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Foreword

The papers included in this RECORD deal with highway costs and needs. Robley Winfrey and Phebe D. Howell present the latest in a series they have written dealing with service life of highways and street pavements. This report gives the average service life and curves of the retirement distributions for the composite data from 26 states and Puerto Rico. Data on mileages surviving by year and type of pavement, reason for retiring pavements, and type of replacement are provided. Comparisons with the preceding paper published in 1956 show no significant changes in average service lives of pavements.

Ralph D. Johnson and Henry A. Thomason describe a computerized system for continuously updating highway needs by means of simulation. The process involves the establishment and maintenance of a long-range highway plan, the determination of needs and priority factors pertinent in achieving the plan goals, and the objective development of current, short-range (4-5 year) programs contributing to eventual accomplishment of the long-range plan. Traffic estimates in computer program are increased annually in keeping with traffic assignment projections. While the program is not designed to reflect actual conditions, it is useful for determining future needs since it reflects the same total traffic and traffic base design standards.

Kozmas Balkus and Walter Srour used region-wide expressway installation cost criteria to provide cost estimation approaches for overall road-miles, overall lane-miles, lane-mile and separate interchange estimates, and for separate road elements. All four approaches gave satisfactory results.

In "Impact of Toll Changes on Traffic and Revenue for Bridge and Tunnel Facilities," John A. Dash and Arnold H. Vey measure effects of toll increases on traffic usage. Computation of traffic loss in terms of each 1 percent increase in toll, averaged for six facilities, yielded a shrinkage ratio for river-crossing facilities of 0.17 percent traffic loss for each 1 percent increase in average toll. Revenue productivity is shown to range from about 65 to 87 percent. In the facilities studied the toll decreases generally would not increase usage sufficiently to offset loss in toll revenue.

Contents

Highway Pavements—Their Service Lives

ROBLEY WINFREY and PHEBE D. HOWELL, U. S. Bureau of Public Roads

This paper is another in a series starting about 1935 dealing with the service life of highway and street pavements. Average service life and curves of the retirement distributions for the composite data from 26 states and Puerto Rico are given. The study includes only primary rural state highways and covers the following pavement types: bituminous surface-treated (F), mixed bituminous (G-1), mixed bituminous (G-2), bituminous penetration (H-1), bituminous penetration (H-2), bituminous concrete (I), and portland cement concrete (J).

The data analyzed represent the condition on the state highways as of January 1, 1960. The paper includes the original data on the mileages surviving year-by-year by vintage for the seven types of pavements and illustrative examples of the details of calculation of the survivor curves and service lives. The reasons for retiring pavements and the replacement types are given. Replacements show a steady upgrading to higher types. Comparisons with the preceding paper, published in 1956, show no significant changes in average service lives.

•BEGINNING about 1934, highway, road, and street pavements drew the attention of those interested in the economics of highway transportation and in developing methods of determining the service lives of various types of man-made properties, particularly those used in the public utility industries. With the inauguration of the statewide highway planning surveys in 1935, the state highway departments began compiling the necessary records to indicate the miles and cost of highways constructed year by year for the main system of primary rural highways. The data collected indicated the year and the vintage (year of original construction) of the mileages of pavement by surface type that were retired from use and the total mileage of each type constructed each year. This data collection and analysis has continued, affording the sole source of extensive life histories of highway pavements by type of paving material.

The references to the literature indicate the main publications on the subject that have appeared over the years. Particular attention is directed to the papers by Winfrey and Farrell (4), Farrell and Paterick (11), and Gronberg and Blosser (15). This paper is another in this series on the service lives of highway pavements.

USES OF THE SERVICE LIVES OF HIGHWAY PAVEMENTS

A knowledge of the period of time that highway pavements can be expected to render satisfactory service before requiring resurfacing or reconstruction[1] is useful. The main applications of the service lives are to be found in (a) analyses for the relative economy of different types of materials of construction as well as of different designs, (b) forecasting needed resurfacing and reconstruction as a phase of the highway needs studies, (c) long-range studies of the financial requirements to keep a given highway

[1]See Appendix for definitions of technical terms, reasons for retiring pavements, and descriptions of surface types.

Paper sponsored by Committee on Highway Costs and Programming and presented at the 47th Annual Meeting.

system in satisfactory condition, and (d) studies of the relative cost of transportation by different basic modes.

These four applications relate specifically to the highway engineers' responsibilities in designing, to highway department management with respect to financial requirements, and to the longer-range planning studies. The service life is also involved in public policy in determining, particularly in urban areas, the mix of transportation systems that is desirable. In private industry, service lives in the various types of physical properties are needed as a basis of making annual depreciation allocations, including those for income tax returns.

The methods and practices of estimating service lives of physical properties have been developed primarily in the public utility industries, where the rates charged to customers and the net return permitted to be earned by the utility are regulated by public commissions. Depreciation as an operating expense is an important factor in public utility rate determination.

Although public highway departments do not customarily practice depreciation accounting with respect to their highways, roads, and streets, the cost of owning and operating highway systems is determined periodically for use of management and in economy studies. Therefore, it is highly desirable that the service lives of highways be determined periodically by reference to the experience over the years with the different components and types of components making up the total highway.

Most of the past studies of the service lives of highways have been restricted to a study of highway surfacings and pavements. Basically, this is because the roadway surface is a component of the highway requiring more frequent renewal than other components, and it can be readily measured both as to physical dimensions and investment cost.

It would add much to our useful knowledge if service life studies could also be made of bridges and other structures, drainage facilities, earthwork, and rights-of-way. Some work has been done on these highway elements (16), but there is a need for further extensive study. These elements can be analyzed using the investment dollar as the accounting unit as opposed to using the mile or lane-mile unit, as is often done for pavements. Rights-of-way and earthwork normally have extremely long lives because they do not wear out structurally or become obsolete as do highway pavements. Even in reconstruction of highways the earthwork is largely salvaged and right-of-way is usually retained. Nevertheless, in some cases, the centerline is shifted, which causes complete abandonment of a highway segment.

VARIABILITY OF PAVEMENT SERVICE LIVES

The record-keeping and the analysis of the records of the service lives of pavements or of any other component of the highway becomes a continuing operation because the item being measured (the service life) is a variable.

The service life of a highway pavement depends on such factors as soil and climatic conditions, structural design, maintenance quality, kind and intensity of traffic, and the criteria used by management in deciding that a given pavement should be resurfaced or reconstructed. Over the years the structural quality of pavements has been improved through design and construction methods. There is some evidence that these two factors have produced potentially longer-lived pavements. However, what the engineer has gained through design and construction to a certain extent has been absorbed by the increase in traffic volume and in axle weights applied to the pavements. The result has been, therefore, a noticeable increase in the total load carried by pavements over their life span, but no great gain in the years of service prior to their resurfacing or reconstruction.

Because of the many variable factors affecting the service life of highway pavements, it is necessary to make studies periodically (e.g., every five years) of the experiences with pavements. Another factor causing variations in the service lives between highway conditions, geographical areas, or highway departments is that the pavements themselves have different potential services even though they may be called by the exact identical name. The specifications of design and construction differ among highway departments. This fact is particularly applicable to bituminous pavements, but it is also applicable to portland cement concrete, or rigid pavements.

The AASHO road test results afford the opportunity to measure the service life in terms of their "work accomplishment" rather than in terms of years of service. In the pavement design procedure developed from the AASHO road test, one of the major factors is the number of load applications to the pavement of equivalent 18,000-lb single axles. A second factor in the design formula is the present serviceability index (PSI), a measure of the permanent deformation and roughness of the pavement at any specific date.

By estimating from traffic counts and classification data the year's application of equivalent 18-kip single axles and by measuring the PSI periodically it is possible to plot curves of E-18 kip axleload application against PSI and between calendar years and PSI. These two observations applied to selected highway pavement sections afford the basis of forecasting retirement years and of measuring durability of pavements in terms of their design strength and actual field loadings. It is hoped that many states will add these two observations to their road life studies.

COLLECTION AND ANALYSES OF SERVICE LIFE DATA

This paper reports the results of the analyses of the road life data supplied by 26 states and Puerto Rico, which reported their past construction and retirement activity for 1921 up to January 1, 1960, the cutoff date (see Fig. 1). Essentially the reports to the Bureau of Public Roads consisted of the yearly constructed miles, miles remaining January 1 each year, and miles retired by 5-year periods for each of seven pavement types. The methods of retirement and the replacement type were also reported in 5-year groups for both vintage years and retirement years.

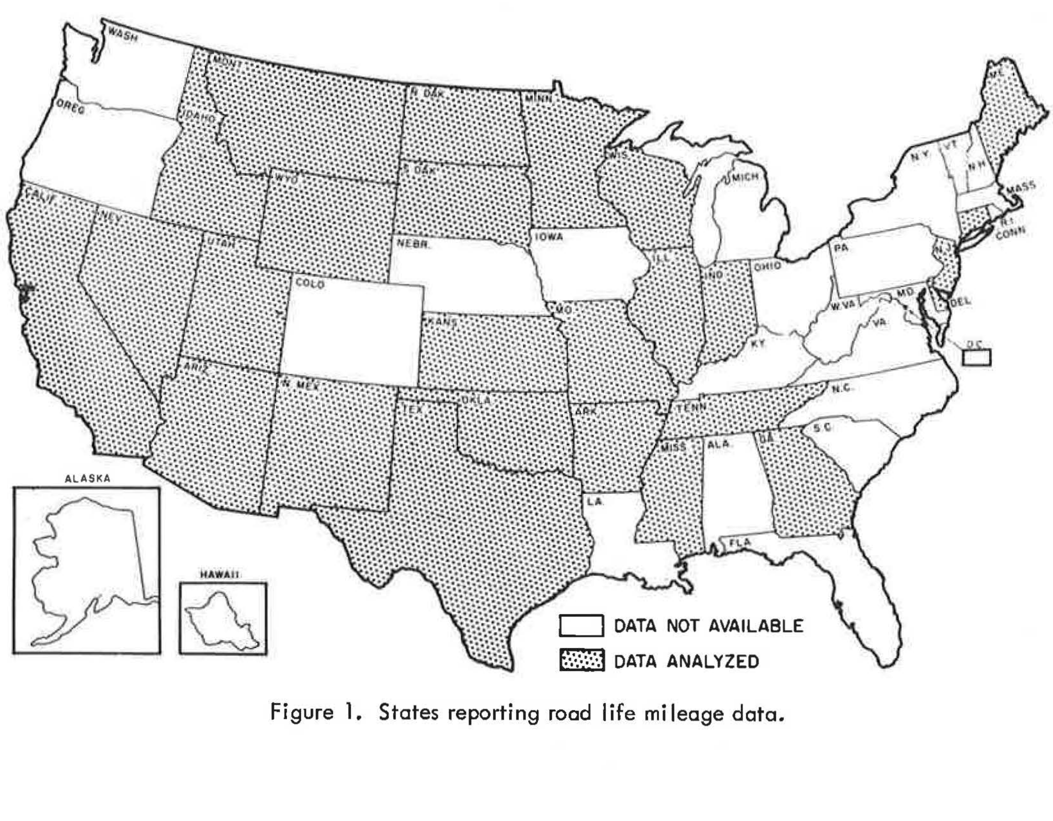

Figure 1. States reporting road life mileage data.

The seven surface types analyzed in this report are as follows (see Appendix for detailed descriptions):

F. Bituminous surface-treated

G. Mixed bituminous

G-1 Mixed bituminous (combined thickness of surface and base less than 7 in. and/or low load-bearing capacity)

G-2 Mixed bituminous (combined thickness of surface and base 7 in. or more and/or a high load-bearing capacity with or without rigid base)

H. Bituminous penetration

H-1 Bituminous penetration (combined thickness of surface and base less than 7 in. and/or low load-bearing capacity)

H-2 Bituminous penetration (combined thickness of surface and base 7 in. or more and/or a high load-bearing capacity with or without rigid base)

I. Bituminous concrete with or without rigid base

J. Portland cement concrete with or without bituminous surface less than 1 in. in thickness

The states reported their surviving mileages by pavement types and the data are given in Tables 1 to 7. Such data permit analyses to be made that will give the distribution of retirements by age, survivor curves, and average service lives. The methods of analysis are those given by Winfrey (2), which for many years has been a standard source for this kind of work and for similar work by private industries and public utilities. The methods are closely related to those used by life insurance actuaries. One

TABLE 1

BITUMINOUS SURFACE-TREATED (F) MILEAGE CONSTRUCTED EACH YEAR AND MILEAGE REMAINING IN SERVICE JANUARY 1 OF EACH YEAR

Construction		Mileage Remaining in Service January 1 Each Year														
Year	Miles	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
1921	107.3	9.5	9.5	9.5	9.5	9.0	8.7	8.7	8.7	6.5	6.5	6.5	6.5	6.2	6.2	4.6
1922	146.9	30.7	29.5	28.1	27.9	27.9	27.9	26.7	26.7	26.0	25.5	25.5	25.4	24.1	23.1	21.4
1923	158.2	38.5	37.7	35.6	31.4	30.5	30.5	30.1	30.0	19.5	19.4	15.8	15.2	13.6	12.9	11.0
1924	288.2	81.6	81.6	80.9	75.5	61.4	59.0	56.0	53.0	47.0	44.2	37.5	32.4	32.4	30.4	30.4
1925	304.7	122.4	122.4	118.0	109.5	106.3	96.3	95.3	83.9	70.3	67.1	65.3	56.7	56.2	56.1	53.1
1926	322.4	98.6	91.8	75.4	75.4	63.8	63.1	48.2	36.7	30.4	18.8	16.5	13.8	13.1	12.0	10.0
1927	316.2	121.4	117.3	100.9	98.2	92.5	92.5	92.1	90.9	87.7	76.2	75.8	71.6	50.8	47.7	47.6
1928	862.3	190.6	190.3	184.1	174.9	164.2	155.9	152.6	149.5	127.1	125.7	106.1	104.7	102.3	92.5	80.4
1929	1,075.7	185.5	183.0	179.5	154.2	146.7	145.5	136.6	111.6	104.6	96.0	83.3	70.6	51.3	46.4	41.7
1930	1,496.5	349.3	349.3	343.0	284.1	269.7	259.1	218.7	209.8	172.5	123.1	98.1	79.3	75.6	74.1	59.3
1931	1,924.9	608.1	589.3	585.5	546.2	505.8	452.9	430.2	398.7	374.2	341.3	279.4	254.5	240.4	220.5	201.4
1932	2,174.7	399.1	371.6	343.1	325.4	325.0	319.4	303.9	264.8	249.1	231.7	195.0	165.5	145.2	138.7	135.1
1933	2,728.2	865.4	823.3	797.3	779.1	726.8	687.2	645.6	618.3	559.3	505.2	458.3	392.2	347.3	326.0	266.8
1934	2,276.3	968.6	862.3	803.3	756.4	734.6	696.1	651.6	601.3	556.8	533.9	456.9	429.8	387.2	370.1	362.0
1935	1,590.9	622.0	578.5	554.8	512.5	477.8	440.5	424.4	383.7	356.0	307.4	266.0	238.1	162.4	150.8	121.1
1936	2,603.4	1,099.7	1,075.0	1,016.2	951.1	900.4	882.2	834.4	799.2	712.4	627.6	550.9	524.1	472.7	403.9	359.7
1937	1,857.8	1,115.8	1,023.4	984.5	915.2	893.1	868.6	798.6	736.3	657.5	631.1	592.7	546.8	390.1	345.9	303.0
1938	3,498.2	2,586.9	2,435.8	2,201.3	1,982.7	1,853.3	1,683.5	1,543.3	1,445.8	1,293.8	1,206.8	1,117.2	1,059.0	951.5	894.9	786.2
1939	2,887.3	2,147.9	1,993.9	1,847.8	1,755.1	1,653.1	1,565.4	1,387.7	1,279.0	1,148.8	1,066.5	942.2	881.0	800.9	675.7	624.8
1940	3,453.2	2,962.5	2,822.3	2,684.5	2,596.8	2,361.5	2,192.6	2,096.5	1,948.4	1,764.5	1,614.7	1,517.9	1,412.5	1,344.7	1,267.9	1,117.9
1941	2,992.0	2,738.6	2,689.9	2,547.1	2,442.1	2,389.9	2,270.9	2,136.6	1,949.4	1,844.3	1,692.6	1,606.1	1,510.5	1,228.9	1,120.1	1,031.7
1942	2,233.2	2,067.9	2,008.0	1,927.4	1,800.5	1,696.5	1,623.6	1,527.6	1,450.0	1,357.9	1,232.5	1,134.2	1,058.3	954.5	898.3	818.3
1943	1,604.6	1,484.6	1,414.2	1,351.4	1,303.9	1,258.2	1,193.2	1,080.5	1,032.8	954.5	889.5	817.9	794.0	706.9	665.8	624.9
1944	1,282.4	1,218.6	1,176.8	1,087.2	1,015.6	920.1	876.3	823.0	762.3	725.9	651.5	586.1	529.7	470.9	437.4	408.8
1945	1,122.5	1,089.7	1,039.9	971.9	877.7	856.1	823.7	762.5	716.6	688.8	636.2	611.1	560.7	515.2	462.1	393.5
1946	2,142.2		2,125.1	2,056.6	1,990.8	1,902.8	1,842.6	1,787.8	1,727.1	1,664.1	1,607.0	1,465.2	1,397.2	1,176.1	1,118.9	1,042.3
1947	2,347.0			2,339.5	2,298.1	2,198.3	2,106.8	1,989.9	1,863.9	1,745.0	1,656.9	1,572.1	1,502.9	1,382.7	1,311.9	1,216.2
1948	2,706.4				2,620.7	2,544.6	2,511.8	2,408.3	2,286.7	2,195.1	2,033.6	1,913.7	1,775.1	1,657.3	1,535.3	1,432.1
1949	2,342.3					2,338.4	2,290.6	2,212.7	2,170.3	2,082.4	1,974.0	1,847.6	1,720.7	1,556.7	1,472.1	1,346.4
1950	2,228.5						2,219.3	2,195.4	2,097.8	2,034.2	1,918.7	1,829.9	1,695.0	1,571.8	1,500.5	1,368.7
1951	1,976.8							1,975.6	1,914.7	1,831.5	1,687.6	1,628.4	1,515.6	1,456.0	1,361.2	1,271.8
1952	2,076.4								2,063.6	2,007.7	1,922.7	1,844.0	1,742.7	1,668.5	1,553.5	1,434.3
1953	2,138.6									2,130.2	2,009.3	1,892.4	1,800.8	1,787.0	1,756.5	1,692.5
1954	1,917.3										1,895.2	1,778.6	1,678.3	1,629.1	1,553.2	1,475.7
1955	1,772.5											1,769.6	1,701.7	1,652.1	1,568.9	1,477.1
1956	1,654.9												1,645.5	1,608.9	1,551.8	1,453.4
1957	1,262.2													1,240.5	1,134.2	1,084.9
1958	1,440.8														1,430.5	1,355.1
1959	1,451.5															1,435.8
Total	66,765.4	23,203.5	24,241.7	25,254.4	26,510.5	27,508.3	28,486.0	28,881.1	29,311.5	29,625.6	29,476.0	29,203.8	29,008.4	27,931.1	27,628.0	27,001.0

TABLE 2

MIXED BITUMINOUS (G-1) MILEAGE CONSTRUCTED EACH YEAR AND MILEAGE REMAINING IN SERVICE JANUARY 1 OF EACH YEAR

Construction		Mileage Remaining in Service January 1 Each Year														
Year	Miles	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
1921	16.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
1922	18.6	6.3	6.3	4.5	4.5	4.5	2.5	2.5	2.5	2.0	0.0	0.0	0.0	0.0	0.0	0.0
1923	10.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1924	25.3	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0	0.0	0.0	0.0
1925	60.4	13.1	13.1	13.1	11.5	11.1	11.1	11.1	11.1	11.1	4.9	4.9	4.9	4.9	4.9	4.9
1926	222.8	37.3	34.5	33.9	32.9	32.9	2.5	2.5	2.0	2.0	2.0	1.5	1.5	0.5	0.5	0.5
1927	358.9	127.9	117.9	102.2	96.7	92.7	88.6	68.6	67.4	63.6	59.3	59.3	51.6	51.6	43.5	16.5
1928	710.7	228.8	201.5	170.6	153.7	145.6	121.7	114.1	83.7	64.7	52.0	47.1	44.4	35.1	29.8	23.9
1929	799.1	257.8	241.2	203.0	175.8	154.7	124.4	120.8	98.5	89.7	86.2	78.7	75.2	63.4	44.2	24.7
1930	1,644.0	712.9	636.1	562.9	503.1	476.5	416.7	367.9	332.0	290.9	214.3	190.9	177.5	156.5	134.1	110.5
1931	3,178.4	1,546.9	1,383.3	1,235.2	1,093.6	983.4	880.1	817.4	720.8	611.0	515.7	437.9	390.2	366.5	342.9	318.4
1932	3,444.4	1,616.2	1,522.1	1,378.8	1,237.5	1,114.9	1,022.8	938.8	797.5	659.4	604.8	525.5	457.3	369.7	328.2	281.0
1933	1,774.6	894.9	841.3	806.7	753.5	720.9	659.8	633.7	579.9	558.2	491.3	421.5	404.9	363.6	326.6	302.8
1934	2,402.2	735.9	674.7	643.5	595.9	573.1	505.2	477.0	428.8	391.9	351.5	327.1	300.6	265.5	229.6	171.5
1935	2,278.1	884.9	828.4	647.3	601.5	549.1	474.5	403.5	370.9	334.4	287.6	244.8	218.5	196.5	186.0	168.3
1936	2,942.8	1,671.5	1,578.2	1,430.4	1,285.8	1,201.3	1,127.0	1,031.6	981.8	901.5	824.9	715.9	636.2	582.6	560.5	521.2
1937	4,600.9	1,910.8	1,773.1	1,550.8	1,393.3	1,281.6	1,208.0	1,138.6	1,068.4	978.7	851.2	781.9	722.3	674.8	642.3	586.0
1938	3,514.1	2,142.1	1,925.1	1,756.2	1,491.2	1,366.5	1,267.5	1,207.1	1,100.4	934.5	831.7	743.0	667.1	614.1	581.8	567.1
1939	2,173.1	1,429.5	1,291.6	1,121.6	958.8	820.9	757.1	683.9	629.1	586.7	513.4	483.0	437.8	425.8	407.5	353.2
1940	815.8	704.8	655.9	618.9	585.9	563.8	494.0	474.4	422.4	352.2	300.3	224.1	192.2	172.6	147.8	143.2
1941	1,224.8	1,056.9	966.8	904.8	791.7	728.6	675.4	589.5	551.0	515.0	450.7	384.8	359.3	307.1	269.4	232.5
1942	481.4	428.6	398.8	377.8	341.3	317.7	287.3	266.1	249.0	227.3	207.9	203.9	166.3	155.6	143.2	133.5
1943	361.8	340.0	302.9	288.7	241.1	233.4	216.5	210.4	180.6	176.1	157.4	136.4	117.1	116.0	106.2	105.0
1944	865.9	861.1	791.5	715.1	560.8	505.4	450.3	378.1	314.7	264.7	205.5	165.3	127.5	91.8	83.4	71.5
1945	1,029.6	1,029.6	985.1	963.7	882.9	804.6	741.3	636.5	527.4	451.3	341.4	309.9	235.4	198.0	189.5	175.8
1946	1,293.4		1,291.7	1,238.9	1,180.9	1,107.5	1,035.6	953.2	848.7	750.9	662.2	598.6	551.9	522.3	445.6	387.3
1947	1,569.0			1,567.5	1,529.8	1,460.2	1,407.6	1,348.1	1,223.0	1,153.7	1,079.2	1,002.2	843.8	741.5	634.3	578.6
1948	1,735.8				1,732.2	1,703.7	1,635.0	1,585.8	1,466.8	1,352.8	1,271.3	1,178.0	1,074.8	985.6	919.9	792.7
1949	1,358.0					1,357.9	1,335.3	1,276.4	1,163.2	1,100.9	999.7	935.3	857.4	826.1	755.0	717.2
1950	1,019.8						1,016.4	1,004.2	928.6	852.3	794.2	746.0	689.8	628.9	590.1	566.2
1951	990.3							990.3	946.9	878.2	841.6	800.5	768.9	729.7	708.6	645.8
1952	1,025.1								1,020.4	985.5	946.5	928.7	851.2	821.2	804.9	776.6
1953	755.9									755.9	722.9	684.9	655.6	633.2	605.8	589.5
1954	957.1										972.1	939.4	898.1	853.4	824.4	764.5
1955	489.1											479.5	472.5	431.2	426.1	407.3
1956	761.7												761.7	757.4	715.4	701.9
1957	512.9													512.7	503.5	498.4
1958	671.7														671.2	632.0
1959	887.8															887.8
Total	48,999.9	18,641.4	18,464.7	18,339.7	18,239.5	18,316.1	17,967.8	17,735.7	17,123.1	16,299.8	15,646.4	14,783.2	14,215.1	13,657.0	13,408.3	13,259.4

