A MORTALITY CURVE STUDY OF THE ACTUAL SERVICE LIVES OF BRICK-ON-CONCRETE PAVEMENTS, DES MOINES, IOWA, 1909–1928

By Anson Marston

Senior Dean of Engineering Iowa State College

SYNOPSIS

Owing to dearth of data of the actual service lives of different types of highway pavements, present estimates of their probable lives are based mostly on opinions instead of on facts.

This paper presents the results of a "mortality curve" study of the actual service lives of brick-on-concrete pavements in the city of Des Moines, Iowa, as indicated by their actual mortality data during the years 1909–1928, inclusive The collection, arrangement, and calculation of the mortality data are explained and illustrated The resulting "mortality curves" are given, and the method of using them to assist in estimating the probable lives of similar pavements still in service is explained

Similar studies of rural highway pavement actual service lives, in at least four different states, are being undertaken, in a cooperative highway research project, by the U S Bureau of Public Roads and the Iowa Engineering Experiment Station

THE PRESENT DEARTH OF DATA OF THE ACTUAL SERVICE LIVES OF HIGHWAY PAVEMENTS

There is at present so nearly a complete lack of collected and studied reliable data of the *actual* service lives of different types of highway pavements that our knowledge of the *probable* lives of the billions of dollars worth of existing pavements is merely what we can surmise from the *opinions* of highway engineers Even when collected by such respected authorities as the Interstate Commerce Commission, and even when expressed by such competent engineers as those employed by our state highway commissions and our large cities, engineering *opinions* upon pavement lives have a range of from about 10 to about 40 years for concrete, brick and asphalt, with corresponding variations for other types Manifestly, estimates based upon opinions which vary 400 per cent cannot be considered reliable

Pavement life is one of the most essential of the factors whose numerical values must be known in order to determine the annual costs of highway systems and/or the costs of different classes of highway services; correct records of both of which are especially important at the present time; in highway economics in deciding upon correct highway policies, and in highway accountancy in developing and using satisfactory uniform highway accounting systems.

The fact that a large mileage of rural highway pavements built since the World War has now reached service ages of 10–20 years combines with the need to substitute facts for guesses of pavement life to make the present an opportune time to collect and study by the best and most advanced methods, a large amount of reliable data of the *actual service lives* of rural highway pavements

A MORTALITY CURVE STUDY OF THE RETIREMENTS OF BRICK-ON-CONCRETE PAVEMENTS AT DES MOINES, IOWA, 1909–1928

In his paper on the "Engineering Valuation of Highway Systems,"[1] the author explained briefly the "mortality curve" method of studying actual retirement data of different kinds of industrial property In January to June, 1934, Mr J Phil Starbuck,[2] of Ames, Iowa, a graduate student working under the direction of Mr. Robley Winfrey and the author, made a detailed study of the actual retirement data of all brick-on-concrete and brick-on-sand pavements in Des Moines, Iowa, using the "mortality curve" method The newest brick-on-sand pavements found had been built in 1899, so that Mr Starbuck's data did not include their retirements at ages 1 to 9 years For this reason, only the data for brick-on-concrete pavements will be presented in this paper

By careful search of the city paving records, Mr Starbuck obtained and tabulated for each year, 1909 to 1928, inclusive, data of:

1 The actual pavement retirements each calendar year, classified by service ages
2 The total amounts of pavement of each age actually in service each calendar year

The retirement data were tabulated, in square yards, as shown in Table I for the years 1919–1928, inclusive; and were averaged to give the average annual retirements for each age Similarly, the amounts of pavement of each service age in service during each calendar year were tabulated and averaged as shown in Table II Finally, the averaged annual pavement retirements and pavements in service each calendar year were tabulated and calculated as shown in Table III, to give the calculated mortality survivor curve data in columns (5) and (7), column (5) for the "annual rate method" and column (7) for the "individual unit method"

Computations corresponding to those illustrated in Tables I, II and III for 1919–1928 were made for the 1909–1918 and the 1909–1928

[1] Proceedings Highway Research Board, Vol 13, p 43 (1933)

[2] In his progress report to the author, June, 1934, Mr Starbuck acknowledged indebtedness for assistance to John M Tippee, City Engineer, and C C Green, Office Engineer, both of Des Moines, Iowa, to John C Hultquist, a fellow graduate student, and to Robley Winfrey and E R Davis of the staff of the Engineering Experiment Station, Iowa State College.

