culated by the Commission's rule is clearly shown.

It is, therefore, evident that a standard uniform system of classification of maintenance costs is needed, in which investments in maintenance equipment shall be reported as investment instead of annual maintenance operation cost

PRELIMINARY STUDIES OF THE ACTUAL SERVICE LIVES OF PAVEMENTS

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SYNOPSIS

This paper reports the actual service lives realized from pavements in the cities of Buffalo, New York, and Des Moines in Wayne County, Michigan, and in the State highway systems of Massachusetts and Rhode Island The determinations of average lives were made by statistical methods applied to the records of construction and retirement of pavement for different years The statistical methods are briefly explained and some discussion is given of the forces that cause retirement No conclusions are reached as to general probable average lives for various pavement types as these limited studies do not warrant them, but additional studies now in progress should afford a proper basis for conclusions Mention is made of the need of reliable salvage values and maintenance costs as important factors in the total annual cost of a given pavement type

To remove from the realm of speculation the important item in highway transportation economics of the average life of pavements, the Engineering Experiment Station of Iowa State College and the U S Bureau of Public Roads, last January began a study of the years of service actually being realized from pavements A study of five road systems—city of Buffalo, city of New York, city of Des Moines, Wagne County, Michigan, State highways in Massachusetts, and the State highways in Rhode Island—has been completed Studies are in progress in Connecticut, New Hampshire, Vermont, and Michigan, while plans are being formulated to conduct the study in many additional states during the coming year.

To those interested in the development and maintenance of excellent and economical highway systems, the importance of correct average lives of the several types of roadway surfaces need not be stated It is only with correct average lives that the time of needed future reconstruction can be forecast, that the actual cost of highway transportation can be calculated, and that the true annual cost of various road surfaces can be determined

The average lives of pavements can be determined only by study of the actual lives realized from particular sections, which lives are definitely fixed when the surfaces are reconstructed or abandoned From an analysis of these actual lives and the total pavement exposed to retirement over the same period, it is possible by statistical treatment, to calculate a general average life for the type of pavement under consideration While this average life is determined from past retirements, it will reflect the correct average life of the future to the extent that the forces causing the past retirements continue to act in the same magnitude Since these forces are likely to be changed under future conditions of service, judgment must be exercised in setting a probable average life for existing pavements and those of future construction Three points in this connection must be kept in mind

(1) Unless retirements have been made it is impossible to calculate by any means whatsoever the average life of the pavement under consideration For instance, try to calculate the average life of ship canals, of monuments, of streamlined trains, or of pavements made of cast-iron blocks This requirement prohibits a specific, or direct, calculation of the service life of the relatively new pavement types and of the newer designs of older types, such as, concrete constructed since 1925

(2) Determining the probable average service life of any given existing pavement is at its best an attempt to peer into the future, the actual realized average life as determined by the future dates of retirements may be greater than or less than this probable average life For any given individual section of pavement the actual life may vary greatly from the probable average

(3) The best estimations of probable average lives of existing properties are those whose foundations of forecast are the experiences of the past and well-informed judgment on probable future experience.

The average lives presented herein were determined by study of the retirements from the road systems investigated They pertain to the conditions and types of surface existing during the years studied. Unfortunately, it was not always possible to determine an average life because sometimes no, or but few, retirements had been made Particularly was this true of concrete pavement in Des Moines and Rhode Island, of bituminous surfaces on concrete base in the State highways studied, and for most high type construction since about 1925

The average lives determined to date in this investigation are insufficient in number and too narrow in conditions encountered to warrant generalizations They are, however, accurate and reliable for the conditions prevailing in the road systems and for the retirement periods studied As investigations are completed in other states, and as these five road systems are re-studied in the next few years, quantitative as well as qualitative facts will be amassed on which reliable forecasts and generalizations can be based

METHODS EMPLOYED

Collection of Data

Briefly, the methods employed were to compile three tabulations for each type of surface for the road system as a whole· (1) The square yards constructed each year; (2) the square yards of each year's construction remaining in service each year thereafter, and (3) the square yards retired each year, arranged to show the ages at retirement These data are illustrated in Tables I and II.

