as follows $528 in 1929, $1246 in 1930, and $3544 in 1931 The snowfall for these years was 44 8 inches, 29 9 inches, and 63 6 inches, respectively Although the snowfall in 1929 was more than in 1930, the actual cost of removal was less This wide variation in annual expenditure also occurs in the costs for the entire State in these same three years, and may be explained by the fact that ploughing was not as generally or thoroughly done in 1929 as in later years. The 1929 cost was therefore disregarded and the average of

1930 and 1931 costs was used after being modified to apply to the average snowfall in the district (49 inches), as follows

$$\left(\frac{1246}{29\ 9} + \frac{3544}{63\ 6}\right)\frac{49}{2} = \$2385, \text{ or } \$328 \text{ per mile}$$

No actual records were available for the cost of policing the section or Route No 111 in Boxboro and Acton The road is patroled, but, as it is a secondary road with light traffic, the patrol is not frequent, probably once or twice a day The policing cost chargeable to this road was obtained by the following method The total cost of policing all Massachusetts State Highways in 1931 was $827,370 (obtained from State Police Headquarters, Department of Public Safety) The total vehicle miles traveled on Massachusetts State Highways in 1931, estimated from gasoline consumption, was 6,000,000,000 Prorating this cost on the basis of vehicle miles gives $370 per year or $51 per mile per year This figure is about $1 per day which is not an unreasonable charge for patroling 15½ miles of road (7 28 miles once each way)

The total cost of maintaining the Massachusetts Registry of Motor Vehicles for 1931 was approximately $1,580,000 Apportioning this by vehicle mileage as was done for policing costs gives $710, or $97 50 per mile

In Massachusetts the gas tax is collected by the Department of Internal Revenue which is also engaged in many other tax collections The expenses of this Department chargeable to the collecton of the gas tax are not over $2000 The amount is so small that it may be neglected in this analysis

Summary of Operating Maintenance Costs

Traffic Signs, Lines, and Signals	$135
Snow Removal	2385
Policing	370
Registration Cost	710
Total Operating Maintenance	$3600
Total Operating Maintenance per Mile	494

Summary of Annual Maintenance Costs

(1) Surface Maintenance	$4102
(2) Right-of-Way Maintenance	860
(3) Operating Maintenance	3600
Total Maintenance	$8562
Total Annual Maintenance per Mile	1176

Periodic Maintenance It is probable that the annual maintenance cost computed for Route No 111 will continue to provide a suitable road for the existing traffic for five years hence and that then reconstruction will be required The average age of the 7 28 miles of pavement at that time (1937) will be about 30 years The cost to resurface

the existing pavement so that it will adequately serve existing traffic is estimated at $10,000 per mile, or $72,800 for the 7 28 miles It is further assumed that, with the same annual maintenance cost as computed for present pavement, this new pavement would have to be replaced every 20 years The interval between replacements is less than the life of the present pavement, because the present pavement carried only light traffic during the first part of its life The annual deposit at 4 per cent interest compounded annually that will accumulate $72,800 every 20 years is $2445 for the entire section, or $336 per mile

The charge of $336 per mile for periodic maintenance is assumed to provide in perpetuity a pavement equivalent to the present one and sufficient to serve present traffic When the reconstruction is made in 1937, the pavement probably will not be replaced in kind but a higher type will be constructed and minor changes made in alignment and grades, so that the first reconstruction in 1937 will be a betterment as well as a replacement The present road is narrow, has a high crown and is improperly banked at curves The policy of the Massachusetts Highway Division has been to reconstruct roads similar to the Concord-Harvard Road with either bituminous penetration macadam or bituminous concrete, to widen pavements to a minimum of 20 feet and to reduce crown and curvature to meet the requirements of modern traffic When this better pavement is constructed it will modify the annual road costs by increasing the interest on capital and decreasing the maintenance At that time a new estimate of annual road costs must be made

For example, if $25,000 per mile is spent five years hence in reconstructing the road instead of $10,000 per mile, the betterment value will be $15,000 per mile which should be added to the capital cost of the road Interest at 4 per cent on this amount is $600 per year The $10,000 is absorbed in periodic maintenance This higher type pavement should last longer, say 25 years, but will cost more for periodic maintenance, say $15,000 per mile for resurfacing in kind On this basis the annual charge for periodic maintenance for the higher type pavement will be $360 per mile, or $24 more than the $336 computed above for replacing the old surface in kind The annual saving in maintenance effected by adopting the higher type surface is estimated at $440 per mile, based on records of the State Highway Division Combining these costs gives a net increase in annual road cost of $600 + $24 − $440 = $184 This indicates that after the contemplated improvement the annual road cost will be only slightly greater than now, which will justify the proposed improvement