TABLE I

BRICK ON CONCRETE PAVEMENT RETIREMENTS, DES MOINES, IOWA, 1919–1928

Age Interval, Years	Square Yards Retired During Each Age Interval For Each Year											
	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	Total	Average 1919–28
0–½												
½–1½												
1½–2½												
2½–3½												
3½–4½	649										649	64 90
4½–5½												
5½–6½												
6½–7½												
7½–8½					5143						5143	514 30
8½–9½					2029						2029	202 90
9½–10½	4214				510						4724	472 40
10½–11½			12762								12762	1276 20
11½–12½	735										735	73 50
12½–13½												
13½–14½												
14½–15½												
15½–16½	1006				577	2951					4534	453 40
16½–17½					2624		6150				8774	877 40
17½–18½	518			7846							8364	836 40
18½–19½					1156						1156	115 60
19½–20½												
20½–21½									1670		1670	167 00
21½–22½	18591							1461			20052	2005 20
22½–23½												
23½–24½												
24½–25½				5942	284						6226	622 60
25½–26½	1152										1152	115 20
26½–27½												
27½–28½												
28½–29½												
29½–30½							1947		11103		13050	1305 00
30½–31½								1916		9016	10932	1093 20
31½–32½									1122		1122	112 20
32½–33½												

brick-on-concrete pavement mortality data [3] The mortality "survivor curve" data thus obtained by the "annual rate method" have been

[3] All Mr Starbuck's tables and curves for brick-on-concrete pavements have been recomputed and corrected by Mr E. R Davis

TABLE II

BRICK ON CONCRETE PAVEMENTS IN SERVICE, DES MOINES, IOWA, 1919–1928

Age Interval, years	Square Yards In Service At Beginning of Each Age Interval For Each Year											
	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	Total	Average
0–½	65014	37342	31643	51636	11451	78741	90499	99054	46444	67315	579139	57913 9
½–1½	65014	37342	31643	51636	11451	78741	90499	99054	46444	67315	579139	57913 9
1½–2½	46529	65014	37342	31643	51636	11451	78741	90499	99054	46444	558353	55835 3
2½–3½	69238	46529	65014	37342	31643	51636	11451	78741	90499	99054	581147	58114 7
3½–4½	56208	69238	46529	65014	37342	31643	51636	11451	78741	90499	538301	53830 1
4½–5½	13131	55559	69238	46529	65014	37342	31643	51636	11451	78741	460284	46028 4
5½–6½	21580	13131	55559	69238	46529	65014	37342	31643	51636	11451	403123	40312 3
6½–7½	7087	21580	13131	55559	69238	46529	65014	37342	31643	51636	398759	39875 9
7½–8½	5346	7087	21580	13131	55559	69238	46529	65014	37342	31643	352469	35246 9
8½–9½	66838	5346	7087	21580	13131	50416	69238	46529	65014	37342	382521	38252 1
9½–10½	21718	66838	5346	7087	21580	11102	50416	69238	46529	65014	364868	36486 8
10½–11½	52732	17504	66838	5346	7087	21070	11102	50416	69238	46529	347862	34786 2
11½–12½	35859	52732	17504	54076	5346	7087	21070	11102	54016	69238	324430	32443 0
12½–13½	13460	35124	52732	17504	54076	5346	7087	21070	11102	50416	267917	26791 7
13½–14½	21012	13460	35124	52732	17504	54076	5346	7087	21070	11102	238513	23851 3
14½–15½	24459	21012	13460	35124	52732	17504	54076	5346	7087	21070	251870	25187 0
15½–16½	16503	24459	21012	13460	35124	52732	17504	54076	5346	7087	247303	24730 3
16½–17½	19060	15497	24459	21012	13460	34547	49781	17504	54076	5346	254742	25474 2
17½–18½	6490	19060	15497	24459	21012	10836	34547	43631	17504	54076	247112	24711 2
18½–19½	1708	5972	19060	15497	16613	21012	10836	34547	43631	17504	186380	18638 0
19½–20½	9964	1708	5972	19060	15497	15457	21012	10836	34547	43631	177684	17768 4
20½–21½	36059	9964	1708	5972	19060	15497	15457	21012	10836	34547	170112	17011 2
21½–22½	61093	36059	9964	1708	5972	19060	15497	15457	21012	9166	194988	19498 8
22½–23½	50265	42502	36059	9964	1708	5972	19060	15497	13996	21012	216035	21603 5
23½–24½	29968	50265	42502	36059	9964	1708	5972	19060	15497	13996	224991	22499 1
24½–25½	15657	29968	50265	42502	36059	9964	1708	5972	19060	15497	226652	22665 2
25½–26½	5486	15657	29968	50265	36560	35775	9964	1708	5972	19060	210415	21041 5
26½–27½		4334	15657	29968	50265	36560	35775	9964	1708	5972	190203	19020 3
27½–28½	4306		4334	15657	29968	50265	36560	35775	9964	1708	188537	18853 7
28½–29½		4306		4334	15657	29968	50265	36560	35775	9964	186829	18682 9
29½–30½			4306		4334	15657	29968	50265	36560	35775	176865	17686 5
30½–31½				4306		4334	15657	28021	50265	25457	128040	12804 0
31½–32½					4306		4334	15657	26105	50265	100667	10066 7
32½–33½						4306		4334	15657	24983	49280	4928 0
33½–34½							4306		4334	15657	24297	2429 7
34½–35½								4306		4334	8640	864 0
35½–36½									4306		4306	430 6
36½–37½										4306	4306	430 6
37½–38½												