From these three tabulations it was then possible to compute the rate of retirement during any year or series of years, for the total pavement in service or for the construction of any one particular year, provided sufficient retirements had been made

STATISTICAL METHODS

The statistical treatment accorded construction and retirement data in or-

TABLE I

BITUMINOUS MACADAM, ASPHALT PENETRATION, IN SERVICE—MASSACHUSETTS

Year laid	Square yards remaining in service January 1*							
	1920	1921	1922	1923	1924	1925	1926	1927
1911	29,272	29,272	29,272	29,272	29,272	29,272	29,272	29,272
1912	139,305	139,305	139,305	139,305	139,305	139,305	139,305	123,389
1913	178,199	178,199	172,389	172,389	172,389	172,389	123,020	101,839
1914	219,580	219,580	219,580	219,580	214,926	214,926	199,083	199,083
1915	293,300	293,300	293,300	293,300	270,886	242,528	222,260	216,956
1916	435,285	435,285	435,285	435,285	433,219[a]	374,862	374,565[b]	358,544
1917	452,066	452,066	452,066	452,066	446,745	379,430	353,394	350,594[c]
1918	197,084	197,084	197,084	197,084	173,133	165,184	165,184	150,696
1919	312,304	312,304	312,304	312,304	312,304	312,304	307,861	307,861
1920	84,844	84,844	84,844	84,844	84,844	84,844	84,844	84,844
1921		228,218	228,218	228,218	228,218	228,218	228,218	228,218
1922			472,689	472,689	472,689	472,689	472,689	460,083
1923				398,212	398,212	398,212	398,212	398,212
1924					492,462	492,462	492,462	492,462
1925						503,063	503,063	503,063
1926							610,599	610,599
1927								1,198,831

Year laid	Square yards remaining in service January 1*							
	1928	1929	1930	1931	1932	1933	1934	1935
1911	29,272	29,272	29,272	29,272	29,272	29,272	29,272	29,272
1912	123,389	116,158	81,830	64,214[g]	64,214	64,214	64,214	64,214
1913	95,501	95,501	85,989	51,801	41,260	41,260	41,260	41,260
1914	161,991	161,991	140,158	74,607	57,317	34,386	34,386	34,386
1915	195,716	188,116	162,433	61,684	54,748	46,132	44,565	29,416
1916	332,906	330,417	310,882[d]	263,480	230,694	185,724	185,724	182,724
1917	325,912	316,776	298,715	232,895[h]	232,895	217,454	217,454	217,454
1918	135,237	131,058	124,133	111,271	110,481	110,481	110,481	100,242
1919	307,861	298,486	269,578	219,723	219,234	219,234	219,234	219,234
1920	65,844	48,446	48,446	48,446	48,446	40,408	40,408	40,408
1921	228,218	225,290	209,474	207,669	206,367	190,609	190,609	190,609
1922	460,083	457,604	456,776	357,760	357,287	357,287	357,287	357,287
1923	389,956	389,956	389,956	366,660	366,660	321,878	320,217	306,699
1924	492,462	471,432	471,432[e]	451,609	445,600	405,199	404,306	404,306
1925	503,063	502,794	500,584[f]	495,842	494,085	486,445	486,445	482,947
1926	610,599	610,599	610,599	610,599	606,566	596,728	596,728	596,728
1927	1,198,831	1,198,831	1,198,831	1,188,672	1,188,672	1,188,672	1,188,672	1,180,299
1928	1,394,860	1,394,860	1,394,860	1,394,860	1,382,122	1,370,952	1,370,952	1,351,172
1929		1,756,960	1,756,960	1,756,960	1,756,960	1,756,960	1,755,073	1,754,103
1930			1,191,954	1,191,954	1,191,954	1,191,954	1,191,954	1,191,954
1931				1,293,907	1,293,907	1,293,907	1,293,907	1,293,907
1932					1,572,802	1,572,802	1,572,802	1,572,802
1933						680,803	680,803	680,803

* The yardage opposite and under the same year is the total construction for that year and was not in service until the end of the year.

Sq. yd. returned to towns: [a]25,000; [b]4,048; [c]6,191; [d]28,800; [e]19,823; [f]2,655; [g]4,580; [h]7,556.

TABLE II

RETIREMENTS OF BITUMINOUS MACADAM, ASPHALT PENETRATION—MASSACHUSETTS

Year laid	Square yards retired during year							
	1920	1921	1922	1923	1924	1925	1926	1927
1911	0	0	0	0	0	0	0	0
1912	0	0	0	0	0	0	15,916	0
1913	0	5,810	0	0	0	49,369	21,181	6,338
1914	0	0	0	4,654	0	15,843	0	37,092
1915	0	0	0	22,414	28,358	20,268	5,304	21,240
1916	0	0	0	2,066	33,357	297	11,973	25,638
1917	0	0	0	5,321	67,315	26,036	2,800	18,491
1918	0	0	0	23,951	7,949	0	14,488	15,459
1919	0	0	0	0	0	4,443	0	0
1920	0	0	0	0	0	0	0	19,000
1921		0	0	0	0	0	0	0
1922			0	0	0	0	12,606	0
1923				0	0	0	0	8,256
1924					0	0	0	0
1925						0	0	0
1926							0	0
1927								0

