In the case of an ordinary utility it is necessary for the utility to make an annual depreciation appropriation out of income to make good the depreciation each year, but they do not set it aside in a sinking fund the way this question assumes They reinvest it, and that is what we are doing with our highways out of current road funds We are making replacements and improvements on old roads and are building new roads, all of which constitute investments of the sums which we collect over and above the cost of maintaining the roads

ANALYSIS OF ROAD COST ON THE STATE HIGHWAYS OF WORCESTER COUNTY, MASSACHUSETTS

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SYNOPSIS

The report presents the methods used in analyzing road costs on the state highways of Worcester County, Massachusetts The complete analysis will include about 300 miles of state highways, which in their physical layout and traffic densities constitute a traffic pattern, such as has been suggested by the author as a unit for studying road costs

Complete data are included for one typical continuous route, comprising 27 miles of state highway in 23 sections of different surface type, width or condition, and with traffic densities ranging between 870,000 and 3,700,000 vehicles per year Three tabulations have been prepared. the first giving descriptions of surfaces and annual maintenance costs, the second giving construction history and computation of capital costs, and the third summarizing the above and showing computation of annual road costs by an approximate method, and in comparison the annual contributions paid in state taxes by vehicles using the different sections

Previous reports of the Committee on Highway Transportation Economics have presented analyses of road cost for a 6-mile section of the Boston Post Road in Connecticut and a 26-mile stretch of the Des Moines-Ames road, Iowa (1930), and for the Concord-Harvard and the Tyngsboro roads (about 7 miles and 3 miles long, respectively) in Massachusetts (1932) Those studies related to isolated portions of roads having different traffic densities They were not intended to develop road costs for general use, their purpose was to develop the application of the fundamental principles set forth in the report of the Committee in 1929

The current study comprises the State System in Worcester County in Massachusetts because it constitutes a traffic pattern centering in the City of Worcester which has a population of 195,300 (See Figure 1) A statewide study could be readily developed by investigating the remaining county highway systems and assembling them Much the same problems would be encountered in studying one county as in studying an entire state The State System of Massachusetts is especially suitable for such studies because construction and maintenance costs have been kept since 1895 and traffic counts made since 1909

Worcester County was chosen because it comprises the center portion of the state and represents a fair average of Massachusetts conditions both with respect to topography and traffic density Furthermore, most types of pavement are represented in this study, they vary from waterbound macadam 15 feet wide and 35 years old to cement concrete 60 feet wide and 2 years old Traffic densities on the state highways of this county vary from 1000 to 10,000 vehicles per average day

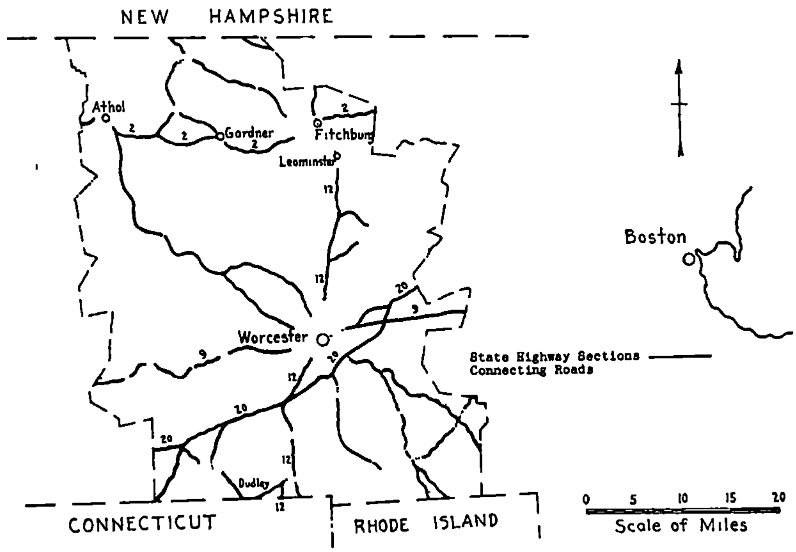


Figure 1 State Highways in Worcester County, Massachusetts

The City of Worcester is the center of a traffic pattern from which roads of heavy traffic density radiate, diminishing in density toward the county boundaries to the east, south and west where they join other patterns To the north there are minor patterns within the county, centering about Fitchburg and Gardner Worcester County has about 4300 miles of rural road of which 319 miles are state highways The portions of these routes lying within the business sections of towns and cities are usually not included in the State System and were therefore omitted from this study Route markings are of necessity continuous, including alternate sections of state and town road as indicated in road descriptions in Table I

An analysis of road cost on these town or city sections would be difficult to make, because it would be necessary to examine the records of each town or city involved In some cases reliable cost data would not be available, and in other cases the methods of accounting would vary so much between towns that costs would not be comparable There are, however, many miles of state-aid roads in Massachusetts for which cost records are available, these town roads are built by the state, but are financed partly by the state and partly by the town or county concerned In many states these state-aid roads would be a part of the state highway system, but in Massachusetts they remain town roads and are therefore not included in this study By limiting this study to state highways only, the scope of the study has been limited, with few exceptions, to heavily traveled roads, because in Massachusetts the state highway system includes only 10 per cent of the total rural mileage, upon which the heaviest rural traffic is concentrated.

DESCRIPTION OF ROADS ANALYZED

The state highway system of Massachusetts has been built up section by section over a period of 37 years and is therefore made up of great diversity of kinds and ages of pavements Within a given mile of road there are often several types of pavement While this diversity of pavements makes a study of road cost more lengthy than would be the case if, as in many states, long sections had been built at one time, yet it also offers an opportunity to compare several types of pavement under nearly identical traffic conditions

In this report a complete analysis is presented for only one typical route within the Worcester pattern Other routes may show different costs, but the method of analysis will be the same The typical route which has been chosen is State Highway Route No 12, which is described in Table I, columns (1) to (18) The surfaces are arranged in consecutive order from Leominster at the north to the Connecticut Line at Dudley to the south Nearly every kind of pavement used on Massachusetts state highways exists on this route. The portions of town or city roads are indicated in Table I where they connect sections of state highway The descriptions of pavement details were obtained from the state maintenance files and are complete only for the more recent pavements The descriptions of old pavements which are missing from Table I could have been filled in from project plans or construction records As these descriptions were considered relatively unimportant, the necessary time was not taken for this work

The data are arranged according to two route numbering systems as indicated in columns (1) and (2) The "Auto Route No ," column (1), refers to the number with which route is marked out on the road, the "Maintenance Route No ," column (2), gives the number used by the Maintenance Engineer in keeping cost and descriptive data The auto route may change from year to year, and in many places the same road

TABLE I

DESCRIPTION OF SURFACES—ANNUAL MAINTENANCE COSTS—ROUTE NO 12—LEOMINSTER TO CONNECTICUT LINE

27,558 Miles State Highways, 13,911 Miles Town and City Roads

Auto Route No	Maint Route No	Town	Maint Sec No	Length Miles	Year Constructed	Description of Existing Surface: Type	Description of Existing Surface: Width Feet	Description of Existing Surface: Area Sq Yds	Thickness Inches: Top	Thickness Inches: Base	Asphalt Penitra Gal Per s y	Foundation: Type	Foundation: Thickness Inches	Shoulders: Type	Shoulders: Width Feet	Shoulders: Thickness Inches	Shoulders: Treatment	Annual Maintenance Cost—Per Mile: Surface	Right of Way	Operating: Snow Removal	Operating: Registration	Operating: Traffic Police	Eng and Adm 15% on (19) (20) (21)	Total Maint (19)-(24)	Total Annual Maint Per Sq Yd	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
12	4	Leominster	1	3 5	—	BMA	18–25	—										$—	$—	$—	$—	$—	$—	$—	$—	Town Road
		Leominster	2	0 371	1929	BMA	24	5,223	2½	4½	2¼	Gravel	12-Var †		1			5	600	239	195	134	127	1 300	0 092	† Variable
		Leominster	3	2 161	1927	BMA	24	30,427	2½	2	2¼	Stone	8					9	570	239	195	134	123	1 270	0 090	
												Gravel	4	Gravel												
		Sterling	1	0 592	1927	BMA	24	8,335	2½	2	2¼	Stone	8					9	570	235	195	134	122	1 265	0 090	
												Gravel	4	Gravel												
		Sterling	2	1 759	1913	BCA	18	18,575										194	458	177	195	134	124	1,282	0 121	
		Sterling	3	0 701	1913	WB	18	7,402										409	458	177	195	134	157	1,530	0 145	
		Sterling	4	0 3	—	BMA	15–30											—	—	—	—	—	—	—	—	Town Road
		Sterling	5	1 296	1913	WB	15	11,404										409	458	147	229	158	152	1,553	0 176	
		Sterling	6	1 087	1912	BCA	15	9,566										194	458	147	221	152	120	1,292	0 147	
		Sterling	7	0 093	1929	BMA	24	1,308	2½	4½	2¼	Gravel	Var					22	458	235	213	147	107	1 182	0 084	
		Sterling	8	0 042	—	BMA		—										—	—	—	—	—	—	—	—	Town Road
		Sterling	9	0 232	1929	BMA	24	3,266	2½	4½	2¼	Gravel	Var	Gravel	1	6		22	458	235	213	147	107	1 182	0 084	
		W Boylston	1	0 898	1928	BMA	24	12 644	2½	2	2¼	Stone	10					51	328	186	211	145	85	1 006	0 071	Sec 1 and 4 are
												Gravel	4													Adjacent
		W Boylston	4	0 653	1915	BCA	18	6 897										354	328	140	205	141	123	1 291	0 122	
		W Boylston	5	0 736	1927	BMA	30	12,954	2½	4½†	2¼	Gravel	6§	Gravel				51	328	233	323	222	92	1,249	0 071	§ Only under 12 ft Widened Portion
		W Boylston	6	0 017	—	BCA		—										—	—	—	—	—	—	—	—	Town-Bridge
		W Boylston	7	0 459	1925	BMA	18	4,847				Gravel	12 Var					51	328	140	323	222	78	1,142	0 108	