TABLE 3

MIXED BITUMINOUS (G-2) MILEAGE CONSTRUCTED EACH YEAR AND MILEAGE REMAINING IN SERVICE JANUARY 1 OF EACH YEAR

Construction		Mileage Remaining in Service January 1 Each Year														
Year	Miles	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
1921	0.4	0.4	0.4	0.4	0.4	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1922	22.9	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1923	18.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	0.6	0.6	0.6	0.6	0.0	0.0	0.0
1924	25.4	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	0.0	0.0	0.0	0.0	0.0
1925	37.9	3.9	3.9	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1926	68.0	9.2	9.2	9.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0	0.0	0.0	0.0	0.0
1927	130.5	17.9	17.9	16.1	16.1	13.0	13.0	13.0	6.9	6.9	6.9	5.5	5.5	5.5	5.5	0.7
1928	285.5	67.3	58.3	58.3	43.3	41.2	28.8	25.7	25.3	25.3	23.0	17.3	7.6	6.5	5.9	5.9
1929	490.2	259.5	259.4	241.1	216.6	209.7	186.6	166.6	136.1	119.5	104.4	103.4	81.8	74.6	67.9	61.1
1930	1,156.1	624.5	620.4	599.3	537.2	472.7	426.0	407.3	362.5	335.0	277.9	234.9	202.9	176.8	153.8	129.9
1931	1,722.8	1,125.9	1,099.6	997.9	918.5	838.9	784.5	730.4	629.0	581.2	534.8	454.8	359.0	330.0	290.2	254.4
1932	2,452.5	1,734.2	1,676.8	1,650.4	1,574.3	1,513.4	1,378.4	1,314.3	1,215.4	1,123.4	1,002.5	927.0	849.5	804.0	722.6	684.3
1933	1,715.2	1,316.4	1,306.0	1,264.7	1,163.8	1,084.8	1,029.2	982.1	892.7	820.5	776.3	717.6	674.6	619.2	547.8	473.0
1934	2,243.2	1,867.7	1,853.1	1,747.5	1,661.7	1,577.1	1,529.0	1,481.3	1,381.1	1,272.1	1,190.0	1,136.1	1,089.3	1,030.2	959.4	884.1
1935	1,686.0	1,362.9	1,339.3	1,272.3	1,205.5	1,147.0	1,111.6	1,070.6	1,005.0	959.4	865.5	829.7	797.1	763.2	714.2	660.0
1936	1,784.0	1,504.4	1,436.0	1,398.5	1,362.8	1,334.2	1,280.6	1,215.5	1,163.4	1,119.5	1,014.0	938.8	885.4	813.8	777.2	739.0
1937	2,206.7	1,898.8	1,847.6	1,777.9	1,729.7	1,669.5	1,585.7	1,542.1	1,467.8	1,394.1	1,296.3	1,220.6	1,111.8	1,043.6	993.4	943.2
1938	2,164.1	1,954.0	1,916.1	1,857.1	1,748.8	1,695.7	1,643.0	1,580.6	1,520.1	1,446.1	1,385.2	1,313.8	1,205.5	1,155.5	1,091.2	1,023.4
1939	1,328.5	1,240.8	1,211.0	1,125.2	1,091.3	1,055.2	1,006.3	960.9	908.7	866.2	809.1	790.7	719.2	696.4	648.2	609.9
1940	1,345.7	1,292.5	1,270.6	1,251.9	1,214.3	1,178.7	1,153.1	1,139.0	1,110.4	1,075.7	1,063.8	1,038.2	969.3	940.4	872.6	833.1
1941	1,410.9	1,276.3	1,243.0	1,202.8	1,164.6	1,113.4	1,039.5	1,005.8	956.9	935.5	882.4	831.5	723.3	693.5	655.4	619.4
1942	1,021.2	977.1	935.5	909.0	839.7	807.9	741.2	700.0	668.4	628.7	612.1	572.0	523.7	492.5	469.5	462.2
1943	1,220.9	1,177.5	1,146.4	1,093.0	1,012.3	968.1	930.2	887.9	827.8	762.0	721.8	669.2	628.7	587.5	545.1	500.8
1944	1,330.2	1,318.5	1,296.6	1,284.1	1,244.6	1,183.3	1,140.3	1,107.1	963.0	868.8	751.0	665.4	588.6	563.6	503.0	426.6
1945	894.4	879.2	869.4	840.7	824.4	793.3	747.4	709.1	640.1	613.1	569.1	504.5	445.5	403.2	379.3	341.3
1946	1,469.9		1,469.9	1,446.0	1,417.6	1,393.1	1,380.2	1,343.8	1,291.4	1,224.9	1,143.9	1,077.4	971.8	914.3	831.8	776.0
1947	2,337.8			2,334.1	2,314.0	2,294.7	2,257.2	2,226.8	2,076.0	1,989.4	1,879.4	1,819.1	1,731.1	1,674.0	1,545.2	1,461.2
1948	2,464.0				2,462.4	2,427.8	2,388.9	2,289.8	2,228.3	2,168.0	2,067.5	1,953.3	1,839.5	1,759.2	1,625.6	1,570.8
1949	2,259.5					2,257.3	2,206.8	2,187.8	2,042.2	1,996.4	1,937.8	1,855.6	1,717.2	1,623.9	1,570.6	1,516.0
1950	2,472.6						2,470.3	2,441.0	2,395.5	2,313.4	2,257.3	2,188.1	2,114.4	2,006.8	1,958.5	1,880.2
1951	2,933.8							2,927.3	2,873.8	2,839.3	2,784.2	2,725.8	2,692.0	2,621.9	2,481.6	2,389.7
1952	3,604.0								3,574.7	3,543.2	3,475.8	3,417.2	3,339.5	3,194.3	3,046.3	2,865.8
1953	3,338.1									3,316.7	3,255.2	3,184.9	3,075.9	3,022.7	2,932.2	2,861.8
1954	3,594.1										3,589.1	3,526.8	3,452.3	3,383.1	3,244.9	3,157.9
1955	3,692.4											3,666.2	3,548.4	3,465.4	3,331.9	3,234.1
1956	3,755.3												3,740.8	3,686.7	3,617.5	3,558.3
1957	3,617.5													3,591.4	3,516.4	3,456.4
1958	3,176.8														3,170.3	3,114.8
1959	2,803.6															2,803.1
Total	68,281.4	21,932.6	22,910.1	22,405.1	25,788.7	27,095.2	28,482.8	30,480.8	32,387.3	34,354.1	36,286.1	38,386.2	40,092.0	42,144.8	43,275.2	44,298.6

TABLE 4

BITUMINOUS PENETRATION(H-1) MILEAGE CONSTRUCTED EACH YEAR AND MILEAGE REMAINING IN SERVICE JANUARY 1 OF EACH YEAR

Construction		Mileage Remaining in Service January 1 Each Year														
Year	Miles	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
1921	23.6	1.3	1.3	1.3	1.3	1.3	1.3	1.3	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
1922	37.5	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1923	54.9	12.7	12.7	10.4	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	1.4	1.4	0.0	0.0
1924	35.3	26.5	23.8	23.8	23.8	23.8	23.8	21.2	13.5	13.5	5.0	0.4	0.4	0.4	0.4	0.0
1925	35.0	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	4.7	4.7	4.7	4.7	4.7
1926	22.8	7.0	7.0	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.0	0.0	0.0	0.0
1927	59.5	28.0	28.0	15.9	14.0	14.0	14.0	14.0	14.0	5.9	3.7	2.3	2.2	2.2	2.1	1.2
1928	42.7	21.2	21.2	20.8	17.9	16.5	16.5	16.5	16.5	16.5	13.9	13.9	13.9	0.0	0.0	0.0
1929	65.9	24.8	24.8	24.8	24.8	22.9	19.5	14.8	14.8	14.8	14.0	8.1	8.1	8.1	8.0	7.0
1930	37.9	20.1	19.9	19.9	17.0	17.0	17.0	17.0	17.0	17.0	16.8	16.8	16.0	15.5	15.5	15.5
1931	93.4	45.3	45.2	45.2	45.2	45.2	40.8	33.5	33.5	31.4	24.1	23.5	19.8	19.8	18.8	13.5
1932	23.6	21.7	21.7	21.7	16.4	16.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
1933	394.7	206.6	204.8	192.8	183.2	179.5	176.7	164.9	164.9	160.7	130.7	112.5	102.9	96.4	63.9	48.9
1934	39.8	31.0	31.0	25.7	25.7	25.7	25.7	25.7	25.5	23.3	23.1	18.9	16.3	16.3	16.3	6.4
1935	36.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	26.0	18.6	15.8	15.0	7.6	7.6	7.6
1936	79.8	59.9	56.4	56.4	53.4	35.7	35.6	35.2	23.3	21.0	21.0	21.0	21.0	21.0	11.6	11.6
1937	52.1	28.2	28.2	25.8	23.8	23.1	16.2	16.2	16.2	16.2	15.3	15.3	15.2	13.2	13.2	7.2
1938	44.0	36.9	36.9	36.9	33.5	33.4	33.3	33.3	33.3	33.3	33.3	18.3	13.4	13.1	13.1	13.0
1939	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.0	14.0	12.1	3.0	3.0	3.0	2.5	2.5	2.5
1940	25.5	25.5	25.5	25.2	25.2	25.2	25.0	25.0	24.2	24.1	21.1	20.8	20.5	20.4	20.4	20.4
1941	13.5	13.5	13.5	13.5	13.5	13.5	6.2	6.2	6.2	6.2	5.1	5.1	5.0	5.0	5.0	5.0
1942	38.5	29.2	28.1	26.0	26.0	26.0	26.0	26.0	26.0	25.9	20.7	18.0	10.6	10.6	10.5	10.5
1943	30.5	30.3	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	9.5	8.6
1944	29.1	29.1	29.1	21.5	20.0	20.0	20.0	20.0	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
1945	38.1	38.1	38.1	38.1	12.9	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	10.6
1946	14.5		14.5	14.5	14.5	9.9	9.9	9.5	9.5	9.4	9.4	9.4	9.4	9.4	6.8	6.6
1947	8.0			8.0	8.0	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
1948	29.6				29.6	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	19.4	19.4	19.4
1949	39.5					39.5	39.5	39.5	39.5	39.4	39.4	26.1	26.1	25.9	25.7	25.7
1950	3.0						3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	0.1
1951	0.1							0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1952	43.6								43.6	43.6	43.6	42.9	42.9	42.9	42.9	42.9
1953	6.4									6.4	6.4	6.4	6.4	6.4	4.9	4.1
1954	9.9										9.9	8.7	8.7	8.7	8.7	8.7
1955	0.7											0.7	0.7	0.7	0.7	0.7
1956	17.1												17.1	17.1	17.1	17.1
1957	1.6													1.6	1.6	1.6
1958	25.6														25.6	25.6
1959	0.3															0.3
Total	1,567.7	788.6	781.5	740.7	708.2	705.6	667.4	640.2	656.9	640.1	571.5	496.6	475.8	441.9	410.0	366.2

TABLE 5

BITUMINOUS PENETRATION (H-2) MILEAGE CONSTRUCTED EACH YEAR AND MILEAGE REMAINING IN SERVICE JANUARY 1 OF EACH YEAR

Construction		Mileage Remaining in Service January 1 Each Year														
Year	Miles	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
1921	130.8	65.5	65.4	52.5	47.8	46.2	42.8	40.1	40.0	39.9	37.9	37.9	36.6	36.0	36.0	32.3
1922	172.4	96.8	96.8	93.5	83.9	82.4	73.0	55.0	54.8	54.8	52.2	50.5	47.0	46.5	45.3	45.3
1923	173.2	92.4	89.3	88.1	76.5	48.0	42.5	42.4	39.9	39.8	33.6	30.6	30.0	29.0	29.0	25.6
1924	182.9	119.9	102.5	101.5	77.3	74.0	69.8	63.4	59.0	46.7	32.4	32.4	31.6	25.2	24.5	18.6
1925	221.1	148.8	148.8	133.3	115.0	103.8	103.6	103.5	80.2	71.1	67.0	66.4	66.3	61.6	51.5	38.2
1926	179.2	132.6	110.8	91.5	75.3	65.6	65.5	65.0	59.5	57.8	57.2	54.9	48.8	43.8	28.9	25.1
1927	167.9	130.0	122.1	120.5	118.5	96.6	91.5	86.6	73.9	73.5	59.3	52.2	40.6	40.4	39.3	39.1
1928	105.5	71.0	57.0	56.7	56.0	55.2	49.4	49.3	47.0	43.9	43.6	39.8	32.8	26.5	24.1	22.7
1929	120.3	95.7	95.7	80.9	80.8	72.8	72.4	58.6	49.7	42.7	42.2	42.2	38.8	36.6	29.0	28.8
1930	160.7	102.1	100.4	83.7	81.3	77.9	71.2	65.7	47.9	32.9	30.1	30.1	28.5	26.6	23.8	23.8
1931	586.8	317.6	313.1	313.1	302.0	295.6	290.3	272.9	234.2	201.2	197.9	148.8	123.5	117.2	107.9	104.7
1932	624.8	359.0	328.5	286.9	272.6	241.4	214.6	209.8	167.3	124.4	103.9	103.5	100.5	100.3	87.2	87.3
1933	522.8	364.5	358.8	337.3	277.5	274.8	245.7	242.4	229.2	196.0	185.4	185.4	167.3	159.6	135.8	119.5
1934	580.2	388.9	375.3	358.4	338.9	338.1	338.1	337.7	310.4	280.8	257.1	243.0	221.3	213.0	173.6	170.9
1935	770.0	657.8	649.7	634.0	603.0	599.5	593.7	590.9	567.5	539.1	494.9	463.6	434.6	393.7	358.9	328.9
1936	536.5	449.4	431.4	421.1	419.3	419.1	410.3	400.6	393.3	359.9	326.0	284.6	266.0	257.0	243.1	230.7
1937	506.9	430.5	420.1	401.5	397.2	395.7	378.6	378.4	363.0	354.0	333.0	302.8	288.5	287.9	250.6	249.6
1938	335.8	274.0	274.0	273.8	262.3	249.4	249.1	249.1	231.2	218.2	214.6	209.2	197.0	195.7	187.5	176.6
1939	164.1	148.7	148.7	148.6	148.1	147.9	145.4	145.0	145.0	144.9	143.5	131.2	131.1	130.7	130.4	126.7
1940	414.5	400.4	400.3	391.0	391.0	389.6	387.8	385.9	373.0	357.1	326.8	312.0	305.4	286.9	273.3	260.2
1941	263.2	260.7	259.8	259.4	258.6	257.5	251.6	250.6	235.1	229.0	212.9	208.0	207.0	192.6	170.0	165.5
1942	304.5	302.2	299.2	298.9	286.3	276.9	272.4	269.9	251.1	243.4	240.8	238.6	230.9	211.3	195.7	193.6
1943	409.7	384.4	384.4	365.3	365.2	362.3	353.4	342.0	334.8	282.7	248.8	218.2	185.3	172.1	171.8	144.7
1944	396.0	395.6	395.6	384.4	373.8	370.4	352.6	345.0	328.2	319.8	243.1	211.1	204.5	202.7	181.9	173.7
1945	221.7	221.7	219.9	219.9	212.5	196.9	196.7	193.0	189.1	181.7	181.7	177.0	167.2	166.4	156.3	130.9
1946	98.3		98.3	98.1	98.0	98.0	88.0	88.0	88.0	70.8	70.5	67.8	65.1	54.5	50.1	30.0
1947	112.8			112.8	112.7	112.7	112.3	111.9	111.9	101.6	95.8	79.4	76.8	70.9	70.7	70.6
1948	185.3				185.3	178.5	166.8	160.0	155.4	141.6	122.2	122.2	118.8	117.7	109.2	93.2
1949	112.3					112.3	112.3	103.1	102.7	94.4	93.9	91.1	90.3	90.0	84.5	79.9
1950	39.4						39.4	39.4	39.4	37.0	36.6	31.9	31.0	31.0	30.9	21.0
1951	56.8							56.8	56.8	54.8	45.7	43.8	38.6	38.6	38.4	37.7
1952	39.8								39.8	39.8	39.8	39.7	37.8	36.3	36.0	34.5
1953	205.9									205.9	205.8	195.9	190.4	189.8	190.0	172.4
1954	294.5										292.9	261.9	235.8	213.7	209.7	192.7
1955	111.3											111.3	110.7	102.8	89.1	83.9
1956	96.8												96.8	96.2	96.1	93.1
1957	165.9													165.9	164.0	163.5
1958	118.9														118.5	117.2
1959	125.3															125.3
Total	10,014.8	6,410.2	6,345.9	6,206.7	6,116.7	6,039.1	5,880.8	5,802.0	5,498.3	5,281.2	5,169.1	4,919.0	4,723.2	4,666.7	4,442.6	4,280.0

TABLE 6

BITUMINOUS CONCRETE (I) MILEAGE CONSTRUCTED EACH YEAR AND MILEAGE REMAINING IN SERVICE JANUARY 1 OF EACH YEAR

Construction		Mileage Remaining in Service January 1 Each Year														
Year	Miles	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
1921	112.7	51.5	51.5	49.3	43.5	23.8	23.8	20.8	14.9	12.4	12.4	11.0	11.0	11.0	11.0	10.9
1922	205.5	130.4	122.4	104.9	102.0	82.8	82.8	81.0	74.8	56.2	56.1	44.8	36.1	31.9	23.9	21.5
1923	238.4	104.2	103.6	84.5	84.1	58.6	56.8	40.1	40.1	29.0	25.5	20.8	20.8	20.8	20.0	17.1
1924	140.8	63.7	62.2	58.1	56.4	45.2	45.2	43.5	42.6	42.6	38.4	28.1	26.0	26.0	21.6	20.9
1925	164.7	110.2	106.0	101.2	84.2	76.0	76.0	64.3	59.6	58.1	54.7	54.6	52.8	52.6	36.3	33.5
1926	135.0	84.8	84.8	65.6	60.5	48.5	44.2	41.1	40.3	40.2	36.7	34.5	33.7	31.7	27.0	24.2
1927	189.2	111.6	99.4	93.1	87.8	87.4	75.6	75.0	70.1	52.9	40.9	33.9	32.5	30.8	26.2	23.5
1928	266.0	145.6	137.2	125.1	116.0	105.3	100.6	88.6	75.3	64.0	59.4	42.3	38.7	38.3	32.7	31.4
1929	397.2	194.5	189.2	169.8	146.5	128.7	126.5	121.2	106.0	86.2	73.8	70.1	68.2	58.5	47.8	44.5
1930	405.1	222.9	198.4	170.0	158.6	133.0	116.7	79.3	55.9	39.3	24.6	21.6	19.4	19.0	12.9	10.9
1931	507.0	356.0	334.0	330.6	319.1	301.6	276.3	239.4	195.9	175.9	169.9	135.7	116.5	95.7	84.2	60.0
1932	406.4	176.8	160.4	158.1	146.8	126.7	117.8	101.8	75.4	67.2	60.3	54.6	53.3	46.9	43.9	40.5
1933	818.8	535.8	515.4	489.2	477.5	452.8	443.5	401.9	364.6	319.3	297.9	230.6	178.1	155.8	126.6	88.7
1934	533.6	449.2	415.5	396.6	365.9	345.5	324.4	320.2	287.9	276.0	241.2	223.4	205.0	190.6	185.8	164.2
1935	362.6	323.0	321.4	320.0	298.3	289.6	281.6	279.6	267.6	246.1	215.5	201.9	197.3	191.9	187.2	178.3
1936	495.8	396.8	392.8	388.9	367.5	349.4	299.9	295.3	266.5	227.2	216.5	190.8	189.3	175.9	170.3	150.0
1937	617.3	541.7	536.2	528.9	519.0	502.8	460.9	405.2	389.8	339.5	327.6	302.4	285.6	266.9	254.4	241.3
1938	640.0	488.5	469.2	440.4	431.9	407.8	381.8	350.1	309.0	284.2	248.6	222.3	197.1	178.0	164.3	161.7
1939	502.6	447.8	430.4	422.7	422.6	412.1	374.0	341.8	321.7	317.9	296.6	278.0	222.9	213.4	185.6	173.8
1940	748.0	691.2	666.9	642.8	639.5	630.0	621.0	609.0	598.0	567.1	513.3	481.6	451.3	426.4	363.2	334.9
1941	654.7	600.7	576.6	546.7	527.7	522.3	516.5	470.3	448.2	431.2	409.6	397.2	383.2	364.4	338.5	290.1
1942	562.2	554.4	550.3	545.6	541.4	533.4	512.4	482.0	440.5	396.0	359.7	334.2	258.0	244.5	234.8	215.5
1943	626.5	622.3	613.6	608.2	588.3	582.4	578.0	559.8	517.8	507.2	477.8	472.5	442.5	422.9	390.4	345.5
1944	1,182.3	1,180.9	1,171.1	1,143.6	1,140.8	1,133.4	1,119.5	1,071.1	1,016.8	955.6	926.5	845.6	796.6	738.0	650.6	588.8
1945	798.4	798.4	794.7	781.9	773.4	766.2	681.8	633.5	600.7	588.4	578.1	542.7	514.8	497.7	464.8	387.9
1946	1,168.8		1,163.3	1,143.9	1,139.4	1,128.1	1,123.7	1,115.9	1,080.6	1,058.4	1,016.8	954.7	842.8	788.2	722.9	666.9
1947	1,686.9			1,686.7	1,684.3	1,668.5	1,655.0	1,647.1	1,605.4	1,537.6	1,507.3	1,433.3	1,357.7	1,249.2	1,121.0	1,018.7
1948	1,709.8				1,709.0	1,696.3	1,688.6	1,659.5	1,606.7	1,576.7	1,525.5	1,462.7	1,381.1	1,326.9	1,237.5	1,113.8
1949	1,720.1					1,719.4	1,712.4	1,700.0	1,688.0	1,672.6	1,646.9	1,605.1	1,552.2	1,473.8	1,369.3	1,291.1
1950	1,469.2						1,468.0	1,459.5	1,452.2	1,424.9	1,388.6	1,357.6	1,288.3	1,228.5	1,165.3	1,100.3
1951	2,253.1							2,253.0	2,240.1	2,213.2	2,163.3	2,138.8	2,050.5	2,007.8	1,944.2	1,833.7
1952	3,499.6								3,499.1	3,488.4	3,459.5	3,385.3	3,319.3	3,246.4	3,150.7	2,989.1
1953	2,954.0									2,945.3	2,916.6	2,859.4	2,796.7	2,780.4	2,732.7	2,563.3
1954	3,100.2										3,096.3	3,088.7	3,042.0	2,977.9	2,948.1	2,821.4
1955	3,176.6											3,175.8	3,134.9	3,117.2	2,998.7	2,908.7
1956	3,533.2												3,526.8	3,522.4	3,478.7	3,411.3
1957	2,817.5													2,814.7	2,794.2	2,750.2
1958	3,890.2														3,890.1	3,872.7
1959	3,910.5															3,905.6
Total	48,600.5	9,382.9	10,257.5	11,596.4	13,032.0	14,357.6	15,385.3	17,050.9	19,852.1	22,096.8	24,482.4	26,736.6	29,123.0	31,063.0	33,659.4	35,906.4