Year laid	Square yards retired during year							
	1928	1929	1930	1931	1932	1933	1934	1935
1911	0	0	0	0	0	0	0	
1912	7,231	34,328	17,616	0	0	0	0	
1913	0	9,512	34,188	10,541	0	0	0	
1914	0	21,833	65,551	17,290	22,931	0	0	
1915	7,600	25,683	100,749	6,936	8,616	1,567	15,149	
1916	2,489	19,535	18,602	32,786	44,970	0	0	
1917	9,136	18,061	65,820	0	7,885	0	0	
1918	4,179	6,925	12,862	790	0	0	10,239	
1919	9,375	28,908	49,855	0	0	0	0	
1920	17,398	0	0	0	8,038	0	0	
1921	2,928	15,816	1,805	1,302	15,758	0	0	
1922	2,479	828	99,016	473	0	0	0	
1923	0	0	23,296	0	44,782	1,661	13,518	
1924	21,030	0	0	6,009	40,401	893	0	
1925	269	2,210	2,087	1,757	7,640	0	3,498	
1926	0	0	0	4,033	9,838	0	0	
1927	0	0	10,159	0	0	0	8,373	
1928	0	0	0	12,738	11,170	0	19,780	
1929		0	0	0	0	1,887	970	
1930			0	0	0	0	0	
1931				0	0	0	0	
1932					0	0	0	
1933						0	0	

der to determine the average life realized is often controlled by the form and completeness of the available records since it is not always possible to construct Tables I and II in complete form Not all statistical methods are applicable to every set of data Further, the average lives determined by the various methods have special meanings and must be used accordingly

Following are brief descriptions of five methods of determining average life [1] Each, except the first, makes use of a survivor curve, a curve showing the percentage surviving in service at any age

Individual Unit Method The average life determined by the individual unit method is in reality the average age at retirement, for it is calculated by finding the weighted average age at which the retirements were made The method can be applied to the retirements for any one year or for any series of years No survivor curve need be drawn This method is not to be recommended when other ones can be applied, since it does not take into consideration the units remaining in service, for example the rate of retirement

Original Group Method The original group method is one that requires the construction of a survivor curve Usually a stub curve results which has to be extended to zero percent surviving in order to determine the average life This method is quite applicable to the construction for any single year from which the retirements have been sufficient to produce a survivor curve The construction chosen for study, however, is usually that of an early year for but a fraction (the smaller the more accurate the results) of the pavement can be left in service if the application of the method

TABLE III

CALCULATION OF AVERAGE LIFE BY THE ANNUAL RATE METHOD BITUMINOUS MACADAM, ASPHALT PENETRATION—MASSACHUSETTS

(Retirements during 1925–1934 of pavement laid 1911–1933)

Age interval, years	Retirements during 1925–1934 of pavement laid 1911–1933			
	Sq yd in service at beginning of interval	Sq yd retired during interval	Annual rate of retirement, per cent	Percent surviving at beginning of interval
0 – ½	10,203,779	0		100 00
½– 1½	10,696,241	0		100 00
1½– 2½	10,413,650	0		100 00
2½– 3½	9,313,537	23,166	0 25	100 00
3½– 4½	8,224,682	57,159	0 69	99 75
4½– 5½	7,060,413	7,090	0 10	99 06
5½– 6½	5,608,869	38,297	0 68	98 96
6½– 7½	4,364,761	68,074	1 55	98 29
7½– 8½	3,495,818	213,155	6 10	96 77
8½– 9½	3,060,797	79,382	2 59	90 87
9½–10½	2,740,996	86,782	3 17	88 52
10½–11½	2,454,595	141,977	5 78	85 71
11½–12½	2,178,308	112,059	5 14	80 76
12½–13½	1,847,778	152,018	8 23	76 61
13½–14½	1,534,423	66,539	4 34	70 30
14½–15½	1,398,676	163,253	11 67	67 25
15½–16½	1,008,633	144,439	14 32	59 40
16½–17½	763,952	94,422	12 36	50 89
17½–18½	452,076	52,655	11 65	44 60
18½–19½	213,697	15,149	7 09	39 40
19½–20½	169,132	0		36 61
20½–21½	134,746	0		36 61
21½–22½	93,486	0		36 61
22½–23½	29,272	0		36 61
23½–24½				36 61