		W Boylston	8	1 672	1932	BMA	30	29 427	2½	4½	2½							30*	300*	300*	323	222	94	1 269	0 072	* Estimated
		Worcester	1	1 074	1932	BMA	30	18, 902	2½	4½	2½	Gravel	Var					30*	300*	300*	323	222	94	1 269	0 072	
		Worcester	2-6	7 4	—	Miscl	—											—	—	—	—	—	—	—	—	City Streets
12	4	Auburn	1	1 634	1918	BMTR*	21	20, 130										988	393	223	517	356	241	2 718	0 221	* Retread surface Laid by Maint Forces in 1930
		Auburn	2	0 026	—	Plank		—										—	—	—	—	—	—	—	—	R R Bridge
		Auburn	3	0 258	1918	BMTR*	21	3 178										988	393	223	517	356	241	2 718	0 221	
		Auburn	4	1 430	1924	RCC	20	16 778	8			Gravel	6-12	Gravel	2	8	2½ gal	119	393	223	517	356	110	1 718	0 146	
		Auburn		1 361	1925	RCC	20	15 969	8			Gravel	6-12	Gravel	2	8	2½ gal	119	393	223	517	356	110	1 718	0 146	
12		Auburn		0 570	1925	RCC	40	13 376	8									150	393	446	830	572	148	2 539	0 108	Widened from 20 to 40 ft in 1932
20					1932																					
12		Oxford	1	0 894	1925	RCC	20	10 489	8			Gravel	12 Var	Gravel	3	8		88	299	223	249	171	91	1 121	0 096	
		Oxford	2	3 164	1921	PCC	20	37 123	6			Gravel	6-9	Gravel	4	4		112	299	223	262	181	95	1 172	0 100	
												Stone	6-9	Gravel	2	4										
		Oxford	3	0 9	1920	BMT	18	—										—	—	—	—	—	—	—	—	Town Road
		Oxford	4	2 290	1913-16	BMT	15	20, 152										404	299	167	319	220	130	1 539	0 175	
		Webster	1	0 831	1911	BMT	18	8, 775										319	183	134	418	288	95	1 437	0 136	
		Webster	2-6	1 25	—	BMT	18	—										—	—	—	—	—	—	—	—	Town Road
						PCC																				
		Dudley	1-2	0 46	1920	PCC	18-30	—										—	—	—	—	—	—	—	—	Town Road
		Dudley	3	0 464	1920	PCC	18	4, 900	7½ Center 5 Sides			Gravel	6					216	183	196	232	159	89	1 075	0 103	
		Dudley	4	0 016				—										—	—	—	—	—	—	—	—	R R Grade Crossing
		Dudley	5	0 878	1920	PCC	18	9 272	7½ Center 5 Sides			Gravel	6					216	183	196	232	159	89	1,075	0 102	

↑ Connecticut Line

Pavement Legend BMA—Bituminous Macadam—Asphalt BMT—Bituminous Macadam—Tar BCA—Bituminous Concrete—Asphalt BCD—Bituminous Concrete—Cold Type PCC—Plain Cement Concrete RCC—Reinforced Cement Concrete Dual—Two lanes of RCC divided by one lane of BMA WB—Waterbound Macadam (Surface Treated) GR—Gravel (Surface Treated) may have two or more auto route numbers But the Maintenance Route Numbers usually remain unchanged from year to year, and there are no duplications For convenience road cost data were assembled by Maintenance Routes, but the equivalent auto route numbers are given to identify the routes as known locally or as shown on road maps Throughout this report the route shown in Table I will be referred to as State Highway Route 12, because this is the number by which it is best known

MAINTENANCE COST DATA

Surface and Right-of-Way Maintenance costs shown in columns (19) and (20), Table I, are in most cases the average costs for years 1928–32, inclusive For roads less than five years old, an average of the maintenance costs was taken for the number of years available, and for new pavements where no records were available the annual maintenance cost was estimated based on records of other similar pavements Average costs over five years were used rather than actual costs for a single year, because surface maintenance costs often vary from year to year particularly for a road requiring a seal coat every two or three years

Costs were taken directly from the maintenance records of the Third District, which includes all of Worcester County These records separate maintenance costs as follows.

Surface Repairs
Surface Treatment
Roadbed
Drainage
Right-of-Way
Traffic Markings
Trees

Of the above classification "surface repairs" and "surface treatment" have been combined in column (19), Table I, and called "surface," and all the other items have been combined in column (20), Table I, and called "right-of-way "

In Massachusetts, surface items include only work done on the paved portion of the road Repairs to shoulders and ditches are included in "roadbed " This may explain why surface costs in Massachusetts are low and right-of-way costs are high in comparison with other states

Surface costs are segregated by types as indicated by section numbers in column (4), Table I Right-of-way costs are not separated by types of pavement, but by township boundaries Hence, for the state highway portions of any route lying within a certain town there will be only one cost figure available for right-of-way maintenance, but there may be several cost figures available for surface maintenance depending upon the number of pavement sections in that town Wherever right-of-way costs were found separated between sections in the same town, advantage was taken of the separation, and the right-of-way maintenance will not necessarily always be the same within each town

Marking of traffic lanes belongs strictly in operating maintenance This work is done, however, by the ordinary maintenance crew and is not charged to the account of the Traffic Engineer and his staff For this reason, and also to avoid the work of separating this item for every section, it was included with right-of-way maintenance

OPERATING MAINTENANCE

Snow Removal costs were obtained by averaging the costs for the two winters 1930–31 and 1931–32 The average snowfall for these two years was nearly the same as the average over many years, and therefore the average cost for these two years was considered as representative of a typical year

Snow removal costs were obtained from District Engineer's reports which segregate costs by auto routes, and also for each town through which the route passes No separation is made in original records between sections of different type or width of pavement In order to take into account the different widths of pavement between town boundaries on the same route, the average cost of snow removal per mile for the entire length of route ploughed within the town was allocated to the several sections in proportion to their width The costs thus obtained are shown in column (21) Table I

Registration Expense The expenses of operating the registry of motor vehicles in 1932 amounted to $1,508,236, which has been allocated to each mile of road in the ratio of vehicle miles traveled on that road to vehicle miles traveled in the entire state, including all rural roads and city streets The latter was estimated at 6,700,000,000 vehicle miles, based on a total gasoline consumption for all classes of vehicles of 560,194,000 gallons in 1932, at an average rate of one gallon consumed for every 12 miles of travel

This method of distribution spreads the registration costs over all roads, state, local, and city, in proportion to their use by motor vehicles, and results in much higher charges per mile to heavily traveled roads than to the lighter traveled roads The registry charges made against road sections on Route 12 are shown in Table I, Column 22

The method of distributing the registration expense back to the roads was given considerable thought Two other methods were considered and abandoned as less logical than that adopted The abandoned methods were

(1) Deduct registration expense from registration and license fee receipts and then allocate what is left This method was abandoned because it leaves out of consideration an important annual cost which is paid out of the motor vehicles tax contributions If a complete

picture is to be gained of the relation between highway income on the one hand and annual road cost on the other, all items of expense should be included

(2) Consider the registration expense as a stand-by "ready to serve" charge for all public ways anywhere in the State and levy the charge as a flat rate to each mile of road There are approximately 24,600 miles of public roads, including state, local and city highways Dividing the expense of the registry, $1,508,236 by 24,600 miles gives an annual flat rate cost of $61 30 per mile of public road This method was abandoned because it makes the same charge against a dirt road on a country by-way as for a heavily traveled state road or city street

Traffic Control The expenses of the Traffic Division in the Department of Public Works for 1932 were $189,144, which has been allocated to each section of road in the ratio of vehicle miles traveled on that section to the total vehicle miles traveled in the state, i e , in the same manner as registration expense was distributed The traffic control costs were charged against all roads rather than only to state highways, because although the Traffic Division is a state organization, it also takes counts on town roads, gives advice to towns and cities on traffic control problems, and must by law approve all legal traffic control signs and signal control installations located anywhere in the state

Policing The policing of state highways is performed by state police operating under the Department of Public Safety, which is not a part of the Department of Public Works These police devote part of their attention to the regulation of traffic and law observance among automobile drivers, but their duties also extend to the protection of the public anywhere along their route For this reason only a part of their cost should be charged as a road cost In 1932 the amount expended for state police from motor vehicle contributions was $312,028, which is roughly one-third of the cost of maintaining these police This amount has been allocated to the state highway system in the ratio of vehicle miles traveled on any particular section of road to the total vehicle miles traveled on state highways The latter has been estimated at 2,450,000,000 vehicle miles per year, which is equivalent to an average traffic of 3700 vehicles per day on every mile of the 1800 miles of state highways The estimate of vehicle miles on state system was obtained from actual counts, not from gasoline consumption It is interesting to note that in Massachusetts 36 5 per cent of the total vehicle miles traveled is on state highways In the Michigan traffic survey published in "Public Roads," February, 1933, it was found that about 33 per cent of all travel was on the state highway system of that state The Michigan state system, however, has 7691 miles, and the average traffic per day on this system is only 1143 vehicles per day, compared with 3700 on the Massachusetts state system

ENGINEERING, SUPERVISION, AND ADMINISTRATION ON MAINTENANCE

In Massachusetts these costs average about 15 per cent of the total of surface maintenance, right-of-way maintenance and snow removal costs The percentage was not applied to registration, traffic, or policing costs because these are not supervised by the maintenance staff The percentage method of obtaining these costs is not recommended if actual administrative costs of each section are known The figure, 15 per cent, was chosen as a result of a study of several recent annual reports of the Department of Public Works and represents the ratio between maintenance expenses and all maintenance overhead items for the entire state system It appears high when compared with 0 43 per cent and 5 5 per cent used in cost analyses of Ames-Des Moines, Iowa, road, and Boston Post Road, Conn , respectively (See 10th Annual Report Highway Research Board) However, the 15 per cent includes many items not included in the former analyses It not only includes the actual supervision of road repairs but also the engineering and overhead expenses at district offices and at the main office in Boston

