It is believed that the mortality curves given in Dean Marston's paper can be drawn easily on logarithmic probability paper The data given in Table III, when plotted on this paper seems to be fairly well represented by a straight line, as is shown in Figure I While it is theoretically possible to write the equation for this curve, it would, no doubt, be cumbersome, and the result would be to lead back into the very difficulties that are avoided by the use of the logarithmic probability paper

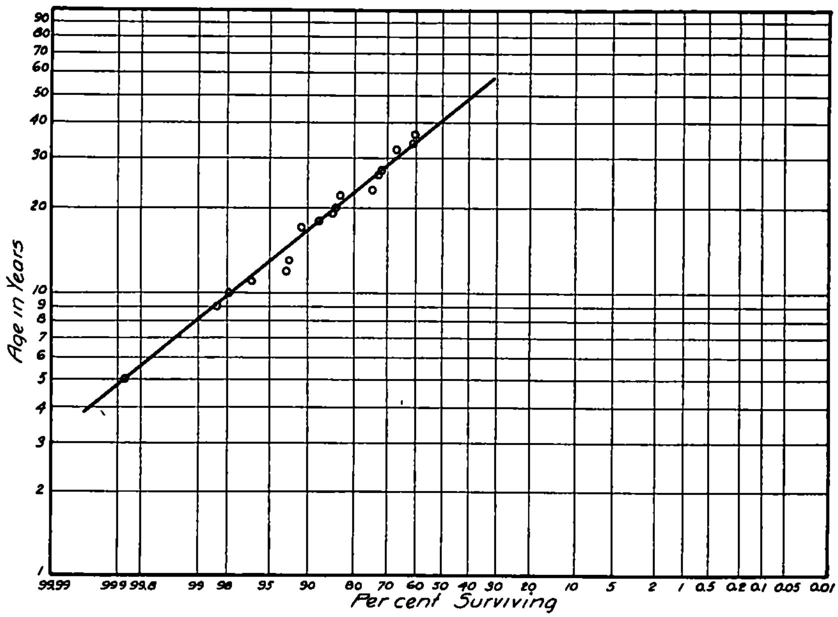

Figure 1 Percentage of Brick-on-Concrete Pavement Surviving at Different Age Intervals. Data from "Marstan" Table III.

ROAD COSTS AS AFFECTED BY RECONSTRUCTION ON STATE HIGHWAY ROUTE NO 12, WORCESTER COUNTY, MASSACHUSETTS

By C B Breed

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SYNOPSIS

This report supplements a paper presented at the 13th Annual Meeting of the Highway Research Board, entitled "Analysis of Road Cost on the State Highways of Worcester County, Massachusetts," in which application of the method developed was applied to State Route No 12 between Leominster and the Connecticut line at Dudley, Mass These data were compiled as of November 30, 1932 Since that time, much of this route has been reconstructed which has materially altered the annual road cost This paper is a discus-

sion of the lessons to be drawn from the analysis of the annual cost before and after these improvements It also points out some of the practical uses that can be made of such studies and indicates the value of them

LOCATION AND NATURE OF RECONSTRUCTION OF ROUTE NO. 12

In 1933 Section No 4 in Oxford and No 1 in Webster (3.375 miles) were rebuilt The old pavement was bituminous macadam bound with tar, varying from 15 to 18 feet in width The new pavement is bituminous macadam bound with asphalt, 30 feet wide

In 1934 a portion of Section No 1 and Sections Nos 2 and 3 in Auburn (.446 miles) were replaced with reinforced concrete pavement 40 feet wide. The old pavement was bituminous macadam bound with tar, 21 feet wide This project also included two bridges under separate contract, one over the N Y., N H & H R. R and the other over Dunn's Brook

Two contracts were also let during 1934 for widening asphalt macadam sections (4 217 miles) and reconstructing old asphalt concrete and waterbound sections (6 176 miles) in Leominster, Sterling and West Boylston The modern bituminous macadam sections built in 1927–8–9 were widened from 24 feet to a minimum width of 30 feet The old sections were replaced partly with asphalt macadam 30 feet wide and partly with dual type, consisting of two 10-ft strips of concrete separated by one 10-ft strip of asphalt macadam.