Engineering and Administration on Maintenance The records of the Fourth Maintenance District which includes both the Concord-Harvard and Tyngsboro roads show the following costs for the years 1931 and 1932

	1931	1932
Maintenance including Snow Removal	$257,576	$228,142
Supervision Salaries, Expenses, Office Overhead, Auto Charges	23,757	25,515
Supervision of Maintenance	9 2%	11 2%
Average for Years 1931 and 1932	10 2%	

Adopting this average percentage as typical, the maintenance items to which it applies are as follows

Surface	$4102
Right of Way	860
Snow Removal	2385
	$7347

10 2 per cent of $7347 is $749 or $103 per mile

TABLE V

CALCULATION OF ANNUAL COST

State Highway Route No 111, Boxboro and Acton, Massachusetts

Interest on Investment at 4%	$5,181
Annual Maintenance	8,562
Periodic Maintenance	2,445
Engineering and Administration on Maintenance	749
Total Annual Road Cost	$16,937
Annual Road Cost per Mile	2,327

Annual Road Cost Apply the basic formula for road costs as given on page 341 of the 10th Annual Report

$$C = r\left(A + \frac{B}{r} + \frac{E}{(1+r)^n - 1} + \frac{E'}{(1+r)^{n'} - 1} \cdot \text{ etc}\right)$$

wherein

C = Average annual road cost

A = Cost to construct = $129,536

B = Annual maintenance cost (every year) = $8562

E = Expenditure for periodic reconstruction every n (= 20) years = $72,800

r = Rate of interest prevailing for current state funds in Massachusetts = 04

The results are set forth in Table V

TRAFFIC

Latest counts made by the State Highway Division give the annual Traffic as 338,000 passenger cars, 17,000 trucks of 2-tons capacity and less, and 15,000 trucks of over 2-ton capacity

These amounts are the averages of observations taken in 1930 at two

different stations, viz , at the junction of Routes 111 and 2, and in the town of Harvard at the junction of Routes 111 and 110 The former is at the east end of the section investigated, the latter is two miles west of the other end of the section but there are no roads joining Route 111 in that two-mile stretch The counts were actually taken for one day in August and then expanded for the week, month and year by correlating them to a comparable station on Route 2 where counts were taken for a continuous week in August, then the yearly expansion was made on the basis of gasoline purchased

Motor Vehicle Operating Costs

In the analysis of the sections of Boston Post Road and of the Des Moines-Ames Road, the motor vehicle operating costs were arbitrarily assumed to be 5 44 cents per mile for passenger automobiles, which was the cost of operating the "average" passenger car of the Iowa Engineering Experiment Station investigation in 1928, for the average commercial vehicle 15 15 cents per mile was used, which was obtained from results of an investigation made by General Motors Corporation in 1929 These costs were both for high type pavements For intermediate type pavements like the Concord-Harvard road passenger vehicle operating costs were 6 43 cents per mile, corresponding truck costs would be about 17 cents per mile

These costs are higher than prevail today, but present day values are not available In the absence of up-to-date costs, the above figures may be used although probably they are too large Investigations are underway which when published will give more current costs which can then be readily substituted for the obsolete ones

Total annual transportation cost per mile is merely the sum of the road and vehicle costs

Contribution to Road Funds

The gas tax and registration and license fees comprise this item In Massachusetts a three cent gas tax prevails (exclusive of Federal Tax) In 1931 the gas tax amounted to $15,306,376 of which $12,535,626 was spent on state highways Assuming the average passenger car travels 14 miles on a gallon of gasoline, that trucks of 2 tons or under capacity travel 9 miles per gallon, and that the truck of over 2 tons capacity travels 6 miles per gallon, the motor vehicles using this Boxboro-Acton section of road contributed per mile through the gas tax $724 for passenger cars, $57 for light trucks, $75 for heavy trucks, or a total of $856 of which $\frac{125}{153}$ = $699 went to state roads

The registration and license receipts of $7,000,306 were all devoted to State highways and administration of the Registry Allocating this amount on the basis of vehicle miles (assuming 6,000,000,000 for the

entire state) gives $3143 for the entire section, or a contribution through registration and license fees of $432 per mile

The total contribution was then $1131 per mile, which is about 49 per cent of the annual road cost