CONSTRUCTION HISTORY AND CAPITAL COST

Prior Construction—Its Value to Present Roads

The value of prior construction to an existing road must be estimated as it forms part of the capital value In Massachusetts the state highway system has been built up gradually over a period of nearly 40 years, with the result that nearly all of the existing state roads have had one or more prior constructions It was necessary therefore to investigate the construction history of each section of pavement in order to arrive at a reasonable figure for the value of this prior construction to the present road structure This value could have been obtained from records of old contracts together with the layout plans which show the extent to which the old road was utilized in the present construction, but for a great many sections, such as are included in the Worcester study, this method would have taken more time than its importance justified It was therefore decided to limit the investigation of prior costs to the data available in Annual Reports of the Massachusetts Highway Commission Fortunately these reports included down to 1921 an accumulative table of construction expenditures by sections of state highway which could be identified with maintenance sections used in this report The figures in column (8), Table II, were obtained from this source

These figures include only the costs for the first construction performed by the state on any road, which usually occurred directly after the road was taken into the state highway system Some of these roads, particularly the older ones, have been resurfaced one or more times between their first construction and the present construction

TABLE II

CONSTRUCTION HISTORY—CAPITAL COST—ROUTE NO 12—LEOMINSTER TO CONNECTICUT LINE—STATE HIGHWAY SECTIONS ONLY

Auto Route No	Maint Route No	Town	Maint Sec No	Length, Miles	Prior Construction: Year Built	Prior Construction: Type of Surface	Prior Construction, Costs Per Mile: Original Const	Salvage Value at 30% of (8)	(9) Brought to Av 1928–32 Prices	Value to Present Rd Adopted	Present Road: Year Built	Present Road: Type of Surface	Present Road, Costs Per Mile: Construction Cost	Engineering and Over Head at 13% of (14)	Cons Cost + Engr & Over Head	(16) Brought to Av 1928–32 Prices	Right of Way	Betterments	Total (17) + (18) + (19)	Total Capital Cost Per Mile [(11) +(20)]	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	
12	4	Leominster	2	0 371	1915	BCA	$21,432	$6,430	$7 610	$7 600	1929	BMA	$26,525	$3,448	$29,973	$24,953	$731	$ —	$25 584	$33 184	Resurfaced and widened in 1929
		Leominster	3	2 161	1901–2	GR	9 876	2,963	4 165	4,100	1927	BMA	48,784	6,342	55,126	39 616	731	—	40 347	44 447	Reconstructed, 1927
		Sterling	1	0 592	1913	BCA	9 940	2,982	3,089	3 000	1927	BMA	48,784	6 342	55 126	39 616	731	336	40 683	43,683	Reconstructed, 1927
		Sterling	2	1 759						None	1913	BCA	9 940	1,292	11 232	11 633	731	336	12 700	12 700	
		Sterling	3–5	1 997						None	1913	WB	8 825	1,147	9 972	10 328	731	—	11,059	11 059	
		Sterling	6	1 087						None	1912	BCA	8 359	1 087	9 446	10 417	731		11 148	11 148	
		Sterling	7–9	0 325	1912	BCA	8 359	2 508	2 765	2 800	1929	BMA	37,577	4 885	42 462	35,208	731	—	35 939	38 739	Reconstructed, 1929
		W Boylston	1	0 898	1913	WB	15 700	4,710	4,878	4 900	1928	BMA	29,555	3 842	33 397	24 609	731	—	25 340	30,240	Reconstructed, 1928
		W Boylston	4	0 653						None	1915	BCA	14,098	1,833	15 931	18 853	731	—	19 584	19 584	
		W Boylston	5	0 736	1915	BCA	14,098	4,229	5 005	5,000	1927	BMA	28,553	3,712	32,265	23 187	731	—	23 918	28 918	Resurfaced and widened in 1927
		W Boylston	7	0 459	1915	BCA	14,098	4 229	5,005	5 000	1925	BMA	48 912	6,358	55 270	33 056	731	—	33,787	38 787	Reconstructed, 1925
		W Boylston	8	1 672						None	1932	BMA	30 052	3,907	33 959	56 892	731	—	57 623	57 623	New location
		Worcester	1	1 074						None	1932	BMA	30,052	3,907	33 959	56 892	731	—	57,623	57 623	New location
		Auburn	1–3	1 892						5 800	1918	BMT*	16 274	2 116	18 390	10 206	731	108	11 045	16 845	* Retread Surf added in 1930, charged to Maint
		Auburn	4	1 430	1898–					5 800	1924	RCC	69 394	9 021	78 415	45 149	731	—	45 880	51 680	
		Auburn	4	1 361	1903	WB	13,200	3,960	5,761	5 800	1925	RCC	59 165	7 691	66 856	42 667	731	—	43 398	49 198	
12		Auburn	4	0 570						5,800	1925	RCC	59 165	7 691	66,856	42,667	731	—	43 398	49 198	
and											and										
20										None	1932	RCC	22 379	2 909	25 288	41 839	—	—	41 839	41 839	Widening to 1925 pavement
12		Oxford	1	0 894	1906–7	WB	10,350	3,105	3,710	3 700	1925	RCC	59 165	7 691	66 856	42 667	731	—	43 398	47 098	Reconstructed, 1925
		Oxford	2	3 164						None	1921	PCC	45 899	5 967	51 866	30 271	731	50	31 052	31 052	
		Oxford	4	2 290						None	1913–16	BMT	15 340	1 994	17 334	16 460	731	—	17,191	17 191	
		Webster	1	0 831						None	1911	BMT	12 257	1 593	13 850	15 174	731	—	15 905	15 905	
		Dudley	3–5	1 342						None	1920	PCC	48,643	6 324	54 967	24 825	731	—	25,556	25 556	

For Pavement Descriptions and Legend see Table I

The cost of these resurfacings has not been included in the cumulative tables in the Annual Report mentioned above, because this subsequent work is classified as reconstruction under the general heading of "Maintenance" in the state highway accounts Time has not permitted running down each of these resurfacing contracts to determine what added salvage value they may have contributed to the existing structure The salvage value allowed for the prior construction is, therefore, conservative This omission does not introduce any considerable error because the resurfacings referred to were in the nature of replacements of original road surface made during the period 1908–20 when few changes were made in location Reconstruction on a large scale, transforming old pavements into modern pavements, has been accomplished for the most part during the last 15 years, and these pavements are still in service, and are therefore carried at their full cost in column (14)

The proportion of the cost of prior construction carried forward to the present road was arbitrarily taken as 30 per cent of original cost regardless of the type of pavement produced by the prior construction The 30 per cent is intended to represent the portion of the original cost invested in the more permanent parts of the construction, namely, the grading and durable drainage structures No value has been assigned to the old surface material which may or may not be of value to present road, because usually much of the old surface is either abandoned, covered up, or excavated, in order to provide alignment and grades suitable for modern traffic In places where relocations have been made the old grading likewise has no value to the new road The sections where the old surface serves as a foundation tend to balance the sections where old locations have been abandoned, so that the 30 per cent allowance appears to be a reasonable percentage to use generally The relation between cost of grading and cost of pavement is not the same for all types of surface, but considering the uncertainties involved in estimating prior construction costs in the first place it did not seem advisable to adopt different percentages for different types The early bituminous types and the waterbound pavements show about the same ratio between surface and grading costs, the gravel roads have a much smaller proportion in the surface However, the grading and drainage structures provided for gravel roads, particularly the older ones, are generally of a lower order than those provided for higher type surfaces and for that reason usually of less value to surfaces which replace them For this reason the 30 per cent is not unreasonable when applied to these old gravel roads If the gravel roads had been constructed as a step in "stage" construction as is common today, then their grading and surface could and would be fully utilized in construction of a higher type pavement

The "Adopted Value to Present Road" in column (11), Table II, was obtained by rounding off the figures in column (10) Where the word "none" appears, this means that no previous pavement has been constructed by the state on that location, i e , the present road may be on new location, it may have replaced an undeveloped country byway, or it may have replaced a surfaced town road In the latter case the previous road probably was of some value to the present one; but usually these town roads required reconstruction by the state upon becoming a part of the state system

Capital Cost of Present Road

The construction cost for each section of present road was obtained from the final amount paid to the contractor at the conclusion of the contract under which the work was done This amount divided by the length of the project in miles gave the amounts recorded in column (14), Table II No attempt was made to separate construction costs between grading, drainage and pavement, as the final estimate of cost prepared by the state does not contain this separation The only way to obtain such a separation would be to make a quantity separation from the engineer's final estimate and apply bid prices to these quantities

Engineering and overhead on construction shown in column (15), Table II, was taken as 15 per cent of contract construction cost This percentage was obtained by examining the financial statements of Public Works Department for several years back It applies to state highway construction throughout the state, and is intended to include all overhead costs incident to construction both in the district offices and in the main office in Boston

Cost Index

In order to place the construction costs of the many sections of road on a comparable basis, it was necessary to bring the costs to some common price level In previous analyses presented by the Committee, the Engineering-News Cost Index was used, and costs brought down to the date of the analysis In the present study a new cost index has been developed based on contract prices in Massachusetts, which is therefore directly applicable to Massachusetts costs The common level chosen was an average of 1928–32 prices If the costs had been brought "to date," the date used would have been November 30, 1932, which is the end of the Massachusetts Department of Public Works' fiscal year As 1932 prices were at a low ebb in road construction history, costs brought to this level would be so low as not to be representative of either past or expected future conditions The average of 1928–32 prices reflects both a high and a low period and is therefore a more representative basis of comparison This also places construction costs on the same basis as maintenance costs which were averaged over the same period, 1928–32

The cost index curves developed are shown in Figure 2 They are based upon contract bid prices on state highway work as published annually in reports of Massachusetts Highway Commission (1895–1919) and Department of Public Works (1920–32) An unweighted average was taken for each year of the amounts bid on the following items:

Earth Excavation—as an index of grading costs
Plain Cement Concrete—as an index of drainage costs
Broken Stone—as an index of surface costs
Asphalt—as an index of surface costs
Gravel—as an index of foundation cost
Concrete Surfacing—as an index of concrete surface costs