ESTIMATING CAPITAL COST

(a) Prior Construction

The pavement sections which have been replaced between 1932 and 1934 now become prior surfaces The amounts which were allowed for their anticipated salvage value in column (11) of Table III of the 1932 analysis have been carried forward as their value to the new road, even though a larger fraction of these roads was relocated than is usual A revaluation of these sections would have taken more time than was justified, on any reasonable assumption they were small (10 per cent or less) compared with the value of the new work The value assigned to prior surfaces may in any case vary through rather wide limits without greatly affecting the final annual road cost, as brought out on pp 98–99 Vol 13, Proceedings, Highway Research Board

All of the old pavements which were replaced had reached the end of the life assigned to them in the 1932 analysis and were therefore fully depreciated to the salvage value there allowed and brought forward

In the case of the sections which were only widened the cost of the original pavement was increased by the cost of the added widening A shorter life was given to the widening so that it would come to the end of its economic life in the same year as the original pavement.

(b) *Capital Cost of 1933 and 1934 Construction*

This was derived from the amount of the contract for the work in Oxford, Webster and Auburn, and from the amount of the proposals accompanying the contracts in West Boylston-Sterling and Sterling-Leominster. The proposals had to be used in place of actual amounts because the final cost estimates on these projects are not yet available. The final amounts usually exceed the proposals slightly The difference will not be enough to change materially the interest charge used in compiling annual road costs The contract amounts are given in Table I

The Oxford-Webster project was all bituminous macadam of uniform width, so that the construction cost per mile was obtained by dividing the contract amount by the number of miles constructed

The Auburn project was all of reinforced concrete 40 feet wide, but included two bridges as noted above Combining the two contract

TABLE I

Town	Miles	Amount of Contract	Right-of-Way and Damages
Oxford, Webster	3 375	$149,337	$11,000
Auburn	0 420	41,007	7,300
Bridges	0 026	61,131	
West Boylston, Sterling	4,939	192,000	4,000
Sterling, Leominster	5,504	165,000	10,000

amounts and dividing by the short mileage, 446, resulted in an excessive cost per mile for this section, and a resulting high annual road cost as shown by the peak in road cost curve in Fig 1. As an alternate the construction cost per mile was computed for the pavement contract only and spread over 446 miles, and the bridge contract spread over all of Sections 1, 2 and 3 in Auburn, over 4.795 miles. This latter distribution resulted in the road cost curve shown by line of crosses in Fig 1

The projects in West Boylston, Sterling and Leominster included three distinct types of work, namely, widening an existing surface without renewing that surface, reconstruction with bituminous macadam, and reconstruction with the dual type. Obviously it would be incorrect to spread contract amounts uniformly over these three types of work. An estimate was therefore prepared of the cost of the new pavement only for each of these types of construction and the total contract amount allocated in proportion to these estimates As the design of the pavement cross section was available for each class of work and the unit bid prices were known, the cost of the pavement could easily be estimated with some certainty An accurate distribution of the other elements of cost could not be readily made; they were assumed to vary in direct proportion to the cost of the pavement This assumption may tend to exaggerate the difference in first cost between the total costs of the bituminous macadam and the dual sections The dual type, however, actually required more expensive appurtenances than the bituminous type In any case the uncertainty in the first cost of these will but slightly affect their annual road cost

The method used in computing capital costs was the same as that illustrated in Table II, p 88, Proceedings, Vol 13

(c) Cost Index

In order to bring construction costs to the base level of average 1929–32 prices used in the 1932 analysis it was necessary to extend the cost index curve (Fig 2, p 91, Proceedings, Vol 13) to include the years 1933

TABLE II

INDEX NUMBER—AVERAGE 1928–32 PRICES = 100

Year	Concrete	Bituminous Macadam
1928	135 9	135 7
1929	119 2	120 6
1930	103 8	101 6
1931	81 0	82 8
1932	60 4	59 7
1933	76 7	72 4
1934	79 3	84 2

and 1934 The index numbers for the years 1928 to 1934 inclusive are shown in Table II.