TABLE 7

PORTLAND CEMENT CONCRETE (J) MILEAGE CONSTRUCTED EACH YEAR AND MILEAGE REMAINING IN SERVICE JANUARY 1 OF EACH YEAR

Construction		Mileage Remaining in Service January 1 Each Year														
Year	Miles	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
1921	1,281.8	635.4	588.9	521.0	455.0	410.1	376.2	335.2	273.8	242.1	218.9	201.4	162.6	135.5	122.7	110.6
1922	1,729.7	1,098.6	1,034.3	947.7	857.0	781.3	668.1	602.6	501.6	470.2	410.1	373.7	310.4	292.5	248.0	227.0
1923	1,890.6	1,473.8	1,401.8	1,303.0	1,202.0	1,138.4	1,092.0	963.2	837.2	764.3	666.3	604.4	564.1	535.7	482.4	435.9
1924	2,339.7	1,957.9	1,907.7	1,860.3	1,758.9	1,673.5	1,605.3	1,456.3	1,245.2	1,130.3	1,010.0	938.7	880.4	812.7	741.3	653.7
1925	1,525.1	1,331.8	1,311.6	1,273.8	1,240.5	1,194.1	1,157.7	1,085.6	998.6	908.6	854.5	817.8	740.7	684.9	613.3	579.1
1926	1,377.2	1,189.0	1,178.2	1,141.0	1,101.7	1,031.0	1,015.2	939.1	811.8	739.8	705.4	674.4	618.5	561.2	537.6	508.5
1927	2,017.6	1,799.0	1,761.1	1,690.7	1,603.4	1,540.6	1,508.1	1,422.7	1,352.0	1,241.1	1,177.5	1,085.7	984.5	945.0	812.2	742.9
1928	2,219.8	2,101.7	2,066.4	2,011.7	1,941.0	1,871.3	1,817.6	1,784.9	1,687.8	1,610.5	1,561.7	1,471.4	1,407.9	1,337.1	1,231.1	1,118.6
1929	2,301.1	2,175.8	2,130.0	2,078.1	1,992.7	1,884.1	1,830.4	1,734.0	1,601.2	1,544.5	1,482.6	1,428.9	1,357.1	1,279.8	1,170.0	1,046.7
1930	2,918.6	2,817.7	2,759.4	2,690.3	2,603.1	2,492.5	2,421.1	2,299.0	2,165.0	1,981.1	1,901.3	1,830.3	1,727.6	1,657.0	1,568.6	1,427.5
1931	4,218.3	4,009.4	3,945.4	3,889.8	3,791.7	3,670.6	3,596.0	3,460.4	3,186.2	3,058.8	2,925.5	2,813.2	2,665.0	2,494.7	2,269.6	2,097.6
1932	3,376.0	3,283.7	3,265.4	3,185.4	3,138.2	3,038.7	3,006.9	2,906.5	2,768.6	2,678.9	2,649.2	2,521.5	2,371.9	2,339.1	2,223.7	2,052.5
1933	3,658.1	3,296.6	3,259.3	3,209.1	3,155.0	3,081.9	3,049.4	2,976.2	2,817.7	2,681.0	2,506.3	2,366.8	2,209.5	2,106.8	1,969.6	1,890.7
1934	1,327.5	1,300.4	1,287.7	1,276.4	1,259.2	1,241.1	1,228.4	1,188.0	1,146.9	1,065.1	1,047.1	1,016.7	965.8	930.2	857.7	797.0
1935	1,054.3	1,039.9	1,028.9	1,025.0	999.9	977.3	952.5	919.3	879.9	823.8	811.7	781.6	754.3	727.2	649.7	625.9
1936	1,316.4	1,303.3	1,301.1	1,296.5	1,269.2	1,244.1	1,210.9	1,146.4	1,112.2	1,040.0	989.7	959.1	923.6	887.6	820.6	778.8
1937	1,878.5	1,854.7	1,845.6	1,837.8	1,802.8	1,764.7	1,758.1	1,718.0	1,666.1	1,603.7	1,531.1	1,521.0	1,457.5	1,442.5	1,374.7	1,288.0
1938	1,540.7	1,533.0	1,529.3	1,520.6	1,498.7	1,471.0	1,458.5	1,426.9	1,390.8	1,347.8	1,325.9	1,272.6	1,235.2	1,210.2	1,195.9	1,155.4
1939	1,144.1	1,124.2	1,124.2	1,119.6	1,118.4	1,115.2	1,077.7	1,073.8	1,036.3	1,006.7	956.6	916.9	892.1	865.6	816.3	786.9
1940	786.3	783.7	783.7	774.2	772.0	759.8	751.3	731.3	687.8	658.1	634.6	608.5	593.9	575.6	556.4	536.9
1941	764.7	761.6	760.6	756.3	754.3	752.5	747.7	716.5	711.9	689.3	663.3	640.3	617.9	604.6	600.6	581.8
1942	566.4	566.4	563.4	563.1	552.2	545.0	538.1	528.9	502.1	490.8	474.9	464.9	452.0	438.7	421.6	397.5
1943	437.8	433.2	411.6	407.5	405.3	401.9	399.0	393.1	381.3	363.3	351.2	338.9	311.5	310.0	284.3	260.3
1944	194.1	194.1	194.1	193.6	193.4	191.7	182.8	182.0	166.7	164.8	152.2	151.8	142.3	128.4	97.0	71.4
1945	141.2	141.0	140.7	140.3	139.1	138.7	138.7	121.3	120.9	120.9	119.3	119.3	117.5	110.7	108.6	104.0
1946	380.0		380.0	380.0	380.0	379.9	379.9	379.1	378.6	377.1	375.9	374.8	373.7	369.8	366.2	353.2
1947	538.2			537.0	537.0	532.0	531.2	527.8	527.0	523.2	509.5	507.6	495.0	485.2	479.1	474.6
1948	652.5				652.4	651.4	651.4	651.0	650.8	649.8	647.6	644.7	641.8	640.2	637.6	621.8
1949	660.2					653.0	652.8	651.8	650.6	644.3	643.9	629.6	628.4	625.4	614.9	610.7
1950	463.2						459.7	458.5	458.5	458.5	458.4	458.4	445.1	444.3	436.0	433.0
1951	377.8							377.8	377.2	377.2	374.9	374.7	370.8	369.2	364.3	361.8
1952	591.9								583.0	574.0	571.6	571.5	566.0	562.7	551.3	549.0
1953	566.2									564.9	563.0	552.9	546.3	545.2	543.7	541.3
1954	488.1										486.1	485.4	482.6	482.2	480.0	478.6
1955	499.6											499.6	496.7	495.5	491.0	489.7
1956	514.3												514.2	514.2	505.6	503.1
1957	384.0													384.0	370.0	367.0
1958	597.7														596.5	591.6
1959	743.9															743.9
Total	49,463.2	38,205.9	37,960.4	37,629.8	37,174.1	36,627.4	36,262.7	35,157.2	33,675.3	32,594.5	31,759.8	31,019.0	30,024.4	29,331.2	28,209.7	27,394.5

TABLE 8

MILEAGES CONSTRUCTED AND MILEAGES AND PERCENTAGES REMAINING IN SERVICE ON JANUARY 1, 1960, FOR VARIOUS CONSTRUCTION YEARS BY SURFACE TYPE

Construction Year	Miles Constructed	Remaining in Service January 1, 1960		Miles Constructed	Remaining in Service January 1, 1960	
		Miles	Percent		Miles	Percent
	Bituminous Surface-Treated			Mixed Bituminous G-1		
1921-25	1,005.3	120.5	12.0	130.9	6.5	5.0
1926-30	4,073.1	239.0	5.9	3,735.5	176.1	4.7
1931-35	10,695.0	1,086.4	10.2	13,077.7	1,242.0	9.5
1936-40	14,299.9	3,191.6	22.3	14,046.7	2,170.7	15.5
1941-45	9,234.7	3,277.2	35.5	3,963.5	718.3	18.1
1946-50	11,766.4	6,405.7	54.4	6,976.0	3,042.0	43.6
1951-55	9,881.6	7,351.4	74.4	4,235.5	3,183.7	75.2
1956-59	5,809.4	5,329.2	91.7	2,834.1	2,720.1	96.0
Total	66,765.4	27,001.0	40.4	48,999.9	13,259.4	27.1
	Mixed Bituminous G-2			Bituminous Penetration H-1		
1921-25	105.4	0.2	0.2	186.3	4.7	2.5
1926-30	2,130.3	197.6	9.3	228.8	23.7	10.4
1931-35	9,819.7	2,955.8	30.1	587.5	76.8	13.1
1936-40	8,829.0	4,148.6	47.0	215.5	54.7	25.4
1941-45	5,877.6	2,350.3	40.0	149.7	49.6	33.1
1946-50	11,003.8	7,204.2	65.5	94.6	55.6	58.8
1951-55	17,162.4	14,509.3	84.5	60.7	56.5	93.1
1956-59	13,353.2	12,932.6	96.9	44.6	44.6	100.0
Total	68,281.4	44,298.6	64.9	1,567.7	366.2	23.4
	Bituminous Penetration H-2			Bituminous Concrete		
1921-25	880.4	160.0	18.2	862.1	103.9	12.1
1926-30	733.6	139.5	19.0	1,392.5	134.5	9.7
1931-35	3,084.6	811.3	26.3	2,628.4	531.7	20.2
1936-40	1,957.8	1,045.8	53.4	3,003.7	1,061.7	35.3
1941-45	1,595.1	808.4	50.7	3,824.1	1,827.8	47.8
1946-50	548.1	294.7	53.8	7,754.8	5,190.8	66.9
1951-55	708.3	521.2	73.6	14,983.5	13,116.2	87.5
1956-59	506.9	499.1	98.5	14,151.4	13,939.8	98.5
Total	10,014.8	4,280.0	42.7	48,600.5	35,906.4	73.9
	Portland Cement Concrete					
1921-25	8,766.9	2,006.3	22.9			
1926-30	10,834.3	4,844.2	44.7			
1931-35	13,634.2	7,463.7	54.7			
1936-40	6,666.0	4,546.0	68.2			
1941-45	2,104.2	1,415.0	67.2			
1946-50	2,694.1	2,493.3	92.5			
1951-55	2,523.6	2,420.4	95.9			
1956-59	2,239.9	2,205.6	98.5			
Total	49,463.2	27,394.5	55.4			

product of the analysis is a survivor curve that indicates the percentage of the property surviving in use at each age subsequent to its original construction.

From the data in Tables 1 to 7 service lives were calculated by two procedures using the original group method and one procedure using the retirement rate method. These methods are described in the section on service lives.

The summary data in Table 8 gives by 5-year groupings of construction vintages the miles constructed for each of the seven pavement types and the miles remaining in service as of January 1, 1960. The percentage remaining in service is much less for the earlier than for the later vintages and is also much less for the same vintage groups for the lower types of pavements than for the higher types.

METHODS OF RETIREMENT

The reasons for retiring pavements may be classified as follows: completely reconstructed, resurfaced, abandoned in place, or transferred to another authority. These methods for retirement result from the following reasons: poor structural quality, poor riding quality, encroachment of other highway improvements, encroachment of other public works or public programs such as water resources projects, urban renewal, and building programs. Strictly speaking, the transfer of a pavement to another highway authority is not a retirement in the sense that the property has ended its usefulness but it is a retirement from that particular highway system of which it was a part (see Appendix for more detailed descriptions).

TABLE 9

MILES RETIRED FOR EACH SURFACE TYPE AND PERCENTAGE DISTRIBUTION ACCORDING TO METHOD OF RETIREMENT
(Total for 1959 and Prior)

Surface Type	Miles Retired	Method of Retirement (%)			
		Resurfaced	Reconstructed	Abandoned	Transferred
Bituminous surface-treated	42,368.7	58.5	32.6	2.5	6.4
Mixed bituminous					
G-1	35,796.1	59.8	30.3	2.0	7.9
G-2	24,239.3	56.6	30.3	3.9	9.2
Bituminous penetration					
H-1	1,520.2	46.0	34.1	6.1	13.8
H-2	7,466.4	45.4	39.9	3.1	11.6
Bituminous concrete	13,722.5	57.4	27.7	2.2	12.7
Portland cement concrete	27,805.9	66.0	22.8	1.8	9.4
Total	152,919.1	59.0	29.8	2.5	8.7

Table 9 summarizes the total miles retired by pavement type and gives the percentage of the total retirements classified by resurfaced, reconstructed, abandoned, and transferred, for all types combined. Almost 89 percent of all retirements were either by resurfacing or reconstruction, 2.5 percent of the mileage was abandoned in place, and 8.7 percent was transferred to another highway authority. It was expected that the high-type bituminous concrete and portland cement concrete would have high percentages resurfaced and such was the case. The lower quality bituminous types (bituminous surface-treated) show relatively high percentages resurfaced (up to 59.8 percent), which probably is characteristic of this type since it lends itself to frequent resurfacings to restore the riding quality of the surface.

The same retirement data given in Table 9 are classified in Table 10 to show the percentages of all types of pavements retired by method of retirement for 5-year intervals from 1930 and prior to 1956-1959. No marked trend is indicated in Table 10 except that following World War II the percentage resurfaced decreased and the percentage reconstructed increased. There was also a slight increase in the mileage transferred to other systems.

Table 11 for each of the seven pavement types indicates replacement type for each retirement by method of retirement. There was a trend in pavement types to higher quality pavements and in the relative frequency by surface type of replacement to the same type of pavement as compared to a different type. For instance, bituminous surface-treated (type F) was resurfaced with mixed bituminous (types G-1 and G-2) for 24.3 percent of the mileage retired, and 12.9 percent was resurfaced with bituminous concrete (type I). For the bituminous concrete (type I), 45.5 percent of the retirements were replaced with bituminous concrete resurfacing. On the other hand, 55.3 percent of the retirements of portland cement concrete pavement were resurfaced with bituminous concrete and only 1.7 percent was resurfaced with portland cement concrete. Further, 10.4 percent of the portland cement concrete retirements were reconstructed to bituminous concrete (type I) and only 7.4 percent of portland cement concrete was reconstructed in kind.

The trend in pavement replacement type as compared to the pavement type retired is indicated in Table 12 for each of the four retirement methods. The percentage of retirements replaced with the two highest types of pavement—bituminous concrete and

TABLE 10

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

Method of Retirement	Retirement Period							
	1930 and Prior	1931-35	1936-40	1941-45	1946-50	1951-55	1956-59	Total 1959 and Prior
Resurfaced	57.9	63.1	58.1	65.8	60.0	58.3	54.6	59.0
Reconstructed	32.3	22.1	27.5	25.3	30.5	31.5	33.6	29.8
Abandoned	3.0	3.4	3.4	2.2	2.2	1.9	2.8	2.5
Transferred	6.8	11.4	11.0	6.7	7.3	8.3	9.0	8.7

TABLE 11

PERCENTAGE DISTRIBUTION OF TOTAL RETIRED MILEAGES FOR EACH SURFACE TYPE BY METHOD OF RETIREMENT AND REPLACEMENT TYPE FOR 1959 AND PRIOR RETIREMENTS

Replacement Type	Method of Retirement					Method of Retirement				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Bituminous Surface-Treated (F)					Bituminous Penetration (H-2)				
None	—	—*	0.2	0.5	0.7	—	—	0.1	0.7	0.8
C	—*	0.2	0.1	0.1	0.4	—	0.5	—*	0.1	0.6
D	—*	0.3	0.4	1.4	2.1	—	0.5	0.3	3.8	4.6
E	1.3	1.8	0.1	0.2	3.4	0.1	0.3	0.2	0.2	0.8
F	8.0	6.8	0.3	1.9	17.0	0.5	1.7	0.2	0.4	2.8
G-1	14.3	2.3	0.2	0.2	17.0	4.9	1.1	0.1	0.1	6.2
G-2	10.0	3.9	0.3	0.5	14.7	6.0	2.6	0.1	0.6	9.3
H-1	5.0	7.7	0.4	0.5	13.6	1.0	13.6	1.0	0.9	16.5
H-2	6.7	1.5	0.1	0.1	8.4	10.1	4.1	0.3	3.0	17.5
I	12.9	5.3	0.2	0.3	18.7	22.6	13.1	0.4	0.5	36.6
J, K, and L	0.3	2.8	0.2	0.7	4.0	0.2	2.4	0.4	1.3	4.3
Total	58.5	32.6	2.5	6.4	100.0	45.4	39.9	3.1	11.6	100.0
Total miles retired	24,795.5	13,797.6	1,047.8	2,727.8	42,368.7	3,386.1	2,982.4	228.6	869.3	7,466.4
	Mixed Bituminous (G-1)					Bituminous Concrete (I)				
None	—	—	0.2	0.6	0.8	—	—*	0.2	0.9	1.1
C	—*	1.3	—*	0.6	1.9	—*	0.4	0.1	0.1	0.6
D	—	0.2	—*	0.1	0.3	—*	0.2	0.1	1.1	1.4
E	1.7	5.3	0.3	1.5	8.8	0.1	0.4	—*	0.1	0.6
F	1.0	4.4	0.2	0.5	6.1	0.4	0.6	0.1	0.1	1.2
G-1	43.1	3.7	0.2	1.1	48.1	1.0	0.3	—*	0.2	1.5
G-2	11.2	9.9	1.0	2.0	24.1	8.9	2.3	0.3	0.5	12.0
H-1	0.2	0.3	—*	—*	0.5	0.3	3.5	0.4	0.4	4.6
H-2	0.2	—*	—*	—	0.2	1.1	0.6	—*	0.1	1.8
I	1.8	1.2	—*	0.2	3.2	45.5	15.4	0.5	6.6	68.0
J, K, and L	0.6	4.0	0.1	1.3	6.0	0.1	4.0	0.5	2.6	7.2
Total	59.8	30.3	2.0	7.9	100.0	57.4	27.7	2.2	12.7	100.0
Total miles retired	21,404.2	10,832.4	726.1	2,833.4	35,796.1	7,878.5	3,802.0	303.5	1,738.5	13,722.5
	Mixed Bituminous (G-2)					Portland Cement Concrete (J)				
None	—	—*	0.2	0.9	1.1	—	—*	0.1	0.6	0.7
C	1.2	0.3	—*	0.3	1.8	—	0.3	—*	0.4	0.7
D	—	0.1	0.1	0.3	0.5	—	—*	0.1	0.5	0.6
E	0.5	1.1	0.1	0.1	1.8	—*	0.1	0.1	0.2	0.4
F	0.7	1.8	0.3	0.3	3.1	0.1	0.4	—*	0.1	0.6
G-1	1.6	0.8	0.1	0.1	2.6	0.2	0.2	—*	0.1	0.5
G-2	45.2	18.9	2.6	4.7	71.4	8.3	3.7	0.3	0.7	13.0
H-1	0.3	1.5	0.1	0.1	2.0	—*	0.2	0.1	0.1	0.4
H-2	0.5	0.2	—*	—	0.7	0.4	0.1	—*	—*	0.5
I	6.3	2.1	0.2	0.4	9.0	55.3	10.4	0.3	0.4	66.4
J, K, and L	0.3	3.5	0.2	2.0	6.0	1.7	7.4	0.8	6.3	16.2
Total	56.6	30.3	3.9	9.2	100.0	66.0	22.8	1.8	9.4	100.0
Total miles retired	13,709.2	7,343.0	947.0	2,240.1	24,239.3	18,362.1	6,329.9	507.6	2,606.3	27,805.9
	Bituminous Penetration (H-1)					Total All Surface Types				
None	—	—	—	1.1	1.1	—	—*	0.2	0.6	0.8
C	—	0.3	0.6	—*	0.9	0.2	0.5	0.1	0.3	1.1
D	—*	0.1	0.1	2.7	2.9	—*	0.2	0.1	0.9	1.2
E	0.9	1.3	0.2	0.3	2.7	0.8	2.0	0.2	0.5	3.5
F	0.3	1.5	0.3	0.1	2.2	2.7	3.4	0.2	0.7	7.0
G-1	11.3	2.7	1.5	1.0	16.5	14.8	1.8	0.1	0.4	17.1
G-2	11.3	7.2	2.4	2.4	23.3	15.3	7.5	0.8	1.6	25.2
H-1	10.3	4.6	0.3	2.0	17.2	1.6	3.5	0.2	0.3	5.6
H-2	1.7	2.7	0.5	0.5	5.4	2.7	0.7	—*	0.2	3.6
I	8.5	5.4	—*	0.2	14.1	20.3	6.0	0.3	0.9	27.5
J, K, and L	1.7	8.3	0.2	3.5	13.7	0.6	4.2	0.3	2.3	7.4
Total	46.0	34.1	6.1	13.8	100.0	59.0	29.8	2.5	8.7	100.0
Total miles retired	698.9	518.0	93.7	209.6	1,520.2	90,234.5	45,605.3	3,854.3	13,225.0	152,919.1

*Less than 0.05 percent.

TABLE 12

PERCENTAGE DISTRIBUTION OF ALL SURFACE TYPES COMBINED BY METHOD OF RETIREMENT AND REPLACEMENT TYPE BY RETIREMENT YEARS

Replacement Type	Method of Retirement: Resurfaced	Reconstructed	Abandoned	Transferred	Total
1930 and Prior					
None	—	—*	0.1	0.6	0.7
C	—	0.9	—*	0.8	1.7
D	—	—*	0.1	0.2	0.3
E	1.6	1.7	0.7	0.6	4.6
F	17.3	2.7	0.2	0.3	20.5
G-1	8.6	0.7	0.2	0.1	9.6
G-2	2.1	0.9	0.2	—*	3.2
H-1	0.6	1.3	—*	0.2	2.1
H-2	5.1	3.3	0.1	0.2	8.7
I	16.4	4.2	0.2	0.2	21.0
J	6.2	16.6	1.2	3.6	27.6
Total	57.9	32.3	3.0	6.8	100.0
Total miles retired	2,048.0	1,140.3	107.0	240.5	3,535.8
1931 to 1935					
None	—	—	0.5	0.3	0.8
C	—*	0.8	0.3	0.8	1.9
D	—*	0.5	0.7	2.6	3.8
E	1.8	2.3	0.3	0.7	5.1
F	11.6	1.2	0.2	0.6	13.6
G-1	31.9	2.7	0.2	0.8	35.6
G-2	3.3	1.7	0.3	0.3	5.6
H-1	2.2	0.2	—*	0.2	2.6
H-2	4.7	1.5	—*	0.3	6.5
I	5.6	2.0	0.3	0.2	8.1
J	2.0	9.2	0.6	4.6	16.4
Total	63.1	22.1	3.4	11.4	100.0
Total miles retired	7,569.5	2,646.2	407.0	1,367.9	11,990.6
1936 to 1940					
None	—	—*	0.4	0.8	1.2
C	0.6	1.1	0.2	0.9	2.8
D	—*	0.5	0.2	2.5	3.2
E	0.8	3.0	0.3	0.7	4.8
F	3.5	5.2	0.2	0.8	9.7
G-1	29.5	3.3	0.4	0.9	34.1
G-2	7.5	4.8	1.0	0.9	14.2
H-1	3.3	1.5	0.1	0.5	5.4
H-2	5.0	0.9	0.1	0.1	6.1
I	7.3	1.6	0.1	0.2	9.2
J	0.6	5.6	0.4	2.7	9.3
Total	58.1	27.5	3.4	11.0	100.0
Total miles retired	11,864.3	5,618.9	685.4	2,244.4	20,413.0
1941 to 1945					
None	—	—*	0.1	0.4	0.5
C	0.2	0.5	—*	0.1	0.8
D	—*	0.2	0.1	1.1	1.4
E	3.4	2.1	0.2	0.7	6.4
F	2.2	5.4	0.1	0.6	8.3
G-1	14.9	2.1	0.3	0.4	17.7
G-2	15.0	5.2	0.5	0.5	21.2
H-1	5.0	3.5	0.4	0.2	9.1
H-2	7.8	0.5	—*	0.2	8.5
I	17.0	1.3	0.1	0.7	19.1
J	0.3	4.5	0.4	1.8	7.0
Total	65.8	25.3	2.2	6.7	100.0
Total miles retired	11,347.8	4,358.4	379.9	1,161.2	17,247.3

Replacement Type	Method of Retirement: Resurfaced	Reconstructed	Abandoned	Transferred	Total
1946 to 1950					
None	—	—*	—*	0.8	0.8
C	0.2	0.3	—*	0.1	0.6
D	—*	0.1	0.3	0.6	1.0
E	0.7	2.1	0.1	0.6	3.5
F	1.6	5.4	0.1	0.5	7.6
G-1	15.9	2.4	0.1	0.2	18.6
G-2	17.3	8.8	1.0	1.5	28.6
H-1	1.6	3.8	0.2	0.3	5.9
H-2	1.2	0.3	—*	0.2	1.7
I	21.2	3.3	0.1	0.5	25.1
J	0.3	4.0	0.3	2.0	6.6
Total	60.0	30.5	2.2	7.3	100.0
Total miles retired	16,836.8	8,564.6	606.7	2,044.9	28,053.0
1951 to 1955					
None	—	—*	0.1	0.7	0.8
C	0.1	0.5	0.1	0.1	0.8
D	—	—*	—*	0.3	0.3
E	0.2	2.4	—*	0.5	3.1
F	0.8	2.3	0.2	0.9	4.2
G-1	9.0	1.0	—*	0.4	10.4
G-2	19.2	9.8	0.8	2.1	31.9
H-1	0.3	4.6	0.2	0.3	5.4
H-2	0.9	0.8	—*	0.2	1.9
I	27.5	8.0	0.2	0.9	36.6
J	0.3	2.1	0.3	1.9	4.6
Total	58.3	31.5	1.9	8.3	100.0
Total miles retired	22,673.6	12,253.8	739.9	3,202.5	38,869.8
1956 to 1959					
None	—	—*	0.3	0.6	0.9
C	0.1	0.1	—*	0.2	0.4
D	—*	0.1	0.1	0.1	0.3
E	—*	0.7	—	0.2	0.9
F	0.7	1.8	0.4	0.8	3.7
G-1	5.8	0.8	0.1	0.1	6.8
G-2	19.8	9.3	1.1	2.6	32.8
H-1	0.3	4.6	0.3	0.2	5.4
H-2	0.8	0.6	0.1	0.2	1.7
I	26.8	13.0	0.3	2.0	42.1
J	0.3	2.6	0.1	2.0	5.0
Total	54.6	33.6	2.8	9.0	100.0
Total miles retired	17,894.5	11,023.1	928.4	2,963.6	32,809.6
Total 1959 and Prior					
None	—	—*	0.2	0.6	0.8
C	0.2	0.5	0.1	0.3	1.1
D	—*	0.2	0.1	0.9	1.2
E	0.8	2.0	0.2	0.5	3.5
F	2.7	3.4	0.2	0.7	7.0
G-1	14.8	1.8	0.1	0.4	17.1
G-2	15.3	7.5	0.8	1.6	25.2
H-1	1.6	3.5	0.2	0.3	5.6
H-2	2.7	0.7	—*	0.2	3.6
I	20.3	6.0	0.3	0.9	27.5
J	0.6	4.2	0.3	2.3	7.4
Total	59.0	29.8	2.5	8.7	100.0
Total miles retired	90,234.5	45,605.3	3,854.3	13,225.0	152,919.1

*Less than 0.05 percent.

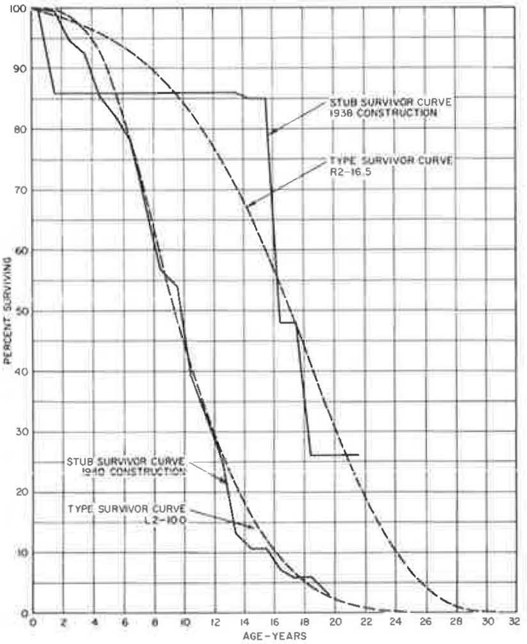

Figure 2. Survivor curves of 1938 and 1940 construction for mixed bituminous (G-1) pavement. Typical survivor curves from individual states.

portland cement concrete—was high (48.6 percent) prior to 1930; it decreased to a low of 18.5 percent in 1936-40, after which it increased steadily to 47.1 percent in 1956-59. Thus, these data are additional evidence of the increase over the years of higher types of pavement structures in the main rural primary systems. In agreement with this trend, the use of bituminous surface-treated type F decreased from 20.5 percent of the retirements replaced in 1930 and prior years more or less steadily to a low of 3.7 percent in 1956-1959.