TABLE III

Calculation of Survivor Curve for Brick on Concrete Pavements, Des Moines, Iowa, 1919–1928

Age Interval Years	Annual Rate Method				Individual Unit Method	
	Average retirements during age interval sq yd	Average square yards in service at beginning of age interval	Annual rate of retirement %	Percent surviving at beginning of age interval	Summation of average retirements Col 2 sq yd	Percent surviving at beginning of age interval
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0–½	0	57913 9		100 000	10307 4	100 000
½–1½	0	57913 9		100 000	10307 4	100 000
1½–2½	0	55835 3		100 000	10307 4	100 000
2½–3½	0	58114 7		100 000	10307 4	100 000
3½–4½	64 9	53830 1	0 121	100 000	10307 4	100 000
4½–5½	0	46028 4		99 879	10242 5	99 370
5½–6½	0	40312 3		99 879	10242 5	99 370
6½–7½	0	39875 9		99 879	10242 5	99 370
7½–8½	514 3	35246 9	1 459	99 879	10242 5	99 370
8½–9½	202 9	38252 1	0 530	98 422	9728 2	94 381
9½–10½	472 4	36486 8	1 295	97 900	9525 3	92 412
10½–11½	1276 2	34786 2	3 669	96 632	9052 9	87 829
11½–12½	73 5	32443 0	0 227	93 087	7776 7	75 448
12½–13½	0	26791 7		92 876	7703 2	74 735
13½–14½	0	23851 3		92 876	7703 2	74 735
14½–15½	0	25187 0		92 876	7703 2	74 735
15½–16½	453 4	24730 3	1 833	92 876	7703 2	74 735
16½–17½	877 4	25474 2	3 444	91 174	7249 8	70 336
17½–18½	836 4	24711 2	3 385	88 034	6372 4	61 824
18½–19½	115 6	18638 0	0 620	85 054	5536 0	53 709
19½–20½	0	17768 4		84 527	5420 4	52 587
20½–21½	167 0	17011 2	0 982	84 527	5420 4	52 587
21½–22½	2005 2	19498 8	10 284	83 697	5253 4	50 967
22½–23½	0	21603 5		75 090	3248 2	31 513
23½–24½	0	22499 1		75 090	3248 2	31 513
24½–25½	622 6	22665 2	2 747	75 090	3248 2	31 513
25½–26½	115 2	21041 5	0 547	73 027	2625 6	25 473
26½–27½	0	19020 3		72 628	2510 4	24 355
27½–28½	0	18853 7		72 628	2510 4	24 355
28½–29½	0	18682 9		72 628	2510 4	24 355
29½–30½	1305 0	17686 5	7 379	72 628	2510 4	24 355
30½–31½	1093 2	12804 0	8 538	67 269	1205 4	11 695
31½–32½	112 2	10066 7	1 115	61 526	112 2	1 089
32½–33½	0	4928 0		60 840	0 0	0 000
33½–34½	0	2429 7		60 840		
34½–35½	0	864 0				
35½–36½	0	430 6				
36½–37½	0	430 6				

plotted and are shown in Figure 1, together with the "individual unit" survivor curve for the period 1909–1918

