LIFE CHARACTERISTICS OF HIGHWAY SURFACES

FRED B. FARRELL, *Chief, Highway Cost Section* AND HENRY R. PATERICK, *Head, Annual Cost Unit, Public Roads Administration*

SYNOPSIS

Among the objectives of the road life study phase of the highway planning surveys are the assembly and analysis of data relating to service life characteristics of surfaces constructed on primary rural highways. The first comprehensive report on this subject was presented at the 20th annual meeting of the Highway Research Board in 1940. The present report gives further data and compares the original life estimates with the actual later experience.

The analyses included in this report are based upon construction and retirement data up to January 1, 1946 submitted by 16 States for rural State or Federal-aid Primary systems. There are 248,783 miles of construction and 129,593 miles of retirements included in the tabulations which were analyzed. Estimates of average lives of surfaces were obtained from statistical analyses involving the use of survivor curves and show average lives varying from 4.5 years for lower type surfaces to 27 years for the higher type paved surfaces.

Data from 12 of the States included in the 1940 Report are also included in the present report. For these particular States, estimates of future mileages remaining in service were obtained from the average life analyses included in the 1940 Report, based upon actual experience up to January 1, 1937. These forecasted amounts were then compared with the subsequent actual amounts remaining in service as of January 1, 1942 and January 1, 1946. Reasonably close agreement was obtained between the forecasted and actual amounts remaining in service as of January 1, 1942, whereas greater differences exist as of January 1, 1946. The differences at this latter date are no doubt in large measure due to the lagging highway program during the war period.

On January 1, 1946, the average age was 10.6 yr. for low type, 8.2 yr. for intermediate type, and 13.5 yr. for high type surfaces. The corresponding remaining life expectancies of the miles in service were 4.5 yr., 7.6 yr., and 12.0 yr., respectively.

On the basis of the service life data included in this report, forecasts were prepared of the probable mileages remaining in service. Of the mileages in service on January 1, 1946, it is estimated that 94 percent of low type, 74 percent of the intermediate type, and 44 percent of the high type surfaces will require rebuilding by January 1, 1956.

An analysis of 92,565 miles of retirements through 1945 according to method of retirement shows that 58.0 percent was resurfaced, 29.8 percent reconstructed, 2.4 percent abandoned, and 9.8 percent transferred to the counties or other public authorities. During the war period the percentage of resurfacing of the high types increased noticeably.

Preliminary salvage value studies afford an indication of the average life of the dollars invested in highway surfaces. Because of salvage at retirement the average life of dollars invested in surfaces exceeds the average service life of the surface on a mileage basis. Salvage value studies on gravel surfaces constructed in Wisconsin from 1920 to 1925 show the life of dollars was 8.6 yr., whereas the average service life on a mileage basis was 5.6 yr.

The present stage of development of the Nations's highways, roads, and streets is the result of tremendous accomplishments over the past 30 years. Proper management of this vast transportation system requires the collection, analysis, and interpretation of complete factual data relating to the construction, maintenance, operation, use, and administration of the highway plant. The highway planning surveys, undertaken in the middle 1930's by the State highway departments in cooperation with the Public Roads Administration, were conceived for this purpose.

The highway plant itself is the proving

ground from which can be obtained the facts relating to past and present performance of various types of highway construction under varying degrees of use. An evaluation of these facts in relation to known conditions is essential in order that plans for orderly future development can be undertaken with confidence. The road life study phase of the comprehensive highway planning surveys provides the means for obtaining the data upon which such evaluations can be made. Among its objectives is the determination of the annual cost of highways, embracing such items as rates of wearing out, construction costs, maintenance costs, extent of functional obsolescence and structural deterioration, and life of the investment.

Up to the present time the road life studies in the individual States have been confined largely to the primary State highway system or the Federal-aid Primary system. They are gradually being extended to State Secondary and Federal-aid Secondary systems and to city streets.

The principal progress in this field of research has been the determination of the life characteristics of highway surfaces. The first comprehensive report on this subject is the article "Life Characteristics of Surfaces Constructed On Primary Rural Highways" by Robley Winfrey and Fred B. Farrell published in the Proceedings of the Twentieth Annual Meeting of the Highway Research Board in December 1940.[1] In that report were included the results of service life analyses on 210,000 miles of construction up to January 1, 1937 of various surface types in 26 States.

Activity on the road life study was considerably curtailed during World War II, and the work was not resumed on a broad scale until 1946. Of the 37 States which now have prepared road life mileage tabulations, there are 16 with a cut-off date of January 1, 1946. The tabulations for the remaining 21 States are not sufficiently current to warrant inclusion in the present analysis.

[1] Hereafter, this earlier report will be referred to simply as the 1940 Report.

Data for the following 16 States are included in this report:

Idaho	Nevada
Illinois	New Mexico
Indiana	Oklahoma
Kansas	Texas
Maryland	Utah
Minnesota	West Virginia
Missouri	Wisconsin
Montana	Wyoming

The basic data compiled for the purpose of this report embrace 248,783 miles of construction of various surface types on the rural portions of the primary State or Federal-aid systems of the above States. In general, all mileage in incorporated places of greater than 1,000 persons has been excluded. Construction of widening has also been excluded in this report in those cases where the widening was done as a separate operation. Where the widening was done in conjunction with the resurfacing or reconstruction of the previous surface, the mileage of the new construction, which includes widening, is included in the tabulations. The basic summaries cover the period from January 1, 1900 to January 1, 1946 and include:

1. Miles constructed each year for each surface type (for 16 States)
2. Miles of each year's construction of each surface type remaining in service January 1 each year after construction (for 16 States)
3. Replacement surface types for miles of each surface type retired each year (for 13 States)
4. Method of retirement (resurfaced, reconstructed, abandoned, or transferred) for miles of each surface type retired each year (for 13 States).