Tables 11 and 12 indicate a replacement type for abandonments and transfers, which, of course, is not logical. Abandonments are not replaced, and transfers are to another highway system, usually without change in surface type. The explanation of these illogical entries is that the coding of data for machine analysis was not adjusted to separate out the abandonments and transfers, so they were assigned replacement types in accordance with the resurfacing or reconstruction work on the major highway locations that caused the abandonment or transfer.

AVERAGE SERVICE LIFE OF VINTAGES

Two analyses to determine the average service life of each pavement type are presented. In Analysis A, the service life of each pavement type was determined individually state by state and then these service lives were weighted by the total miles constructed in each vintage year. In Analysis B, the miles constructed and miles remaining in service each January 1 were added to consolidate the 26 states and Puerto Rico data into one table for each pavement type. The average service lives were then calculated directly from these tables.

Analysis A—Average Service Lives of Vintages by Weighting State Service Lives

Weighting by the miles constructed by individual states was achieved by determining for each vintage of construction the percentages surviving at the beginning of each year, which percentages were then plotted to form survivor curves, samples of which are illustrated in Figures 2 and 3. These curves were then matched with the Iowa-type curves, as given in (2). In order to find the average service life represented by a survivor curve it is necessary to find the total area enclosed by the survivor curve and its two axes. In those cases where the survivor curve is short, necessitating a long extension to zero percent surviving, or in cases where the curve is highly irregular, there may be introduced a high probable error in the estimated service life.

This type of analysis was used by Farrell and Paterick (11) and by Gronberg and Blosser (15) and has been used in this study in order to afford a direct comparison. However, it is not as reliable as might be desired because of the low statistical population in the individual state data.

Analysis B—Service Lives Estimated by Method of Consolidating the Basic Data

Two methods of determining the service life of each of the seven pavement types will be illustrated using Tables 1 to 7 as the source of exposure to retirement and the

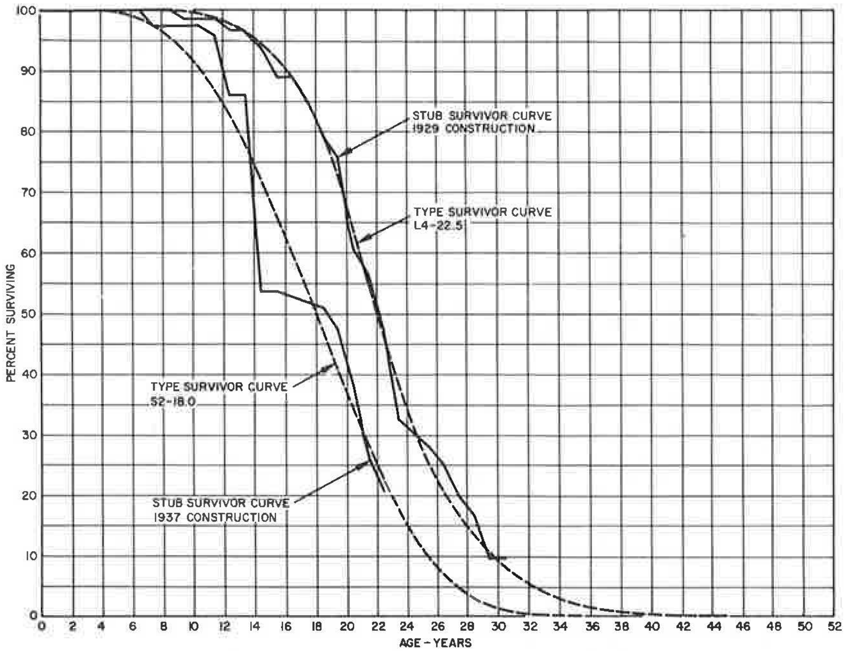

Figure 3. Survivor curves of 1929 and 1937 construction of portland cement concrete (J) pavement. Typical survivor curves from individual states.

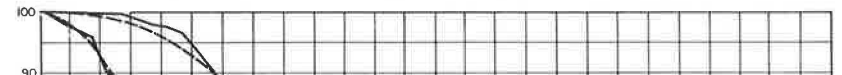

Figure 4. Survivor curves of mixed bituminous (G-1) and portland cement concrete (J) for 1940 and 1921 construction, calculated from the composite data of Method 1.

TABLE 13

AVERAGE SERVICE LIVES OF CONSTRUCTION VINTAGES FROM STATE-WEIGHTED AND COMPOSITE DATA

Construction Year	Bituminous Surface-Treated (F)		Mixed Bituminous (G-1)		Mixed Bituminous (G-2)		Bituminous Penetration (H-1)		Bituminous Penetration (H-2)		Bituminous Concrete (I)		Portland Cement Concrete (J)	
	State-weighted	Composite Data	State-weighted	Composite Data	State-weighted	Composite Data	State-weighted	Composite Data	State-weighted	Composite Data	State-weighted	Composite Data	State-weighted	Composite Data
1921	16.5	L_2-15.5	13.0	L_0-13.0	29.8	S_6-29.8	17.2	S_2-17.2	26.5	L_1-26.0	22.9	S_1-23.0	24.6	S_1-24.0
1922	16.5	L_0-15.4	16.7	L_2-16.7	19.6	R_1-19.5	16.9	L_5-16.9	25.6	L_1-25.5	25.4	R_2-25.5	27.0	S_3-26.5
1923	16.9	L_0-17.0	9.2	L_0- 9.2	16.9	L_1-16.9	18.6	L_2-19.5	23.5	L_1-22.0	20.3	L_1-20.0	29.0	L_3-30.0
1924	17.6	L_1-17.5	13.2	L_1-13.2	21.0	R_2-21.0	25.3	R_3-25.2	23.8	R_2-23.5	22.3	L_2-22.5	29.7	L_3-31.0
1925	19.8	L_0-20.0	12.7	L_0-13.0	9.9	L_2- 9.9	18.3	L_0-18.0	24.7	R_2-24.0	24.8	S_1-24.5	31.1	R_3-30.5
1926	14.0	L_0-14.5	11.6	L_0-11.6	10.3	L_0-10.3	14.7	S_0-14.7	22.8	L_2-23.0	23.7	L_3-23.0	29.2	R_3-29.0
1927	17.1	L_0-16.5	13.9	L_0-14.0	10.6	L_0-10.6	13.9	L_0-13.7	23.5	R_2-24.0	20.5	S_0-20.0	29.6	R_3-28.5
1928	10.3	10.0[a]	12.8	L_0-13.0	11.9	L_0-11.9	17.1	S_0-17.1	22.1	S_0-21.5	19.2	S_0-18.5	29.5	S_2-32.0
1929	8.2	8.1[a]	12.7	L_0-13.0	17.2	L_0-17.0	16.3	L_0-16.5	24.2	R_2-22.0	18.1	L_1-18.0	28.8	S_2-29.5
1930	9.0	8.9[a]	13.4	L_0-13.5	17.4	L_1-17.0	21.5	S_0-23.0	18.5	S_0-18.5	16.2	S_0-16.0	28.9	S_2-29.5
1931	11.3	11.1[a]	14.3	L_0-14.5	18.2	S_0-18.0	16.1	L_0-16.5	18.8	S_0-18.0	19.4	S_1-19.5	28.3	S_2-28.5
1932	7.0	6.8[a]	12.9	L_0-13.0	20.8	R_1-19.5	16.7	R_3-16.6	16.5	L_1-16.0	14.9	L_1-15.0	29.2	S_2-30.0
1933	9.7	9.5[a]	14.2	L_0-13.0	20.2	S_0-20.0	15.1	L_0-15.0	18.7	L_1-18.5	16.9	R_1-17.0	26.3	R_2-26.0
1934	11.8	L_0-11.4	8.5	L_0- 8.5	22.0	S_0-22.0	19.2	R_1-19.5	19.3	L_1-20.0	20.0	S_1-20.0	26.9	S_2-28.0
1935	9.7	9.6[a]	8.4	L_0- 8.5	21.0	S_0-20.5	19.6	R_2-19.5	23.4	S_1-23.0	22.2	S_1-23.0	25.6	S_2-26.5
1936	10.6	10.4[a]	12.3	L_0-12.0	20.8	R_1-19.5	14.9	L_2-15.0	21.0	R_1-21.0	18.2	L_1-19.0	25.1	S_2-25.0
1937	12.5	L_0-13.0	8.7	L_0- 8.5	19.5	S_0-20.0	12.8	L_1-13.0	21.2	R_1-21.0	19.2	S_1-18.5	25.7	S_2-26.0
1938	14.0	L_0-14.0	10.9	L_0-10.5	19.7	S_0-20.5	18.3	R_1-17.0	24.4	L_0-24.0	15.2	L_1-15.0	26.1	S_1-30.5
1939	12.8	L_0-13.0	11.1	L_0-10.5	18.8	S_0-18.5	16.6	L_5-16.5	33.1	R_3-23.0	17.0	S_1-17.0	23.7	S_2-24.0
1940	14.7	L_1-14.5	13.4	L_1-13.0	20.8	S_2-24.5	20.8	R_3-24.0	28.8	R_2-21.5	17.9	S_1-18.5	22.3	S_1-24.5
1941	15.1	L_1-16.0	11.5	L_0-11.5	16.1	L_0-18.5	15.6	L_2-15.0	25.9	S_2-20.5	16.7	R_1-16.0	22.7	S_1-26.5
1942	15.3	L_0-15.5	12.2	L_0-12.0	15.3	L_0-16.5	13.0	L_0-13.5	25.9	R_2-19.0	15.7	L_2-16.0	20.6	S_1-23.0
1943	14.5	L_0-14.0	11.1	L_0-11.0	14.0	L_0-15.0	12.8	L_0-13.5	14.9	S_1-13.0	17.0	S_1-17.5	17.8	R_2-17.5
1944	11.2	L_0-11.5	7.7	L_0- 8.0	12.7	S_0-12.5	15.5	L_0-14.0	15.3	L_1-15.0	15.4	S_1-15.5	15.4	S_2-14.5
1945	11.2	L_0-11.5	8.8	L_0- 8.5	12.4	S_0-12.0	7.6	L_0- 9.0	15.9	R_2-15.0	14.0	S_0-14.5	18.7	S_0-22.5
1946	13.1	L_0-15.0	9.7	L_0-10.0	14.6	S_0-14.5	12.8	L_0-13.0	13.1	R_2-11.5	14.4	S_1-15.0	21.9	S_2-25.0
1947	12.5	L_0-13.5	10.6	L_0-11.5	14.9	S_0-15.5	8.8	L_0- 9.0	15.1	L_2-13.0	14.4	S_1-15.0	21.2	S_1-23.0
1948	11.6	L_0-13.5	10.7	L_0-12.0	14.1	S_0-14.5	12.7	L_0-14.0	12.8	L_0-12.0	14.1	L_1-16.5	22.9	S_2-24.0
1949	12.0	L_0-14.0	10.5	L_0-11.5	13.6	S_0-13.0	12.3	L_1-14.0	13.9	R_1-14.0	14.6	S_1-15.5	20.7	S_1-23.0
1950	11.8	L_0-13.5	10.3	L_0-11.0	14.3	S_0-15.0	9.2	S_6- 9.0	13.1	S_1-10.5	14.2	S_0-16.0	22.3	S_1-23.0

[a]An acceptable fit was not found among the original 18 type survivor curves. Most probably an acceptable fit could be found in the 4 origin-modal curves later developed (see 2, Appendix D, p. 177-204).

Note: Because every State did not construct every surface type every construction year, some entries in this table are a composite of less than 26 states and Puerto Rico. Retirements for years 1951 to 1959 were insufficient to indicate a reliable trend or average service life.

annual retirements. Method 1 applies the original group method, or vintage method, and Method 2 applies the annual rate method, or retirement rate method. Both methods are given elsewhere (2). The vintage method develops the service life of each individual year's construction. Such average service life is independent of all other vintages.

Analysis B, Method 1—Vintage, or Original Group Method—From the basic tables (Tables 1 to 7) the percentage surviving each year following construction for each vintage was calculated and plotted (Fig. 4 is an example). As was done in Analysis A, these Method 1 survivor curves were matched with the Iowa-type curves to determine the type curve designation and the average service life. The service lives determined by Analysis A (state-weighted) and by Method 1 of Analysis B (composite data) are summarized in Table 13 by individual vintage years.

A comparison of the two sets of results in Table 13 indicates that the average service lives by the two analyses are relatively the same but there are certain inherent differences. In Analysis A there is a higher degree of probable error of service life by each type by each state because the plotted survivor curves result from a much smaller population than is available in Method 1 of Analysis B, which consolidates the basic data of the 26 states and Puerto Rico. It is, therefore, concluded that consolidating the basic data of surviving mileage is the preferable method.

A comparison of the calculated service lives in Table 13 by their year of construction indicated a general decrease in service life as the vintages approach 1950. This is seen by comparing the service lives from top to bottom of the column of Table 13. This trend may be caused by the steady increase in traffic volume, traffic speed, and the desire for a smoother ride.

Analysis B, Method 2—Retirement Rate Method—This method may be applied to a single year's experience or to a band of one or more years during which the exposure to retirement and the retirements from each vintage are available. Thus, it results in an average service life that is a measure of the retirement activity during the band of observation years. The service life is then a composite experience of all the pavement in service during the band of years. Thus, by this retirement rate method and, for example, a 5-year band, the analysis includes for the retirements only the younger vintages up to age 5. The lower end of the curve at high ages is based solely on the older vintages in service during the time of the observation band. The survivor curve, therefore, represents a different group of vintages at each age.

Tables 14 and 15 illustrate the basic calculation by the retirement rate method. Table 14 comes directly from Table 6. The mileages surviving in Table 6 are subtracted horizontally to produce the yearly retirements given in Table 14. Columns 2 and 3 in Table 15 come directly from the corresponding Tables 6 and 14. The exposure to retirement of the pavement in service at the beginning of each age interval is taken by summing on a stair-step diagonal in Table 6 for the band of years chosen. The pavement retired at each age (column 3, Table 15) is obtained by summing on the stair-step diagonal for the same band of years to get the total mileage retired at each age as given in column 3.

The retirement rate in column 4 is calculated from the miles retired each age interval as shown in Table 15. This rate is then applied successively to the percent surviving in column 5 and subtracted from the percent surviving to get the percent surviving at the beginning of the next age interval. The survivor curve is plotted from column 5. Figures 5, 6, and 7 are curves illustrating the survivor curves obtained by the annual rate method.

COMPARISON AND DISCUSSION OF SURVIVOR CURVES

Table 16 gives the type survivor curves and average lives of the seven pavement surface types for each of the retirement bands analyzed by the retirement rate method. Results of the calculations indicate the average service lives corresponding to the rates of retirement from all vintages that were in service during the 5 or 10-year band analyzed. A horizontal comparison of the lines in the table gives the trend in service life with calendar years. The post World War II period (1945 to 1959) shows no material

TABLE 14

MILES OF BITUMINOUS CONCRETE (I) RETIRED EACH YEAR

Construction		Miles Retired													
Year	Miles	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
1921	112.7	0.0	2.2	5.8	19.7	0.0	3.0	5.9	2.5	0.0	1.4	0.0	0.0	0.0	0.1
1922	205.5	8.0	17.5	2.9	19.2	0.0	1.8	6.2	18.6	0.1	11.3	8.7	4.2	8.0	2.4
1923	238.4	0.6	19.1	0.4	25.5	1.8	16.7	0.0	11.1	3.5	4.7	0.0	0.0	0.8	2.9
1924	140.8	1.5	4.1	1.7	11.2	0.0	1.7	0.9	0.0	4.2	10.3	2.1	0.0	4.4	0.7
1925	164.7	4.2	4.8	17.0	8.2	0.0	11.7	4.7	1.5	3.4	0.[illegible]	1.8	0.2	16.3	2.8
1926	135.0	0.0	19.2	5.1	12.0	4.3	3.1	0.8	0.1	3.5	2.2	0.8	2.0	4.7	2.8
1927	189.2	12.2	6.3	5.3	0.4	11.8	0.6	4.9	17.2	12.0	7.0	1.4	1.7	4.6	2.7
1928	266.0	8.4	12.1	9.1	10.7	4.7	12.0	13.3	11.3	4.6	17.1	3.6	0.4	5.6	1.3
1929	397.2	5.3	19.4	23.3	17.8	2.2	5.3	15.2	19.8	12.4	3.7	1.9	9.7	10.7	3.3
1930	405.1	33.5	19.4	11.4	25.0	16.3	37.4	23.4	16.6	14.7	3.0	2.2	0.4	6.1	2.0
1931	507.0	22.0	3.4	11.5	17.5	25.3	36.9	43.5	20.0	6.0	34.2	19.2	20.8	11.5	24.2
1932	406.4	16.4	2.3	11.3	20.1	8.9	16.0	26.4	8.2	6.9	5.7	1.3	6.4	3.0	3.4
1933	818.8	20.4	26.2	11.7	24.7	9.3	41.6	37.3	45.3	21.4	67.3	52.5	22.3	27.2	39.9
1934	533.6	33.7	18.9	30.7	20.4	21.1	4.2	32.3	11.9	34.8	17.8	18.4	14.4	4.8	21.6
1935	362.6	1.6	1.4	21.7	8.7	8.0	2.0	12.0	21.5	30.6	13.6	4.6	5.4	4.7	8.9
1936	495.8	4.0	3.9	21.4	18.1	49.5	4.6	28.8	39.3	10.7	25.7	1.5	13.4	5.6	20.3
1937	617.3	5.5	7.3	9.9	10.2	41.9	55.7	15.4	50.3	11.9	25.2	16.8	18.7	12.5	13.1
1938	640.0	19.3	28.8	8.5	24.1	26.0	31.7	41.1	24.8	35.6	26.3	25.2	19.1	13.7	2.6
1939	502.6	17.4	7.7	0.1	10.5	38.1	32.2	20.1	3.8	21.3	18.6	55.1	9.5	27.8	11.8
1940	748.0	24.3	24.1	3.3	9.5	9.0	12.0	11.0	30.9	53.8	31.7	30.3	24.9	63.2	28.3
1941	654.7	24.1	29.9	19.0	5.4	5.8	46.2	22.1	17.0	21.6	12.4	14.0	18.8	25.9	48.4
1942	562.2	4.1	4.7	4.2	8.0	21.0	30.4	41.5	44.5	36.3	25.5	76.2	13.5	9.7	19.3
1943	626.5	8.7	5.4	19.9	5.9	4.4	18.2	42.0	10.6	29.4	5.3	30.0	19.6	32.5	44.9
1944	1,182.3	9.8	27.5	2.8	7.4	13.9	48.4	54.3	61.2	29.1	80.9	49.0	58.6	87.4	61.8
1945	798.4	3.7	12.8	8.5	7.2	84.4	48.3	32.8	12.3	10.3	35.4	27.9	17.1	32.9	76.9
1946	1,168.8	5.5	19.4	4.5	11.3	4.4	7.8	35.3	22.2	41.6	62.1	111.9	54.6	65.3	56.0
1947	1,686.9		0.2	2.4	15.8	13.5	7.9	41.7	67.8	30.3	74.0	75.6	108.5	128.2	102.3
1948	1,709.8			0.8	12.7	7.7	29.1	52.8	30.0	51.2	62.8	81.6	54.2	89.4	123.7
1949	1,720.1				0.7	7.0	12.4	12.0	15.4	25.7	41.8	52.9	78.4	104.5	78.2
1950	1,469.2					1.2	8.5	7.3	27.3	36.3	31.0	69.3	59.8	63.2	65.0
1951	2,253.1						0.1	12.9	26.9	49.9	24.5	88.3	42.7	63.6	110.5
1952	3,499.6							0.5	10.7	28.9	74.2	66.0	72.9	95.7	161.6
1953	2,954.0								8.7	28.7	57.2	62.7	16.3	47.7	169.4
1954	3,100.2									3.9	7.6	46.7	64.1	29.8	126.7
1955	3,176.6										0.8	40.9	17.7	118.5	90.0
1956	3,533.2											6.4	4.4	43.7	67.4
1957	2,817.5												2.8	20.5	44.0
1958	3,890.2													0.1	17.4
1959	3,910.5														4.9
Total	48,600.5	294.2	348.0	274.2	394.5	441.5	587.5	698.4	709.3	714.6	922.4	1,146.8	877.5	1,293.8	1,663.5

TABLE 15

RETIREMENT-RATE COMPUTATIONS OF SURFACE-TYPE BITUMINOUS CONCRETE (I) FOR 1955-1959 RETIREMENTS

Age Interval (yr)	Miles in Service at Beginning of Interval	Miles Retired During Interval	Retirement Rate (%)	Survivors at Beginning of Interval (%)
0 - 0½	17,328.0	15.0	0.09	100.00
0½- 1½	16,503.7	90.8	0.55	99.91
1½- 2½	15,456.8	209.3	1.35	99.36
2½- 3½	15,956.8	386.9	2.42	98.02
3½- 4½	14,321.9	226.6	1.58	95.65
4½- 5½	12,575.2	366.6	2.91	94.14
5½- 6½	11,034.1	418.9	3.80	91.40
6½- 7½	9,577.4	400.7	4.18	87.93
7½- 8½	7,694.9	407.7	5.30	84.25
8½- 9½	6,470.3	361.4	5.59	79.78
9½-10½	5,586.7	423.4	7.58	75.32
10½-11½	4,798.7	415.3	8.65	69.61
11½-12½	3,747.4	239.0	6.38	63.59
12½-13½	2,849.4	203.0	7.12	59.53
13½-14½	2,389.1	272.5	11.41	55.29
14½-15½	2,242.0	153.5	6.85	48.98
15½-16½	1,796.3	122.3	6.81	45.62
16½-17½	1,577.1	151.5	9.61	42.51
17½-18½	1,537.7	171.5	11.15	38.42
18½-19½	1,292.6	117.7	9.11	34.14
19½-20½	1,055.5	59.3	5.62	31.03
20½-21½	1,063.6	50.9	4.79	29.29
21½-22½	1,148.9	109.8	9.56	27.89
22½-23½	858.1	97.6	11.37	25.22
23½-24½	780.4	71.5	9.16	22.35
24½-25½	555.2	77.4	13.94	20.30
25½-26½	387.4	69.6	17.97	17.47
26½-27½	288.5	34.3	11.89	14.33
27½-28½	254.6	50.6	19.87	12.63
28½-29½	180.7	16.7	9.24	10.12
29½-30½	207.8	11.5	5.53	9.18
30½-31½	190.2	20.0	10.52	8.67
31½-32½	164.3	14.4	8.76	7.76
32½-33½	182.5	30.4	16.66	7.08
33½-34½	140.3	17.3	12.33	5.90
34½-35½	89.5	5.7	6.37	5.17
35½-36½	62.9	10.9	17.33	4.84
36½-37½	34.9	2.4	6.88	4.00
37½-38½	11.0	0.1	0.91	3.72
38½-39½				3.69

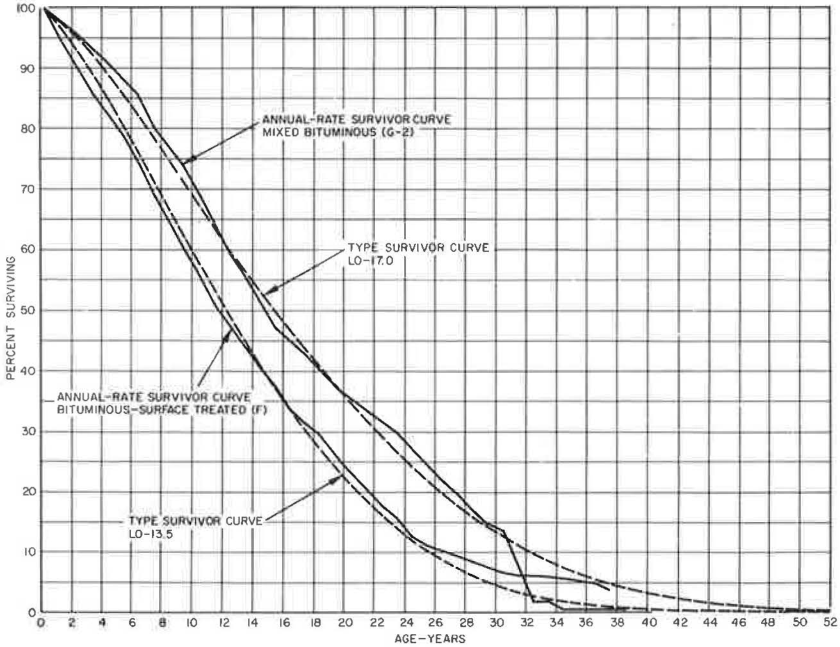

Figure 5. Annual-rate and type survivor curves for bituminous surface-treated (F) and mixed bituminous (G-2) surfaces retired 1955-1959 (composite data for 26 states and Puerto Rico).

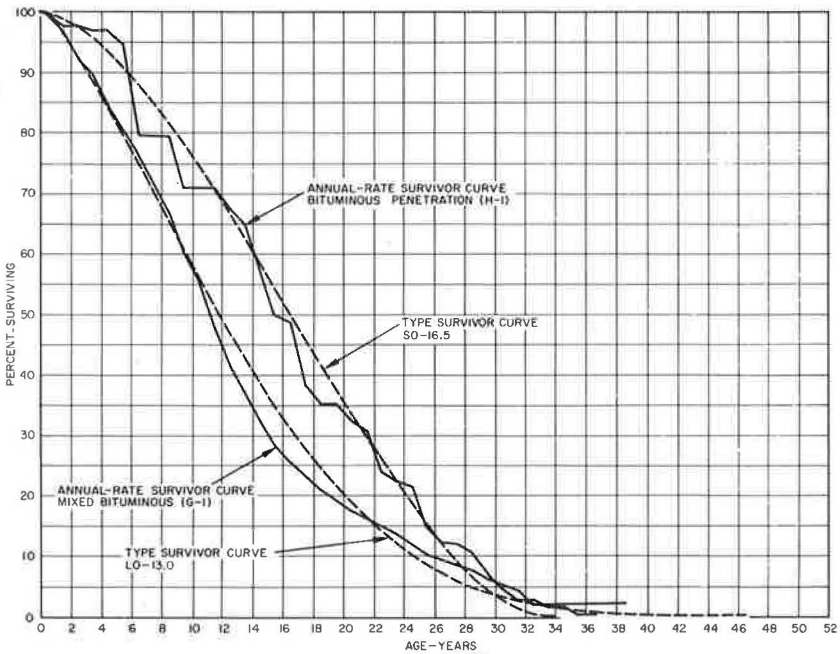

Figure 6. Annual-rate and type survivor curves for mixed bituminous (G-1) and bituminous penetration (H-1) surfaces retired 1955-1959 (composite data for 26 states and Puerto Rico).