The "annual rate method," the final computations by which are illustrated in columns (2), (3), (4) and (5) of Table III, is the correct method for computing mortality "survivor curves" of different classes of industrial property It correctly takes into account *all the pavement in service each year.* The "individual unit method," whose final computations are illustrated in columns (6) and (7) of Table III, takes into account only those pavements actually retired, and hence gives entirely too small percents of survivors at different service ages and entirely too small average life of pavements For example, the average life for the years 1909–1918 by the "individual unit method" was only 17 years, whereas the correct average life indicated by the mortality data was 22 years, as shown by the "annual rate method" It should be noted that estimates of average pavement lives based largely upon first or comparatively early retirements are quite likely to be too small

' *Computations of average-lives of pavements* The average-life of a pavement for which a mortality survivor curve like those in Figure 1 is available must be found by computing the area under the survivor curve (usually divided for this purpose into strips each, except the first, one year wide) and dividing it by 100 (since the survivors are platted in percents)

As explained in the paper[4] on the "Engineering Valuation of Highway Systems," already referred to, the Iowa Engineering Experiment Station has developed some 13 "mortality type curves," which seem to pretty well cover the usual range of the mortality characteristics of the different kinds of industrial property

Four of these are "left mode" curves, designated L_1, L_2, L_3, L_4, five are "symmetrical," S_1, S_2, S_3, S_4, S_5; and 4 are "right mode," R_4, R_3, R_2, R_1

By trial, it was found that the mortality data of brick-on-concrete pavements in Des Moines, 1909–1918 fitted Curve S_2, those for 1919–1928 fitted S_1 and those for 1909–1928 also fitted S_1, all as shown in Figure 1. It would therefore appear that mortality type curve S_1 is the one to use to assist in estimating the probable life of any particular stretch of brick-on-concrete pavement still in service in Des Moines.

The average lives in years, indicated by the mortality survivor curves in Figure 1 are 22 for the retirements of 1909–1918, 36 for the retirements of 1919–1928 and 28 for the entire 20 year retirements, 1909–1928 Information is lacking about the traffic intensities, differences in design, changes in retirement policies and other circumstances which would completely explain these variations in average life It is permissible to point to the improvements in pavement design and construction in later years and to the probability that the heavier traffic streets were more