If we apportion the annual road cost on the basis of tons of traffic, assuming passenger vehicles to average $1\frac{1}{4}$ tons, loaded light trucks 3 tons, and loaded heavy trucks 7 tons, we will assign $1700 to passenger cars, $205 to light trucks, and $422 to heavy trucks These road costs correspond to 0 50 cents per passenger vehicle mile, and 1 96 cents per truck mile

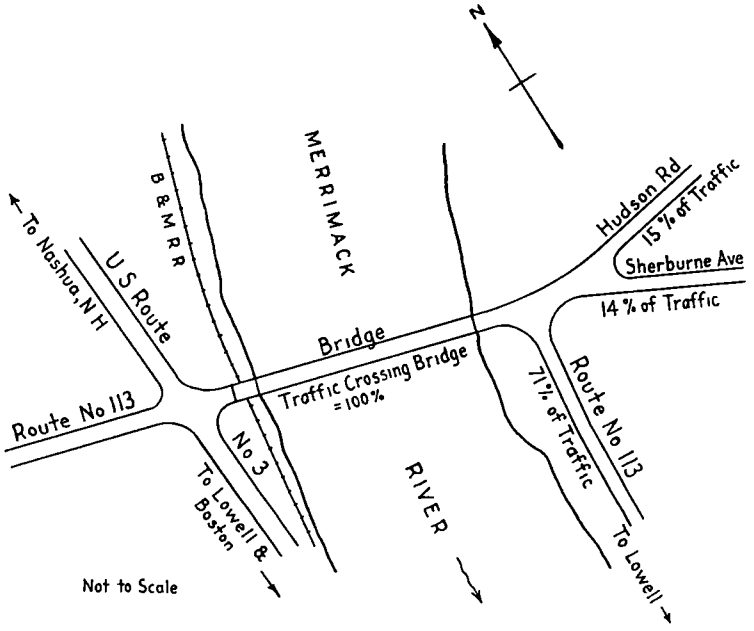

Figure 2. Sketch Map—Tyngsboro Bridge

Distribution of bridge traffic:

	Per cent
Crossing bridge from and to Hudson Rd	13
Crossing bridge from and to Sherburne Ave	14
Crossing bridge from and to Route No 113	71
Total vehicles crossing bridge	100

Computation of the Annual Road Cost of That Portion of Massachusetts State Highway No 113 (Tyngsboro to Lowell) Lying within the Town of Tyngsboro

Route No 113 is a secondary, or connecting, route traversing northeastern Massachusetts The portion of the route studied in this report follows the easterly bank of the Merrimac River in the town of Tyngsboro The section is 2 94 miles long and extends from the Lowell-Tyngsboro boundary to the bridge over the Merrimac River in

Tyngsboro The section carries only a moderate amount of traffic, as most of the cars coming down the Merrimac Valley from New Hampshire follow U S Route No 3 which parallels this portion of Route No 113 on the westerly side of the river (See Fig 2)

The Tyngsboro Bridge joins U S Route No 3 and State Route No 113 This bridge is a steel through arch of 546-foot span, erected in 1930–31 The apportionment of the cost of this structure to the roads it serves will be considered in a separate discussion at the end of the analysis

The section of Route No 113 studied was constructed as a new highway during the years 1895–1897 The type of surface was water-bound macadam, 15 ft wide with 3 ft gravel shoulders The broken stone was laid in two courses with a total depth of 6 in at the center of the road and 5 in at the sides The original surface has never been reconstructed, although it has had repeated bituminous surface treatments

The road is flat in profile and there are few curves

TABLE VI

ROUTE NO 113—TYNGSBORO

From Lowell-Tyngsboro Line to Tygnsboro Bridge = 2 942 miles of State Highway

Actual construction expenditures

Year	Drainage structures	Earthwork	Surface	Miscellaneous	Engineering, administration and inspection	Total
1895	$1,562 18	$5 909 32	$5,066 63	$393 09	$461 94	$13,393 16
1896	800 92	3,020 75	11,924 99	395 91	565 85	16,708 42
1897		266 17	3,696 19	132 14	728 54	4,823 04
Totals	$2,363 10	$9,196 24	$20,687 81	$921 14	$1,756 33	$34,924 62

COMPUTATION OF ANNUAL ROAD COST

Construction Costs

1 Right-of-Way The right-of-way was acquired in 1895 and 1896 It is 60 ft wide and has an area of 21 4 acres Assuming the present value of the land for agricultural and other purposes at $100, if the road were not there, then the present value of the right-of-way is $2140, or $727 per mile