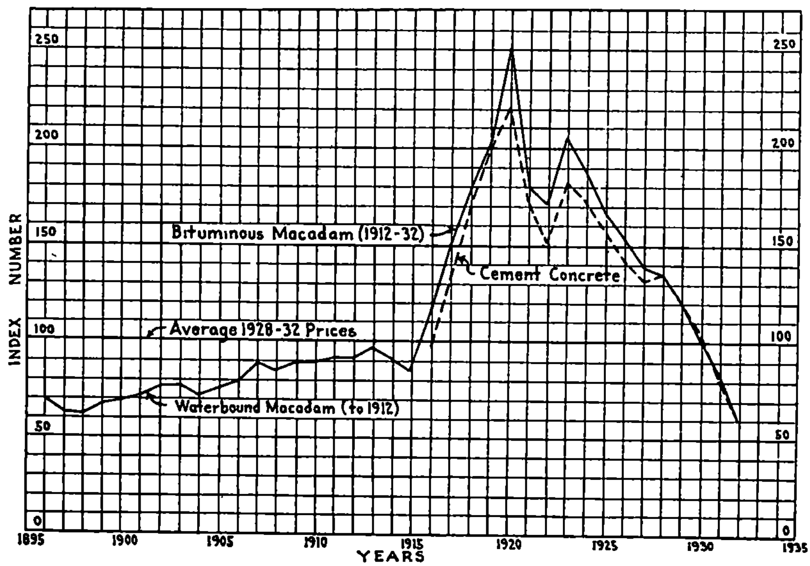


Figure 2. Massachusetts Highway Construction Cost Index

The number of contracts averaged per year varied from 40 to 160, depending upon number of contracts let

The composite curve for bituminous macadam and waterbound roads (Figure 2) was obtained by weighting the above items approximately in proportion as they made up the cost of these road as follows

	Bituminous Macadam 1912–1932 %	Waterbound Macadam 1895–1911 %
Grading (Earth Excavation)	30	30
Drainage (Plain Cement Concrete)	10	10
Foundation (Gravel Borrow)	10	10
Surface (Broken Stone)	40	50
Surface (Asphalt)	10	
	100	100

Few bituminous roads were built prior to 1912, so the asphalt item was not available until that date, however, the influence of this item on the index was so slight that the index curve shows no break between years 1911 and 1912

The index curve for bituminous macadam (asphalt) was also used for adjusting costs of bituminous concrete and tar macadam roads These three types are enough alike so that the index for one was considered applicable to all The same cost index, where it applies to waterbound roads, was also used for gravel roads There were so few miles of gravel road to be considered that a separate index for this type was not warranted Sufficient study was made of the cost trends of these two types to discover that they were nearly alike

A separate cost index was prepared for concrete roads, because it was found impracticable to combine concrete and broken stone roads into one index Concrete roads have only been built since 1916, and show different cost trends from the roads constructed of broken stone and bituminous materials The weighting used for concrete road cost index was as follows:

Grading (Earth Excavation)	20%
Drainage (Plain Cement Concrete)	10
Foundation (Gravel Borrow)	5
Surface (Concrete Surfacing)	65
	100%

The shape of the index curves depends not only upon the price fluctuation of the several classes of materials making up the indexes but also upon the percentage of the total cost assumed for each material During the period from 1923 to 1932 the unit prices bid on highway work in Massachusetts declined every year, but not at the same rate Excavation and gravel borrow dropped the most, from $1 48 and $1 80 per cu yd respectively in 1923 to $ 24 and $ 29 respectively in 1932 During the same period broken stone declined from $3 92 per ton to $1 66, and concrete surfacing declined from $12 99 per cu yd to $5 47 per cu yd The former pair of materials decreased in cost in the ratio of 6 to 1: the latter in the ratio of 2 4 to 1. Evidently the excavation and gravel borrow items tend to make the indexes decline sharply during the last ten years, whereas the other items tend to make the decline less marked The percentages chosen were based upon a study of cost separations given in several of the Annual Reports of the Department of Public Works, supplemented by estimates of cost separations for modern designs The Bureau of Public Roads index ("Public Roads," July, 1933) was also studied This index is based upon a "composite mile" of road which shows the following cost separation.

Excavation	35%
Surface (concrete + steel)	54%
Drainage (structural concrete + structural steel)	11%
	100%

The index developed in this report is not intended, however, to reflect the variation in cost of a mile of road of the same general type, but rather to indicate what a road constructed in any year would have cost if built of identical design at the chosen base price level (1928–1932) The actual cost of road construction per mile has not declined in anything like the manner shown by the index curves because as the width and depth of pavement have been increased for heavier vehicles more materials have been required per mile and more grading has been required to provide greater width of pavement, flatter curves and grades and wider shoulders The increase in usage of highway materials per

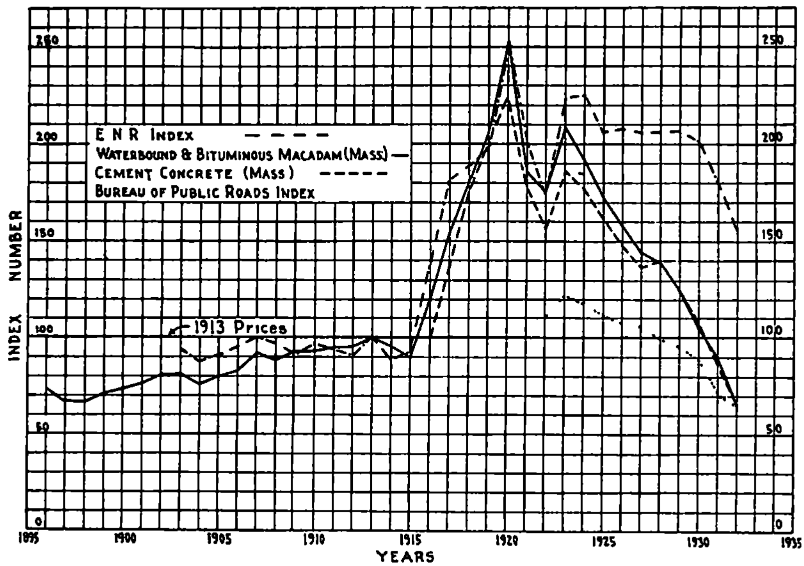


Figure 3 A Comparison of Engineering News-Record Building Construction Cost Index, Bureau of Public Roads Highway Construction Cost Index and Massachusetts Highway Construction Cost Index

mile is discussed at length in "Public Roads," July, 1933, referred to above

For purpose of comparison, the Massachusetts highway construction cost indexes, the E N R index, and the Bureau of Public Roads index have been plotted to the same base level in Figure 3 This figure shows at a glance that neither the E N R nor the Bureau of Public Roads indexes follow the treand of highway construction costs in Massachusetts between years 1922 and 1932 The E N R and the Bureau of Public Roads indexes are both intended to reflect the average national price trends, the former based on general or building construction material and labor, and the latter on highway construction materials with heaviest weighting given to those used in reinforced cement concrete type of construction The E N R index basis is such that it would not necessarily reflect highway trends, but one might expect the Public Roads curve and the Massachusetts curves to be quite similar An inspection of the basic data for the Public Roads index shows, however, that in 1922 Massachusetts highway prices far exceeded those for the nation as a whole For example, excavation in Massachusetts averaged $1 16 per cu yd for this year, whereas the average for the country was only $0 40, but in 1932 the national average and Massachusetts prices were almost alike Figure 3 definitely shows the unreliability of general or average cost indexes for application to the highway construction costs of a particular state

Right-of-way costs were obtained by arbitrarily assuming a cost of $100 per acre for a right-of-way 60 feet wide In most cases the state did not pay anything for right-of-way, but merely took over the existing one when the road became a state highway On new locations where land damages were paid, the actual cost of these will appear in column (18) Table II instead of the nominal figure of $731 per mile

Betterments

In recent years maintenance costs in Massachusetts have been kept in two accounts, ordinary maintenance and betterments Ordinary maintenance costs are those given in columns (19) and (20), Table I Betterments were considered capital expenditures and therefore included with road costs in Table II, column (19) The betterments were not brought to a common cost level, as they all fall within the period 1928–32, and are only a small item in the total road cost Betterments include such work as paving the space left by street railway rails, installing additional drainage structures, and widening of isolated curves

CALCULATION OF ANNUAL ROAD COSTS

Annual road costs were computed by an approximate formula as follows:

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

in which

C = average annual road cost
A = original capital cost
B = annual maintenance cost
r = rate of interest
n = estimated life, in years, of the surface before renewal is required
S = estimated salvage value of highway at the end of n years
E = any periodic maintenance required during life n.