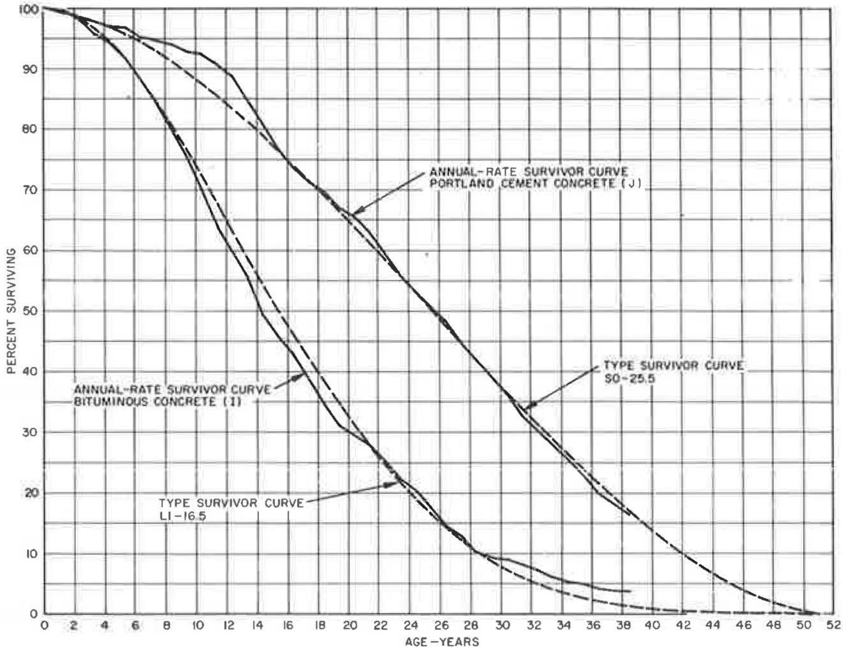

Figure 7. Annual-rate and type survivor curves for bituminous concrete (I) and portland cement concrete (J) surfaces retired 1955-1959 (composite data for 26 states and Puerto Rico).

change in the service life of any pavement type. However, the 1955-1959 band does indicate some reduction in service life from the 1950-1954 band except for the G-1 and J types. No doubt the accelerated highway construction program started in 1956 will result in an increased rate of retirement of roadway surfaces through resurfacing and reconstruction as compared to the preceding years. The type curves and service lives in Table 16 are the best indication now available of the service-life character of these seven pavement types.

AVERAGE AGE OF SURVIVING MILEAGES

The average age of surviving pavement January 1 was calculated from Tables 1 to 7 for each of the seven pavement types as of January 1 for the years 1941, 1946, etc., to January 1, 1960. Table 17 gives these average ages and indicates a generally increasing average age.

TABLE 16

TYPE SURVIVOR CURVES AND AVERAGE LIVES DETERMINED BY RETIREMENT-RATE METHOD BY 5- AND 10-YEAR RETIREMENT BANDS FOR EACH SURFACE TYPE

Surface Type	5-Year Retirement Bands						10-Year Retirement Bands	
	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1945-1954	1950-1959
Bituminous surface-treated (F)	L_0- 7.0	L_0-10.0	L_0-14.0	L_0-15.5	L_0-15.0	L_0-13.5	L_0-15.0	L_0-14.0
Mixed bituminous								
G-1	L_0- 9.0	L_0- 8.5	L_0-17.5	L_0-12.5	L_0-11.0	L_0-13.0	L_0-12.0	L_0-12.5
G-2	L_1-14.5	L_2-12.0	R_1-21.5	L_1-19.0	L_0-17.5	L_0-17.0	L_0-19.0	L_0-17.5
Bituminous penetration								
H-1	L_0-12.5	R_1-14.5	R_1-16.0	L_0-13.0	L_2-20.5	S_0-16.5	L_0-16.5	S_0-18.0
H-2	S_1-18.0	R_1-21.5	L_1-19.0	R_1-21.0	L_0-18.0	L_0-16.0	S_0-20.0	L_0-17.5
Bituminous concrete (I)	S_0-21.0	S_0-20.5	L_1-18.5	S_0-19.5	L_1-17.5	L_1-16.5	L_1-18.5	L_1-16.5
Portland cement concrete (J)	S_2-23.5	R_3-26.0	R_4-25.5	R_3-26.5	R_1-25.0	S_0-25.5	R_2-26.5	R_1-25.0

TABLE 17

AVERAGE AGE IN YEARS OF MILEAGES IN SERVICE AT 5-YEAR INTERVALS

Year (Jan. 1)	Surface Types						
	Bituminous Surface-Treated F	Mixed Bituminous G-1	Mixed Bituminous G-2	Bituminous Penetration H-1	Bituminous Penetration H-2	Bituminous Concrete I	Portland Cement Concrete J
1926	1.9	1.8	1.8	2.4	2.3	2.5	2.4
1931	2.7	1.7	1.4	4.6	5.1	4.0	4.5
1936	3.9	3.5	3.2	5.2	4.8	5.3	6.8
1941	4.4	5.5	5.4	8.4	7.4	6.8	10.1
1946	6.9	8.9	8.4	11.0	9.9	7.8	14.3
1951	8.2	9.8	9.1	14.6	13.2	7.3	17.6
1956	9.6	11.3	8.8	16.6	15.7	6.4	20.3
1960	10.9	12.0	9.3	16.4	17.5	6.8	21.7

TABLE 18

MILEAGE IN SERVICE ON JANUARY 1, 1960, AND ESTIMATED MILEAGES AND PERCENTAGES REMAINING IN SERVICE ON JANUARY 1, 1970, AND 1980 BY SURFACE TYPE

Surface Type	Miles in Service Jan. 1, 1960	Remaining in Service[a] Jan. 1, 1970		Remaining in Service[a] Jan. 1, 1980	
		Miles	Percent	Miles	Percent
Bituminous surface-treated (F)	27,001.0	6,359.4	23.6	1,450.4	5.4
Mixed bituminous (G-1)	13,259.4	2,620.2	19.8	641.3	4.8
Mixed bituminous (G-2)	44,298.6	16,297.7	36.8	2,916.5	6.6
Bituminous penetration (H-1)	366.2	60.8	16.6	3.5	1.0
Bituminous penetration (H-2)	4,280.0	784.4	18.3	62.6	1.5
Bituminous concrete (I)	35,906.4	18,096.3	50.4	6,366.8	17.7
Portland cement concrete (J)	27,394.5	8,912.4	32.5	3,144.2	11.5
Total	152,506.1	53,131.2	34.8	14,585.3	9.6

[a]Calculated on the basis that would-be retirements are not replaced. The type curves and service lives of Method 1 from Table 13 were used in calculating surviving mileages for 1970 and 1980.

FUTURE SURVIVALS

What can be anticipated in the future with respect to pavements surviving beginning in 1960 and extending to 1980? Table 18 was calculated by applying the survivor curve with its appropriate service life to the pavements surviving January 1, 1960, and calculating the remaining mileage successively at the end of each 10-year period. The rapid reduction in the number of miles surviving is not surprising in the light of the experience of the last few years. Highway pavements do not last forever, and the highway program must consider continuous resurfacing and reconstruction operations in order to maintain a highway system in a usable and safe condition.

SUMMARY AND CONCLUSIONS

This analysis of the service lives of roadway surfacings on the main rural state highways indicates that as of 1960 the service lives of the seven types were relatively stable. For economy studies and highway cost analyses the following average service lives could be used (when local experience does not indicate the adoption of other lives):

Surface type	Type Curve	Average Service Life (yr)
F. Bituminous surface-treated	L_0	14.0
G-1. Mixed bituminous	L_0	12.0
G-2. Mixed bituminous	L_0	17.5
H-1. Bituminous penetration	L_1 or S_0	17.0
H-2. Bituminous penetration	L_0 or S_0	17.0
I. Bituminous concrete	L_1	17.0
J. Portland cement concrete	R_1	25.0

Service lives of pavements (and of other types of man-made physical properties) will vary according to design, use, and maintenance operations. Therefore, in a given state or for a particular project the service life may differ appreciably from the composite lives resulting from combining the data for 26 states and Puerto Rico.

Now that the equivalent 18-kip single axle design concept and the present serviceability index for pavements have been developed, highway departments could improve the utility of service life data by periodically measuring these two factors.

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*Appendix**

GENERAL DEFINITIONS

Construction and reconstruction—The construction of a new highway or the reconstruction of a highway or of its component parts to a degree that new, supplementary, or substantially improved traffic service is provided, and significant geometric or structural improvements are effected.

Betterments—The improvements, adjustments, or additions to a highway that more than restore it to its former good condition and that result in better traffic serviceability without major changes in the original existing construction. Such betterments properly should be termed "capital betterments" since the funds used to pay the cost are considered a capital investment on which the return is increased service to the traveling public, much the same as funds used for new construction or reconstruction, but in the interests of convenience the single word "betterment" is used herein.

Resurfacing—Laying on top of existing pavement a new surfacing material of one inch or more in thickness that in effect provides for a new riding surface but utilizes the former pavement structure in whole or in part as the base or foundation of the new surface. Resurfacing may or may not result in a change in the surface type classification.

Physical maintenance—The preservation and upkeep of a highway, including all of its elements, in as nearly as practicable its original as-constructed condition or its subsequently improved conditions.

Traffic services—The operation of a highway facility, and services incidental thereto, to provide safe, convenient, and economical highway transportation.

Retirement—The removal from service of a significant portion of a highway facility through abandonment or reconstruction to a different type.

Abandonment—A retirement in which the roadway, facility, structure, or other property is discarded in place.

SURFACE TYPES

A. Primitive road—An unimproved route (on which there is no public maintenance) usable by 4-wheel vehicles and publicly traveled by small numbers of vehicles.

B. Unimproved road—A road using the natural surface and maintained to permit bare passability for motor vehicles, but not conforming to the requirements for a graded and drained earth road. The road may have been bladed, and minor improvements may have been made locally.

C. Graded and drained earth road—A road of natural earth aligned and graded to permit reasonably convenient use by motor vehicles and drained by longitudinal and transverse drainage systems (natural or artificial) sufficiently to prevent serious impairment of the road by normal surface water, with or without dust palliative treatment or a continuous course of special borrow material to protect the new roadbed temporarily and to facilitate immediate traffic service.

D. 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 (a) a course of mixed soil having A-1 or A-2 characteristics, such as sandclay, soft shale, or topsoil, or (b) an admixture such as bituminous material, portland cement, calcium chloride, sodium chloride, or fine granular material (sand or similar material).

E. 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 sandclay, bituminous, chemical, or portland cement stabilizing admixture or light penetrations of oil or chemical to serve as a dust palliative.

F. 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

*Definitions are from references 4, 11, 15, and 17.

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.

G. Mixed bituminous road—A road the surface course of which is one inch 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.

G-1—the base course of which is of other than types J, K, or L and the combined compacted thickness of surface and base is less than 7 inches.

G-2—on a base of types J, K, or L, or on any other type of base where the combined compacted thickness of surface and base is 7 inches or more (or equivalent).

H. Bituminous penetration road—A road the surface course of which is one inch or more in compacted thickness composed of gravel, stone, sand, or similar material bound with bituminous material introduced by downward or upward penetration.

H-1—the base course of which is of other than types J, K, or L and the combined compacted thickness of surface and base is less than 7 inches.

H-2—on a base of types J, K, or L, or on any other type of base where the combined compacted thickness of surface and base is 7 inches or more (or equivalent).

I. Bituminous concrete, sheet asphalt, or rock asphalt road—A road on which has been constructed a surface course one inch 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.

J. Portland cement concrete road—A road consisting of portland cement concrete with or without a bituminous wearing surface less than one inch in compacted thickness.

K. Brick road—A road consisting of paving brick with or without a bituminous wearing surface less than one inch in compacted thickness.

L. Block road—A road consisting of stone block, wood block, asphalt block or other form of block, except paving brick, with or without a bituminous wearing surface less than one inch in compacted thickness.

METHODS OF RETIREMENT

Resurfacing—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. For surfaces that are retired by this method, it is obvious that the new or replacement construction must necessarily be along the same alignment and practically the same grade.

Reconstruction—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 alignment (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.

Abandonment—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, may be barricaded to public travel, or may be 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.

Transfer—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 and is maintained by 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 alignments and grades that are unsatisfactory for existing traffic conditions. A new road is built on new alignment 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.

Simulation Procedure for Automatic Highway Needs Updating

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This paper describes a computerized system for maintaining a continuously updated evaluation of highway needs, through simulation of future long-range improvement programs.

The system is designed to provide for the determination of highway needs as a regular part of a threefold planning process involving (a) the establishment and maintenance of a long-range highway plan, (b) the determination of needs and priority factors in achieving goals, and (c) the objective development of current, short-range (4-5 year) programs contributing to eventual accomplishment of the long-range plan.

Computer programs provide for detailed evaluations of highway and city street characteristics and conditions as related to traffic service requirements. The computer determines deficiencies and selects and schedules future improvements. Through a recycling process, traffic is increased annually in keeping with traffic assignment projections, conditions are depreciated by statistical factors, and road or street sections are reevaluated each year in the needs study period. Maintenance costs are assigned to road sections each year, changing when the improvement program schedule calls for a new surface type. The entire future highway program is simulated in accordance with ground rules which may be changed easily to "test" needs on different premises.

•ALTHOUGH the American Association of State Highway Officials, since 1947, has encouraged state highway departments to maintain an up-to-date evaluation of highway needs as a logical basis for obtaining highway program support from Congress and the state legislatures, only a few states are in a position to produce an objective, up-to-date evaluation. In most states, overall needs determinations are performed sporadically, in answer to requests from AASHO or federal authorities, and by methods that are considerably lacking in objectivity. Results of the needs studies reported every few years since 1947 show a lack of consistency. A search of the current needs reports for back-up data to support the figures given therein indicates the true value of these reports.

Where the expected costs of future highway development and maintenance are supported by specific references to the nature and extent of deficiencies on the present highway systems, this most often is the result of a comprehensive needs study recently performed, under contract, by a consultant. These studies, of course, are valid—until the traffic patterns and construction and maintenance cost bases begin to change. Unfortunately, we do not now have the foundation for solid predictions of the rate and nature of these changes.

A foundation like this can only be constructed through a procedure allowing for the tracing and evaluation of specific changes as they occur. The conduct of a major needs study every 5 or 10 years does not provide for tracing these patterns of change. Most likely these studies will be conducted in accordance with methods and philosophies that

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are somewhat different. As a result, it is difficult, if not impossible, to determine values associated with changes. The ability to provide measures of change in a dynamic situation, as a basis for predicting future changes, is dependent on the ability to trace the continuity of changes through the regular use of consistent procedures. If the planning job is to be performed adequately it is necessary for state highway departments to face up to the task of maintaining a continuously up-to-date highway needs inventory. Such an inventory provides the basis for appearing before state legislatures or the Congress with a consistent report on funding requirements to develop adequate highways, and it also provides the only logical basis for objectively established highway improvement and maintenance programs.

Without this type of inventory, highway programs tend to be established on a political basis. The executive authorities lack any other basis for making decisions between a number of competing highway improvement projects. The result is a program that has not been structured for the accomplishment of previously defined highway development goals. The exception, of course, is the Interstate systems for which goals have been defined and needs are up to date. This is not to suggest that politics can be removed altogether from program decisions. But the experience in states that have established some rational basis for project selections based on priority needs is that the Commissions and other executive authorities do tend to appreciate, accept, and follow rational methods, to a large extent.

THE PLANNING PROCESS

Through long experience in the highway planning field, our organization has concluded that good highway planning dictates (a) the establishment and up-to-date maintenance of an overall highway plan for the future, (b) a continuously up-to-date determination of highways needs and priorities, and (c) the development of a relatively short-range program geared to eventual accomplishment of the plan, in accordance with the current needs and priorities.

The plan represents the specifically defined objectives for future highway development: the completion of the Interstate System; the transportation system envisioned as a result of comprehensive urban or rural transportation planning studies; or the less sophisticated plans for traffic service in areas of relatively low population density. Resources to develop the plan include comprehensive transportation planning studies and route and area studies that involve the projection of land uses, economic effects, and traffic requirements. As a result of studies of this kind, a plan can be developed for providing future traffice service to the state or community, establishing the basic design concept and relationship of each highway or street facility. This plan should be continuously revised as time goes on. At any one time, it represents the established goal for future highway development.

The next logical step in highway planning is the determination of needs and priorities. Part of the total needs already will have been developed as a result of cost and benefit studies performed to establish elements of the plan, particularly where new locations or types of facilities are involved. However, the plan will incorporate many existing highways and streets without basic changes in location or design character. Most of these will require improvement between that time and the projected date for plan accomplishment. Some will require more than one improvement in the intervening period. The total future needs bill is the accumulation of costs for all the interim and ultimately planned improvements, plus maintenance and administration costs. Requirements for the successful reckoning of these costs include

1. An up-to-day inventory of geometric features, roadway condition, and traffic on all segments of the system;
2. Projection of traffic growths on all segments;
3. Evaluation of geometric features and road conditions as related to traffic;
4. Standardized improvement solutions for traffic, geometric, and condition relationships; and
5. Evaluation and application of statistical improvement and maintenance cost relationships.

Improvement solutions need to be standardized because it is impossible to specify improvements exactly without careful design analyses. For the same reason, costs need to be applied on a statistical basis—costs per mile experienced for defined improvement types and maintenance (condition) situations.

The analysis is designed to provide valid total needs figures through a summation of average improvement types, maintenance characteristics—and costs. Some refinements of statistical cost data by areas with respect to terrain, construction and maintenance materials, and rural and urban environment, may lead to better total needs values. Others only give the appearance of greater accuracy and should be avoided.

There are two broad classes of needs requiring determination: needs currently existing on the highway systems, often called backlog needs, and needs that may be expected to accrue in the future through traffic growth and condition obsolescence.

Actually, provided the needs analyses are made on a regularly scheduled basis with current data, it is only necessary to analyze existing needs in detail to make a valid determination of total future needs. In making this determination, changes in existing needs are related to the construction performed in periods between needs evaluations. Some of the current construction is lost to obsolescence. From the relationships, an obsolescence rate can be determined and future accruing needs established. The method has been basically outlined by Jorgensen (1).

However, the more usual method of determining future accruing needs has involved a section-by-section prognostication based on present indications of traffic growth and surface life expectancy. In the past, the method has not been any more reliable than the statistical method of determining accruing needs in total—perhaps less so. By hand rules, it is difficult to define an improvement on a section of highway that is expected to become deficient in the future. The method has usually required some arbitrary program-juggling and guesswork with respect to so-called "stopgap improvements" and "second generation replacements." Recent developments in electronic data processing technology and equipment, however, have eliminated many of the problems and shortcomings of the section-by-section method of determining accruing needs. Through a computer program, it is now possible to make a consistent application of firm ground rules both to predict future section-by-section accruing deficiencies and to establish appropriate improvements. Since the rules provide for stopgaps and replacements, the resulting program is realistic.

It still is highly unlikely that the actual order of deficiencies occurring 10 years from now can be accurately predicted, or the actual improvement program, in that year, accurately detailed. However, because the ground rules are applied consistently, because the resulting program is realistic in terms of the total traffic situation, and because the projected traffic, in total, is considered valid, the variances are largely a matter of event-order and should average out so as not to greatly influence total needs.

This computerized method of determining needs, which will be described presently, is considered capable of sound needs determination. One of the advantages is the ability to make future predictions of deficiency occurrences by applying ground rules and then comparing actual occurrences. This permits evaluating and amending the ground rules to improve predictions. Over a period of time, it allows measurement of changes that are taking place in the dynamic traffic situation.

Nevertheless, whatever method of needs determination is utilized, practically attainable objectives are limited to the following: (a) a good estimate of the cost of overcoming existing highway system deficiencies, (b) good estimates of the cost of meeting future deficiencies over varying program periods; and (c) objective listings of needs priorities.

No matter how well done, a needs study does not provide adequate project estimates for the development of a 4- or 5-year construction program. As noted previously, the section-by-section costs used in a needs study are statistical averages for the situations encountered. For any specific situation, the project cost could be considerably different. For this reason, selection of projects in the short-range program should be based on project planning reports, documenting the results of planning studies that establish location control points and basic design features and that provide preliminary estimates of project work quantities and costs.

The needs output provides a sound priority basis for making these planning studies and, ultimately, for project selection. However, other priority factors also need to be considered. Some of these are earmarked funds such as federal aid, district workloads, continuity of construction, and immediate highway safety needs. The needs study, therefore, does not stand by itself either as a total highway planning objective or as a basis for program selection. Instead, it forms a necessary link between the total plan objective and the immediate program in the complete highway planning process.

This process, composed of three integral parts—plan development, needs study, and programming—is not dissimilar from the process that has proved successful in the development of the Interstate System. It is as follows:

1. The master plan for the Interstate was developed. This was subject to restudy and revision during the development period.
2. The needs to complete the System were determined at regular intervals. These were regularly reported to Congress in seeking funds to complete the System.
3. The short-range programs were developed in accordance with the states' priority procedures.

The end result will be the successful completion of the System.

CONTINUOUS NEEDS UPDATE SYSTEM

This system has been designed, as part of the regular planning process, to fulfill the function of needs studies, which have been outlined. It has the following characteristics:

1. It allows incorporation of the master plan in the determination of long-range needs to the extent the plan has been developed. In Iowa, for example, where this system is being placed in operation, the Commission has approved the plan for the supplemental freeway system, which was established on the basis of statewide traffic assignments. The needs study procedures will simulate the annual construction of this system, part by part, in the priority order of needs occurring in its corridors. Other defined plans for the future likewise will be incorporated with improvements scheduled.
2. Needs on segments of the system being replaced (for example, the freeways) are determined on the basis of the reduced traffic at the expected time of replacement. The traffic reduction is carried over from the traffic assignment program.
3. Stopgap improvements are automatically simulated on a logical basis, depending on the time period chosen to catch up with the backlog of needs. Second-generation replacements (some early improvements may become deficient a second or third time during a lengthy future period) are automatically simulated at the appropriate time.
4. More than one alternative future program decision, such as catch-up in 10 or 15 years, can be quickly tested by running a new needs bill. The effect on needs of the overall level of systems improvement can be determined just as easily. In Nebraska, in one instance, it was found that raising the adequacy critieria for road improvements produced only a nominal increase in needs. This increase was easily justified by the improved overall travel conditions anticipated. In a typical case, the lower criterion might result in a new base and surface and a second-generation resurfacing within 15 years—no basic improvement in geometrics. The higher criterion would require early reconstruction to design (20-year traffic) standards, higher surface type, and no resurfacing. The 15-year difference in cost between the sum of the improvements, on one hand, and the single improvement, on the other, did not justify retention of the borderline facility. Thus, the analysis can help make important economic decisions.
5. Maintenance costs are simulated in accordance with improvement program decisions. (This and all of the foregoing features have actually been applied in the Nebraska needs study.) Appropriate maintenance costs are applied to a section annually until the year the ground rules indicate an improvement changing the surface type. Beginning in that year, annual maintenance costs appropriate to the new surface type are applied automatically. The potential to test the effects of improvement program decisions on maintenance is obvious.

6. Although it has not been done as yet, the currently adopted 4- or 5-year program can be incorporated in the simulated long-range program. This requires some minor adaptation of the present procedures and computer programs.

7. Needs are produced from the programs in priority order. A summary current adequacy or suficiency rating is given for each road section. Procedures for determining this rating incorporate a capacity analysis based on the new capacity manual—all performed automatically in the computer.

8. A new adequacy rating is projected for each section of road for each future year in the needs study period. The computerized system automatically projects traffic in annual increments, route segment by route segment, to tie in with projected systems-wide traffic assignments, and accordingly, it reevaluates the current geometrics and makes a new capacity analysis year by year. The conditions of roadway elements are depreciated annually by using statistical depreciation factors based on an analysis of previous sufficiency rating experience. Based on these programmed obsolescence determinations, the computer recycles to make the projected annual adequacy ratings.

9. The future construction program is simulated, through ground rules, on the basis of the total adequacy ratings and the component ratings of individual roadway elements. When a section deficiency is found to exist—it may be in a future year—the computer "decides" on an improvement. It may select a stopgap measure, "reach" for a solution from the master plan, or use a statistically derived solution. It then "schedules" the improvement in accordance with the selected catch-up period and other program decisions, enters the cost in the appropriate year, reevaluates the maintenance cost, etc.

The result is a complete simulation of the future long-range construction and maintenance program based on predetermined logic-oriented ground rules and the best present prediction of future obsolescence. Since the predictions, in every case, are based on measurements of current trends, the method is basically statistical. In this respect, it is sound.