[4] Proceedings Highway Research Board, Vol. 13, p. 52 et. seq

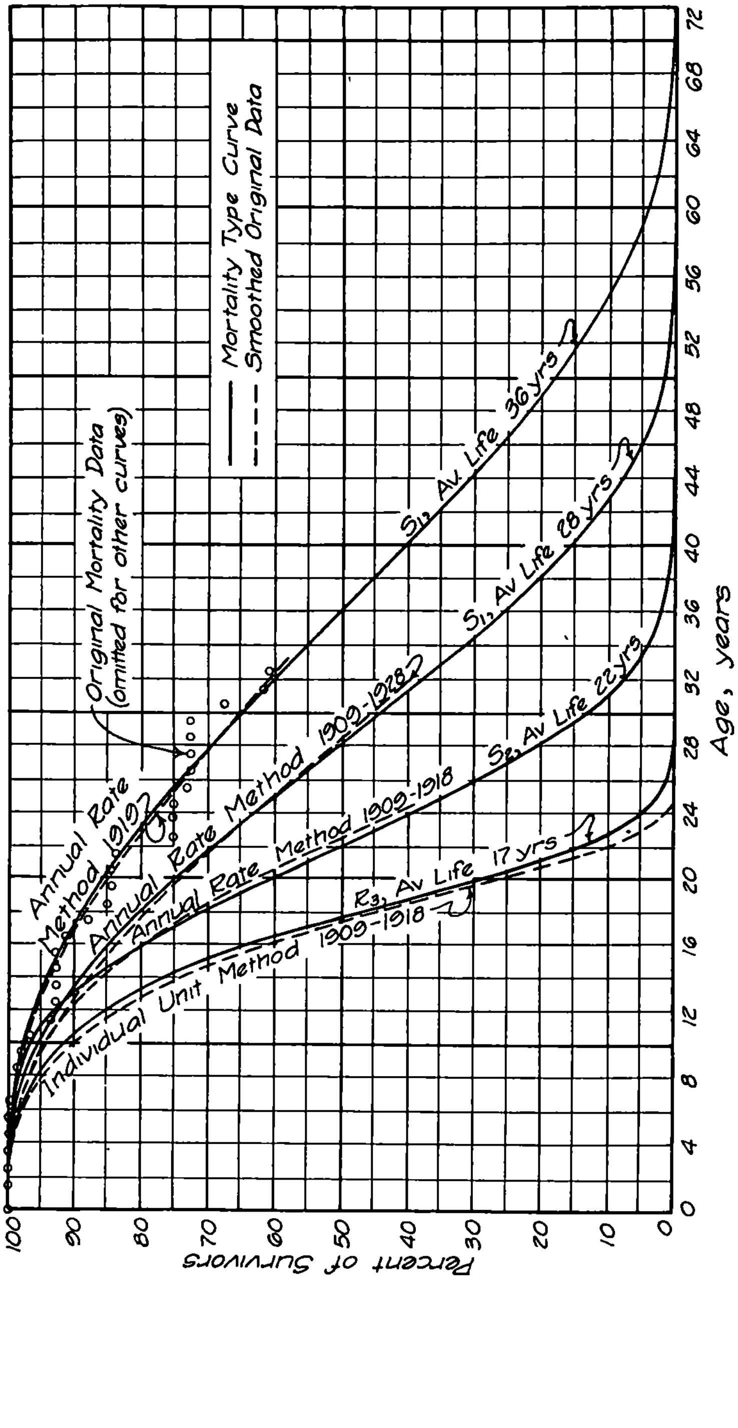

Figure 1. Mortality Curves of Brick on Concrete Pavements, Des Moines, Iowa, 1909–1928.

likely to be paved first as circumstances which may partially explain the apparent increase in the average life of the pavements retired in the later years

THE USE OF PAVEMENT MORTALITY CURVES IN FORECASTING THE PROBABLE LIVES OF PARTICULAR EXISTING PAVEMENTS

The mortality type curves which fit the actual pavement mortality data of particular kinds of pavements (See Figure 1) can be of great service in forecasting the probable lives of particular existing pavements

TABLE IV

NUMERICAL DATA OF MORTALITY TYPE CURVE, S_1

Age Interval, % of Average Life	Renewal During Age Interval, %	Percent Surviving at Beginning of Age Interval	Expectancy Percent of Average Life	Probable Life Percent of Average Life
0–10	0 1584	100 0000	100 00	100 00
10–20	0 8872	99 8416	90 15	100 15
20–30	2 0108	98 9544	80 91	100 91
30–40	3 3294	96 9436	72 49	102 49
40–50	4 6964	93 6142	64 89	104 89
50–60	5 9971	88 9178	58 05	108 05
60–70	7 1408	82 9207	51 89	111 89
70–80	8 0578	75 7799	46 31	116 31
80–90	8 6971	67 7221	41 22	121 22
90–100	9 0250	59 0250	36 56	126 56
100–110	9 0250	50 0000	32 26	132 26
110–120	8 6971	40 9750	28 26	138 26
120–130	8 0578	32 2779	24 53	144 53
130–140	7 1408	24 2201	21 02	151 02
140–150	5 9971	17 0793	17 72	157 72
150–160	4 6964	11 0822	14 61	164 61
160–170	3 3294	6 3858	11 67	171 67
170–180	2 0108	3 0564	8 94	178 94
180–190	0 8872	1 0456	6 52	186 52
190–200	0 1584	0 1584	5 00	195 00
200–210	0 0000	0 0000	0 00	200 00

The mortality type curves are "generalized" by stating and platting their service ages in *percents of average life*

Just as average life can be computed[5] by dividing the entire area under the mortality curve by 100, so the expectancy of the average survivor at any age can be computed by dividing the area under the mortality curve to the right of the age ordinate by the percent of survivors at the age Expectancy plus service age is probable life, and "probable life

[5] See ante.

curves," computed in this manner, can be platted on the same diagram as survivor curves

Table IV shows the results of the computations of expectancies and probable lives of the AVERAGE SURVIVOR at different service ages for mortality type curve S_1

Figure 2 shows mortality type S_1, "survivor" and "probable life" curves platted on the same diagram and "generalized" by platting service ages in percents of average life