[1] These methods, related factors, and the type curves later referred to are fully discussed by Robley Winfrey in "Methods of Calculating Average Lives of Industrial Properties " Iowa Engineering Experiment Station (In process of publication) See also, Anson Marston "A Mortality Curve Study of the Actual Service Lives of Brick-on-Concrete Pavements," Des Moines, Iowa, 1909–1928 Proceedings Highway Research Board Vol 14, p 49, 1934 Also, Public Roads, 16 3–6 and 14, March, 1935

TABLE IV

TYPICAL CALCULATIONS OF SURVIVOR CURVES BY THE ORIGINAL AND MULTIPLE ORIGINAL GROUP METHODS FOR BITUMINOUS MACADAM ASPHALT PENETRATION—MASSACHUSETTS

Original group, 1917 construction				Multiple original group Jan 1, 1935				
Year	Age Jan 1, years	Sq yd remaining in service Jan 1	Per cent surviving	Year laid	Sq yd laid	Age Jan 1, 1935, years	Sq yd remaining in service Jan 1, 1935	Per cent surviving
1918	0½	452,066	100 0	1934		0½		
1919	1½	452,066	100 0	1933	680,603	1½	680,603	100 0
1920	2½	452,066	100 0	1932	1,572,802	2½	1,572,802	100 0
1921	3½	452,066	100 0	1931	1,293,907	3½	1,293,907	100 0
1922	4½	452,066	100 0	1930	1,191,954	4½	1,191,954	100 0
1923	5½	452,066	100 0	1929	1,756,960	5½	1,754,103	99 8
1924	6½	446,745	98 8	1928	1,394,860	6½	1,351,172	96 9
1925	7½	379,430	83 9	1927	1,198,831	7½	1,180,299	98 4
1926	8½	353,394	78 2	1926	610,599	8½	596,728	97 7
1927	9½	350,594	77 6	1925	503,063	9½	482,947	96 0
1928	10½	325,912	72 1	1924	492,462	10½	404,306	82 1
1929	11½	316,776	70 1	1923	398,212	11½	306,699	77 0
1930	12½	298,715	66 1	1922	472,689	12½	357,287	75 6
1931	13½	232,895	51 5	1921	228,218	13½	190,609	83 5
1932	14½	217,454	48 1	1920	84,844	14½	40,408	47 6
1933	15½	217,454	48 1	1919	312,304	15½	219,234	70 2
1934	16½	217,454	48 1	1918	197,084	16½	100,242	50 9
1935	17½	217,454	48 1	1917	452,066	17½	217,454	48 1
				1916	435,285	18½	182,724	42 0
				1915	293,300	19½	29,416	10 0
				1914	219,580	20½	34,386	15 7
				1913	178,199	21½	41,260	23 2
				1912	139,305	22½	64,214	46 1
				1911	29,272	23½	29,272	100 0

is to be successful The pavement must be observed each year following its construction and the quantity remaining in service each year recorded Table IV illustrates this method

Composite Original Group Method In certain cases the construction for any single year may be of insufficient quantity to result in a good survivor curve when treated by the original group method When the construction quantities for more than one year are available they may be combined into a composite original group and the average life determined for the construction during the group of years treated as a whole

Multiple Original Group Method A second method of combining the construction for a series of years is found in the multiple original group method of drawing survivor curves, which usually results in stub curves By this method, the several groups are observed as of a given date (usually the present) and the