2 Drainage Structures (a) Ordinary structures The expenditures for drainage structures by years is given in Table VI These costs were brought to date by the method described under "Cost Index" The total cost of Drainage Structures as of October, 1932, is $5727, or $1947 per mile

(b) Major Stream Crossings The Tyngsboro Bridge over the Merrimac River lies adjacent to the section of road being studied The

proportioning of the cost of this structure is discussed later in the report

3 Earthwork and Prior Surfaces There were no prior surfaces The expenditures for earthwork are tabulated by years in Table VI The total cost as of October, 1932, is $22,246, or $7561 per mile

4 Road Surface The expenditures for road surface are tabulated by years in Table VI The total cost as of October, 1932, is $49,817, or $16,933 per mile

5 Miscellaneous Construction Costs These include fences, cobble gutters and dry rubble masonry The expenditures for these items by years are tabulated in Table VI The total cost as of October, 1932, is $2217, or $754 per mile

6 Engineering and Administration These costs were also available and are tabulated by years in Table VI The total cost as of October, 1932 is $4153, or $1412 per mile

TABLE VII

SURFACE MAINTENANCE COSTS

Route No 113—Town of Tyngsboro Length 2 942 miles

Year	1927	1928	1929	1930	1931	Average 1927–1931	Average cost per mile 1927–1931
Repairs	$427 87	$352 18	$359 69	$182 67	$114 15	$287 31	$97 66
Treatment .	378 00	460 70	851 67	1061 40	1122 71	774 90	263 39
Road Bed	121 90	236 07	454 02	296 01	272 02	276 00	93 81
Total	$927 77	$1048 95	$1665 38	$1540 08	$1508 88	$1338 21	$454 86

Summary of Construction Costs as of October, 1932

Item 1	Right-of-Way	$2,140
2	Drainage Structures	5,727
3	Earthwork	22,246
4	Road Surface	49,817
5	Miscellaneous Construction Costs	2,217
6	Engineering and Administration	4,153
	Total Construction Cost	$86,300
	Total Construction Cost per Mile	29,334

Maintenance Costs

Annual Maintenance is grouped under the three headings Surface Maintenance, Right-of-Way Maintenance, and Operating Maintenance as was done for Boxboro-Acton section of Route 111

1 Surface Maintenance Table VII shows annual surface maintenance costs for the Tyngsboro road for 1927–1931 The average for these five years has been assumed to represent the yearly maintenance cost This average is $1,338, or $455 per mile

2 Right-of-Way Maintenance Table VIII shows annual right-of-way maintenance costs for 1927–1931 The average of these five years is $192, or $65 per mile

3 Operating Maintenance This item has been divided into traffic, snow removal, policing, and registration costs

The annual costs of each of these estimated in the same manner as for the Concord-Harvard road are as follows

Traffic Signs, Lines, and Counts	$62
Snow Removal	962
Policing	222
Registration Cost	424
Total Operating Maintenance	$1670
Total Operating Maintenance per Mile	568

Summary of Annual Maintenance Costs

(1) Surface Maintenance	$1338
(2) Right-of-Way Maintenance	192
(3) Operating Maintenance	1670
Total Maintenance	$3200
Total Annual Maintenance per Mile	1088

TABLE VIII

RIGHT-OF-WAY MAINTENANCE COSTS

Route No 113—Town of Tyngsboro Length 2 942 miles

Year	1927	1928	1929	1930	1931	Average 1927–1931	Average cost per mile 1927–1931
Drainage	$53 29	$21 50	$28 00	$71 27	$46 39	$44 09	$14 99
Right-of-Way	5 00	317 54	3 00	145 15	248 10	143 75	48 85
Trees	8 40	4 65			7 50	4 11	1 40
Totals	$66 69	$343 69	$31 00	$216 42	$301 99	$191 95	$65 24

Periodic Maintenance It is probable that the annual maintenance cost computed above will continue to provide a suitable road for the existing traffic for 10 years hence and that then reconstruction will be required The cost to replace the surface of the existing pavement so that it will adequately serve existing traffic is estimated at $10,000 per mile, or $29,400 for the entire section It is further assumed that, with the same annual maintenance cost as computed for present pavement, this new pavement would have to be replaced every 20 years The age of the existing pavement when first resurfaced in 1942 will be about 45 years It can not be assumed, however that after resurfacing the new pavement would last another 45 years, because the present pavement has carried only light traffic during most of its life The present traffic probably represents the maximum that the road has carried Therefore 20 years has been assumed as the life of pavement for the existing traffic.