Data for Idaho, Wisconsin, and Wyoming were not available for the summaries prepared in connection with items 3 and 4 above.

In addition there are certain data from Missouri, West Virginia, and Wisconsin, relating to dollars invested each year and remaining in service each subsequent year. Some results of these analyses are also included in this report. Individual service life analyses were made for eight major surface types:

1. Soil surfaced
2. Gravel or stone

3. Bituminous surface treated
4. Mixed bituminous
5. Bituminous penetration
6. Bituminous concrete[2]
7. Portland cement concrete
8. Brick or block

The following definitions are used in all phases of the highway planning surveys in determining the general type classification of surfaces constructed in each individual State:

1. *Soil-surfaced road.*—A road of natural soil, the surface of which has been improved to provide more adequate traffic service by the addition of: (1) a course of mixed soil having A-1 or A-2 characteristics, such as sand-clay, soft shale or topsoil, or (2) an admixture such as bituminous material, portland cement, calcium chloride, sodium chloride, or fine granular material (sand or similar material).
2. *Gravel or stone road.*—A road the surface of which consists of gravel, broken stone, slag, chert, caliche, iron ore, shale, chat, disintegrated rock or granite, or other similar fragmental material (coarser than sand) with or without sand-clay, bituminous, chemical or portland cement stabilizing admixture or light penetrations of oil or chemical to serve as a dust palliative.
3. *Bituminous surface-treated road.*—An earth road, a soil-surfaced road, or a gravel or stone road to which has been added by any process a bituminous surface course, with or without a seal coat, the total compacted thickness of which is less than one inch. Seal coats include those known as chip seals, drag seals, plant-mix seals and rock asphalt seals.
4. *Mixed bituminous road.*—A road the surface course of which is 1 in. or more in compacted thickness composed of gravel, stone, sand or similar material, mixed with bituminous material under partial control as to grading and proportions.
5. *Bituminous penetration road.*—A road the surface course of which is 1 in. or more in compacted thickness composed of gravel, stone, sand, or similar material bound with bituminous material introduced by downward or upward penetration.
6. *Bituminous concrete, sheet asphalt or rock asphalt road.*—A road on which has been constructed a surface course 1 in. or more in compacted thickness consisting of bituminous concrete or sheet asphalt, prepared in accordance with precise specifications controlling gradation, proportions and consistency of composition, or of rock asphalt. The surface course may consist of combinations of two or more layers such as a bottom and a top course, or a binder and a wearing course.
7. *Portland cement concrete road.*—A road consisting of portland cement concrete with or without a bituminous wearing surface less than 1 in. in compacted thickness.
8. *Brick or block road.*[3] A road consisting of paving brick, stone block, wood block, asphalt block or other form of block, with or without a bituminous wearing surface less than 1 in. in compacted thickness.

The average life of a road surface is the average period after construction that the surface remains in service prior to being replaced, resurfaced, reconstructed, or otherwise taken out of service for any reason or by any method. Stated in another manner, it is that period after construction during which the only operations performed on the road surface are those of maintenance as practiced by by the various States. It is a recognized fact, however, that a significant amount of construction work is done by maintenance forces and paid for out of maintenance funds in many States. In recording the original data summarized in this report, an attempt was made in each State to segregate construction from maintenance in a uniform manner regardless of the particular accounting practices in effect in a given State. The classifications of construction and maintenance operations generally followed in the road life study are those included in the tentative draft of the report

[2] This type includes sheet asphalt and rock saphalt.

[3] Vitrified paving brick roads are reported separately from other types of brick or block roads. Because of the small mileages involved, these two types are combined. Approximately 99 percent of the construction of these two types included in this report is vitrified paving brick.

to the 1938 meeting of the Subcommittee on Uniform Accounting of the American Association of State Highway Officials.[4]

The survivor curve analysis procedures employed in this report are the same as those which are discussed at some length in the 1940 Report. Reference should be made to this earlier report for an explanation of the mechanics of computing average service life. There is one difference in the manner of analyzing the State data. In the 1940 Report, a single analysis was made upon the combined data for all States. In the present report, individual analyses were made for each State and the results combined by weighting. The two procedures will yield the same result, however.

The average life data included in this report represent estimates based upon actual experience. Over the years there have been changes in construction methods and design standards. There have been periods of accelerated activity and periods when little or no construction work was accomplished. Some roads have been kept in service too long while others have been rebuilt before the end of their useful life. Maintenance has frequently been inadequate. There have been many instances of over design and under design.

Throughout the past 30 years, nevertheless, there has been sustained improvement in the standards of highway design, construction, maintenance, and administration. Each of these has its influence upon service life, but their individual effect cannot be evaluated with certainty. As a result of improvements

TABLE 1

MILEAGES CONSTRUCTED AND REMAINING FOR EACH SURFACE TYPE

(Compiled from data submitted by 16 States for rural State or Federal-aid Primary systems)

Construction-year grouping	Soil surfaced		Gravel or stone		Bituminous surface treated		Mixed bituminous	
	Miles constructed	Miles remaining in service 1-1-46	Miles constructed	Miles remaining in service 1-1-46	Miles constructed	Miles remaining in service 1-1-46	Miles constructed	Miles remaining in service 1-1-46
1905 & prior			36.0	0.0				
1906–10			198.7	0.0				
1911–15	34.9	0.0	4,330.2	45.8	18.3	9.4	3.7	2.4
1916–20	160.0	0.0	6,307.1	146.3	202.1	60.9	182.1	126.4
1921–25	436.3	7.6	21,521.4	1,194.9	618.7	120.0	1,043.1	640.8
1926–30	146.9	18.5	23,176.3	2,177.9	4,104.7	984.6	5,801.0	1,966.1
1931–35	667.9	48.2	18,998.6	3,376.5	9,300.6	2,782.1	22,470.4	10,970.9
1936–40	1,364.7	125.5	10,911.2	3,388.6	12,155.7	8,167.9	22,997.9	15,062.9
1941–45	588.5	165.6	4,913.0	3,348.8	8,487.4	7,819.9	7,561.4	7,082.6
Total	3,399.2	365.4	90,392.5	13,678.8	34,887.5	19,944.8	60,059.6	35,852.1