The term $\left(\frac{A + S}{2}\right) r$ is the approximate average annual interest charge during the life n, and the term $\frac{A - S}{n}$ is the annual depreciation on a straight line basis

The formula differs in principle from the basic formula for road cost presented at 1929 meeting of Highway Research Board, because it sets up road cost for the period n years only instead of in perpetuity It also neglects compound interest The approximate formula is simple in form and practical in its application, because it does not call for any assumptions beyond the life of the existing surface The method of amortizing capital invested is similar to that used for retiring serial bonds The most difficult terms to evaluate are n and S

The results obtained by using the approximate formula agree closely with those found by the exact one as brought out by the following illustration

The exact formula may be written as follows

$$C = Ar + B + \frac{Er}{(1 + r)^n - 1} + \frac{E'r}{(1 + r)^{n'} - 1}$$

where

C = Annual Road Cost
A = Cost to construct (capital cost)
B = Annual maintenance cost
r = Rate of interest (4 per cent)
n = Life, in years
E = Replacement Cost at end of n years
E' = Periodic Maintenance needed every n' years

Assuming the following costs A = \$30,000, B = \$1000, r = 04,
n = 20 years, E = \$20,000, E' = 0

Then

$$C = 30{,}000 \times 04 + 1000 + \frac{20{,}000 \times 04}{1\ 191} + 0 = \$2871$$

Using the Approximate Formula, where $S = A - E$ = \$10,000,

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

$$C = \left(\frac{30{,}000 + 10{,}000}{2}\right) 04 + \frac{30{,}000 - 10{,}000}{20} + 1000 + 0 = \$2800$$

Estimated Life of Present Surface

The lengths of life estimated for the different pavements on Route 12, Table III, are indicated in column (9) of the table The bituminous macadam roads (BMA) have been given a life of 20 years This type as now built was developed about 1923 no roads of this design are old enough to have worn out Roads of this type constitute 65 per cent of the Massachusetts state highway system They have the lowest surface maintenance cost per square yard of any type except the dual type in which two lanes of concrete are separated by one of bituminous macadam There are some miles of an older type of bituminous macadam that are now 20 years old and still giving good service Judging by the performance of these roads, 20 years seems a proper estimate of the life of the "high type" bituminous macadam pavement before any new surface layer must be added Allowance has been made for one seal coat during the 20-year life This is item E in column (15), which has been spread uniformly over the 20-year period by dividing by n Bituminous macadam roads penetrated with asphalt do not require a seal coat as often as do roads penetrated with tar Massachusetts engineers expect many of these asphalt-bound roads to last longer than 10 years without a seal coat

The old pavements, sections 2, 3, 5, 6, in Sterling, section 4 in West Boylston, and sections 1, 3, in Auburn, are scheduled for reconstruction in 1934, each of these has been assigned life to 1934 Section 4 in Oxford and section 1 in Webster were being reconstructed in 1933, so they have been given their actual length of life

Reinforced concrete pavements (RCC) built since 1923 have been given life of 25 years before resurfacing with bituminous concrete or other materials will be needed These pavements are of 8-inch uniform thickness and are reinforced with about 100 lbs of steel per 100 sq ft

Plain concrete pavements have been given a life of 20 years, but provision has been made for covering these pavements with a layer of bituminous concrete at the end of 10 years It is evident from descriptions that the plain concrete sections in Oxford and Dudley have not been covered although they are now 12 and 13 years old, respectively. However, as they are pavements of inferior design, being only 5 inches thick at edges, they are badly cracked and will need resurfacing before long As the cost of this resurfacing (E) is distributed over the 20-year life (n), it makes no difference in the road cost whether the resurfacing is done at the end of ten years or later A "Symposium on Resurfacing of Pavements," published in the 12th Annual Proceedings of Highway Research Board, indicated that plain concrete pavements on heavily traveled routes require a surface layer when 10–12 years old Some plain concrete sections on Newburyport Turnpike in Massachusetts, of similar design to Oxford and Dudley sections, were covered at ten years The 20-year life assigned to plain concrete pavements represents two ten-year periods, one bare and one covered

The widening to the reinforced concrete pavement, section 4 in Auburn, represents a special case The 1925 and 1932 sections now constitute one pavement, so that when any surface layer is applied it will be applied to both at the same time, therefore, the 1932 sections (10 feet on each side) have been given a life of only 18 years, so that they will reach their salvage value in the same year as the 1925 pavement

Salvage Value of Present Surfaces

The salvage value of a highway at the end of the estimated life of the wearing surface is usually measured by the value of the grading, structures and surface left in that road as a foundation for a new wearing course If it is practical and desirable to place this new layer directly upon the old pavement, then the salvage value of the old pavement will be its original cost minus the cost of the new layer which is required to produce a road adequate for present traffic

Applying this principle to the high type of bituminous macadam so common in Massachusetts, the new surface layer required would probably be a 2-inch course of penetration macadam costing $8000 to $10,000 per mile for a 24-foot width at 1928–32 price level If the original pavement cost $30,000 per mile, then the salvage value would be roughly 70 per cent of original cost However, the intangible item of obsolescence should also be taken into consideration Many roads reconstructed during recent years have been relocated to obtain straighter alignment and flatter grades Wherever the new road did not follow the old, obviously the old road had no salvage value to contribute to the new road Most roads of recent design appear adequate to meet traffic demands for years to come, but there is no certainty that this will prove true

In highway financing it is not customary to issue refunding bonds against the residual value remaining indefinitely in the road, such as is represented by the "refunded debt" in railroad financing In fact, if money is borrowed at all, the bond issue is usually amortized in 10 years, a period less than the life of the pavement alone Massachusetts state highways are practically free from debt, for many years highway funds have been obtained exclusively from motor vehicle revenue

In view of these considerations a salvage value for the existing pavements of 30 per cent of capital cost has been assumed for all bituminous pavements including waterbound macadam with a surface treatment, and 40 per cent has been allowed for cement concrete pavements A higher value has been given to concrete because concrete pavements are usually laid with more attention to alignment and grades than are other types, so the likelihood of future relocation for better alignment is less

The percentage method of obtaining salvage value is not recommended where other facts are available which definitely influence the amount of salvage value left in a road The amount of salvage value adopted, however, can vary through a wide range without greatly influencing the total road cost, as illustrated by the following.

In the formula

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

TA

SUMMARY SHEET—ROAD COSTS—TRAFFIC—VEHICLE CONTRIBUTIONS—ROU

Auto Route No	Maint Route No	Town	Maint Sec No	Type of Surface	Year Constructed	Length Miles	Width of Pavement Ft	Estimated Life (n) Yrs	Capital Cost A	Salvage Value S	Annual Road Cost— Interest at 4% on $\frac{A+S}{2}$	Depreciation $\frac{A-S}{n}$	Annual Maint B	Periodic Maint E
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
12	4	Leominster	2	BMA	1929	0 371	24	20	$33,184	$9 955	$863	$1,161	$1,300	$70
			3	BMA	1927	2 161	24	20	44,447	13,334	1,156	1,556	1,270	70
		Sterling	1	BMA	1927	0 592	24	20	43 683	13 105	1 136	1,529	1,265	70
			2	BCA	1913	1 759	18	20	12,700	3,810	330	445	1,282	—
			3	WB	1913	0 701	18	20	11,059	3,318	288	387	1,530	—
			5	WB	1913	1 296	15	20	11,059	3 318	288	387	1,553	—
			6	BCA	1912	1 087	15	21	11,148	3,344	290	372	1,292	—
			7-9	BMA	1929	0 325	24	20	38,739	11,622	1 007	1 356	1,182	70
		W Boylston	1	BMA	1928	0 898	24	20	30 240	9,072	786	1,058	1 006	70
			4	BCA	1915	0 653	18	19	19,584	5,875	509	721	1,291	—
			5	BMA	1927	0 736	30	20	28,918	8,675	752	1,012	1,249	88
			7	BMA	1925	0 459	18	20	38,787	11,636	1,008	1 357	1,142	53
			8	BMA	1932	1 672	30	20	57,613	17 284	1,498	2,016	1,269	88
		Worcester	1	BMA	1932	1 074	30	20	57,613	17,284	1,498	2,016	1,269	88
		Auburn	1-3	BMT	1918	1 892	21	16	16,845	5,053	438	737	2,718	—
			4	RCC	1924	1 430	20	25	51,680	2,672	1 447	1 240	1 718	—
				RCC	1925	1 361	20	25	49 198	19,679	1,378	1 181	1,718	—
12 and 20				RCC	1925		20	25	49,198	19,679	1,378	1,181		
				RCC Widening	and 1932	0 570	20	18	41,839	16,736	1,171	1 395	2,539	—
12		Oxford	1	RCC	1925	0 894	20	25	47,098	18,839	1 319	1,130	1 121	—
			2	PCC	1921	3 164	20	20	31,052	12 421	869	931	1,172	587
			4	BMT	1913-16	2 290	15	20	17,191	5 157	447	601	1 539	—
		Webster	1	BMT	1911	0 831	18	22	15,905	4 771	413	506	1 437	—
		Dudley	3-5	PCC	1920	1 342	18	20	25 556	10 222	715	767	1 075	528

For Pavement Descriptions and Maintenance Costs see Table I
For Calculation of Capital Costs see Table II

assume $A = \$30{,}000$, $n = 20$ years, $B = \$1000$, $E = 0$, and $r = 04$
Then, if $S = 60\%$ of A,

$$C = \left(\frac{30{,}000 + 18{,}000}{2}\right) 04 + \frac{30{,}000 - 18{,}000}{20} + 1000 = \$2560$$

and if $S = 30\%$ of A,

$$C = \left(\frac{30{,}000 + 9000}{2}\right) .04 + \frac{30{,}000 - 9000}{20} + 1000 = \$2830$$

and if $S = 0$,

$$C = \left(\frac{30,000}{2}\right) 04 + \frac{30,000}{20} + 1000 = \$3100$$

Periodic Maintenance. A value for E was allowed for only two types of pavement For the bituminous macadam-asphalt (BMA) provision has been made for a seal coat costing $ 10 per sq. yd and applied at