There are problems with respect to the data on current trends that have been available in the two states where it is now being applied. Office updating of all or part of the annual sufficiency rating, or failure to record component rating data have made condition obsolescence trends difficult to evaluate. It is anticipated that these problems will disappear with time and experience on the new system. Indeed, the ability to compare actual adequacy ratings, in total and for individual roadway elements, with previously predicted adequacy ratings ought to lead to ever-improving predictive capability.

The problem—if it is one—of using a "pat" procedure for ordering the future construction program is minimized because of the ability to vary the ground rules in many ways and to recalculate needs for each variance. Because the current ground rules are logic-oriented and produce a sound program—although it is certain not to be duplicated in actual experience—it is believed that logic-oriented variances in the ground rules will not produce significantly different total needs values. All alternatives are directed toward providing for the same total traffic using essentially the same traffic-based design standards for whatever future year that is selected.

In the program simulation method used in Nebraska and Iowa needs determinations for local roads and streets are made on the basis of an inventory sample. The methods are similar to those already described—analysis of current deficiencies, determination of obsolescence, simulation of the future program; all performed through the computer program—but the analytical steps are simpler in keeping with the characteristics of local roads and streets. Once the sample program is determined, the results are expanded automatically to represent the universe.

The recommended scheme calls for full coverage of the local systems over a period of years by scheduling inventories of a different sample each year, with some replication. In this way, changing conditions on the local roads and streets eventually can be noted and analyzed. Also, as time goes on and the sample size is increased, the universe can be more truly represented. The procedures will involve statistical updating of data from samples a few years old before these data are combined with data from the latest sample. This, largely, is the reason for replication. The sampling process

CHANGES TO THE INVENTORY RECORD OF
MUNICIPAL STREETS OF IOWA

Date ____________

1. City Name ____________. 2. Street Name ____________.

3. State or U.S. Route Number ____________.
(If not on Primary State Highway System leave blank)

4. Location of Change
From ____________ To ____________
(Example: From Grand Ave. to 16th Street, or from ½ block North of Grand Ave. to 500 ft. South of 18th St., etc.)

5. Length of Change: __:_ _ Mi. or ______ ft.

6. Date of Changes Made ______ (Month and Year of Completion)

7. Type of Change - (Mark one "X")

( ) New Construction - New Location
( ) Reconstruction - Same location
( ) Widen Only
( ) Resurface
( ) New Shoulders
( ) Widen and Resurface
( ) New Base and Surface
( ) New Curbs
(*) Other

* Describe other briefly:

8. Latest Traffic count: ADT ________ Year of count ________

9. Old Street Width ________ ft. Street Width after change _____ ft.
(If no change in width, enter old width in first blank and "same" in second blank. Width should be measured from curb face to curb face, including parking lanes, or from edge of surface to edge of surface where curbs are not provided.)

10. New Shoulder Width ________. (Each shoulder, if provided)

11. Surface Type (Mark "X" in Old and New)

Old		New
( )	Brick	( )
( )	Portland Cement Concrete	( )
( )	Asphaltic Concrete Resurfacing on Portland cement concrete, brick or block	( )
( )	Asphaltic Concrete	( )
( )	Bituminous Surface Treatment	( )
( )	Oil	( )
( )	Gravel	( )
( )	Dirt	( )
( )	Other	(*)

*Explain other briefly:

12. Curb or Shoulder Type (Mark one "X")

Old		New
( )	Curbs	( )
( )	Paved Shoulders	( )
( )	Stabilized Gravel Shoulders (compacted)	( )
( )	Gravel Shoulders (not compacted)	( )
( )	Sod Shoulders	( )
( )	Other	(*)

*Explain other briefly:

13. Median Width ______ ft. and type. (Mark one or more "X" in old and new)

Old		New
( )	Curbed	( )
( )	Not Curbed	( )
( )	Grass	( )
( )	Surfaced	( )
( )	Center Parking	( )

14. Type Parking (Mark "X" in old and new)

Old		New
( )	No Restrictions	( )
( )	No Parking Allowed	( )
( )	Allowed During Low Traffic Hours Only	( )
( )	Parallel Parking One Side Only	( )
( )	Parallel Parking Both Sides	( )
( )	Angle Parking One Side	( )
( )	Angle Parking Both Sides	( )
( )	Combination Angle and Parallel	( )

15. Turning lanes provided in Addition to Normal surface width.

Old		New
( )	No Turning Lane Provided	( )
( )	Left Turning Lane Provided	( )
( )	Right Turning Lane Provided	( )
( )	Left & Right Turning Lane Provided	( )

16. Cost of Improvement

Total cost $ ________
Approximate Amount Spent on:
Base and Surface $ ________
Grading and Drainage $ ________
Right of Way $ ________
Engineering $ ________
Miscellaneous $ ________

Return to: Needs Study Engineer Iowa State Highway Commission Ames, Iowa

Figure 1. Sample form for distribution to municipalities in Iowa.

eventually may be extended to the condition inventory of all systems. Once it has been noted that condition changes on parts of the systems are in accord with previous predictions, these parts will not need to be field checked as often.

After the first complete field inventory of any system, subsequent field coverages will only be for the purpose of updating condition information. Geometric and traffic data will be kept up to date through a system of regular reports to the needs analysis unit as changes occur through construction improvements and as new traffic counts are made. The recommended scheme calls for local units of government to report changes on geometrics and surface types immediately as contracts are let or work orders issued. Figure 1 shows a sample form prepared for distribution to municipalities in Iowa. As these forms are completed and returned, the basic record data can be continually updated throughout the year. This day-to-day procedure will avoid the necessity for time consuming year-end searches of construction and maintenance records by the local subdivisions. In particular, very small units of government often do not have knowledgeable highway personnel who can properly interpret records on highway work. These units may be asked to have their contractors report current work to the State as a regular contract obligation. Practical working relationships to obtain regular reports of road and street changes still need to be worked out in Nebraska and Iowa. Nebraska has only had one statewide determination of needs through use of the system. Development of the system in Iowa has not yet progressed to the extent of establishing the regular reporting procedures. However, in Iowa, the Association of County Engineers and the League of Municipalities are kept abreast of the developing system and are ready to assist in the establishment of the necessary cooperative relationships. In fact, the counties and cities already have supplied data for initial statistical analyses.

There is every indication that the regular determination of needs on county and city facilities will be performed by the Iowa State Highway Commission as a service to the local subdivisions. The state authorities need to have the information from all systems for regular reports to the legislature, as a basis for legislative actions on highway funding and distribution of funds. However, successful operation of the system also will make detailed data on their systems continually available to local agencies for their own programming purposes. It is because of this mutual interest that little difficulty is anticipated in developing workable reporting relationships and procedures.

All initial field inventories in Iowa are being performed by state or state-trained crews. To maintain proper control, the consultant has recommended that all subsequent condition inventories be performed by the Commission's district crews as part of the regular off-season work program. By scheduling regular highway and street systems coverage, the additional district workloads will not be excessive, and the experience provides good training for district personnel.

A unique feature of the system application in Iowa is the development of a single set of road inventory records compatible with all planning requirements, including the requirements of the needs update system. All current data on the roadway are being placed on tape consecutively by road section. The data recorded for each individual section of roadway are shown in Figure 2. Included are administrative classifications, sequencing, log mileages, physical dimensions and features, conditions, traffic and traffic factors, percentages of commercial vehicles, maintenance cost factors, and construction controls and cost factors. Municipal sections follow rural sections in proper route sequence order. All inventory data on structures and railroad crossings similarly are being placed on a single tape record with identity codes that locate the structures in relation to the roadway or street sections.

This format of roadway and structures records lends itself to the coincident evaluation. By this method, a structural deficiency may influence the scheduling of a complete road section improvement (this is characteristic of practical programming).

INVENTORY AND EVALUATION PROCEDURES

The needs characteristics of city streets are markedly different from those of rural roads, there are different relationships between traffic and deficiencies, especially

IOWA STATE HIGHWAY COMMISSION
PRIMARY ROAD DATA TAPE FORMAT

NEEDS STUDY UNIT
PROGRAM AND PLANNING DEPARTMENT
OCTOBER 1967

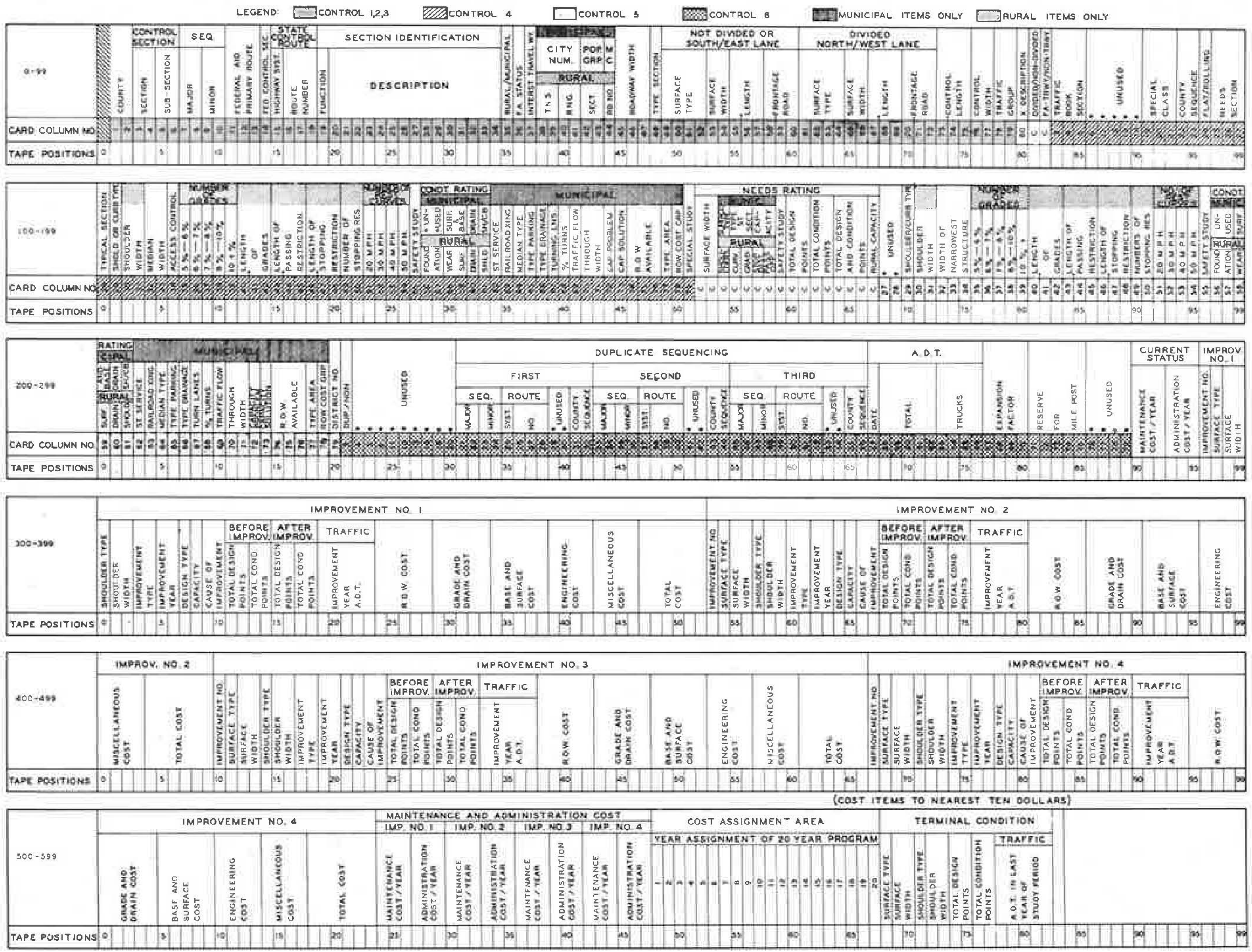

Figure 2. Primary road data tape format.

capacity relationships, and different improvement solutions. For this reason, inventory and evaluation procedures are distinctively different. However, the computer evaluation programs are structured in the same way for the development of compatible outputs, and a single system of identification codes is used to embrace both classes. This allows the computer programs to be fitted together, as one program, to make runs by administrative system—a procedure followed in Iowa.

Because the differences in inventory and evaluation are differences in analytical detail, and because it is beyond the scope of this paper to describe the detailed analytical methods, one outline will be used to describe the basic concepts of the computer evaluation program applicable both to rural roads and city streets. As the basic steps are given, distinctive differences in evaluation methods will be noted.

First, a note about the differences in inventory methods. Aside from the collection of detail relative to capacity on city streets, city inventories differ from rural inventories in that the city crews are given criteria for indicating solutions to apparent capacity problems. This is necessary because of the several possible alternatives to a city street capacity problem—widening in place; one-way couplets; an alternative street; or a facility on new location, possibly a bypass. So that the city inventory crews will obtain the necessary inventory data on other streets that may figure in the alternatives, they are provided with formulas to roughly project traffic, formulas for approximately determining capacities, and a step-by-step procedure for investigating alternative solutions if the indications are that capacities will be exceeded by projected traffic.

The only purpose in following these procedures is to obtain inventory data on streets possibly figuring in alternative solutions. Later, the computer program makes a detailed capacity analysis, based on the Highway Capacity Manual, and objectively determines a solution based on the inventory data. Thus, more data are obtained than may be needed, but this avoids calling for unrealistic widening of streets that cannot be widened because of adjacent property development.

In rural inventories, the crews obtain only the data on the existing facilities and their environmental situation. The computer performs all evaluations. In both cases the computer begins by reading the identification codes and selecting the appropriate analytical routine. The flow diagram in Figure 3 shows the basic steps in these analyses.

The paths to the left and right distinguish between arterial highways or streets and local roads or streets in the rural and urban programs. The arterial routine begins with an evaluation of existing road or street elements against design standards for the existing traffic. This evaluation is accomplished by assigning rating values to the elements, including surface and shoulder or curb characteristics, sight distances, grades, alignments, and other pertinent features. The rating depends on the relationship of existing measurements to traffic standards. Typical point ratings for these characteristics as well as the point ratings for physical condition are shown in Figure 4. Traffic versus capacity also is evaluated both for rural highways and arterial streets, in accordance with the new HRB Highway Capacity Manual, but this analysis is more detailed for streets, and the results are more significant in determining improvements requirements.

Local roads and streets are evaluated against a table of acceptable or "tolerable" geometric features and conditions in a less sophisticated analysis appropriate for this class of facility. In the case of the arterials, however, the physical conditions of each appropriate element of the road or street sections are also rated in accordance with variances from "perfect" or newly constructed conditions.

On the arterial side (Fig. 3, left side) the total assigned rating (the sum of geometric and condition values) is compared with a preselected figure representing adequacy based on judgment. Sections that are inadequate by this test then go through a subroutine that selects an appropriate improvement based on the geometric and condition ratings of individual roadway elements and combinations of elements. The improvement year is then set, based on the rating priority, the expected distribution of ratings, and the selected catch-up period. (The distribution of ratings may be known

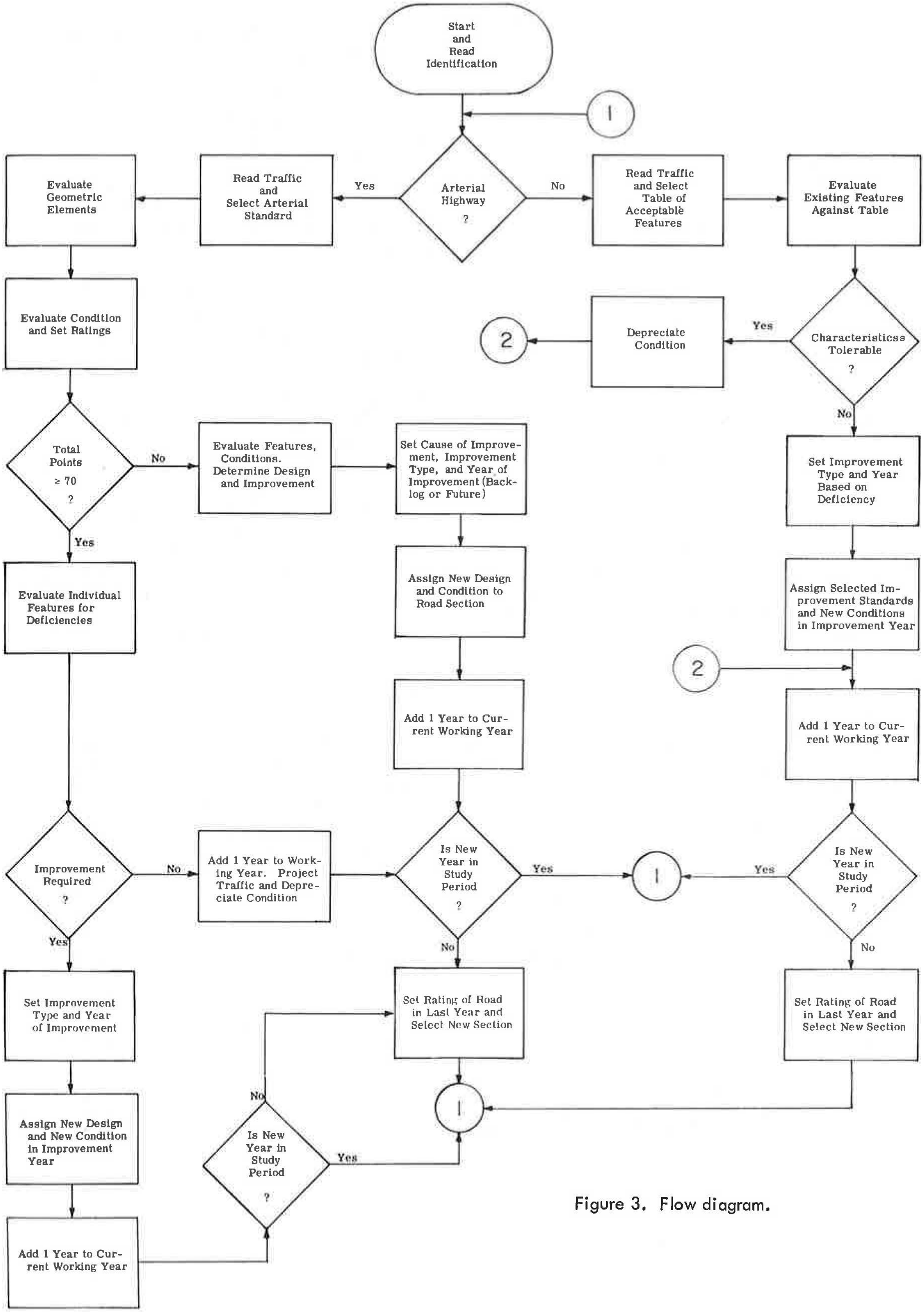

Figure 3. Flow diagram.

Rural Roadway	
Geometrics:	
Surface width	20
Shoulder width and type	9
Stopping sight	8
Alignment	8
Grades	6
Safety study	6
Passing or median	8
Condition:	
Foundation	15
Surface	10
Drainage	5
Shoulder	5
Total	100

Municipal Streets	
Geometrics:	
Surface type	5
Type street section	10
Capacity	35
Surface width	15
Condition:	
Surface and base	25
Drainage	5
Curb or shoulder	5
Total	100

Structures	
Geometrics:	
Structure width	30
Vertical clearance	5
H-Loading	20
Safety study	5
Condition:	
Superstructure	15
Substructure	15
Deck	5
Waterway opening	5
Total	100

Figure 4. Point ratings.

from prior rating experience, or part of the program can be run initially to obtain ratings and summaries.) If the improvement year is several years from the current year and the surface is poor, a stopgap surfacing will be ordered.

Both of the next steps are designed to upgrade the improved facilities to the improvement year. The computer projects the traffic on the arterials for 20 years after the improvement year to select and record the new design standards. When the improvement year is passed, as the computer recycles the program, the new design and condition will be depreciated for further evaluations.

As the computer evaluates sections of arterials that pass the test on total rating points, there still may be outstanding deficiencies in one or more features of these sections, for example, the surface width may be dangerously narrow. The computer evaluates these features against limiting criteria and selects improvements accordingly. An improvement year is scheduled and the new design standards are determined and assigned as described previously.

The other parts on the flow diagram show some of the steps involved in the recycling process (a) when there is no deficiency in the current (working) year, and (b) when an improvement is scheduled. The program is recycled to analyze sections with traffic projected for an additional year and the condition of the roads and streets statistically depreciated.

The foregoing provides an idea of how the system functions. It covers only major steps in the evaluation procedure, and some of these are left out. The structural evaluation, for example, is a completely separate routine that is performed while the corresponding road evaluation is "held in hand." This routine provides for examining the relationship of the structure to the roadway or street, and vice versa. For example, if the road is selected for improvement and the structure does not measure up to the new design standards, the structure is selected for reconstruction in the same year. In the selection of improvements for city streets, the computer may select or reject the improvement solutions suggested by the inventory crews, depending on its own detailed analysis.

The assignment of construction and maintenance costs has not been described. The procedures are relatively simple and easily inferred from the program outline. Improvement costs are statistically related to the improvement types, and of course, are assigned in the same year. Maintenance costs are assigned in accordance with surface types and lives (if data are available) in the current working year.

The flexibility of the system deserves further emphasis. The ground rules with respect to such factors as adequacy levels, catch-up program periods, and even order of improvements can be changed easily to test needs on different premises. In addition, there are potential applications that have not yet been explored. One apparently feasible potential is to evaluate future highway accident occurrences againt long-range program alternatives. With established or assumed relationships between road design and condition features and accident occurrences, future accidents could be simulated for different basic levels of adequacy on the systems, master plan changes, and levels of program expenditure. Simulated accidents could be tested against actual occurrences.

SUMMARY

The system provides a powerful planning tool (a) to keep needs continuously up to date, (b) to analyze long-range program alternatives and the relationship of current

NEBRASKA HIGHWAY NEEDS STUDY
PROGRAM NEEDS COSTS

Source Deck All	Mileage Original	Program Period 1966-1985						Functional System All		
Design Class Group	System Length	Right Of Way -000-	Grade and Drain -000-	Base and Surface -000-	Engineer and Misc -000-	Structures -000-	Total Construction -000-	Maintenance -000-	Adminis-tration -000-	Total -000-
Total Rural Design										
1 High, 48 Ft.	654.87	9,371	37,527	71,062	19,311	28,934	166,205	27,763	6,644	200,612
2 High, 24 Ft.	1,037.84	3,135	27,306	67,316	15,573	9,848	123,178	19,146	4,928	147,252
3 High, 24 Ft.	2,845.35	8,549	71,903	181,949	40,340	19,724	322,465	54,680	12,877	390,022
4 Inter., 24 Ft.	2,009.15	3,401	13,964	53,724	11,838	8,062	90,989	40,103	3,588	134,680
5 Low, 22 Ft.	1,966.74	4,214	10,507	15,966	5,041	4,450	40,178	36,871	1,458	78,507
6 Low, 22 Ft.	1,560.20	2,694	6,337	10,015	2,994	2,150	24,190	24,582	889	49,661
7 Gravel, 22 Ft.	22,186.85	24,396	31,570	9,363	7,302	7,488	80,119	199,282	2,928	282,329
1 Local, Gravel	54,656.66	63,205	146,872	42,921	24,658	27,306	304,563	216,431	12,146	533,140
2 Local, Low	848.13	960	6,399	35,230	6,181		48,770	16,987	1,938	67,695
1 Local, Non-Ess.	4,775.14							2,865		2,865
Total Urban Design										
1 Expressway	62.98	91,091	21,960	24,694	18,380	35,899	192,024	4,707	7,680	204,411
2 Bus. 6-Lane	77.14	21,521	36,394	51,169	16,685	19,751	145,520	4,741	5,822	156,083
3 Bus. 4-Lane	47.26	3,549	3,122	6,904	2,068	3,082	18,725	2,608	745	22,078
4 Bus. 2-Lane	137.43	1,054	1,760	8,335	1,904	2,159	15,212	8,018	605	23,835
5 Resid. 6-Lane	36.66	10,264	17,698	24,966	6,555	840	60,323	2,293	2,411	65,027
6 Resid. 4-Lane	53.00	5,569	4,888	9,179	2,198	468	22,302	3,015	896	26,213
7 Resid. 2-Lane	399.63	2,885	6,328	29,673	5,994	3,406	48,286	22,722	1,918	72,926
8 Rural 6-Lane	6.24	2,023	3,294	4,696	1,274	422	11,709	260	468	12,437
9 Rural 4-Lane	28.76	3,002	2,500	4,729	1,402	1,719	13,352	1,610	534	15,496
0 Rural 2-Lane	390.61	3,181	5,674	23,184	5,082	4,015	41,136	21,051	1,656	63,843
1 Local, Bus.	292.46	12,987	12,383	34,823	7,841		68,034	7,046	2,719	77,799
2 Local, Resid.	5,205.73	57,379	66,721	190,784	39,298	1,874	356,056	102,924	14,229	473,209
3 Local, Resid.	1,244.74	966	10,211	3,310	1,935		16,422	21,995	629	39,046
4 Local, Rural	444.84	5,362	5,281	5,805	1,688		18,136	7,417	709	26,262
TOTAL	100,968.41	340,758	550,599	909,397	245,543	181,597	2,227,894	849,117	88,417	3,165,428

Figure 5. A typical summary output from the Nebraska Highway Needs Study.

programs, (c) to develop priority values for programming purposes, and (d) possibly to relate highway accidents to long-range highway programs.

In order to fulfill these purposes, once the initial field inventories are made, there must be a regular system of reports on changes due to construction or maintenance; updating of traffic counts; traffic assignments; analyses of construction and maintenance costs; incorporation of changes in the highway plan; and regularly scheduled road condition surveys. There also should be a regular updating of financial projections to compare with the needs. Other than this, once the computer programs are written, little more is required than "pressing a button." A typical summary output from the computer (the result of one run made during the Nebraska Needs Study) is shown in Figure 5.