Construction-year grouping	Bituminous penetration		Bituminous concrete		Portland cement concrete		Brick or block	
	Miles constructed	Miles remaining in service 1-1-46	Miles constructed	Miles remaining in service 1-1-46	Miles constructed	Miles remaining in service 1-1-46	Miles constructed	Miles remaining in service 1-1-46
1905 & prior							0.3	0.0
1906–10	4.4	0.0			1.0	0.0	3.7	0.0
1911–15	29.2	4.2	24.8	7.1	398.5	137.8	65.2	16.4
1916–20	231.0	42.2	205.8	57.0	1,457.9	654.4	153.6	30.0
1921–25	1,290.2	371.6	821.6	297.3	8,854.9	6,651.4	331.2	139.8
1926–30	1,850.9	824.9	1,259.6	559.2	12,486.8	11,637.1	135.1	98.7
1931–35	2,886.4	2,041.5	1,521.4	1,014.7	10,581.1	10,331.8	161.8	97.1
1936–40	1,452.6	1,206.8	2,928.2	2,365.3	4,459.6	4,408.8	23.4	20.4
1941–45	1,032.4	1,004.6	3,742.8	3,686.2	1,634.4	1,628.1	14.5	14.5
Total	8,777.1	5,495.8	10,504.2	7,986.8	39,874.2	35,449.4	888.8	416.9

[4] Copies of this tentative draft were transmitted to all State highway departments under date of June 2, 1938 by the Subcommittee on Uniform Accounting, American Association of State Highway Officials.

which are continually being made in design standards, for example, certain factors contributing to early obsolescence or structural failure are gradually being reduced to a minimum or even eliminated.

It must be recognized also, that large backlogs of needed replacements of highway facilities have been accumulating for many years. The extent of these backlogs is forcibly brought to attention in the long-range highway needs studies which are under way or which have been recently completed in several States. If the accumulated deficiencies in the highway plant are to be overcome at the rates recommended in these long-range studies, it is likely the probable remaining service lives may, in some instances, prove to be somewhat less than indicated by the data presented in this report.

While it is true that substantial advances are being made in obtaining greater value from the investment in highways, it should not be concluded that the highway plant can or should be built to last indefinitely. There has been in the past and will continue to be in the future a need for all types of highway facilities. The complexities of modern transportation will also result in shifts in the importance of various roads and streets. Traffic patterns are subject to continual change, and the highway plant must be sufficiently flexible to absorb these changes.

In practice only a small percentage of road sections have a life exactly equal to the average. Thus, when there is need for an estimate of service life for a given road section it is necessary to consider such factors as age, structural condition, design features, location and traffic usage which relate to that section. Only by the exercise of expert engineering judgment in the evaluation of these factors is it possible to arrive at estimates of the remaining service lives for particular road sections.

In Table 1 is listed for each surface type for 5-yr. construction groups the miles constructed during each period and the miles remaining in service on January 1, 1946. Approximately 38 percent of the surfaced mileage on the primary rural State highway systems is represented by these data. Table 1a shows the percentages of total mileage of each surface type on the State system as of Jan. 1, 1946 included in the service life analyses.

There are some mileages, particularly of the lower types, for which the date of retirement is known but for which the date of initial construction was not available. This results primarily from the difficulty in locating records of early construction. The partial data in these cases are not included in the analysis.

TABLE 1a

Surface type	%
Soil surfaced	13
Gravel or stone	27
Bituminous surface treated	32
Mixed bituminous	54
Bituminous penetration	23
Bituminous concrete	32
Portland cement concrete	44
Brick or block	31
Average all types	38

The probable average service lives for each surface type are shown in Table 2 for 5-yr. construction periods. Estimates of average lives are given in this table only when retirements were sufficient to warrant making the estimates. Because of the smaller mileages involved, the retirement trends for earlier construction are frequently more erratic than the trends for the larger mileages of more recent construction. The average life estimates, however, for this earlier construction are more reliable because of the greater retirement experience.

In addition to the major types listed in Table 2 there are certain subtypes for which the average service lives have been computed. Probably the most interesting of these subtypes is old portland cement concrete which has been resurfaced with mixed bituminous surface or bituminous concrete. Approximately 2,500 miles of this subtype are included with the major types in this report. Of this amount, 77 percent involves old portland cement concrete resurfaced with bituminous concrete and the remaining 23 percent has been resurfaced with mixed bituminous surface. For the majority of this subtype, there have been insufficient retirements upon which to base an estimate of average life. During the period 1926 to 1935, however, there were about 230 miles of old concrete resurfaced of which less than 10 percent was still in service on January 1, 1946. On the basis of this retirement experience, the additional service life obtained from old portland cement concrete roads after they are resurfaced is 13.7 yr. The limited retirement experience for later con-

struction of this subtype indicates that the average service life will probably remain in the neighborhood of 14 yr.

Further, unusual construction practices in one State may have considerable effect upon the average for a group of States. In Wisconsin, for example, the practice of frequent resurfacing of bituminous surface-treated and mixed bituminous roads has been followed. If the experience for Wisconsin is excluded from the analyses for the 16 States included in this report, the average lives for these types show a closer agreement with the 1940 Report.[5]

[5] The data for Wisconsin were not included in the 1940 Report.