III

12—LEOMINSTER TO CONNECTICUT LINE—STATE HIGHWAY SECTIONS ONLY

		Annual Traffic				Annual Road Costs			Vehicle Contributions—1932						
									Per Mile						
	Total Per Foot of Width	Passenger Cars	Light Trucks Up to 1½ Tons	Heavy Trucks 1½ Tons and over	Total (18) – (20)	Per Vehicle Mile	Per Ton Mile	Per Ton-Mile Per Ft of Width	Passengers Cars	Light Trucks	Heavy Trucks	Total (25)–(27)	Per Vehicle Mile	Per Ton Mile	Per Ton-Mile Per Ft of Width
	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)
4	141	738,000	57,000	71,000	866,000	$0 0039	$0 0023	$0 000096	$2,199	$231	$483	$2,913	$0 0034	$0 0020	$0 000083
2	169	738,000	57,000	71,000	866,000	0 0047	0 0028	0 000117	2,199	231	483	2 913	0 0034	0 0020	0 000083
0	167	738 000	57 000	71,000	866 000	0 0046	0 0027	0 000112	2,199	231	483	2 913	0 0034	0 0020	0 000083
7	114	738,000	57,000	71,000	866 000	0 0024	0 0014	0 000078	2,199	231	483	2 913	0 0034	0 0020	0 000111
5	122	738,000	57 000	71 000	866,000	0 0025	0 0015	0 000083	2,199	231	483	2 913	0 0034	0 0020	0 000111
8	148	872,000	66 000	81,000	1,019,000	0 0022	0 0013	0 000087	2,599	268	551	3 418	0 0034	0 0020	0 000133
4	130	840,000	63 000	78,000	981,000	0 0020	0 0012	0 000080	2,503	256	530	3,289	0 0034	0 0020	0 000133
5	151	812,000	60,000	76,000	948 000	0 0038	0 0023	0 000096	2,420	244	517	3 181	0 0034	0 0020	0 000083
0	122	803,000	59,000	75,000	937,000	0 0031	0 0019	0 000079	2,393	240	510	3,143	0 0034	0 0020	0 000083
1	140	781,000	57,000	72,000	910,000	0 0028	0 0017	0 000094	2,327	231	490	3,048	0 0033	0 0020	0 000111
1	103	1,186,000	61,000	188,000	1,435,000	0 0022	0 0012	0 000040	3,534	248	1,278	5,060	0 0035	0 0019	0 000063
0	198	1,186,000	61,000	188,000	1,435,000	0 0025	0 0013	0 000072	3,534	248	1,278	5 060	0 0035	0 0019	0 000105
1	162	1,186,000	61,000	188,000	1,435,000	0 0034	0 0018	0 000060	3 534	248	1,278	5,060	0 0035	0 0019	0 000063
1	162	1,186,000	61,000	188 000	1,435,000	0 0034	0 0018	0 000060	3 534	248	1,278	5 060	0 0035	0 0019	0 000063
3	185	1,922,000	75,000	299 000	2,296 000	0 0017	0 0009	0 000048	5 728	305	2,033	8 066	0 0035	0 0019	0 000091
5	220	1,922,000	75 000	299,000	2,296 000	0 0019	0 0010	0 000050	5 728	305	2,033	8,066	0 0035	0 0019	0 000095
7	214	1,922,000	75,000	299,000	2 296,000	0 0019	0 0010	0 000050	5,728	305	2 033	8 066	0 0035	0 0019	0 000095
4	192	3,157,000	257 000	274 000	3,688 000	0 0021	0 0012	0 000030	9 408	1,043	1 863	12,314	0 0033	0 0020	0 000100
0	178	945,000	66,000	94,000	1,105,000	0 0032	0 0019	0 000095	2 816	268	639	3,723	0 0034	0 0020	0 000100
9	178	996,000	80,000	90,000	1,166 000	0 0030	0 0018	0 000090	2 968	325	612	3,905	0 0033	0 0020	0 000100
7	172	1,210,000	109,000	99,000	1,418 000	0 0018	0 0011	0 000073	3,606	443	673	4,722	0 0033	0,0020	0 000133
6	131	1 594,000	110 000	153 000	1 857,000	0 0013	0 0008	0 000044	4,750	447	1 040	6 237	0 0034	0 0020	0 000111
5	171	883 000	60 000	86 000	1 029,000	0 0030	0 0018	0 000100	2,631	244	585	3 460	0 0034	0 0020	0 000111

the end of 10 years, the midpoint in the estimated life of surface. For plain concrete (PCC) allowance has been made for a surface wearing course costing $1 00 per sq yd, also presumably laid at the end of first 10 years The other types require bituminous surface treatments, but these are applied frequently and are included in annual maintenance cost

TRAFFIC

Traffic data were obtained from a state-wide census taken in August, 1933, by the Massachusetts Department of Public Works. The August counts were expanded to yearly volume on a basis of gasoline consumption The distinction between light and heavy trucks cannot be definitely drawn because this separtion as found in the traffic counts depended largely upon the counter's judgment His instructions were to count Fords and delivery trucks as light trucks, and all others as heavy trucks No weight or capacity limits were specified The light truck classification, column (19), Table III, includes, therefore, only trucks weighing little more than a passenger car The heavy truck classification, column (20), includes all other trucks and buses The buses were counted separately in traffic census, but have not been tabulated in this report

MOTOR VEHICLE CONTRIBUTIONS

(a) *State Taxes Collected*

Motor vehicle taxes collected by the State of Massachusetts for the fiscal year 1932 were as follows

Registration Fees, Drivers' License Fees and Examinations, and Court Fines	$ 6,337,418
Gasoline Tax	16,651,868
Total	$22,989,286

The above amounts represent the total contributions made by all classes of vehicles for the use of the public highways anywhere and everywhere in the state These taxes are paid into a special state account called "The Highway Fund" from which disbursements are made for the following purposes

- Maintenance, construction and operation of state highways
- Special projects authorized by legislative acts
- State aid on town road construction and maintenance
- Maintenance of the Metropolitan District Commission (for park roads and reservations in and around Boston)
- Distribution of a portion of the gasoline tax receipts to the cities and towns

Of the above items the first and part of the second are for state highways Projects of unusual magnitude, such as the Boston-Worcester Turnpike, are authorized by special act and later become part of the state highway system Other projects authorized by special acts, notably the construction of park roads in the Boston Metropolitan area, are turned over to the Metropolitan District Commission for maintenance and do not become a part of the state highway system Of the $23,000,000, roughly, received from motor vehicle taxes in 1932, about $14,000,000 were spent on state highways, and about $5,500,000 of the gas tax money were distributed to the cities and towns The balance of the receipts were distributed among the other items The amounts expended upon state highways or allotted to the towns and cities will vary from year to year depending upon what action is taken by the legislature In recent years there has been a strong tendency to decrease expenditures on state highways and increase the proportion of the gas tax moneys given to the towns and cities For example, in 1931 about $16,000,000 were spent on state highways and $2,500,000 of gas tax money given to the towns and cities

(b) *Contributions from Individual Roads*

In order to estimate the motor vehicle contributions from any individual section of road it is necessary to express these total contributions in dollars per vehicle mile The amount contributed from any section of road will be the product of the vehicle miles traveled on that road and the contribution per vehicle mile The gasoline tax contribution is proportional to the number of miles driven and may therefore be readily expressed in dollars per vehicle mile The other fees, however, are independent of mileage and can only be expressed on a vehicle mile basis by making certain assumptions as to annual mileage The contribution per vehicle mile for each of the three classes of vehicles, passenger cars, light trucks and heavy trucks, has been worked out in Table IV The method of compiling this table is described below

(c) *Explanation of Table IV*

Average gross weights of vehicles under item (1) were chosen as a matter of judgment based on the data that were available The total number of vehicles registered, and the total number of trucks and buses registered were available from the registery, but the division between light and heavy trucks had to be estimated This was done by choosing the percentage distribution under item (4) These percentages are such as to satisfy two conditions. first, that the number registered in each class times the average registration fee for that class equals the total registration receipts, and secondly, that registration receipts from the light trucks plus the heavy trucks equal the difference between the total registration receipts and passenger car receipts The values chosen for miles per gallon of gasoline are low compared with figures compiled by the Iowa State Experiment Station (Bulletin 106) However, Massachusetts traffic is characterized by short runs, dense traffic in congested areas, and a relatively high percentage of the heavier passenger cars and trucks All these factors tend to increase the rate of gasoline consumption and thereby decrease the miles that may be driven per gallon of gasoline Vehicle miles for each class were estimated on three presumptions (1) that total gas tax receipts were obtained from each class of vehicles in proportion to the consumption of that class, (2) that the total vehicle miles for all classes equal 6,700,000,000 as previously determined, (3) that light trucks travel an average of 10,000 miles per year The resulting distribution indicates that passenger cars at 14 miles per gallon of gasoline travel an average of 8,000 miles per year, and heavy trucks at 6 miles per gallon travel 11,000 miles per year, which is a reasonable annual mileage for each class in Massachusetts, considering the fact that the heavy truck classification includes practically all trucks except light delivery trucks as explained under "Traffic" heading

Total registration receipts were available for passenger cars and for commercial vehicles unclassified The distribution between light and

TABLE IV

BASIC DATA FOR COMPUTING MOTOR VEHICLE CONTRIBUTIONS

Item	Passenger Cars	Light Trucks	Heavy* Trucks	Totals
(1) Average Gross Weight (Tons)	1¼	2½	5½	—
(2) Average Registration Fee	$3 60	$7 50	$16 65	—
(3) Number Registered (1932)	694,459	47,313	60,137	801,909
(4) Per Cent of Total Registered	86 6	5 9	7 5	100
(5) Miles Per Gallon of Gasoline	14	10	6	
(6) Vehicle Miles Per Year (Millions)	5566	473	661	6,700
(7) Registration Receipts (1932)	$ 2,490,759	$ 354,847	$1,001,216	$ 3,846,822
(8) License Fees, Fines, etc. (1932)	$ 2,156,856	$ 146,945	$ 186,795	$ 2,490,596
(9) Total Fees (7) + (8)	$ 4,647,615	$ 501,792	$1,188,011	$ 6,337,418
(10) Gasoline Tax Receipts† (1932)	$11,928,000	$1,419,000	$3,305,000	$16,652,000
(11) Total Fees [(9)] Per Vehicle Mile	$ 00084	$ 00106	$ 00180	$ 00095
(12) Gas Tax [(10)] Per Vehicle Mile	$ 00214	$ 00300	$ 00500	$ 00248
(13) Total Contributions (11) + (12) Per Vehicle Mile	$ 00298	$ 00406	$ 00680	$ 00343

* Includes 3899 Busses

† State Gasoline Tax in 1932 was 3 cents per gallon

heavy trucks was made on the basis of average fee paid in each case Drivers' licenses, examination fees and court fines, item (11), were distributed among all classes in proportion to numbers registered Gasoline tax receipts, item (10), were distributed among classes of vehicles in proportion to their rate of consumption

The contributions per vehicle mile were obtained by dividing tax receipts from each class of vehicle by the vehicle miles traveled by each class

The contributions per mile of road for each class of vehicle shown in columns 25 to 28 of Table III were obtained by multiplying contributions per vehicle mile for each class by the number of vehicles of that class using the road