The annual deposit at 4 per cent interest compounded annually that will accumulate $29,400 every 20 years is $987 for the entire section, or $336 per mile

The charge of $336 per mile for periodic maintenance is assumed to provide in perpetuity a pavement equivalent to the present one and sufficient to serve present traffic When the reconstruction is made in 1942, the pavement probably will not be replaced in kind but a higher type will be constructed and minor changes made in alignment and grades, so that the first reconstruction will be a betterment as well as a replacement The present road is too narrow and has too high a crown to be classed as a modern highway The policy of the Massachusetts Highway Division has been to reconstruct similar roads with either bituminous penetration macadam or bituminous concrete, to widen pavements to a minimum of 20 feet to reduce crown and curvature to meet the requirements of modern traffic When this better pavement is constructed it will modify the annual road costs by increasing the interest on capital invested and decreasing the annual maintenance At that time a new estimate of the annual road costs must be made

Engineering and Administration on Maintenance The Engineering and Administration is assumed to be 10 2 per cent of the total of surface maintenance, right-of-way maintenance, and snow removal costs, by the same reasoning used for the Concord-Harvard road

Surface Maintenance	$1338
Right-of-Way	192
Snow Removal	962
	$2492

10 2 per cent of $2492 is $254, or $86 per mile

Annual Road Costs The above costs are assembled in Table IX

TABLE IX

CALCULATION OF ANNUAL COST

State Highway Route No 113, Tyngsboro, Massachusetts

Interest on Investment at 4%	$3452
Annual Maintenance	3200
Periodic Maintenance	987
Engineering and Administration on Maintenance	254
Total Annual Road Cost	$7893
Total Annual Road Cost per Mile	$2685

TRAFFIC

Latest counts made by the State Highway Division give the annual traffic as 500,000 passenger cars, 17,500 trucks of 2 tons capacity or less, and 30,500 trucks of over 2 tons capacity

These amounts are based on counts taken on two days in November, 1932, at the easterly end of Tyngsboro Bridge, correlated with more extensive counts taken at other stations in the district

Contribution to Road Funds

The gas tax and registration and license fees comprise this item In Massachusetts a three cent gas tax prevails (exclusive of Federal Tax) In 1931 the gas tax amounted to $15,306,376 of which $12,535,626 was spent on state highways Assuming the average passenger car travels 14 miles on a gallon of gasoline, that trucks of 2 tons or under capacity travel 9 miles per gallon, and that trucks over 2 tons capacity travel 6 miles per gallon, the motor vehicles using this Tyngsboro section of road contributed per mile through the gas tax $1071 for passenger cars, $58 for light trucks, and $152 for heavy trucks, or a total of $1281 of which $1\frac{2}{5}\frac{5}{3}$ = $1046 per mile went to State roads

The registration and license receipts of $7,000,306 were all devoted to state highways and administration of the Registry Allocating this amount on the basis of vehicle miles (assuming 6,000,000,000 for the entire state) gives $1879 for entire section, or a contribution of $639 per mile

The total contribution was then $1685 per mile, which is about 63 per cent of the annual road cost

If we apportion the annual road cost on the basis of tons of traffic, assuming passenger vehicles to average $1\frac{1}{4}$ tons, loaded light trucks 3 tons, and loaded heavy trucks 7 tons, we will assign $1883 to passenger cars, $159 to light trucks, and $643 to heavy trucks These road costs correspond to 0 38 cents per passenger vehicle mile, and 1 67 cents per truck mile

Tyngsboro Bridge

An old highway bridge was constructed across the river in 1874 which was abandoned in 1931 when a new structure costing $322,000 replaced it The old structure was of no value to the new one it was demolished An arbitrary half of the cost of the bridge is assigned to the highways on on each side of the river This makes $161,000 assigned to the roads that approach it on the east side (see Fig 4) Of these roads, Route 113 has 71 per cent of the traffic that crosses the bridge It is 6 miles from this bridge downstream to the next bridge at Lowell, the section of road under study is the 3 miles adjacent to the new bridge of the 6-mile stretch On the 6-mile stretch between the bridges, there are practically no connecting roads Most of the traffic is bound to or from Lowell or cities along the coast, and, practically all of these vehicles travel the entire 6 miles in making use of the Tyngsboro Bridge Most of these vehicles could have crossed the river at Lowell but used Route No 113 to avoid the heavier traffic on U S Route No 3 It seems fair there-

fore to charge against this 3-mile section $\frac{3}{11} \times 0.71 \times \$161,000 = \$57,155$, or \$19,440 per mile Interest on this investment at 4 per cent = \$778 annual cost per mile