TABLE 2

WEIGHTED PROBABLE AVERAGE SERVICE LIVES FOR VARIOUS CONSTRUCTION-YEAR GROUPINGS FOR EACH SURFACE TYPE[a]

(Based upon analyses of data submitted by 16 States for rural State or Federal-aid Primary systems)

Construction-year grouping	Surface type							
	Soil surfaced	Gravel or stone	Bituminous surface treated	Mixed bituminous	Bituminous penetration	Bituminous concrete	Portland cement concrete	Brick or block
	years	*years*	*years*	*years*	*years*	*years*	*years*	*years*
1905 & prior		19.9						40.0
1906–10		12.0			15.6		27.7	24.7
1911–15	6.3	14.7	23.9	24.4	14.8	24.9	23.9	24.7
1916–20	12.1	10.5	17 9	25.4	15 3	18.3	24 5	21.6
1921–25	8.7	9.1	14.4	21.9	16.2	18.1	26 1	20.2
1926–30	7.2	6.6	9 1	12.3	16.0	15.6	28.2	21.1
1931–35	4.5	5.9	7.4	11.6	15.9	14.7		16.4
1936–40	2.9	5.6	10.3	11.6	14.5	13.5		
1941–45	2.1	5.1						

[a] Average lives shown in this table are to the nearest 0 1 yr., but they should not be presumed accurate to this extent. The above averages would be materially affected by excluding certain States or by including additional States.

The war period has had an influence upon the retirement trends of various surface types. Many surfaces were kept in service beyond their normal life even though subjected, in many cases, to greater wear than at any previous period. In order to reflect the additional life thus obtained in the average life estimates included in this report, it was necessary to make a minor adjustment to the analysis procedures outlined in the 1940 Report. This was accomplished by assuming that the backlog of deferred work during the war would be overcome and the normal trend resumed within a maximum of 10 yr. after the war. The rate of recovery estimated in each instance depended upon the percent surviving at the beginning of the war, the age of these survivors, the previous rate of retirement, and the retirements, if any, which were made during the war period.

There are certain differences between the average lives presented in the 1940 Report and those listed in the present report. Table 3 shows a comparison of the average lives for various types for the most recent 5-yr. periods for which data were listed in the 1940 Report.

No particular significance should be attributed to the differences in average lives shown in Table 3. Variations in average lives of this magnitude are not uncommon when the analyses are based upon different groupings of States.

TABLE 3

COMPARISON OF AVERAGE LIVES PRESENTED IN THE 1940 REPORT WITH THOSE LISTED IN THE PRESENT REPORT

Surface type	Comparison period[a]	1940 Report (26 States)		Present report (16 States)	
		Construction	Average life	Construction	Average life
		miles	*years*	*miles*	*years*
Soil surfaced	1931–35	2,542[b]	5.4[b]	668	4.5
Gravel or stone	1931–35	22,793	6 0	18,999	5.9
Bituminous surface treated	1931–35	10,286[b]	11 4[b]	9,301	7.4[c]
Mixed bituminous	1926–30	5,610	14.3	5,801	12.3[d]
Bituminous penetration	1926–30	3,725	17.0	1,851	16.0
Bituminous concrete	1921–25	2,362	17 9	822	18.1
Portland cement concrete	1921–25	6,737	24.4	8,855	26.1
Brick or block	1921–25	980	18.2	331	20.2

[a] The most recent period for which data were presented in Table 18 in the 1940 Report.

[b] 1931 to 1934.

[c] The data for Wisconsin were not included in the 1940 Report. If Wisconsin data were excluded from the present report, average life is 10.2 years.

[d] If Wisconsin data were excluded, average life is 13.0 years.

Data from 12 States[6] included in the present report were likewise included in the 1940 Report. For these 12 States, it is now possible to compare forecasts of mileages remaining in service as obtained from analyses made in 1940 with the actual experience. In the 1940 Report, estimated average lives for the various surface types were presented up to and including the most recent year for which the retirement experience was sufficient to enable a reasonable estimate of the average life to be made. Based upon these previous estimates of average lives, projections were made for each of the 12 States of the probable mileages of each surface type that would still be in service on January 1, 1942 and January 1, 1946. The extent to which these forecasts varied from the actual experience is shown in Table 4.

TABLE 4
COMPARISON OF FORECASTS OF THE AMOUNTS OF SURFACING REMAINING IN SERVICE FOR 12 STATES INCLUDED IN THE 1940 REPORT WITH THE ACTUAL EXPERIENCE FOR THESE SAME 12 STATES

Surface type	Original miles constructed[a]	Percent of original construction remaining in service: As obtained from forecasts based upon analyses of previous tabulations which showed actual experience to Jan. 1, 1937		As obtained from later tabulations which show actual experience to Jan. 1, 1946	
		As of 1-1-42	As of 1-1-46	As of 1-1-42	As of 1-1-46
		per-cent	*per-cent*	*per-cent*	*per-cent*
Soil surfaced	781	11	2	22	8
Gravel or stone	40,416	12	4	14	11
Bituminous surface treated	7,420	51	34	52	40
Mixed bituminous	7,449	56	37	55	49
Bituminous penetration	3,533	53	37	55	37
Bituminous concrete	989	45	27	46	38
Portland cement concrete	3,471	63	48	69	60
Brick or block	408	58	42	56	34
All types	64,467	27	16	29	23

[a] Includes mileage constructed through the latest year for which average life data were presented in the 1940 Report.

For the most part, the forecasted amounts and the actual amounts remaining in service on January 1, 1942 show reasonable agreement. The greatest difference is in the soil surfaced type, but because of its short life and limited mileage, its retirement trend is usually quite erratic. For the other types, the amount remaining in service is within two percentage points except for portland cement concrete where the retirements were overestimated by six percentage points.