(d) *Contributions Considered as Highway Income*

In this report the contributions obtained from each section of road have been considered as the gross income from that road and have been set up in comparison with the road costs as expenses in columns 16 and 28 in Table III In previous road cost analyses, namely, the Des Moines, Iowa, road and the Concord-Harvard and Tyngsboro roads in Massachusetts (10th and 12th Annual Proceedings of Highway Research Board) the vehicle contributions were multiplied by a factor, roughly two-thirds, which was intended to make allowance for the fact that only two-thirds of the gross contributions were devoted to state highways Although such a disposition may have been made of the motor vehicle funds in the aggregate, it should not have been applied to the single sections of state highway studied if a true comparison is to be drawn between the road cost and the road earnings The earnings of a particular road section depend upon the use made of it measured in vehicle miles As indicated above the actual disposition made of the total highway funds in Massachusetts will fluctuate from year to year depending upon the whims of the legislature The earnings of the state highway system as a whole may be estimated roughly from the figures previously derived as follows

Vehicle miles on state system	2,450,000,000
Contribution per vehicle mile of the average vehicle	$ 00343
Earnings of state system, gross income from motor vehicle contributions	$8,400,000
Expended on state highways in 1932	$14,000,000

A comparison between the earnings of the highway system and the amount actually expended upon the system in any year is not necessarily significant Much of the actual expenditure is capital expenditures in new construction and reconstruction which is needed to relieve congested routes and to convert old routes of obsolete design into modern highways The figure which should be set up in comparison with the annual earnings of the state highway system is the annual road cost of the system This can only be obtained by an extension of the analysis outlined above to the entire state system

Any comparison which is drawn between road cost and contributions is not complete unless the highway service provided is taken into consideration For example, old roads usually have a low annual cost because their interest and depreciation charges are low, but these roads are not giving the service that a more expensive, higher type pavement would provide The old roads are usually narrow and crooked, and have a wavy surface and a high crown They are hard-surfaced, durable pavements, but cannot be traveled with the same speed and comfort as afforded by more modern pavements Furthermore, the cost of vehicle operation is undoubtedly higher on these older roads than on modern types. The increment in vehicle operating costs between the old and new types in Massachusetts, at least, would be a small amount per vehicle because even the older roads are hard-surfaced, year-round roads and the difference in operating costs between them and a smoother type would be due largely to the elimination of the wavy surface and high crown No actual tests have so far been conducted upon road surfaces typical of Massachusetts types to determine just what the increments in vehicle operating cost would be between types These increments would have to be known with more precision than is now available in order to have any significance when expanded to the densities of traffic commonly found on Massachusetts highways No attempt has been made in this report to combine road costs and vehicle costs into one cost, namely, the cost of transportation

DISCUSSION OF THE BASIC DATA IN TABLE I

The maintenance costs for certain pavments on Route No 12 are so exceptionally high or low as to require explanation For example, Sections 2 and 3 in Leominster and 1 in Sterling show unusually low surface maintenance costs at $5 and $9 per mile, respectively, and high right-of-way maintenance costs at $600 and $570 per mile, respectively Normal maintenance costs for these sections, based upon a study of all roads of this age and type in Worcester County, would be about $25 per mile for surface maintenance and $300 per mile for right-of-way maintenance

Sections 1 and 3 in Auburn show excessively high surface maintenance (nearly $1000 per mile) They were originally constructed in 1918 as bituminous macadam penetrated with tar In 1930, however, a special surface treatment was given to these sections which is classed as a "retread" in the maintenance records It consisted of an application of ¾-inch pea stone probably not more than one inch average thickness which was penetrated with tar, mixed on the road, and then smoothed out and rolled At the same time the width of road was increased from 18 to 21 feet by extending the new surface over shoulders of the old road The cost of this treatment and subsequent applications of tar in 1931 and 1932 are responsible for the high surface maintenance cost The traffic on these sections is over 2,000,000 vehicles per year, of which 16 per cent are trucks, so it is not surprising that this type of surface has required extensive maintenance These Auburn sections are scheduled for reconstruction in 1934

Sections 8 in West Boylston and 1 in Worcester were completed late in 1932, hence no actual maintenance records are available. the costs shown in columns 19 and 20 were therefore based upon the records of other roads of similar type These records showed that the average surface maintenance during the first five years for the bituminous macadam asphalt type was very nearly $1 00 per mile per foot of width, and that the right-of-way maintenance was roughly $300 per mile

It is characteristic of the modern pavement sections analyzed in Worcester County to have much greater annual right-of-way maintenance costs than surface maintenance costs The former item, therefore, makes up a larger portion of the annual road cost than does the surface maintenance, which has been reduced to a small amount by building a modern type pavement suitable to traffic demands

Many published road costs prepared for the purpose of comparing roads of different surface types, omit the right-of-way maintenance costs, on the assumption that these costs will be the same for any kind of surface Such costs are not true road costs, because regardless of whether the right-of-way maintenance is a constant amount or not, it should be included, as it often contributes a substantial amount to the annual road cost, as illustrated by the sections analyzed on Route No. 12

In the Twelfth Annual Proceedings of the Highway Research Board, page 54, Mr Paustian has allowed a range of only $25 to $50 for "maintenance of shoulders," which is apparently intended to cover all right-of-way costs This is much less than the average of $300 per mile for Massachusetts roads It is probably true, however, that in certain states, particularly in the flat, midwestern area, the right-of-way costs will be small in comparison with surface maintenance costs

DISCUSSION OF RESULTS

Table III shows in tabular form a summary of the analysis made of each of the road sections The annual road costs and the motor vehicle contributions have been expressed in several different units taking into consideration both singly and in combination the effect of width of roadway and volume of traffic expressed both in numbers of vehicles and in gross weight of vehicles Vehicle miles were converted into ton-miles by using the average gross weight for each class of vehicle given in item (1) of Table IV The unit which best represents the annual road costs in terms of the road service provided is the ton-mile cost per foot of width shown in column (24) of Table III A comparison made between annual road costs expressed in this unit shows the relative economic efficiency of the different road sections, such as is not evident when the comparison is made on a per mile basis only For example, Sec 4 in Auburn has the highest annual cost per mile ($7664), but it has the lowest per ton-mile per foot of width (0 003¢) This short section of road not only serves Route 4 but also U S. Route 20 which is on the trunk line from Boston to New York Evidently this section of road is giving the most service for each dollar of annual cost Furthermore, the contributions from the dense traffic using this section of road greatly exceed the annual cost of this 40-foot reinforced concrete pavement The widening of this pavement from 20 to 40 feet in 1932 was therefore clearly justified

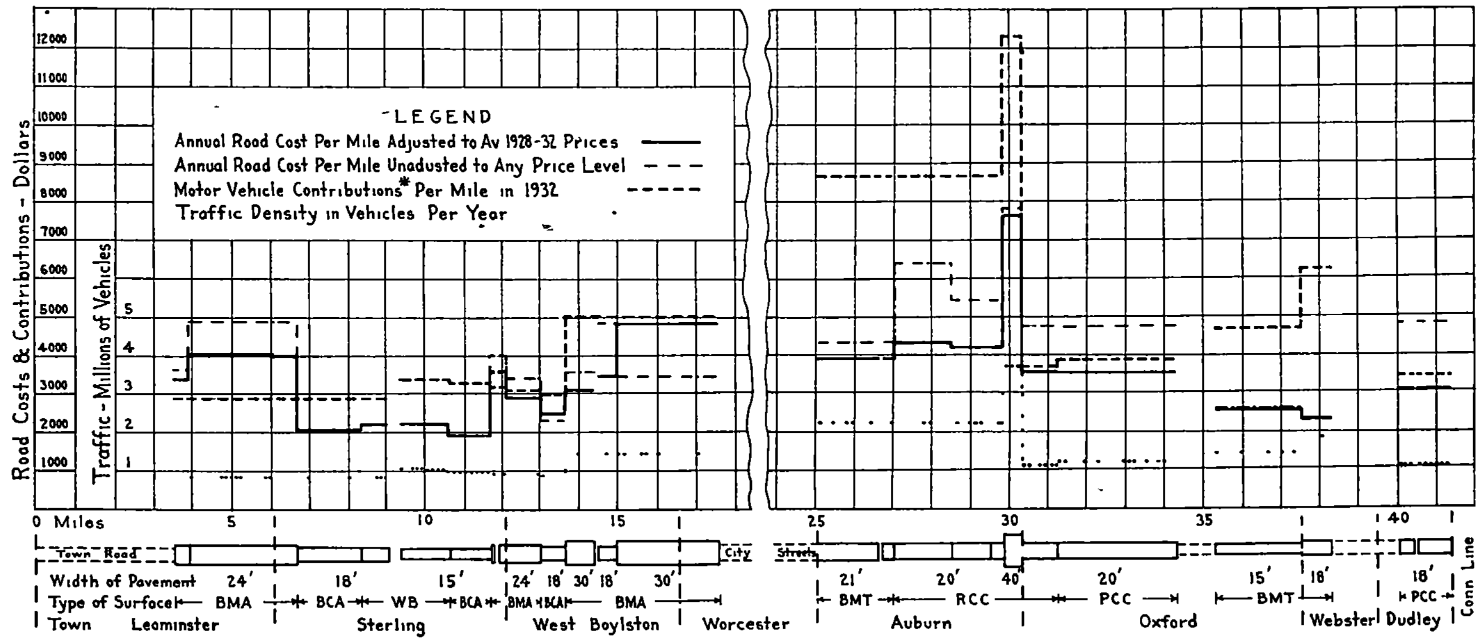
The sections giving the least service per dollar of annual cost are No 3 in Leominster and No 1 in Sterling, these cost 0 0117¢ and 0 112¢ per ton-mile per foot of width respectively An inspection of the motor vehicle contributions in column (28) reveals that these sections do not earn their annual costs

The motor vehicle contributions expressed in dollars per vehicle mile and per ton-mile in columns (29) and (30) are nearly alike for all sections These values would be exactly alike if the distribution of traffic between classes of vehicles agreed in every case with that assumed in Table IV, from which an average value for contributions per vehicle mile was derived, but as the actual traffic distribution varies somewhat between sections, the contributions per vehicle mile and per ton-mile will vary slightly