MAINTENANCE COST

The estimated maintenance costs for roads constructed in 1933 and 1934 were based on the records of Massachusetts roads of similar type.

COMPUTATION OF ANNUAL ROAD COSTS

These were computed in the same manner, and tabulated in the same way as indicated in Table III, page 98, of Vol. 13 of the Proceedings.

The one exception was in the case of the Auburn Bridges. In computing the annual cost of these bridges separately they were given a life of 40 years and no salvage value was allowed at the end of that period.

TRAFFIC AND MOTOR VEHICLE CONTRIBUTIONS.

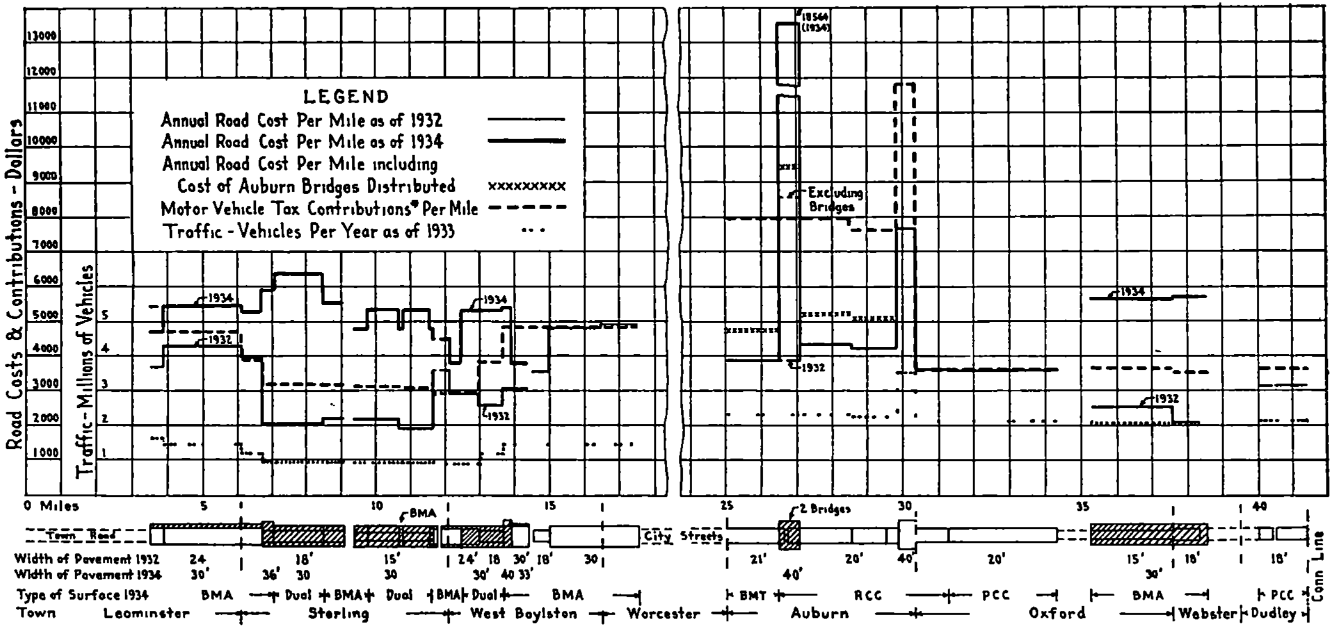
The annual traffic and dependent motor vehicle contributions were considered to be the same for 1934 as for 1932. The traffic was based on counts taken in 1933, midway between these years There was no reason to believe that the traffic varied much on this route between 1932 and 1934 For the state as a whole, motor vehicle registration and gasoline consumption declined slightly from 1932 to 1933, they probably were about the same in 1934 as in 1933 During the 1934 season the traffic on the portion of Route 12 north of Worcester was probably less than normal due to the reconstruction After the work is completed there will probably be an increase in traffic Another count two years hence would show this increase