Among the probable reasons for these differences are a lagging highway program, and the possible tendency to underestimate[7] the average life upon which the forecast was based. There are doubtless other reasons involved, but their specific influence on the previous analyses are most difficult to determine and hence have not been evaluated.

Greater differences are apparent for the comparison of miles remaining on January 1, 1946. In this case, however, the composite average difference of seven percentage points (23 minus 16) can be attributed to a large extent to the lagging highway program during the war period.

The evidence in Table 4 would indicate that the analysis procedures employed in the 1940 Report yielded generally satisfactory results when appraised in the light of actual experi-

[6] Idaho, Indiana, Kansas, Maryland, Missouri, Montana, New Mexico, Oklahoma, Texas, Utah, West Virginia, and Wyoming.

[7] In Bulletin 125 of the Iowa Engineering Experiment Station, Statistical Analysis of Industrial Property Retirements, by Robley Winfrey, pages 86 to 92, the probable error in determining average life by comparison with the 18 type survivor curves is discussed. In this connection tests were made upon the reliability of the average life estimates, which indicate two significant results: ". . . First, the average of the under- and overestimates of probable average life balances close to a zero error; second, the average negative error and the average positive error are about 10 percent at the 70 percent-surviving level and about 15 percent at the 80 percent-surviving level. For certain short curves, however, individual estimates of probable average lives may be greatly in error when compared with the average life determined from the completed curve. Such large errors are caused mainly by two factors: First, often the few data in the upper 10 to 30 percent of the survivor curves are insufficient to definitely fix the curve through this area especially when these few points do not follow a smooth path; second, the succeeding data frequently depart from the trend established by the first few data."

ence. With more experience in construction and retirements to draw upon with each successive year, it can be expected that the analysis techniques will yield results progressively more reliable.

For 13 of the 16 States included in the average life analyses, the retired mileages for various years were classified in accordance with the method by which the retirement was made. These retired mileages are listed in Table 5.

The methods of retirement into which these mileages were classified are: (1) resurfaced, (2) reconstructed, (3) abandoned, and (4) transferred.

TABLE 5
MILES RETIRED FOR WHICH METHODS OF RETIREMENT WERE DETERMINED
(Compiled from data submitted by 13 States for rural State or Federal-aid Primary systems)

Surface type	Miles retired during each year-group						
	1927 and prior	1928–30	1931–33	1934–36	1937–39	1940–42	1943–45
	miles	*miles*	*miles*	*miles*	*miles*	*miles*	*miles*
Soil surfaced	88.9	77.2	256.8	308.9	697.2	907.6	431.4
Gravel or stone	4,335.9	8,310.7	14,459.3	12,227.0	9,552.3	6,950.9	1,979.8
Bituminous surface treated	37.0	136.3	802.6	1,488.4	2,435.8	2,240.5	2,705.5
Mixed bituminous	31.2	153.0	832.3	1,448.2	4,603.0	2,759.9	2,455.4
Bituminous penetration	137.5	145.7	271.5	489.5	433.1	689.8	1,023.4
Bituminous concrete	51.1	39.7	170.5	298.8	435.0	615.3	852.1
Portland cement concrete	109.7	151.6	369.7	347.4	592.4	690.8	1,464.9
Brick or block	18.6	27.0	56.2	35.7	84.1	107.8	143.1
Total	4,809.9	9,041.2	17,218.9	16,643.9	18,832.9	14,962.6	11,055.6

Following are definitions of these four general methods of retirement:

1. *Resurfaced.*—Roads which are resurfaced or used as a base for the replacement type are so classified when the old surface is utilized more or less intact (with the exception of necessary scarifying, reshaping, or partial reworking of the surface) in the new construction which retires the old surface. Examples of this method are the retirement of a soil-surfaced road by surface treating, or the retirement of a gravel or stone road by utilizing it as a base or foundation for a mixed bituminous road or a bituminous penetration road, etc. For surfaces which are retired by this method, it is obvious that the new or replacement construction must necessarily be along the same alinement and practically the same grade.
2. *Reconstructed.*—When surfaces are retired by reconstruction, there is little or no salvage of the old surface and base into the new type constructed. This classification includes old surfaces and bases that are torn up and not reused. Usually, for types that are retired by this method, the replacement type is built along the same general alinement (generally within the limits of the existing right-of-way) involving only minor improvements in horizontal curvature. Substantial improvements are usually made with respect to grades, however.
3. *Abandoned.*—When the new construction is on new location, the old road is classified as abandoned when it is no longer maintained or kept in service at public expense. The abandoned road may revert to a private road, be barricaded to public travel, or torn up and removed. Sometimes, because of changes in land usage, such as abandonment of factories, and removal or construction of railroad facilities, roads may be abandoned without involving new construction that may be considered as replacing the mileage abandoned.
4. *Transferred.*—A retirement by transfer is similar to an abandonment except that the old road is continued in service after being dropped from the State or Federal-aid system by being maintained and resurfaced or reconstructed, when necessary, by the county or other authority responsible for the upkeep of the roads not on the State or Federal-aid system. A transfer is not a retirement in the sense that the road has rendered its

total service to the public, but merely that it has rendered its complete service as a primary State or Federal-aid highway. Retirements by transfer are generally the result of functional obsolescence involving alinements and grades which are unsatisfactory for existing traffic conditions. A new road is built on new alinement and improved grades, and the old road remains in service usually because of the necessity of providing for local traffic usage. After the new road is placed in service on the State or Federal-aid highway system, the State will no longer desire to continue responsibility for further upkeep of the old road, and the county or other local authority generally takes over this responsibility. If the road is entirely discontinued from service it is considered an abandonment.

Reversions in type, in which a surface reverts to a lower type through lack of adequate maintenance, also represent a distinct method of retirement. Retirements of this nature were so few that they did not warrant consideration in this analysis.