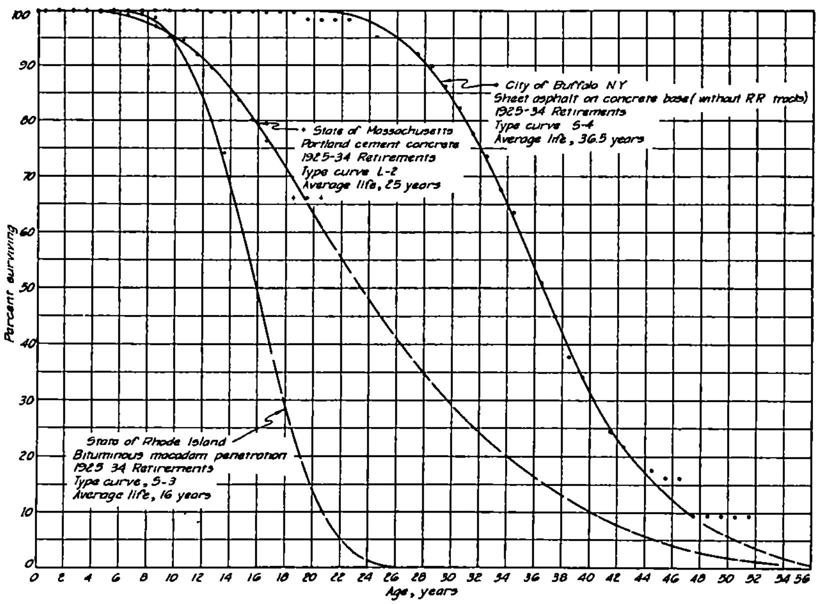

Figure 1 Typical Survivor Curves from which Average Lives Are Determined

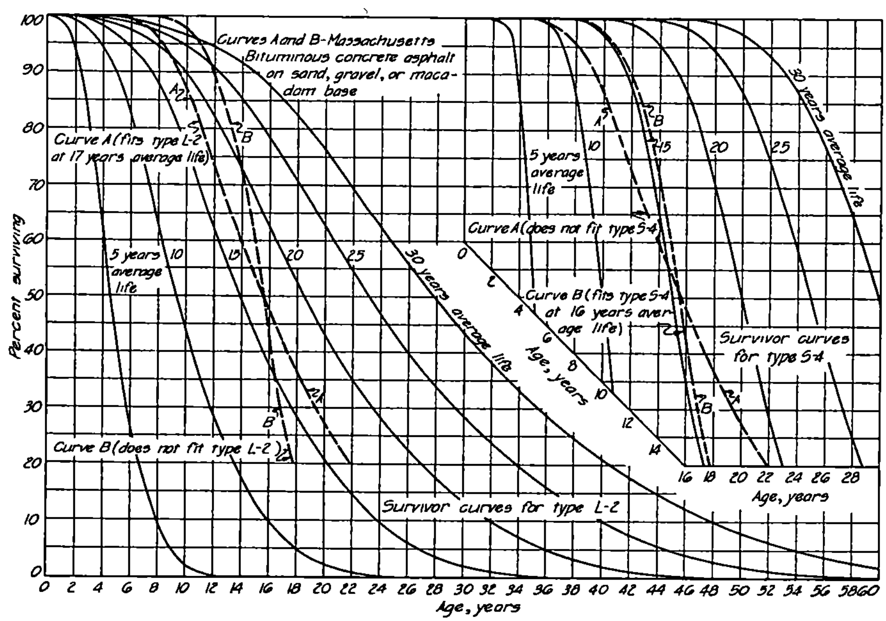

Figure 2. Method of Superimposing Stub Survivor Curves on Type Survivor Curves to Estimate Average Life

TABLE V
Summary of Calculated Average Lives

Surface: No	Surface: Type	Road or street system	Construction period included, years	Retirement period included, years	Type curve	Estimated average life, years	Last point on curve: Per cent surviving	Last point on curve: Age, years	Rating of results	Statistical method
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	Brick on concrete base	Des Moines	1891–1918	1909–1918	S-2	22 0	38	24 5	Fair	A R
		Des Moines	1891–1924	1915–1924	S-1	24 5	47	33 5	Good	A R
		Des Moines	1891–1928	1919–1928	S-1	36 0	61	32 5	Good	A R
		Des Moines	1891–1933	1925–1934	S-3	49 0	79	43 5	Fair	A R
2	Bitulithic on concrete base	Des Moines	1912–1925	1921–1934	S-1	28 0	80	22 5	Fair	A R
3	Sheet asphalt on concrete base	Des Moines	1901–1924	1915–1924	S-2	27 5	87	23 5	Fair	A R
		Des Moines	1901–1933	1925–1934	S-2	46 0	95	33 5	Poor	A R
4	Sheet asphalt on concrete base (without R R track)	Buffalo	1881–1924	1915–1924	L-2	36 0	31	43 5	V Good	A R
		Buffalo	1883–1933	1925–1934	S-4	36 5	10	51 5	V Good	A R
		Buffalo	1885	1885–1907	L-4	14 0	0	22 5	Fair	O G
		Buffalo	1890	1890–1934	S-2	32 5	17	43 5	Fair	O G.
		Buffalo	1895	1895–1934	L-3	39 5	46	38 5	Fair	O G
		Buffalo	1899	1899–1934	S-3	41 0	79	34 5	Poor	O G
5	Sheet asphalt on concrete base (with R R track)	Buffalo	1887–1924	1915–1924	S-3	27 0	36	37 5	Good	A R
		Buffalo	1888–1933	1925–1934	R-3	34 0	10	44 5	Good	A R
		Buffalo	1885	1885–1913	S-3	14 0	0	28 5	Fair	O G
		Buffalo	1890	1890–1934	R-2	18 0	1	43 5	Poor	O G
		Buffalo	1895	1895–1934	S-0	23 0	27	38 5	Poor	O G
		Buffalo	1900	1900–1934	S-3	34 0	51	33 5	Fair	O G
		Buffalo	1905	1905–1934	S-1	35 0	84	28 5	Poor	O G
		Buffalo	1910	1910–1934	S-1	36 0	83	23 5	Poor	O G
6	Block stone on concrete base	Buffalo	1887–1933	1925–1934	S-2	38 0	40	47 5	Fair	A R
7	Portland cement concrete	Wayne County	1909–1924	1915–1924	R-5	13 7	67	14 5	Fair	A R
		Wayne County	1910–1934	1925–1934	R-3	21 5	49	24 5	Good	A R
		Wayne County	1915–1934	1925–1934	R-2	29 0	85	20 5	Fair	A R
		Wayne County	1909–1925	1909–1925	R-5	14 0	0	15 5	Poor	M O G
		Wayne County	1909–1930	1909–1930	R-4	16 0	0	20 5	Poor	M O G
		Wayne County	1909–1934	1909–1934	R-3	21 0	0	25 5	Poor	M O G
		Wayne County	1910	1910–1934	S-2	12 0	8	24 5	Good	O G
		Wayne County	1912	1912–1934	R-4	18 0	28	22 5	Fair	O G
		Wayne County	1917	1917–1934	R-2	16 0	64	17 5	Poor	O G