There has been but slight change in the state motor vehicle fees and gasoline taxes collected during the period 1932–1934 so that the relationships between motor vehicle contributions and traffic volume remains unchanged

ROAD COSTS AS OF 1932 AND 1934 COMPARED

The annual road costs as of 1932 and 1934 are shown graphically in Figure 1 The crosshatched areas on the pavement diagram show the sections which have been widened or rebuilt during 1933 and 1934 The annual road cost for these new or widened sections is shown by the heavy full line An inspection of Figure 1 shows that the annual road cost for these sections in Leominster, Sterling and West Boylston now lies far above the 1932 level, and also far above the contributions line based on 1933 traffic volume For example, in 1932 the annual road cost for the old types was about $2200 per mile, in 1934, after improvements, it increased to from $4600 to $6400 per mile depending upon type of surface and amount of grading and drainage structures required by the new work The motor vehicle contributions from these sections vary between $2900 and $5400 per mile Evidently these expensive improvements have increased the annual road cost to an amount much in excess of the annual motor vehicle tax contributions

Considering as a whole the 13 63 miles of state highway between Leominster and Worcester, the average annual road cost as of 1934 is $5160 per mile, and the average motor vehicle contributions $3990 per mile The excess of road cost over contributions is therefore $1170 per mile The average traffic over these sections as of 1933 was 1,182,000 vehicles per year. In order to have contributions equal the annual road cost an increase of about 27 per cent to 1,500,000 vehicles per year will be necessary The 30-ft high type pavements provided by the 1934 construction are easily capable of carrying this traffic if such an increase is realized, in fact, they could probably carry an average traffic of 2,000,000 vehicles per year if necessary If these sections are to pay for themselves in the long run, that is, over a period of 20 to 25 years, the average traffic must gradually increase in 20 years to about 2,000,000 vehicles vehicles per year in order that the average over that period may be 1,500,000, the traffic necessary for a balance between contributions and road cost. During this 20 to 25 year period, however, both road costs



PAVEMENT LEGEND

BMA - Bituminous Macadam-Asphalt
BMT - Bituminous Macadam-Tar
RCC - Reinforced Cement Concrete
PCC - Plain Cement Concrete
Dual - Two Lanes of RCC separated by one Lane of BMA

Figure 1.

ANNUAL ROAD COSTS - MOTOR VEHICLE CONTRIBUTIONS - TRAFFIC
ROUTE No 12 - LEOMINSTER TO CONNECTICUT LINE AT DUDLEY, MASSACHUSETTS

* Contributions include Registration and License Fees plus a 3 cent State Gasoline Tax. Federal Gasoline Tax and Personal Property Tax not included

and contributions may change The road cost will probably increase due to an increase in maintenance costs with age and increasing traffic, and the contributions will be directly affected by any change in gasoline tax rates or registration fees

Between Worcester and the Connecticut line (Fig 1) there is a pinnacle of road cost for the short section of 40-ft reinforced concrete pavement constructed in 1934 in Auburn, and an increase of about 120 per cent in road cost for the sections rebuilt in 1933 in Oxford and Webster.