These classifications are general in character and should be so interpreted. Resurfacing is an especially significant method of retirement since it affords an approximate measure of the relative extent to which the various types of surfacing construction are salvaged when they are retired.

TABLE 6

RETIRED MILEAGES FOR EACH SURFACE TYPE AND PERCENTAGE DISTRIBUTION ACCORDING TO METHOD OF RETIREMENT (TOTAL FOR 1945 AND PRIOR)

(Computed from data submitted by 13 States for rural State or Federal-aid Primary systems)

Surface type retired	Total retirements	Methods of retirement				
		Resurfaced	Reconstructed	Abandoned	Transferred	Total
	miles	*percent*	*percent*	*percent*	*percent*	*percent*
Soil surfaced	2,768.0	68.6	24.5	1.8	5.1	100.0
Gravel or stone	57,815.9	58.8	29.7	2.3	9.2	100.0
Bituminous surface treated	9,846.1	58.9	27.1	3.4	10.6	100.0
Mixed bituminous	12,283.0	51.3	37.3	2.0	9.4	100.0
Bituminous penetration	3,190.5	56.3	24.7	3.7	15.3	100.0
Bituminous concrete	2,462.5	65.9	19.8	2.4	11.9	100.0
Portland cement concrete	3,726.5	54.8	26.6	3.3	15.3	100.0
Brick or block	472.5	53.3	30.6	2.7	13.4	100.0
Total	92,565.0	58.0	29.8	2.4	9.8	100.0

TABLE 7

PERCENTAGES RETIRED BY VARIOUS METHODS FOR ALL SURFACE TYPES COMBINED FOR VARIOUS PERIODS

(Computed from data submitted by 13 States for rural State or Federal-aid Primary systems)

Method of retirement	Period							
	1927 and prior	1928–30	1931–33	1934–36	1937–39	1940–42	1943–45	Total, 1945 and prior
	percent	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*
Resurfaced	65.2	57.8	51.3	60.4	60.4	52.4	65.7	58.0
Reconstructed	24.3	30.7	34.5	26.0	27.5	35.2	26.0	29.8
Abandoned	1.1	1.1	2.9	2.8	3.1	2.7	1.1	2.4
Transferred	9.4	10.4	11.3	10.8	9.0	9.7	7.2	9.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

In Table 6 are shown the total miles retired and the percentage distribution by methods of retirement. For each surface type the method of retirement for more than half of all retirements has been by resurfacing.

The over-all relationships shown in Table 6 have been fairly consistent throughout the years. This is evident in Table 7.

The higher percentages of resurfacing during the period 1943 to 1945 are due in large measure to the curtailed highway program during

the war years. Undoubtedly many miles that ordinarily would have been reconstructed were given a resurfacing treatment to keep them in operation temporarily. Other mileages which normally would have been replaced because of poor location were also kept in service until they could be rebuilt at some future date. Both of these factors unquestionably contributed to reducing the amount of reconstruction and thereby increased the relative amount of resurfacing during this period.

Table 8 shows for each surface type the amounts of resurfacing for various periods of years. It is most interesting to note that the relative amount of resurfacing for mixed bituminous and higher type surfaces was at its greatest value during the period 1943 to 1945.

These combinations are arbitrary and may be criticized in certain respects. Some of the mixed bituminous roads for example, definitely qualify as high type since they are frequently placed on old rigid bases or on heavy flexible bases of considerable load bearing capacity. On the other hand some of the high types are definitely in the intermediate type category. However, the mileage of questionable classification is small and considerable effort would be required to insure that each mile was properly classified. Accordingly, no adjustments in this respect were made since the increase in accuracy obtained would not be sufficient to justify such refinement.

Estimates of service lives based upon actual retirement experience are shown in Table 2.

TABLE 8

PERCENTAGE OF TOTAL RETIREMENTS BY RESURFACING FOR VARIOUS TYPES FOR VARIOUS PERIODS

(Computed from data submitted by 13 States for rural State or Federal-aid Primary systems)

Surface type retired	Period							
	1927 and prior	1928–30	1931–33	1934–36	1937–39	1940–42	1943–45	Total, 1945 and prior
	percent	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*
Soil surfaced	83.5	38.3	51.3	75.7	82.3	68.3	54.6	68.6
Gravel or stone	65.8	58.8	51.9	66.7	59.8	56.3	49.6	58.8
Bituminous surface treated	63.2	49.2	52.2	51.7	64.8	53.8	64.4	58.9
Mixed bituminous	51.3	52.4	41.5	33.4	59.8	39.9	62.0	51.3
Bituminous penetration	68.8	47.8	30.7	32 7	46.7	49.8	82.2	56.3
Bituminous concrete	4.5	32.2	70.9	38.5	67.2	56 8	85.8	65.9
Portland cement concrete	59.5	50.5	54.9	40.1	38.5	36 4	73.6	54.8
Brick or block	26.9	14.5	28.5	18.8	37.3	55.1	90.4	53.3
Average, all types	65.2	57.8	51.3	60.4	60.4	52.4	65.7	58.0

For portland cement concrete the percentage during this period was double that of the preceding three years.

Figures 1 and 2 show in graphical form some of the results of the analyses presented in the preceding pages. For purposes of simplifying these charts, the eight surface types have been combined into three major groups—low, intermediate, and high—as follows:

Low type: Includes soil-surfaced and gravel or stone roads.

Intermediate type: Includes bituminous surface-treated and mixed bituminous roads.

High type: Includes bituminous penetration, bituminous concrete, portland cement concrete, and brick or block roads.

In order to prepare Figures 1 and 2 certain assumptions of average lives are necessary for the recent years. In general the average lives for the more recent years were assumed to remain about the same or increase slightly (less than 10 percent) in relation to the estimates for the most recent years shown in Table 2. These assumptions will no doubt vary somewhat from the actual future experience, but since the bulk of the retirements within the next few years will come from the older construction, any minor differences from the assumed average lives for the more recent construction will not have any major effect upon the over-all trends which are shown.