8	Bituminous concrete (coarse aggregate) on gravel or macadam base	Rhode Island	1909	1909–1934	L-5	18 0	14	25 5	Fair	O G
		Rhode Island	1912	1912–1934	L-4	17 0	17	22 5	Good	O G
		Rhode Island	1908–1913	1908–1934	L-4	17 0	0	26 5	Good	C. O G
9	Bituminous concrete (graded aggregate) on gravel or macadam base)	Rhode Island	1918–1926	1918–1934	S-5	15 0	62	15 5	Poor	C O G
10	Bituminous macadam penetration on gravel or macadam base	Rhode Island	1913–1934	1925–1934	S-3	16 0	39	21 5	Fair	A R
		Rhode Island	1917	1917–1934	L-4	14 5	33	17 5	Fair	O G
		Rhode Island	1913–1934	1913–1934	S-3	17 0	31	21 5	Poor	M O G
11	Bituminous macadam oil	Massachusetts	1910–1915	1910–1934	S-3	15 5	12	20 5	Good	C O G
12	Bituminous macadam tar penetration on gravel or macadam base	Massachusetts	1913	1913–1934	S-3	17 0	27	21 5	Poor	O G
		Massachusetts	1915	1915–1934	L-3	17 0	34	19 5	Poor	O G
		Massachusetts	1917	1917–1934	L-1	18 0	47	17 5	Fair	O G
		Massachusetts	1908–1927	1918–1927	S-2	17 5	57	18 5	Good	A R
		Massachusetts	1908–1927	1908–1927	L-4	18 0	0	26 5	Fair	M O G.
13	Bituminous macadam asphalt penetration on gravel or macadam base	Massachusetts	1913	1913–1934	L-3	16 0	23	21 5	Poor	O G
		Massachusetts	1915	1915–1934	L-4	14 0	10	19 5	Fair	O G
		Massachusetts	1917	1917–1934	L-2	15 0	48	17 5	Poor	O G
		Massachusetts	1911–1925	1911–1925	L-3	17 5	—	22 5	Poor	M O G.
		Massachusetts	1911–1933	1925–1934	S-2	17 0	37	23 5	V Good	A R.
14	Bituminous gravel or macadam base	Massachusetts	1915	1915–1934	S-4	16 0	23	18 5	Poor	O G.
		Massachusetts	1917	1917–1934	S-4	14 5	29	17 5	Fair	O G
		Massachusetts	1909–1933	1925–1934	L-2	17 0	17	24 5	V Good	A. R
15	Portland cement concrete	Massachusetts	1913–1933	1925–1934	L-2	25 0	75	20 5	Fair	A R
16	Waterbound macadam, surface treated	Massachusetts	1894–1919	1925–1934	L-3	22 0	0	38 5	V Good	A R
17	Surface treated gravel	Massachusetts	1896–1925	1925–1934	L-2	14 0	0	38 5	Good	A R

percentage of each group remaining in service is plotted at its proper age Thus, the survivor curve is formed from a multiple of groups, each group furnishing one point on the survivor curve This method is applicable to any data when the original number of units constructed is known together with the number remaining in service today, or other date of observation, provided there are enough original groups to establish a curve It is not necessary to know the amount remaining in service from each original group for the years prior to the date of observation as it is in both the original group and the composite original group methods (Table IV)