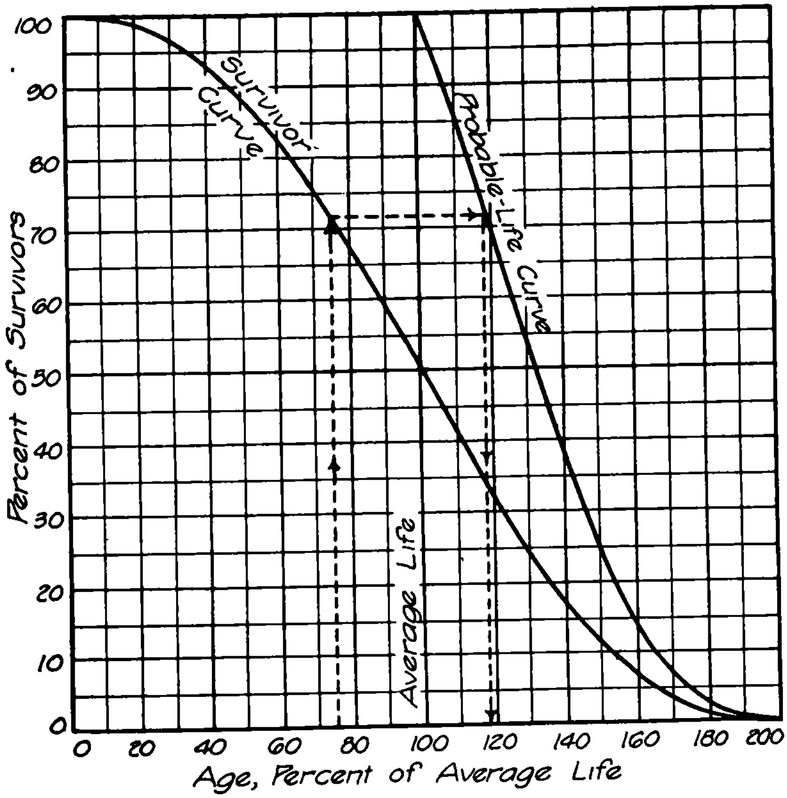

Figure 2. S_1 Mortality Type Curve

The use of Figure 2 in forecasting the probable lives of particular pavements will be illustrated by two (imaginary) cases of brick-on-concrete Des Moines pavements, of which the average life has been found to be 28 years

Case 1 A brick-on-concrete pavement on an important business street The service age is 21 years The present physical condition is poor, in comparison with the average condition of 21 year-old brick-on-concrete pavements in the city The traffic is much heavier than average traffic on such pavements

Solution In Figure 2, follow the 75 per cent age ordinate up to the survivor curve, proceed horizontally across to the probable life curve and thence vertically down (all as indicated on Figure 2 by broken lines and arrows) and find that the probable life of the AVERAGE SURVIVOR would be 119 per cent of 28 years = 33 years But this pavement is in poorer condition than the average and its traffic is much heavier Its probable life will be somewhere between 21 (its present age) and 33 (the probable life of the average survivor under average traffic) Taking those limits and conditions into account, the engineer must forecast its probable life by judgment It would probably be less than 27 and might be about 25 years

Case 2 A brick-on-concrete pavement on a street in a well-to-do residence section Service age 21 years, as in Case 1, but the present physical condition is considerably better than that of the average 21 year old brick-on-concrete pavements in the city, and the traffic is lighter than the average on such pavements

Solution As in Case 1, the probable life indicated in Figure 2 for the AVERAGE SURVIVOR is 33 years; and it may be noted further that only a negligible number of similar pavements have probable lives greater than 170 per cent of 28 years = 41 years Hence the engineer, using his judgment in view of the actual conditions would forecast the probable life of this pavement somewhere between 33 and 41 years (quite probably about 35 years)

As a further illustration of the possible use of mortality type curves in forecasting the probable lives of particular pavements, it may be said that the author and Mr W. O Price of the Iowa State Highway Commission staff are now beginning the preparation of a forecast of the probable amounts of State road pavement reconstruction which will be required from time to time during the next 15 years. Using county maps on which the date and limits of each pavement construction contract are shown, we are making preliminary personal inspections of all existing primary road pavements, rating them tentatively as to present physical condition. Traffic conditions are to be ascertained by a statewide traffic survey which is just being started cooperatively by the Iowa State Commission and the Iowa F.E R A We expect to have the assistance of the best judgment of the Commission's own district and other engineers; and to use mortality type curves, about as explained above, to aid in applying their judgments and our own