Figure 1 shows for each 5-year construction period, the trend of mileages of low, intermediate, and high types in service up to January 1, 1946, for the 16 States included in this

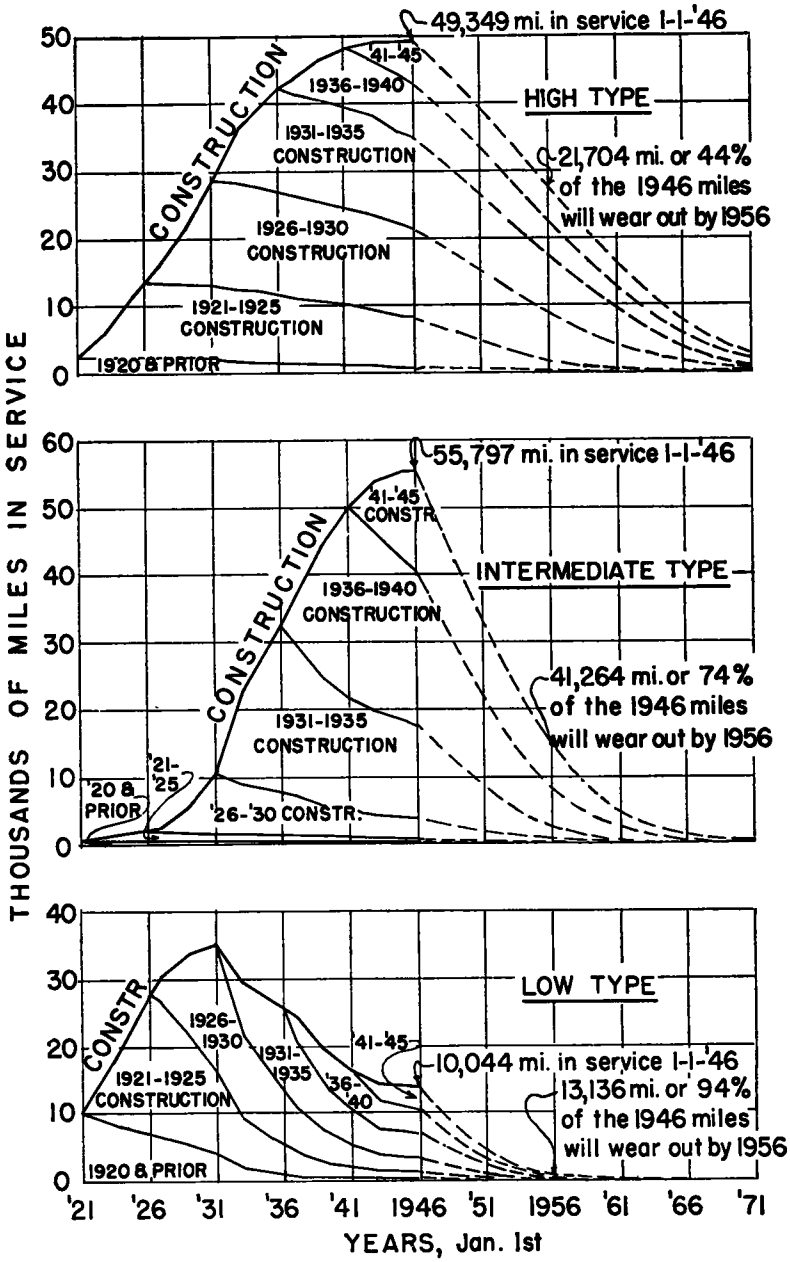

Figure 1. Sixty-four percent of the surfaced mileage on primary rural highways will wear out within the next 10 years—Based upon analysis of data submitted by 10 states for rural, state, and federal aid primary systems.

report, and the rates at which these mileages will go out of service in the future based upon their probable rates of retirement. Table 9 shows the total mileages in service on January

1, 1946 and the probable percentages of these amounts which will still remain in service for 5, 10, 15, and 20 years in the future.

Table 2 shows the probable average lives for various construction-year groupings. These average lives are the expectancies at the time of construction or at age zero. As the road system develops and becomes older, the average age of the surfaces increases and the remaining life expectancy becomes less. Also

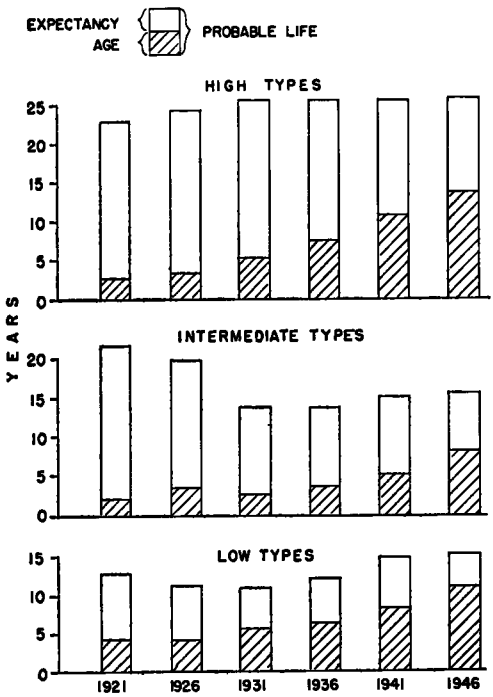

Figure 2. Trends in Average Age, Expectancy, and Probable Life at 5-yr. Intervals—1921 to 1946

as the system becomes older, mileages of earlier retirements are taken out of service thus leaving in service those mileages whose lives will exceed the average life of the total original construction.