The new bridge is a steel arch of 546 ft span, supporting, a reinforced concrete highway forming the floor system It is the type of bridge which will be able for many years to carry any loads that the highways joining it can carry It is proper in this type of structure to put all maintenance into the form of an average annual amount In the absence of any figures (since the bridge is new) \$1,000 has been assumed as ample yearly maintenance to keep this bridge in serviceable condition for the next hundred years or more The portion chargeable to the 3-mile section of Route No 113 is $\frac{3}{11} \times 0.71 \times \$1000 \times \frac{1}{2} = \$177$, or \$60 per mile

TABLE X

COMPARISON OF ANNUAL ROAD COSTS

Road	Yearly traffic			Gas tax		Per mile	
	Total vehicles	Passenger cars	Trucks	Total	To state	Annual road cost	Contribution by vehicle owners
Boston Post, Conn	6,750,000	6,075,000	675,000	2¢	2¢	\$9,445	\$19,703
Des Moines-Ames, Iowa	1,000,000	0	0	3¢	1 7¢	2,620	2,240
Tyngsboro, Mass	548,000	500,000	48,000	3¢	2 45¢	2,685	1,685
Tyngsboro, Mass (including bridge)	548,000	500,000	48,000	3¢	2 45¢	3,523	1,685
Concord-Harvard, Mass	370,000	338,000	32,000	3¢	2 45¢	2,327	1,131

On these assumptions the total annual cost of the Tyngsboro Bridge chargeable to the Tyngsboro road is \$838 per mile, which is equivalent to about 31 per cent of total of all other road costs

Adding this \$838 to the other cost \$2685 gives \$3523 as the total road cost, which is 50 cent per passenger vehicle mile and 2 19 cents per truck vehicle mile, allocated to the two classes of vehicles in proportion to their weight

Table X gives a condensed picture of the road costs on the sections of the four roads so far investigated by the Committee It seems to indicate roughly that, provided the State spends two cents of the gas tax upon roads, the vehicle owners are paying the total road costs in gas tax and registration fees only on those roads that carry over 1,000,000 vehicles per year

In Massachusetts, which has the densest state highway traffic, 61 per cent of the total 1640 miles carry over 1,000,000 vehicles per year, but in many states the mileage that carries that amount of traffic is negligible or does not exist.

In the four roads given in Table X, part of the gas tax did not go to the state roads but was used on county or city roads, which of course serve the motor vehicle owner It is therefore equitable in these analyses of state roads to treat as contributions only that portion of the gas tax that was actually expended by the state on roads, but in those states where some of the gas tax receipts are expended for purposes other than roads the motor vehicle owner should be given credit for his full contribution

A cent or two added to the gas tax (if applied wholly to state roads) would considerably change the amounts in the last column of the table It is also evident from this table that a gas tax of four to six cents in states having many miles of highways with light traffic may be consistent with a three cent tax in Massachusetts, Connecticut or New York

The Committee gratefully appreciates the assistance given by the officials of the Highway Division of the Department of Public Works of Massachusetts

The figures used in this report have not been verified by the Department of Public Works nor have they had an opportunity to criticize them, and therefore the responsibility for their use lies wholly with the Committee

The correlation and assembly of data and computations of road costs were done by Mr Alexander J Bone, under the general direction of the author

A STUDY OF COSTS ON VARIOUS TYPES OF HIGHWAYS

By Raymond G Paustian

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SYNOPSIS

A discussion of the various items that go to make up the cost of highway transportation including roadway costs, vehicle operating costs and contributions to road funds through gasoline taxes and license fees On the basis of average values for the different items a table is presented showing the relations between operating costs, tax contributions, and annual roadway costs for various traffic volumes on the three types of roads Based on the assumptions necessarily made an annual traffic of 675,000 vehicles apparently contributes enough through taxes, on the average to pay the annual cost of a high type road

"A knowledge of all of the factors entering into total cost of transportation is needed to furnish a basis for the equitable taxation of vehicles, for the proper layout of highway improvement programs, and for the economic design of roads In other words, *highway transportation cost* is a dominant factor in the solution of all highway problems

In planning an improvement program, the type of improvement