The excessive road cost of $18,564 per mile for the Auburn section was due to the concentration of the cost of two bridges and an expensive pavement in a distance of only 446 miles Excluding the cost of these bridges, the annual cost for the pavement and accessories would be $8500 per mile, which is still the highest cost per mile for any section on Route No 12 The bridges serve more than this short section of 446 miles, and should logically be allocated to a greater mileage. A careful study of the entire district and all roads affected would be necessary to determine just what portions of Route No 12 should bear the cost of these bridges and also what proportion of the cost, if any, should be allocated to other feeder roads

Such a study has not been made, but for purpose of illustration, the cost of these bridges has been distributed over the 4 705 miles of state highway between the Worcester line and the junction of Routes 12 and 20 in Auburn This distribution adds an increment of $855 per mile to these sections, raising their annual road costs to the level shown by the line of crosses in Figure 1 By this distribution the peak in Auburn is reduced from $18,564 per mile to $9400 per mile

In Figure 1 the contributions line lies sometimes above and sometimes below the annual road cost line Considering this portion of Route No 12 as a unit, the average annual road cost for the 14 05 miles of state highway is $4890 per mile, and the average motor vehicle contributions are $5320 per mile This section of the route is more than paying for itself, and further improvements appear to be justified, particularly in Auburn where the pavement is old and the contributions high

Considering both portions of the route together (27 68 miles) the average annual road cost as of 1934 is $5030 and the average contribution $4670, which indicates that an increase of about 8 per cent in average annual traffic over the entire route would be sufficient to make road costs and contributions balance for the entire 28 miles under investigation It is doubtful, however, whether the portion of Route 12 north of Worcester and that south of Worcester should be considered together, as each part serves a different transportation need To the north of Worcester it is the main artery between Worcester and Fitchburg, to the south of Worcester it connects with Route No 20 to Springfield and with central Connecticut A large proportion of the traffic from Fitchburg and Leominster does not pass through Worcester to the Connecticut line.

BASIC DATA REQUIRED AND METHOD OF DEPICTING RESULTS

The methods so far developed for the analysis of annual road costs on state highways of Worcester County indicate that such an analysis of a state system of highways is practical and valuable

The basic data required are (1) a description of and date of construction and cost for each section of highway, (2) annual maintenance cost on each stretch of pavement, (3) annual traffic on each section of the highway system

With regard to (1), an up-to-date description of the state highway system is usually kept by the state highway departments as a matter of routine The construction cost is usually on record for roads built within recent years, and for many states these records go back 30 to 40 years This item would be rather time-consuming to assemble in the first place, but once assembled would require only occasional revision as improvements are made in the system.

Annual maintenance records are kept by the maintenance divisions of state highway departments and in most cases would require but slight modification for use in road cost analysis

Obviously comprehensive traffic surveys must be made and kept up to date by taking periodic short time counts Massachusetts counts all state highway traffic every three years in August, using the short count method and expanding to annual volumes by gas consumption or seasonal counts where available

The graphical representation of road costs and contributions can be carried further to show all the state routes on one diagram similar to a traffic flow sheet There would be two bands, one plotted to a scale of annual road cost and the other super-imposed on it, plotted to the same scale, showing annual contributions These bands could be so drawn that roads for which contributions exceeded road costs could be easily distinguished from roads for which the reverse was true The widths of bands would show relation between road cost and contributions on any road and the relationships of these items between different roads Such a "road cost" diagram should be prepared periodically, preferably directly after a periodic traffic survey

PRACTICAL USE OF ROAD COST ANALYSES

The practical uses which can be made of these results are many, of which two only will be mentioned here

(1) When such an analysis has been made for the entire state system it will give the total annual cost of the entire system Any diversion of road revenues which leaves a balance for the state system that is less than the aggregate cost simply means that the state system is not self supporting Furthermore, if the amount of diversion of road revenues includes all in excess of the total annual cost, then nothing is left for

betterments and extensions of the state system Such an analysis produces, therefore, a direct answer to the diversion question

(2) Diagrams of road cost similar to that shown in Figure 1 could be prepared for any route and used as a guide in planning improvements. A large excess of contributions over road cost would indicate the possible need and probable justification for improvement, an excess of road cost over contributions would indicate further improvement was not justified unless there were other outbalancing considerations Before any work was actually undertaken, the cost could be estimated and the probable change in road cost computed and plotted in diagrammatic form as shown in Figure 1 This could be done for different pavement types to determine which would be justified on the basis of annual road costs Such an analysis takes the guesswork out of the expenditure of large amounts of money and furnishes specific data upon which to justify expenditures