Annual Rate Method For a property in which a given kind of unit has been constructed or installed, each year over a period of years and up to the last year for which the average life is to be studied, the annual rate method offers the best solution to determination of the correct average life This method requires that the number of units in service each year and their ages be known as well as the number of units retired each year and their ages The annual rate of retirement is then calculated for the property for each age of the units in service This annual rate is the percentage retired during the year of the quantity in service at the beginning of the year or age The method is applicable to any single year or any number of consecutive years A stub survivor curve usually results In Table III is shown a sample calculation, the data for which are given in Tables I and II

The foregoing methods were applied in the calculation of the average lives of the pavements studied in accordance with the limitations of the available data and the methods Tables III and IV illustrate typical calculations while Figure 1 shows survivor curves of the character usually found The average life and type of distribution of retirement were determined by comparing the actual survivor curve (usually a stub curve) with a set of 18 type curves, or standards, developed by the author in a previous study of 176 survivor curves representing various kinds of properties and industries[2] The method of comparison is illustrated in Figure 2 It consists of superimposing the survivor curve for which the average life is wanted on the 18 standards in turn until a reasonable fit, or agreement, is found. The average life and type curve are then read directly from the standard type curve fitted While these type curves were developed from a study of miscellaneous commercial, utility, and industrial equipment, they have been found to apply equally well to pavement and other physical property

The foregoing methods when applied to the data compiled for the five road systems resulted in the average lives shown in Table V

DISCUSSION OF RESULTS

General Limiting Factors

It is a somewhat difficult problem to determine the average lives of the high types of pavement constructed during the past ten years, since experience with them has not yet reached the age whereby a sufficient volume of retirements at ages in the neighborhood of and beyond average life are available for statistical study Until the studies can be made more reliable by a greater volume of retirements and retirements at greater ages, any calculated average lives of the modern surface types should be considered tentative

[2] Op cit

values The average lives determined for those types of surfaces long continued in construction, such as sheet asphalt in Buffalo, and those surfaces constructed in the early years, but abandoned as standard some years ago, such as tar penetration macadam in Massachusetts and bituminous concrete (coarse aggregate type) on gravel base in Rhode Island, are well established and will not greatly depart from these values in the near future

It should be remembered that the average life of pavements or of any physical property is not something fixed and unchanging The realized average life will vary from time to time in accordance with changes in design, construction methods, traffic, maintenance operations, administrative policies and economic influences However, these changes will be relatively small and gradual in the older established types of pavements and in all types when dealing with large mileages of construction Until the average life of a given pavement type in a given road system is shown to be stabilized, frequent periodic calculations of the average life should be made Table VI, illustrates this point in regard to the brick pavement on concrete base in Des Moines, Iowa

It is illustrated again by calculating the probable average life of each year's construction of portland cement concrete pavement in Wayne County, Michigan (see Table VII)

In Des Moines, this brick pavement has not yet reached its probable maximum age, and the rate of retirement has been low in recent years Should heavier retirements occur in the next five years, an average life calculated for the period of 1930 to 1939 would most likely be less than the 49 years calculated for the period 1925 to 1934. This value of 49 years results primarily because of the few retirements, 1925 to 1934, and the small mileage observed It is not a typical case In Wayne County, it is very evident that the life realized from concrete pavement has increased generally since the first construction in 1909 It is of interest to note the short lives of the pavements constructed in the two war years, 1917 and 1918, as compared with those for earlier

TABLE VI

PERIODIC CALCULATION OF AVERAGE LIFE BRICK PAVEMENT ON CONCRETE BASE, DES MOINES, IA

Period of retirement used in calculation	Average life calculated by the annual rate method	Actual average age at retirement (individual unit method)
years	*years*	
1909–1918	22	16
1915–1924	24	17
1919–1928	36	20
1925–1934	49	28

TABLE VII

PORTLAND CEMENT CONCRETE PAVEMENT WAYNE COUNTY, MICHIGAN

Year of construction	Calculated average life
	years
1909	13
1910	12
1911	18
1912	18
1913	19
1914	24
1915	26
1916	26
1917	16
1918	12
1919	28
1920	19
1921	31
1922	24
1923	25
1924	31
1925	24
1926	—

and later years Because of limited retirements the last five values are not reliable, but only indicative of the trend

On the other hand, the average life of sheet asphalt pavement in Buffalo on streets without car tracks was the same, 36 years, for both the 1915 to 1924 and 1925 to 1934 periods It seems to be stabilized