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Limited-Access Highway Construction Costs In the Tri-State Region

KOZMAS BALKUS and WALTER J. SROUR, Tri-State Transportation Commission

Region-wide expressway installation cost criteria have been developed for the Tri-State metropolitan area. Data were drawn from the "1965 Estimates of the Cost of Completing the National System of Interstate and Defense Highways." Expressway installation expenditure estimates were analyzed for overall road-mile and lane-mile costs and for separate cost elements, such as right-of-way, grading and surfacing, structures, interchanges, engineering, and others. All of these costs were related to gross population density. The resulting regression equations provide four different cost estimation approaches: for overall road-miles, overall lane-miles, lane-mile and separate interchange estimates, and estimation by separate road elements. All four criteria were tested by estimating construction costs for road segments, the costs of which were known but not included in the study sample. All four estimation approaches were found to give satisfactory results.

•IN planning transportation systems for metropolitan regions, at some point in the planning process it becomes necessary to estimate the costs of proposed facilities. Since such planning considers facility networks on a region-wide basis, the costs estimation criteria must reflect the regional range of development intensities. Land utilization intensities predicate the facility installation costs, especially for expressways, which require extensive land takings. These considerations influenced the choice of data, variables, and the framework of this study.

DATA USED

The study utilized data contained in the "1965 Estimates of the Cost of Completing the National System of Interstate and Defense Highways." Such estimates were prepared by each state highway department as a revision of earlier plans to complete the Interstate Highway System. As required by the U. S. Bureau of Public Roads, the estimates were to conform with the set of rules outlined in the instruction manual.

The manual emphasized that ". . . there must be substantiating calculations and records in the files of the State for every estimate submitted and accuracy in all respects is of great importance." The highway departments were instructed that the estimates ". . . be made from preliminary or final plans, specifications and estimates . . . . As a minimum for all other work there should be preliminary layouts of line and of all major structures and interchanges in order that reasonably accurate quantity estimates can be made." Right-of-way (ROW) costs were to be assessed by experienced personnel on the basis of 1963 costs.

Although not actual expenditures, the estimates provided a reasonable source of data for this study. The data representing costs that were computed following a con-

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sistent set of rules at one point in time possess homogeneity not readily attainable from actual expenditures.

The cost variations were studied in two approaches. The first dealt with the overall highway and ROW costs, and the second attempted to show costs of separate highway elements.

The overall construction costs first were correlated to population density, disregarding widths and other facility differences. Another set of equations represents a similar correlation of costs by lane-mile, thus giving consideration to the facility size.

In order to learn about the cost variation of different highway elements and the relative influence of such variations upon the total construction cost, statistics were developed for the costs of separate road elements. These statistics can also be employed to estimate the anticipated construction expenditures for extraordinary highway designs and for roadways with a varying number of lanes.

Variables

Unless indicated otherwise, the following symbols and units of variables apply to all equations:

Y = dependent variable: cost in thousands of dollars per specified unit; facility spacing (in miles);
D = gross population density (persons per square mile); and
N = number of lanes.

Cost data and population densities for the observed highway segments were established following the criteria outlined below

Criteria for Establishing Population Density

Population densities were determined from the 1960 U. S. Census tract data. In high-density areas such as Manhattan, extensive nonresidential land uses tend to reduce the average population density if the latter is considered on a small area basis. To eliminate this deficiency in the density variable, the census tract gross population densities were evaluated as follows:

- The average population density of census tracts traversed by the highway segment under consideration was compared with the average density of the adjoining tracts.

- If the traversed track density was lower than the average density of the adjoining tracts, the average of the adjoining tracts was taken to be the corresponding density of the analysis segment.

- If the traversed tract density was higher than the average density of the adjoining tracts that include industry and commerce, the highest of the traversed tract densities was recorded with the highway segment.

- Where the proposed road passed through open areas such as cemeteries or parks, the average population density of the adjoining tracts was taken.

In the outer area of the region, sparsely settled towns comprise a single census tract. In such cases, the average density of the town was recorded.

The determination of densities was guided by the assumption that the ROW cost is influenced not only by the actual development of a given land tract, but also by the development density of adjacent areas. Hence, density figures employed for the estimation of highway costs were made to represent not only the land taken by the road, but also that of the surrounding tracts.

Length of Analysis Segments

There is considerable land cost variation from parcel to parcel in the same vicinity, and a certain minimum land area must be covered by a single highway segment to obtain a reasonably representative average cost.

Within a 10-mile radius of Manhattan, the segments recorded in the data entries averaged 0.8 miles. Some of the segments were as short as 0.2 miles, while others exceeded 1 mile—especially those which were routed through open areas. In densely populated areas, one segment traversed up to six census tracts, but about one-half of the segments in such areas were within the confines of one tract.

In areas located between 10- and 20-mile radii of Manhattan, the average analysis unit was just over 2 miles long. The segments ranged from 1.2 to 3.5 miles. At an average, the segments stretched over five census tracts. In more dense areas, the units traversed six to eight tracts.

Beyond 20 miles, the segments ranged from 2.5 to 7 miles in length. The average unit was 4.4 miles and stretched through two census tracts.

It is not always possible to set the analysis segment length at will. The source of data and a variety of other conditions fix the limits. Nonetheless, to obtain reasonable cost estimates from the given equations, the segment lengths should fall within the ranges similar to these from which the cost equations were developed.

Data Characteristics

The equations were derived from a sample consisting of 44 observations. The availability rather than the requisite of randomness predetermined the choice of data. However, an attempt was made to have the distribution of road segments reasonably representative of the locational pattern of highways in the Region. Consequently, the data should be looked upon not as a random sample, but as a regression sample depicting a road network as shown in Figure 1.

For this kind of data the random sample correlation measures, such as the coefficient of correlation, have little or no meaning. To provide for confidence judgment, however, the data were plotted for each linear regression. The plots present the correlations for visual judgment and for convenience in using the curves.

Population densities in the sample ranged from 100 to 80,000 persons per square mile; the number of lanes were from four to ten. Consequently, any inference made from the following statistics has validity only within these variable limits.

All 44 links represent roads nearly at grade. Continuous elevated roads on structure or depressed segments within retaining walls were excluded. Cost variations in densities beyond the upper limits of this sample and for roads other than at grade are discussed separately.

OVERALL CONSTRUCTION COSTS

The scattergrams, regression lines, and equations for the overall Interstate-type facility costs are shown in Figures 2 to 5. Figure 2 shows the total cost per mile, Figure 3 the ROW part of this cost, Figure 4 the total cost per lane-mile, and Figure 5 the total cost per lane-mile less interchanges. In Figure 3, the ROW costs include land acquisition, clear and grub, demolition, and utility adjustment. The total cost in Figures 2, 4, and 5, represents ROW and construction expenditures.

Figures 2 and 3 reflect neither facility size nor design characteristics. The general segment costs are correlated to population density. Consequently, the resulting statistics represent not only the relation between the development densities and the costs, but also the facility size that corresponds to such densities.

There is a considerable difference in the slope of total cost and ROW cost regression lines, indicating that the ROW cost in high-density areas constitutes a larger percentage of the total cost than in low densities. In fringe areas, on the other hand, construction expenditures mainly determine the cost of highways. Construction costs alone, however, showed an insignificant correlation to population density. This could be the explanation for a rather wide data scatter in low-density regions in Figure 2 and in Figure 4, where the ROW cost is low.

Figure 4 represents the total cost per lane-mile. In reducing data to cost per lane, account is given to the facility size. The regression statistics derived on this basis, therefore, provide a cost estimation criterion when facility needs are considered in lane-mile units.

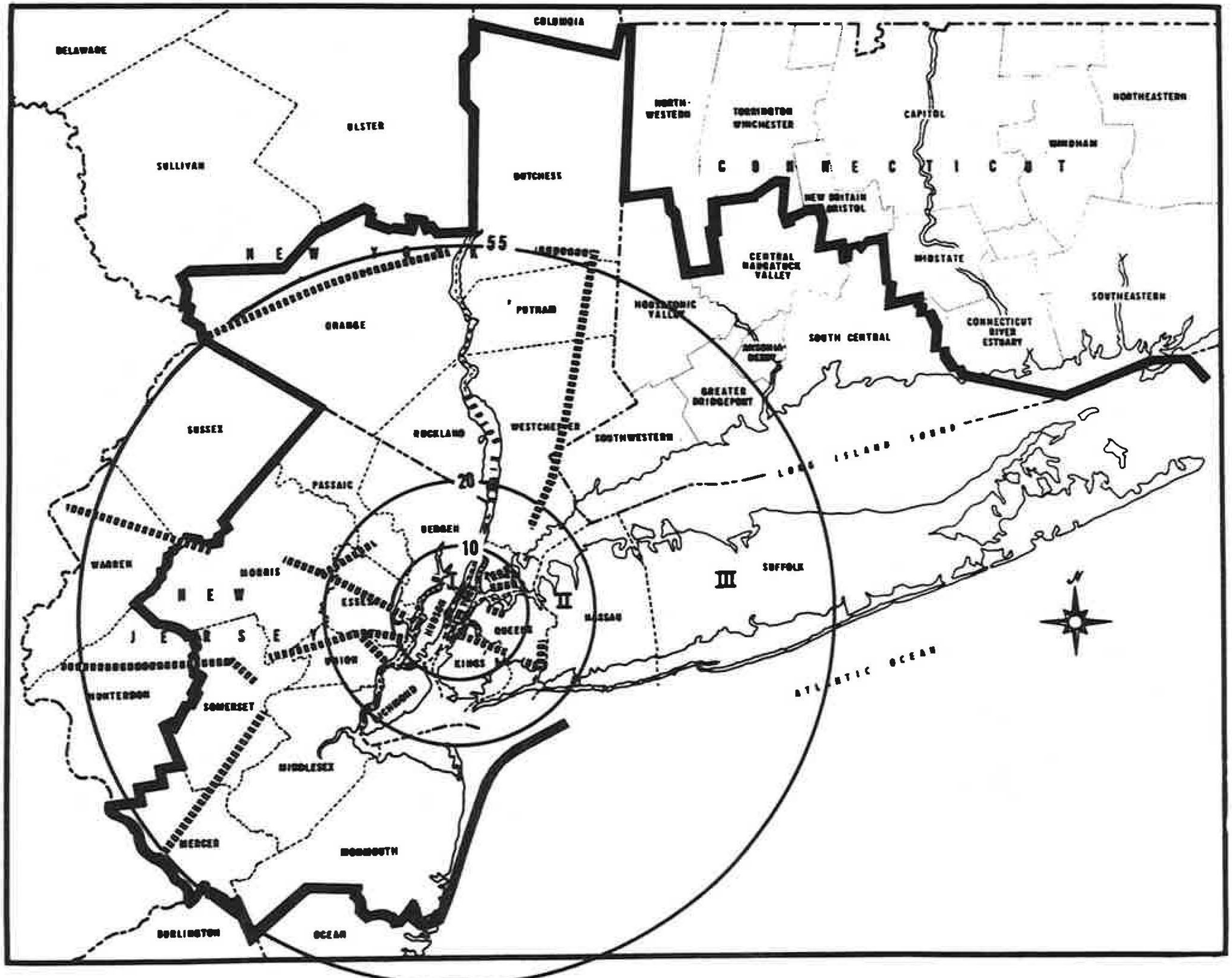


Figure 1. Interstate highways included in the cost analysis study.

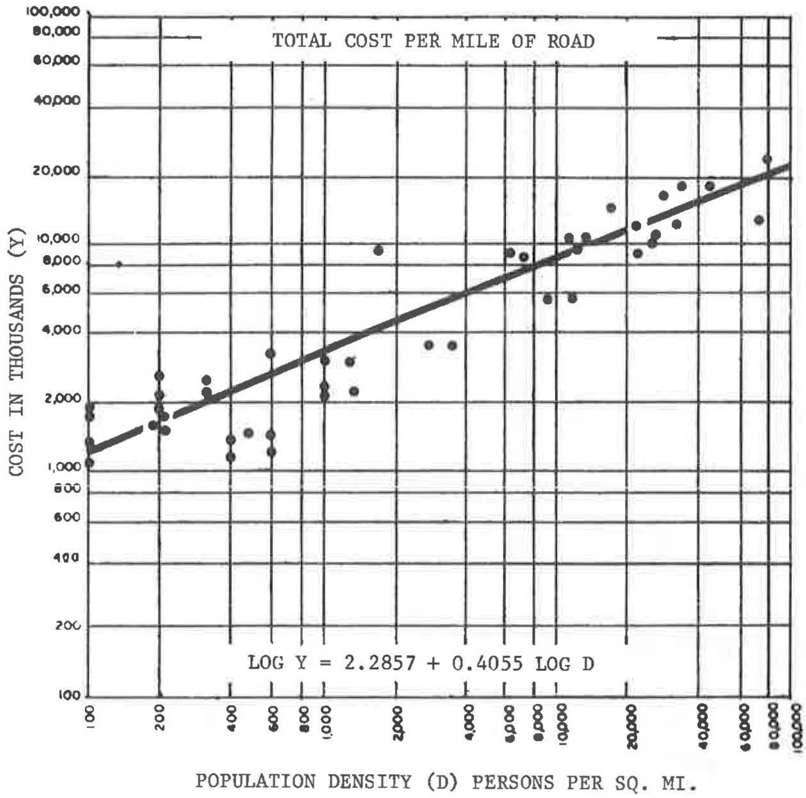
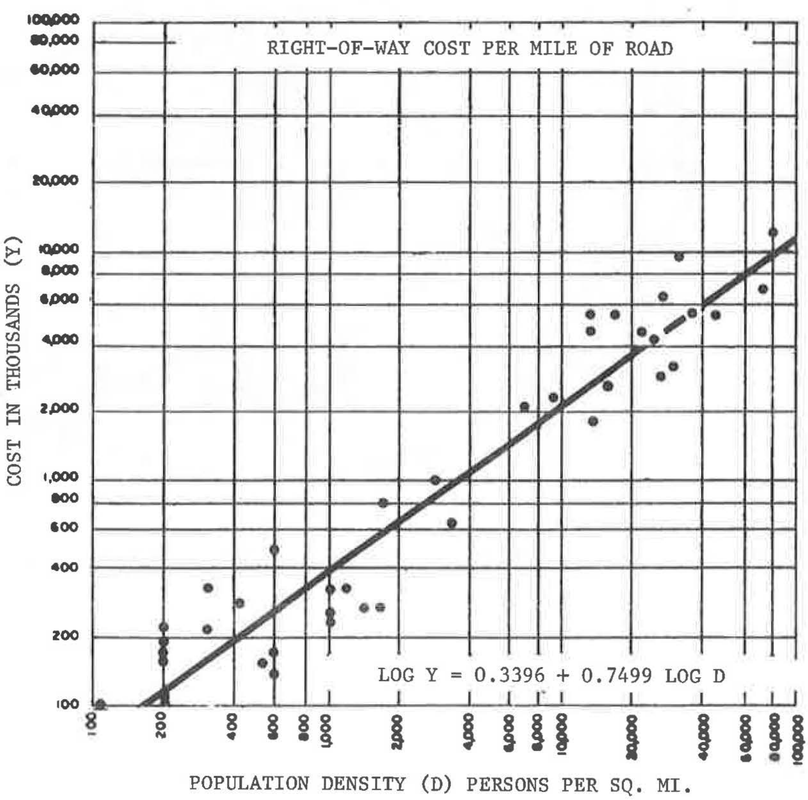

TOTAL COST PER MILE OF ROAD
COST IN THOUSANDS (Y)
100,000
80,000
60,000
40,000
20,000
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
LOG Y = 2.2857 + 0.4055 LOG D
100
200
400
600
800
1,000
2,000
4,000
6,000
8,000
10,000
20,000
40,000
60,000
80,000
100,000
POPULATION DENSITY (D) PERSONS PER SQ. MI.

Figure 2.


RIGHT-OF-WAY COST PER MILE OF ROAD
COST IN THOUSANDS (Y)
100,000
80,000
60,000
40,000
20,000
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
LOG Y = 0.3396 + 0.7499 LOG D
100
200
400
600
800
1,000
2,000
4,000
6,000
8,000
10,000
20,000
40,000
60,000
80,000
100,000
POPULATION DENSITY (D) PERSONS PER SQ. MI.

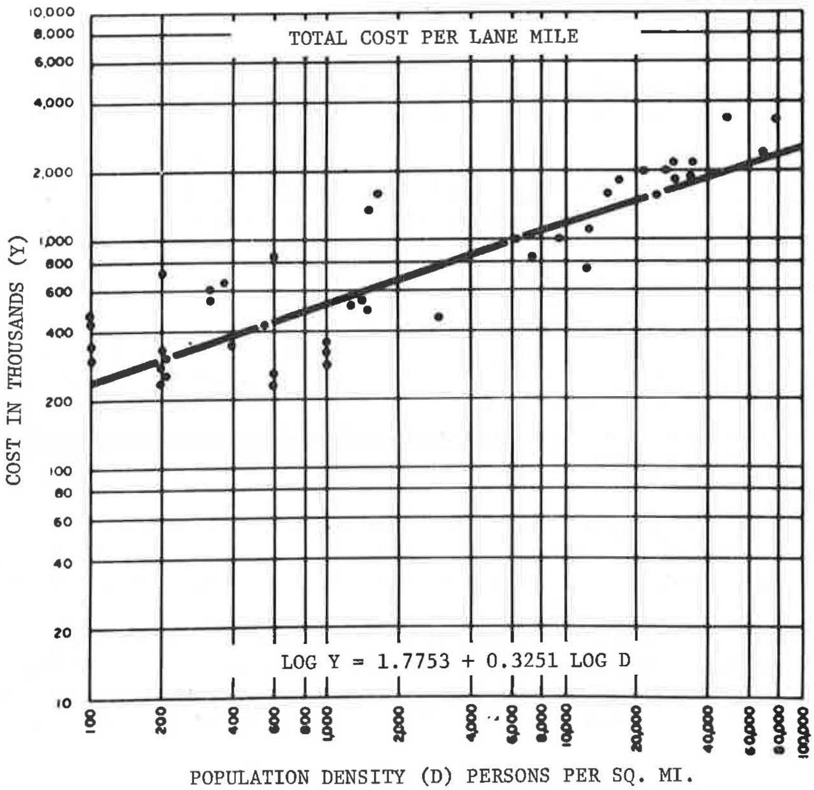


Figure 4.

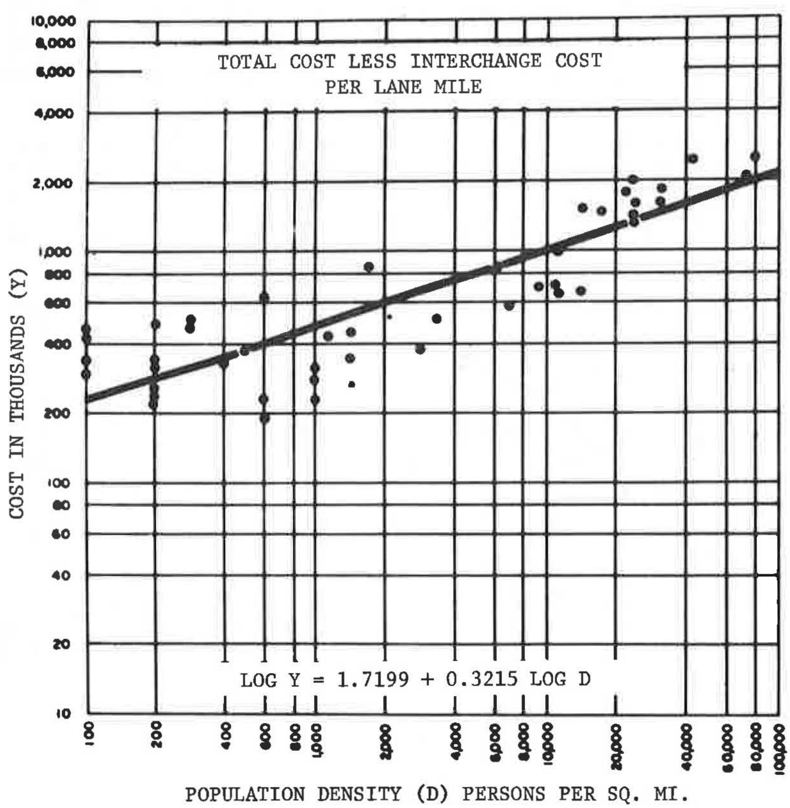


Figure 5.

Figure 5 was constructed on a similar basis as Figure 4, except that the cost of interchanges was deducted from the total segment cost before dividing it over the number of lanes.

The spacing of facilities and, consequently, the spacing of interchanges is one of the several answers sought for in transportation planning. Separation of interchange costs from the cost of the through lanes, therefore, provides flexibility in assessing the economic aspects of different facility spacing alternatives.

COSTS BY ROAD ELEMENTS

This part of the highway construction cost analysis shows the variation in the ROW acquisition and in the highway installation costs by elements, such as grading and surfacing, structures, interchanges, other costs, and engineering. The findings that follow can be employed for the cost estimation of highways that are not typical for their locations. Alternate design considerations of planned facilities can also be evaluated by this method.

1. ROW cost (for land strip 100 ft wide and 1 mile long) includes land acquisition, clear and grub, demolition, and utility adjustment or relocation. Figure 6 shows the correlation of the ROW costs to population density, the corresponding regression line, and equation.

2. Grading and surfacing cost scattergram and the regression equation are shown in Figure 7. Although the cost variation trend is in evidence, the correlation between these two series is not high, and the dispersion of data is considerable for this slope of regression. The correlation is somewhat improved by the introduction of the "num-

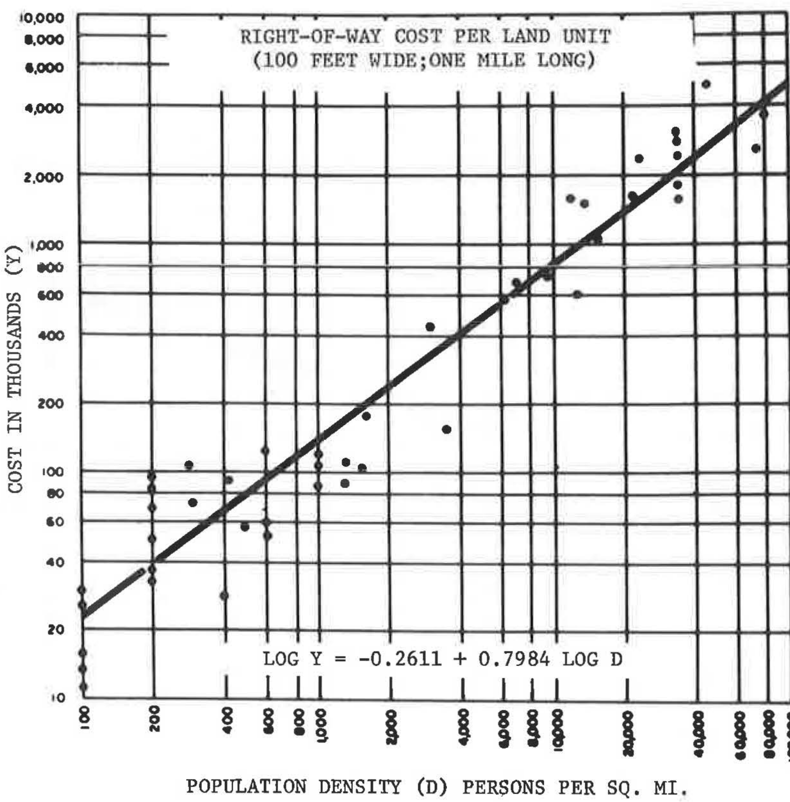


Figure 6.

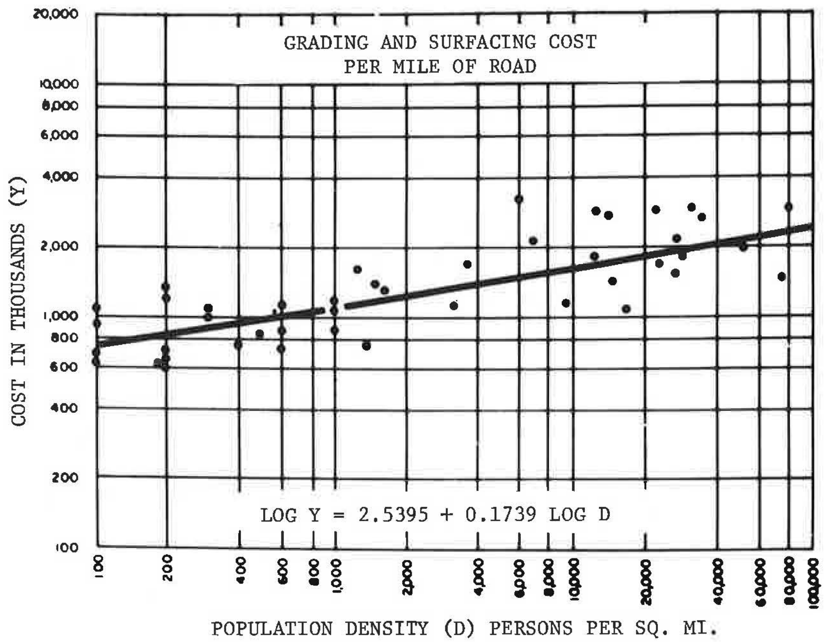


Figure 7.

ber of lanes" variable. Thus, the following equation can be used as an alternate to that given in Figure 7:

$$\text{Log } Y = 2.4985 + 0.1565 \log D + 0.0158 N$$

In addition to grading and surfacing, this cost category includes minor drainage structures, subbase, and shoulders.