Traffic flow sheets keep our minds focussed on *road service* Road cost diagrams will keep our minds as attentive to the *cost of this road service in terms of the service units* Every state department must sooner or later know both of these major facts as a matter of continuous record, year after year, for every mile of the system When road cost data are regularly compiled, it will be found that this work will demand a thorough review and probably a modification in some instances of the methods of auditing cost data on highways, for the mass of cost data every state office has will come out of its buried files and become useful data, consequently, its recording and tabulation will naturally develop into an orderly and accurate process simplified to fit the uses to be made of it The cost of preparing and keeping up-to-date annual road cost data is negligible when compared with its economic value. It is the plain duty of every state department not only to keep road cost data but also to put it into form that coordinates with the traffic service and to make daily use of it

For full consideration of all the costs to the motor vehicle owner it is obviously necessary to consider the difference in vehicle operating costs on the new pavement as compared with the costs on the old pavement

The old surfaces were all of about the same character—hard and firm, but bumpy and wavy with a high crown and sharp curves; the new surfaces are smooth and flat with greatly improved alinement If the vehicles using these new surfaces operate at the same average speed as they did on the old surfaces, then a material saving in vehicle operating cost has been effected by the improvements. Recent investigations by R. G Paustian (Proceedings of the Highway Research Board Vol. 13) and Prof R. A. Moyer (Vol. 14) have produced valuable information regarding gasoline consumption and power requirements on different types of surfaces. These studies also show that for any given surface gasoline consumption increases rapidly with speed. Therefore, if on account of the better facilities offered by the improvements, the motor vehicle operator chooses to operate at a much higher speed than he did on the old surfaces, then his vehicle operating cost may be so much increased on account of his greater speed that no saving in vehicle cost results from the improvement In this case the vehicle operator has elected to transpose the saving in vehicle costs into saving of time, the value of which is intangible, but may be considerable

THE EFFECT OF PAVEMENT WIDTHS UPON ACCIDENTS

By Roger L Morrison

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SYNOPSIS

Studies were made of traffic accidents occurring upon 20-ft , 18-ft and 15-ft pavements in Washtenow County, Michigan, during 1931

The conclusions reached, which may or may not be of more general application, are as follows

1 There are more accidents of all kinds on 15 and 18 foot pavements than on 20 foot pavements carrying similar traffic

2 The greatest percentage of increase is in "side-swipe" accidents No buses were involved in this type of accident

3 The increase in number of non-truck accidents is much greater than the increase in truck accidents

From these items it appears that wider pavements are needed more because of passenger automobile accidents than because of truck and bus accidents

It has been stated that the standard width of 20 feet for two-lane pavements is needed only because they are used by large trucks and buses, and that a width of 18 feet, or less, would be sufficient for passenger automobiles. This conclusion is based upon vehicle widths and clearances and a study of the actual positions occupied by vehicles upon pavement of various widths

Since the largest vehicles permitted by law, in most states, are eight feet wide, it is obvious that, if they are driven carefully, all classes of vehicles can pass each other upon an 18-foot pavement, and the only reason for a 20-foot pavement is added safety. Also it seems obvious that the only true measure of safety is to be found in accident records, but this has apparently not been considered in the various discussions which have been published. Perhaps the reason is that accident records of pavements of various widths are not readily available.

In 1932 a study was made of the motor vehicle accidents which occurred in Washtenaw County, Michigan during 1931 [1] While the effect of pavement widths was not particularly considered at the time,

[1] "An Investigation of Motor Vehicle Accidents in Washtenaw County, Michigan, for the year 1931" by W Sherman Smith, Graduate Student, University of Michigan. Assistant Professor of Civil Engineering, University of Toledo