A better view of the results may be had from Figure 4 which shows graphically the annual road costs per mile plotted from column (16) of Table III, the motor vehicle contributions per mile for 1932 plotted from column (28), the annual traffic plotted from column (21), and another set of annual road costs which have not been adjusted to any base price level The calculations for these latter costs are not included in the report They were obtained by using costs from columns (9) and (16) in Table II in place of those in columns (11) and (17) of that Table The reasons for showing these unadjusted cost lines on the diagram were twofold· first, they indicate at a glance the extent to which the actual costs have been changed in adjusting them to the base price level, and, second, they make possible a comparison between the actual annual cost and the actual contributions As the actual costs are those which must be paid, this comparison has more significance for tax purposes than that between adjusted costs and actual contribution When comparing the road costs of sections constructed at different times, however, the adjusted costs should be used, because these eliminate cost fluctuations due to changing price levels Figure 4 shows that at the present rate of state motor vehicle fees and a 3-cent state gasoline tax the contributions exceed the annual road costs for all sections except Nos 2 and 3 in Leominster and Nos 1, 7 and 9 in Sterling

By taking into consideration not only Route No 12 but also other routes in the county for which costs have been compiled but not presented in this partial report, the following general conclusions may be drawn from Worcester County state roads

(1) Modern, two-lane roads of bituminous macadam or cement concrete built within the last ten years on state highways within Worcester County have an average annual road cost of from $3000 to $3500 per mile The bituminous macadam type has a consistently lower annual



* Registration and License Fees plus 3 Cents Gasoline Tax
Federal Gasoline Tax and City Personal Property Tax not included

Figure 4. Annual Road Costs—Motor Vehicle Contributions—Traffic Route No 12—Leominster to Connecticut Line at Dudley, Massachusetts. BMA—Bituminous Macadam—Asphalt BCA—Bituminous Concrete—Asphalt. WB—Waterbound Macadam—Surface Treated BMT—Bituminous Macadam—Tar PCC—Plain Cement Concrete RCC—Reinforced Cement Concrete

road cost than cement concrete of the same width due mostly to the fact that the standard 8 in reinforced concrete pavement costs about half as much again as the standard 7 in bituminous macadam pavement

Annual traffic of approximately 1,000,000 vehicles is required in order that the contributions from registration, license fees and a 3 cent gas tax shall equal or exceed the annual cost of these 2-lane roads

(2) Modern, 3-lane pavements on state highways in Worcester County have an annual road cost of from $4000 to $5000 per mile, depending on the type, and require an annual traffic of approximately 1,500,000 vehicles in order that the contributions from registration, license fees, and 3-cent gas tax shall equal or exceed the annual road costs

(3) In general, the old types of pavement, i e , surface-treated water-bound macadam or gravel, have the lowest annual road cost, usually $2000 to $2500 per mile The first cost of these old pavements was low, therefore the annual interest and depreciation charges for these pavements are relatively low compared with their annual maintenance cost. This low annual cost is not a complete argument in favor of old types, however, because the vehicle operating cost is probably greater on these old types than on the modern types On Route No 12 the motor vehicle contributions greatly exceed the annual road costs for all of the old types, for Section 4 in Oxford the contributions are nearly double the road cost This particular section was reconstructed and widened during the latter part of 1933

(4) The character of the state highway system is constantly changing both as regards the type and condition of pavements and the traffic density The results presented for Route No 12 represent a "snap-shot" of that route in the year 1932 If the study were repeated in 1934, the results would be different because of the improvements which have been made

In the Sterling district the old pavements are now (1934) being replaced by wider and more modern surfaces coupled with improvements in alignment The new pavements will require less surface maintenance but there will be a considerable increase in interest on investment and depreciation When the exact costs are known it will be found that the annual road cost, represented by the full line on Figure 4, will be raised to well above the annual contributions in this Sterling section While the improvement may bring an increase in traffic, it will probably not be any considerable amount and therefore the contributions will not increase any considerable amount

In West Boylston the old BCA section is now (1934) being reconstructed and the 18-foot and 24-foot sections of BMA are being widened to 30 feet The latter sections were built in 1925 and 1928, respectively, and were assumed to have a life of 20 years After the widening has been made the road cost line in Figure 4 will be very much higher, probably approaching an annual cost of $5000 per year because this cost will include not only the interest and depreciation on the improvement but also on the original pavements, some of which had to be sacrificed to the widening. The contributions line in this district will then be far below annual road cost line if the traffic remains at about 1,000,000 vehicles per year, an increase in traffic to 1,500,000 vehicles per year, however, would justify the improvement.

The BMT section in Auburn is now (1934) being reconstructed. Its annual maintenance has been very high. The annual maintenance of the new pavement will doubtless be low, so that the increase in interest and depreciation on investment due to the betterment will be largely offset by the saving in annual maintenance costs, and the annual road cost line in Figure 4 will not be raised any considerable amount, it will still lie far below the contribution line.

The BMT section in Oxford and Webster was reconstructed in 1933. The interest and depreciation on the cost of this betterment plus the probable annual maintenance of the new surface minus the rather high annual maintenance of the old surface will probably raise the annual road cost line up to a point close to the contribution line.

It is obvious from this discussion that the present improvements in Sterling and West Boylston may not be wholly justified from the standpoint of contributions alone, but may be fully justified when one adds to it the favorable effect on vehicle operating cost, the old Sterling sections were the roughest of all those analyzed on Route 12. The BMA sections in West Boylston were widened to 30 feet in order to provide a pavement of uniform width throughout this district. The recent improvement in Auburn is clearly justified because the annual cost will still lie below the annual contribution line. The new surface in Oxford-Webster appears to be substantially justified.

A diagram like Figure 4 can be used over a period of years by changing the lines upon it to conform to any considerable betterments or changes in annual maintenance cost or in annual traffic. Whenever these changes are made the date can be recorded upon the new lines so that the diagram as a whole will indicate from time to time where improvements are clearly justified. The phrase "clearly justified" is used because if contributions pay for the annual road cost the justification is apparent. The improvement of the road surface, however, will decrease the vehicle operating cost, which is further evidence justifying the improvement, and in some instances it is clear that the decreased cost in vehicle operation due to the construction of a better surface may justify an improvement in which the line representing the annual road cost lies below the annual contribution line.

The officials of the Highway Division of the Department of Public Works of Massachusetts have generously cooperated in providing basic data for this report. The figures compiled from these basic data,

however, have not been verified by the Department of Public Works nor have they had an opportunity to criticize them, therefore, the responsibility for their use lies wholly with the author

The assembly and analysis of the data and all computations and tables have been prepared by Mr Alexander J Bone who has also offered constructive suggestions which have in several instances been adopted without change

DISCUSSION

ON

COST ANALYSIS OF STATE ROADS IN WORCESTER COUNTY, MASSACHUSETTS

MR W A SHELTON, *U S Bureau of Public Roads* Who conducts the traffic counts in Massachusetts?

PROFESSOR BREED. This is done under Mr Taylor, Traffic Engineer of the Massachusetts Department of Public Works

MR SHELTON What length of watch do they use?

PROFESSOR BREED The usual length of count is 16 hours from 7 00 A M to 11 00 P M At certain key counting stations, however, 24-hour counts are made and these are used to expand counts at the 16-hour stations A complete traffic count is made of the State system every three years

DEAN ANSON MARSTON, *Iowa State College* From what source does the funds for the construction of these roads come Is it in part from a general property tax?

PROFESSOR BREED Roughly about one-third of it comes from registration fees and about two-thirds from gasoline taxes and a little from drivers' licenses and fines, etc Our total is a little over 20 million of which something like five million were diverted back to the cities and towns this year and roughly two million last year, and the rest of it spent in betterments, maintenance operations, policing, etc on a pay-as-you go basis, no bonds or property taxes

DEAN MARSTON In 1904 I was in touch with the Massachusetts State Highway Department and at that time automobiles were just starting to be numerous and the revenues must have been very small They had gone into quite extensive construction of roads, and I think they must have secured the main part of their money from other sources up to that time

PROFESSOR BREED: We have a state highway system of 1800 miles and our density of traffic on roads in Massachusetts, I believe, is the greatest in the United States It is over 3000 vehicles per day per mile on the average There are 61 per cent of our highways in the State system which carry upwards of 3000 vehicles per day Such roads as the Newburyport turnpike running north from Boston toward New Hampshire carries an average of 8000 vehicles per day and about 25,000 on Sundays and holidays, and that 25,000 per day is quite comparable with the New Jersey viaduct That road is a three and four lane road Massachusetts has such dense traffic on so many miles that we get quite a lot of money

DEAN MARSTON You do not have to use general State sources?

PROFESSOR BREED Not at all

DEAN MARSTON. Has any study been made into this distribution of a certain percentage to State roads and a certain percentage to something else from the point of view of the source of money?

MR BREED I cannot answer that Some of the State highway department officials have been quite interested in these studies we are making, and there is some hope that the State may make a State-wide analysis of highway costs I feel personally that this is the type of study that could be made in cooperation with the Bureau of Public Roads because it would likely be of national value I believe the problem would be simpler in Massachusetts than in most states because of the very complete record this State has of cost and of traffic

THE ECONOMY OF HIGHWAY IMPROVEMENTS

BY HOWARD BURTON SHAW

Professor of Industrial Engineering, North Carolina State College

SYNOPSIS

In estimating the economy of contemplated road improvements, the question, "how much can we afford to invest now to save a determined amount of annual expense?" can be answered by comparing the additional investment with the saving in cost which it effects

This method of computing economy is illustrated in detail by a project for improving a gravel road by surfacing it with concrete For the cost data assumed it is shown that the improvement is justified for an annual traffic of 200,000 vehicles or more, but that for 100,000 vehicles it does not appear to be economical The computation shows that the saving in annual road cost is relatively small in comparison with the saving in vehicle operating cost when the annual traffic is large Indeed an approximate economy determination can be made by considering the vehicle cost only.