The probable life of the miles in service is equivalent to the age plus the expectancy. Under certain conditions it is possible for the average age of miles in service to exceed the average lives shown in Table 2. This is true for low type surfaced mileage from which the

TABLE 9

MILES IN SERVICE ON JANUARY 1, 1946 AND ESTIMATED PERCENTAGES WHICH WILL REMAIN IN VARIOUS FUTURE YEARS

(Based upon analyses of data submitted by 16 States for rural State or Federal-aid Primary systems)

Surface type	Miles in service 1-1-46	Percentages remaining January 1,			
		1951	1956	1961	1966
		percent	*percent*	*percent*	*percent*
Low	14,044.2	31.2	6.5	1.1	0.1
Intermediate	55,796.9	58.9	26.0	8.3	2.0
High	49,348.9	80.1	56.0	32.8	15.1
Total	119,190.0	64.4	36.1	17.6	7.2

TABLE 10

AVERAGE AGE, LIFE EXPECTANCY AND PROBABLE LIFE OF MILEAGES IN SERVICE AT 5-YEAR INTERVALS

(Based upon analyses of data submitted by 16 States for rural State or Federal-aid Primary systems)

Date January 1	Low types			Intermediate types			High types		
	Age	Expectancy	Probable life	Age	Expectancy	Probable life	Age	Expectancy	Probable life
	years	*years*	*years*	*years*	*years*	*years*	*years*	*years*	*years*
1921	4.2	8.6	12.8	1.9	19.9	21.8	2.6	20.2	22.8
1926	4.0	7.0	11 0	3.5	16.5	20.0	3.2	21.1	24.3
1931	5.3	5.3	10.6	2.7	11.1	13.8	4.9	20.4	25.3
1936	6.1	5.8	11.9	3.7	10.1	13.8	7 3	18.0	25.3
1941	7.9	6.7	14.6	5.2	10.1	15.3	10.4	14.9	25.3
1946	10.6	4.5	15.1	8.2	7.6	15 8	13.5	12.0	25.5

TABLE 11

COMPARISON OF RETIREMENTS OF MILEAGE WITH RETIREMENTS OF CONSTRUCTION INVESTMENT

(Compiled from data submitted by 3 States for rural State primary highways)

Surface type as originally constructed	Total construction		Percentage retired up to 1-1-41	
	Miles	Dollars[a]	Miles	Dollars[b]
			percent	*percent*
Low	21,766	53,300,776	89	57
Intermediate	29,108	[c]56,304,360	68	26
High	12,489	265,681,512	19	12

[a]These are actual expenditures for construction. No adjustment is made for the price index.

[b]These represent total losses of prior construction investments, no portion of which is used or usable in the road as of January 1, 1941. No depreciation is included in these percentages

[c]In the construction of intermediate type, the construction dollars shown fall into two main categories:

1. If the bituminous mat was placed over an existing low type surface, the construction dollars for the intermediate type include only the cost of the mat. In these cases there tends to be a high salvage for the low type when it is retired.
2. If the base and surface mat were built at the same time as a single construction operation, the construction dollars for intermediate type include the dollars for both the mat and the base.

miles in service have gradually been diminishing since 1931 (see Figure 1). When these low types have been retired, the replacement types have been intermediate or high types. Thus there has not been sufficient construction of new low types to keep the average age of all low types in service from increasing year to year. As a result, the low types now in service are quite old and have a short remaining life expectancy.

In Table 10 are shown the average age, remaining life expectancy, and total probable life of the mileages of low, intermediate, and high types in service at 5-yr. intervals from January 1, 1921 to January 1, 1946. This information is also presented graphically in Figure 2, and shows strikingly the trends in the increasing age and decreasing expectancy of the mileages in service.

A phase of the road life work upon which study is currently being given is the life of the dollars expended for the construction of highway facilities. This work is now under way in several States and is conducted in such fashion that a continuous record is maintained of each year's construction investment and the amounts by which this investment is reduced at the time of resurfacing, reconstruction, or other method of retirement. There are three States[8] for which investment tabulations have now been prepared.

Because of salvage at the time of retirement, the life of investment will exceed the service life of the surfaced mileage for all surface types. Indications are that the amount will vary anywhere from a few percent for some types having a low salvage at retirement to as much as several hundred percent in those instances involving stage construction or where there is extremely high salvage. For example, during the period 1920 to 1925, approximately $9,500,000 was expended for the construction of 4,800 miles of gravel surfacing on the primary State highway system of Wisconsin. These gravel surfaces had an average life of 5.6 yr., but the life of the dollars was 8.6 yr. or more than 50 percent greater than the life of the gravel as a surface. Unfortunately, the retirement experience to date has not been sufficient to warrant presentation in this report of similar estimates of the average life of dollars for all years and for each surface type.

It is possible, however, to show a comparison of the miles constructed and retired with the corresponding investments which entered into the construction and which had been retired by January 1, 1941. From the comparison shown in Table 11, it is apparent that the investment in various types is being retired at a slower rate than the mileage.

Since it is a common practice to apply bituminous mats to existing surfaces, the construction dollars shown for intermediate type roads do not reflect the total costs for a complete road including the base. To obtain the total cost for this type, it would be necessary to take into account the salvage value of gravel or stone and other type roads which may be utilized as a base for the intermediate type road.

The data presented in this report relates only to road surfaces. The road life studies also embrace research in construction costs, maintenance costs, and salvage values for all elements of the highway including grading and structures. Knowledge on these subjects will be extended as additional States bring their basic studies up to date and as these studies are continued and extended.

The objective of efficient and economical management of the highway program is to provide highway facilities at such locations and to such standards that they can absorb the inevitable and continuing changes in traffic requirements with the least effect upon the ability of the highway plant to provided maximum service at minimum cost. The data obtained from the road life studies are among the essential facts needed to reach this objective.

[8] Missouri, West Virginia, and Wisconsin.