CAUSES OF RETIREMENT

It would be ideal if a study of the average life of pavement could be made so that the force of retirement from each cause as shown on the following list of reasons of retirement and for definite traffic and maintenance conditions could be isolated This ideal is impossible of attainment for the reasons that the pavements themselves vary in quality, the degree of exposure to these forces of retirement is not measurable, traffic and maintenance conditions cannot be controlled equally for the various sections, and, even if sections of pavements could be controlled in such manner that the risk of retirement from all causes would be comparable, the retirements in any one classification of pavement and risk would be so few that an average life could not be calculated Of necessity, then, the retirements must be pooled without regard to the reason for retirement This does not mean that the reasons for retirement cannot be studied and used in an interpretation of the results and forecasts of future probable average lives

REASONS FOR RETIREMENT OF HIGHWAY PAVEMENTS

1. Surface and structural failures
   - Slab surface failure (rough, wavy, scaling, holes, etc)
   - Failure of base
   - Failure of foundation or subgrade
2. Obsolescence
   - Widening operations
   - Relocation of curves or alignment
   - Grade reduction
   - Change to higher type to meet traffic demands as to load and speed
3. Related highway improvements
   - Grade separations (highway and railway)
   - Bridge and drainage structures
   - Intersections and cross-overs
4. Non-highway construction and catastrophes
   - Public and private construction of dams, reservoirs, canals, buildings, sewers, et cetera
   - Damage due to fires, floods, earthquakes, tornadoes, et cetera
5. Transfer of highway sections to another road authority which will continue them in use (considered a transfer or sale rather than a retirement)

In the consideration of any given section of existing pavement, its probable service life can be estimated in the manner suggested by Marston,[3] on the basis of whether its risks are more or less severe than those pertaining to the pavement as a whole for the time for which the average life was calculated

Undoubtedly, a majority of the roadway surfaces retired since 1920 were removed for a combination of reasons, particularly because of structural condition and obsolescence, when either condition alone would not have demanded retirement Related highway improvements, non-highway construction, and catastrophes cause the retirement of but a comparatively small percentage.

The factors of obsolescence are just as real as are those of physical wear and tear

[3] Anson Marston, op cit

and must be given equal consideration The fact that a given section of pavement is retired largely for reasons of obsolescence in no way justifies adjustment of the average life to bring it into line with that of another section of pavement, which, while subjected to the same factors of obsolescence, was not forced into retirement by them All other factors that determine average life being equal, sections of pavement that survive the forces of obsolescence are entitled to a longer average life than are sections which do not Wise planning by the highway engineer will do much to reduce the hazard of obsolescence

In the problem of determining the annual cost of highway transportation, it makes no difference what the causes of retirement of pavement are, in the matter of selecting the most economical type of surface, it is only necessary to see that the forces of obsolescence are equally balanced in the statistics from which the average life and annual costs are determined

SALVAGE VALUE AND MAINTENANCE COSTS

To date no attempt has been made to determine salvage values for the various types of surfaces, but this will receive attention during the coming year. Before the true annual cost of any surface can be calculated, salvage value and annual maintenance costs, in addition to average life, must be known

Likewise, annual maintenance costs have not yet received attention in this particular study but will during the coming year The U S Bureau of Public Roads now has in operation a long time maintenance cost and traffic study in Rhode Island, Connecticut, and New Hampshire, and in addition, is cooperating with the 48 States in a special study of the maintenance cost on selected sections throughout each State system These studies will bring to light many important facts about maintenance costs.

Certain pavements may be continued in service by heavy and frequent maintenance for years beyond the normal average life. Further, maintenance operations can be of such character that the road is in reality improved each year and extended in life Obviously, the waterbound macadam and gravel surface-treated roads reported in Table V as having average lives of 22 and 14 years,

TABLE VIII

AVERAGE AGES OF MASSACHUSETTS PAVEMENTS, JAN 1935

Surface type (State terminology)	Average age
	years
Surface treated waterbound macadam	24 5
Bituminous macadam, oil	21 2
Surface treated gravel	21 0
Bituminous macadam, tar penetration	16 0
Granite block, concrete base	13 0
Bituminous concrete, gravel or macadam base	8 6
Bituminous macadam, asphalt penetration	6 8
Portland cement concrete	6 5
Bituminous concrete, concrete base	3 7

respectively, received sufficient honing. additional new material, and surface treatments greatly to prolong their lives A compensating factor, however, is their high annual maintenance costs in comparison with the maintenance costs of the other types of surfaces

Maintenance costs need careful study and analysis before reliable annual costs of the various surfaces can be determined. The age of the pavement no doubt has some effect upon the maintenance required A comparison of the average ages of the pavements (omitting 1934 construction) in Massachusetts as of January 1, 1935, is given as an example of the variation to be encountered (Table VIII)

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

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

By A J Bone

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SYNOPSIS

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

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

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

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

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