DISCUSSION—SERVICE LIVES OF BRICK-ON-CONCRETE PAVEMENTS

MR GEORGE F SCHLESINGER, *National Paving Brick Association* It happened that Dean Marston, in testing out his theories, took brick pavements on concrete bases as his "guinea pig" and for that reason I am particularly interested in this presentation Some of the facts may appear to be very gratifying to those who are identified with the paving brick industry but are not surprising in the light of the information on the life of existing brick pavements

According to his Table III—84 per cent of the brick pavements on concrete bases in Des Moines, 20 years old, are still doing service and over 60 per cent of those 32 years old. He reaches the conclusion that the application of his theory of mortality curves to those that were retired between 1919 and 1928 indicate an average life of 36 years Those that were retired in the previous 10 year period indicate an average life of 22 years I would like to inquire the meaning of the term "retirement." Does not that mean that they may have been covered up with a bituminous surface?

DEAN MARSTON: I cannot answer as to every case but in general it means construction of new pavement of the same or different type.

It is quite possible that part of the old pavement was salvaged There are no data here of the amount of salvage, but it is probable that concrete base might have been salvaged.

MR SCHLESINGER: Of course in a great many cases old brick pavements have been covered with asphalt surface courses This should not be considered complete retirement as at least the brick are there performing their function as a base for another type of surface.

There is another angle to this subject—the compilation of mortality curves to predict the life of brick pavements—that is, the question of immortality I do not wish to be sacrilegious. That brick pavements have a second life has been demonstrated conclusively in the last few years during the work relief programs. Literally hundreds and hundreds of brick pavements, quite a few over 40 years of age, have been taken up, the brick reclaimed and relaid on the old reconstructed base, or relaid on a new base and they are going on to a second existence I do not know how this fact will fit in with Dean Marston's mortality theory

DR. BRUCE D GREENSHIELDS, *Denison University* Engineers and officials who have to do with the building and the regulation of highways have largely accepted the business analogy of the highway The importance of correctly estimating depreciation becomes clearer if the criteria for successful business enterprises are stated Any business, to be successful, must have an income equal to operating expenses, interest on the capital invested, taxes, and depreciation Profits are not mentioned for profits and interest earned are each a measure of successful enterprise If profits are not equal to a fair return in interest on the capital invested, then by comparison the enterprise is not successful A business run by the state may not be expected to pay taxes, but perhaps, as an indication of the extent of its worthiness, it should offer a return equal to the lawful tax in excess of the average or social rate of interest for such businesses An improved highway system does not produce profits in the ordinary sense, but effects savings through time saved and reduced vehicle operating costs

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

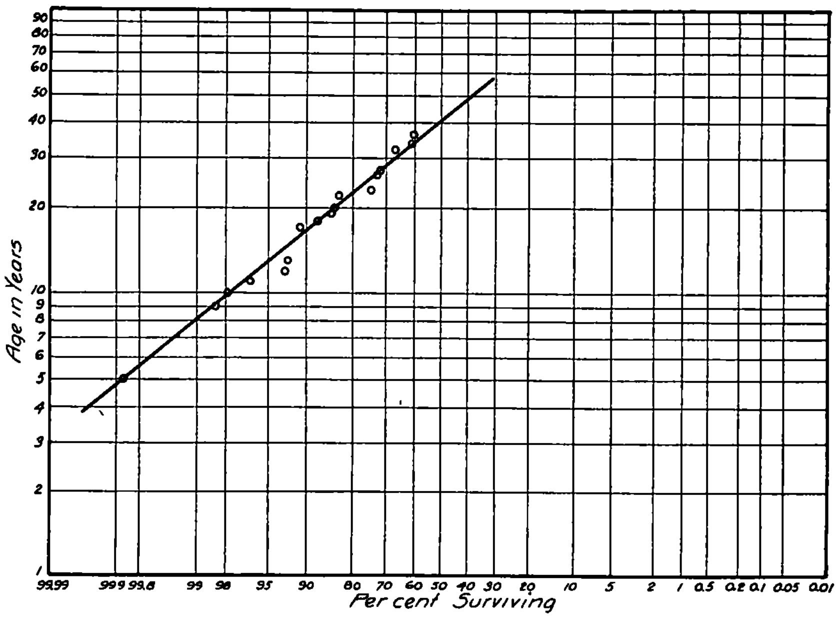

Figure 1 Percentage of Brick-on-Concrete Pavement Surviving at Different Age Intervals. Data from "Marstan" Table III.

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

By C B Breed

Professor of Civil Engineering, Massachusetts Institute of Technology

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-