3. Structure cost, representing highway grade separations without ramps, railroad grade separations, and bridges, did not significantly correlate to the tested variables. Clustering the data in three density ranges, the structure cost for these densities averaged as shown in Table 1. Structure spacing is represented by Figure 8. This correlation is also indicative of the spacing of streets, such as secondary arterials, which cannot be terminated at expressways. This statement presupposes that most of the railroad grade separations and stream crossings also span some kind of arterial or occur infrequently. The spacing ranges from 0.12 miles in high densities to just over 1 mile in fringe areas.

4. Interchange costs depend on the importance of interconnecting facilities and on the complexity of structures. Three classes of commonly occurring interchanges indicated distinct cost characteristics: interchanges between two limited-access facilities, between limited-access and U. S. or state highways, and between limited-access and arterial streets. Table 2 shows the mean cost and the range of costs.

Interchanges of more than two facilities and those requiring elevated ramps or other structures in densely populated areas considerably exceed the above estimates, and no generalization could be drawn from the sample data. Sketch layouts should be prepared to help estimate the cost of these complexes.

To check the representativeness of the mean values for the three interchange types

TABLE 1

COST OF STRUCTURES

Density Range (Persons/sq mile)	Mean Cost ($000)	Cost Range ($000)
100–10, 000	297	180–510
11, 000–30, 000	383	210–560
31, 000–80, 000	489	305–877

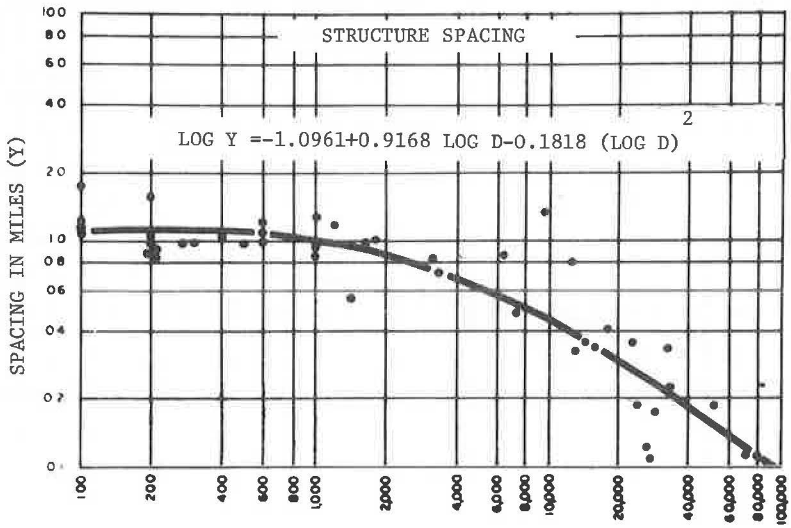


Figure 8.

in Table 2, costs for all interchanges that appeared in the "1965 Estimates" of the three states within the Tri-State Region were extracted and grouped into similar classes. Out of 120 such interchanges, 26 were with Interstate roads or other divided high-volume facilities, 32 with federal or state highways, and 62 with other arterials. The range of costs and the mean values for these groupings are shown in Table 3.

All costs that pertain to the Interstate through-traffic lanes were excluded from the above interchange figures. Included in the interchange costs are those that are part of the interchange development: structure, excavation, walls, grading, drainage and surfacing of all ramps, curbs, slope treatment, roadside improvements, lighting, and traffic control devices. Also included are the costs for the entire improvement of the crossroad, unless it is another Interstate route.

Estimates of actual interchange costs that appear in technical reports and publications do not always correspond to the above definition. Therefore, a comparison between the findings of this report and similar costs from other sources must be made with care and caution.

Interchange spacing was found to correlate to population density as shown in Figure 9. The spacing ranges from 0.6 miles in densely developed areas to 7 miles in the outer region.

5. Other costs include walls, guardrails, fencing, lighting, traffic control devices, roadside improvements, miscellaneous items, and contingencies. Figure 10 shows the correlation of these costs to population density.

TABLE 2

INTERCHANGE COSTS FROM SAMPLE DATA
(Excluding Cost of Interstate Through Lanes)

Connecting Roads	Mean Cost ($000)	Range ($000)
Limited-access facilities		
Predominantly designs at grade	2, 157	2, 010–2, 521
Nonlimited access		
U. S. or state highways	1, 264	943–1, 964
Other arterials	635	497–801

TABLE 3

INTERCHANGE COSTS FROM REGION-WIDE DATA
(Excluding Cost of Interstate Through Lanes)

Connecting Road	Mean Cost ($000)	Range for 90% of Data ($000)
Limited-access facilities		
All interchanges	3, 920	2, 010–7, 338
Complex designs	4, 979	3, 273–7, 338
Predominantly designs at grade	2, 386	2, 010–2, 897
Nonlimited access		
U. S. or state highways	1, 337	727–1, 929
Other arterials	620	330–894

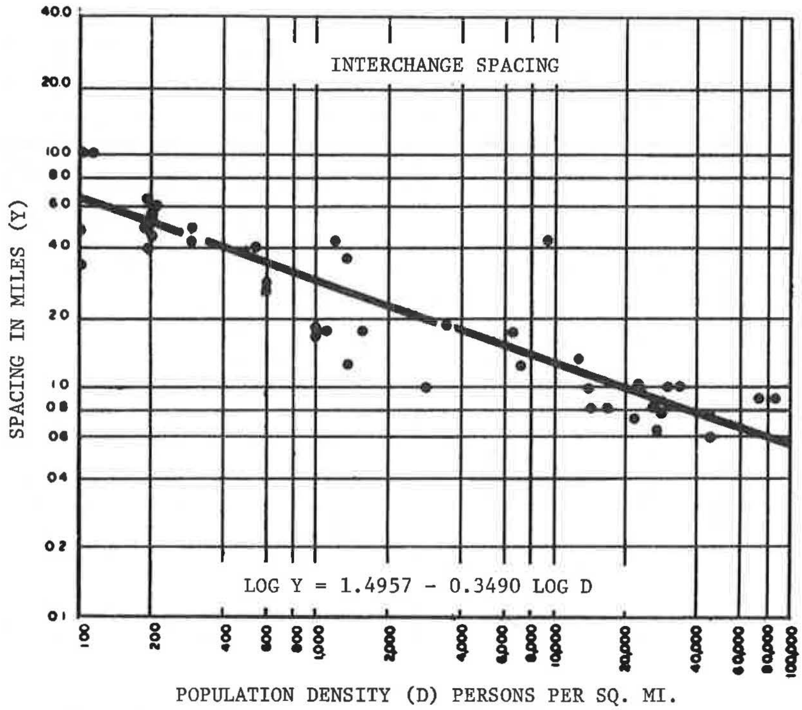


Figure 9.

6. Engineering costs amount to approximately 15 percent of the total construction cost (excluding ROW) in New York City and to 10 percent in the rest of the Region.

To obtain highway construction costs from the above equations and tables, it is necessary to estimate and add up items 2, 3, 4, and 5, and add to this sum the corresponding percent for engineering expenses as described in item 6. This total, plus the ROW cost, would represent the total cost of a given highway segment.

HIGHWAY CONSTRUCTION COST IN HIGH-DENSITY AREAS

ROW and construction costs in areas where the population density exceeds 80,000 persons per square mile could not be incorporated in the preceding study because of the irregularity and paucity of data. The ROW width in such areas is decreased to a minimum, and roads become a chain of elevated structures, tunnels, and depressed roadways. Among the available data there were too few observations for a firm generalization on the cost of these elements. However, approximations, were made to provide an idea about the range of cost for such structures.

1. Right-of-way—ROW in densely developed areas within a 10-mile radius of Manhattan can be estimated by the following equation:

$$\text{Log}\ (Y-1.68) = -\ 0.3563 + 0.125X$$

where Y = cost in millions for a land strip 100 ft wide by 1 mile long, and X = population density in 1,000 persons per square mile.

2. Tunnels—Estimates prepared for the Mid-Manhattan Expressway indicate a $25 million-per-mile construction cost for a four-lane tunnel, excluding the ROW cost at the entrances and auxiliary structures.

3. Elevated Highways—The construction cost of eight elevated highway links totaling 4.7 miles in length averaged to $16.25 million per mile; individual segment costs range from $12.8 to $20.8 million per mile for six- and eight-lane facilities.

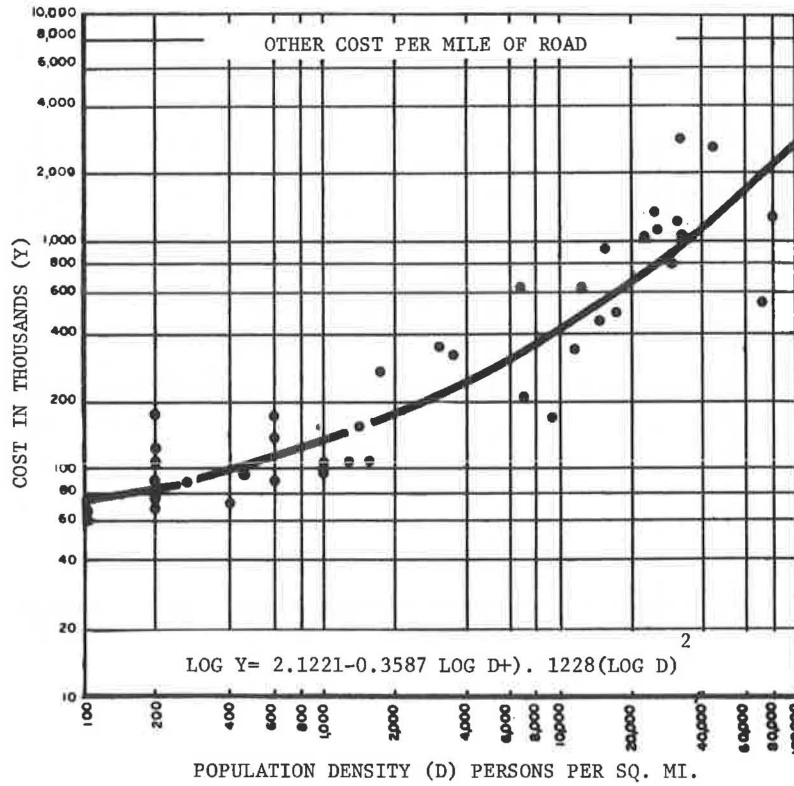


Figure 10.

4. Depressed Highways—Two links, 1.6 miles long, of depressed highways averaged to $20.6 million per mile, excluding ROW cost.

All of the above roads were located in Manhattan and Brooklyn.

Items 2 to 4 represent the total construction cost, which includes structures, interchanges, improvements, and engineering.

TESTING THE EQUATIONS

Parts of I-278 and I-287 not included in the sample data were utilized for testing the equations. The location of these routes is shown in Figure 11.

Following the prescribed procedures for determining the segment length and population density, the test routes were divided into 18 analysis segments and each segment was accorded its density value. The cost of each segment was then estimated on the basis of the four estimation criteria.

The differences between the test and the statistics sample were considerable. The test data consist of 18 segments as opposed to 42 in the statistics sample. Population density in the test data ranges from 200 to 12,400 persons per square mile. The sample covered densities up to 80,000 persons per square mile. While the sample consisted of radial and circumferential roads with respect to the core of the region, both I-278 and I-287 are circumferential.

Because of the disparity between the two samples, chances were that the aggregate estimation error would be larger than that for a system of segments more evenly distributed with respect to population density and road orientation. The resulting errors, however, proved to be low, and the test outcome demonstrates the relative validity of these estimation criteria.

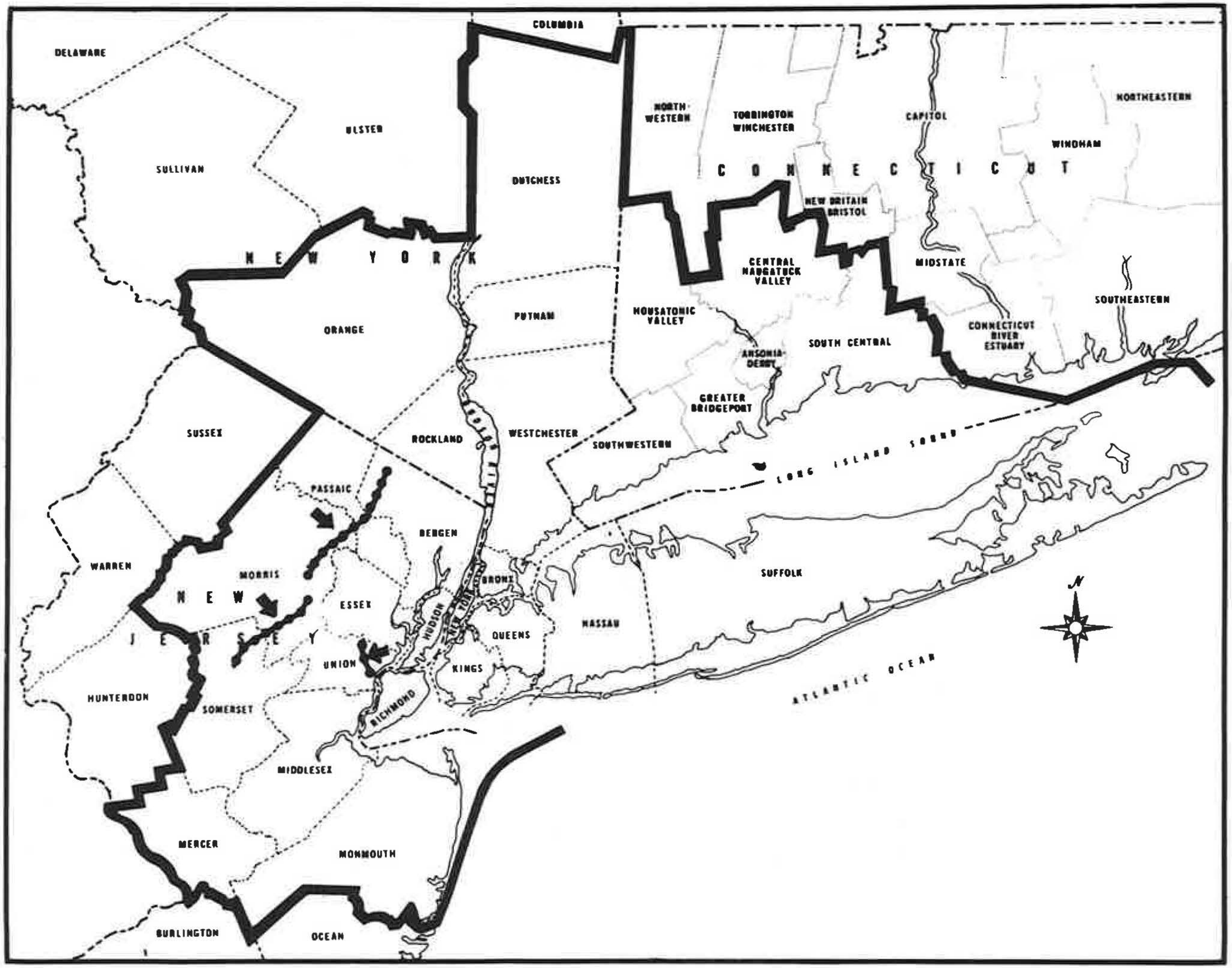


Figure 11. Test segments of I-278 and I-287.

TABLE 4

ESTIMATED COSTS OF ROAD ELEMENTS

Road Element	Actual Cost ($000)	Estimated Cost ($000)	Error (%)
Right-of-way (100 ft by 1 mile)	48,524	39,929	-17.7
Grading and surfacing Y = f (DN)	45,619	52,911	+17.2
Structures	21,255	16,758	-21.2
Interchanges	23,861	21,530	-9.8
Other, includes engineering	22,324	19,114	-14.4
Total	161,583	150,242	-7.0

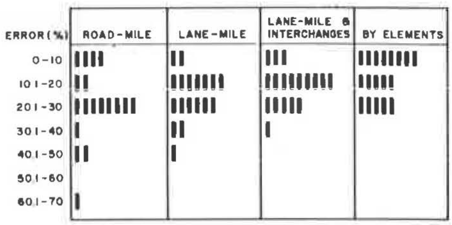


Figure 12. Frequency distribution of errors for cost estimates by link and by four criteria of estimation (in absolute values).

The aggregate errors for estimates by the different criteria are as follows:

Criteria of Estimation	Error (%)
Road-mile	+15.0
Lane-mile	- 1.7
Lane-mile and interchanges	- 2.4
Road elements	- 7.0

The range and the frequency of errors for the cost estimates by segments are illustrated in Figure 12. The estimation approach by road elements shows the lowest range of errors; eight out of 18 segments were estimated with a 10 percent error. The second best in the distribution of errors is the lane-mile and interchanges criterion; lane-mile is third, and road-mile fourth.

Judging from the range and distribution of errors shown in Figure 12, estimates on the basis of road elements yielded the best results. From the point of view of the total error, however, it ranks only third. The estimation method by road elements consists of several steps, each of which showed a resultant error larger than that of the aggregate. The aggregate error is a chance error of the five estimation stages, as may be seen in Table 4.

It cannot be said that the test provided adequate evidence for singling out one estimation method as better than the others. Nonetheless, since the test data in several respects differ from the statistics sample and since, in spite of these differences, the estimates obtained by the four different methods indicate relatively low level of errors, the test suggests that all four cost estimation approaches are suitable for the intended purposes.

CONCLUSIONS

A reasonably good correlation was established between the cost of various expressway installation elements and gross population density. Regression equations derived from this correlation may be employed for expressway cost estimation criteria in transportation planning. The test of four estimation approaches yielded reasonably good results—the aggregate error ranged between +15.0 and -7.0 percent. This test indicates that all four approaches are suitable for the intended purpose. The criteria, however, have been developed for a regional distribution of facilities, and estimates of facilities having similar distribution characteristics would yield better results than isolated segments of roads.

Impact of Toll Changes on Traffic and Revenue for Bridge and Tunnel Facilities

JOHN A. DASH and ARNOLD H. VEY, Simpson and Curtin, Transportation Engineers

Traffic and toll data for six facilities of varied utilization, geographic location, and toll structures were analyzed to reveal toll-related traffic loss. Consideration of monthly and cumulative traffic trends for comparable periods before and after toll changes determined the net percentage impact on traffic of each price increase. Computation of this traffic loss in terms of each 1 percent increase in toll, averaged for the six facilities, yielded a shrinkage ratio for river-crossing facilities—0.17 percent traffic loss for each 1 percent increase in average toll. Forecasts were made for a series of future average tolls, incorporating revenue increases which allow for the 0.17 percent loss ratio. Altogether, revenue productivity was shown to range from about 65 to 87 percent of the percentage increase in tolls. Separate determinations were made for facilities competing with parallel, low-toll crossings and for truck and tractor trailer traffic.

Toll decreases generally resulted in some additional patronage, but the traffic increase has not been nearly enough to offset the reduction in tolls, with a consequent loss in toll revenue.

•THIS study was conducted to forecast the potential revenue gain from several alternate toll structures, each of which represents an increase over the existing toll levels. Such a forecast involves several areas of inquiry, the first being the collection and analysis of data concerning past experience with toll changes on river crossings in several areas of the United States.

Analysis of past experience reveals the degree to which the utilization of cross-river facilities has been affected by toll change, both for passenger cars and for truck traffic. The succeeding sections describe the methodology applied in this analysis and discuss the impact of toll changes on passenger car and truck traffic.

METHODOLOGY

To assess the effect of any price change, it is necessary, insofar as possible, to eliminate the impact of other factors bearing on the use of the product, service, or facility involved. These other factors include both long- and short-term influences.

If there is a discernible trend increase or decrease in the use of a facility, the trend existing at the time of a price change must be taken into account if one is to isolate the impact of the price change itself. Thus, if an attempt were made to measure the result of a toll increase on a facility where there had been a pronounced growth trend prior to the toll change—a trend that was accelerating—consideration of annual data for a period of years before and after the toll change might well lead to the conclusion that the price increase had little or no effect on patronage. The impact, if any, would appear to be swallowed up in the continuing growth of the facility. Conversely, if there has been an accelerating downtrend, consideration of annual periods before and after a toll change would result in seriously overstating the impact of the toll increase on traffic.

Paper sponsored by Committee on Highway Taxation and Finance and presented at the 47th Annual Meeting.

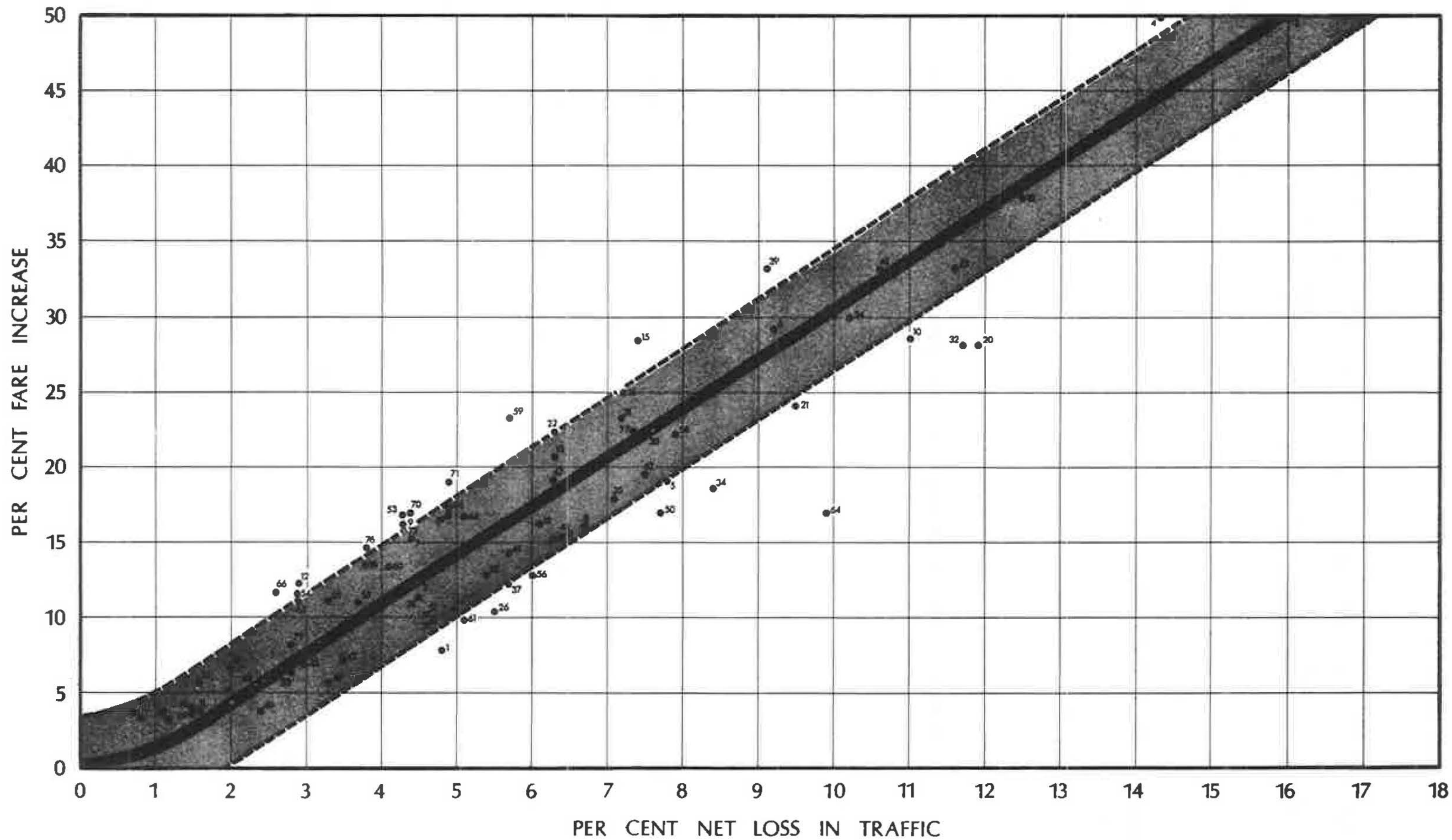


Figure 1. Shrinkage in passenger traffic due to fare increase.

Thus, it was decided that the period for analysis should be confined to no more than one year before and one year after the toll change being studied. Principal attention was directed to the experience three to six months before and after each toll increase, which was considered to be sufficiently close to the increase to eliminate, or at least to minimize, the effect on traffic of changes either in the basic trend of patronage or in economic conditions in the area.

The method employed must also eliminate distortion due to seasonal variations. For this reason, the comparisons made in this study related the traffic and revenue for the same months in succeeding years. Thus the monthly trend before and after each toll change was measured against the corresponding months one year earlier.

THE SIMPSON AND CURTIN FORMULA

For more than 20 years, Simpson and Curtin has conducted continuing studies of the impact of fare changes on patronage throughout the transit industry. In analyzing transit fare changes, it has been our practice to examine the trend of traffic for a period immediately prior to the fare change, usually three months, in relation to the same period of the preceding year. We then determine the traffic trend for a corresponding period following the fare change in relation to the same months of the prior year. Figure 1 shows a study on some 79 fare increases on transit systems throughout the United States. Each of the plotted points represents a particular fare change, relating the percent increase in fare to the percent net loss in patronage resulting from that fare increase. We then determined the overall trend line. The formula expressed by this line is that there will be a loss of 0.33 percent in traffic for each 1.0 percent increase in fare. For example, a 25 percent fare increase would result in a loss of 8.25 percent in traffic.

The traffic loss ratio of one-third of one percent for each one percent increase in fare has become known as the "Simpson and Curtin formula." It has been widely accepted in the industry and is applied by many governmental regulatory agencies dealing with transit fare changes.

Figure 2, based on data from Figure 1, depicts the formula as it pertains to revenue yield, showing the percent increase in passenger revenue resulting from various amounts of fare increase. The solid black line and the parallel dash lines correspond to the lines in Figure 1. In the range of most fare increases, i.e., between 15 and 30 percent, the increase in passenger revenue is generally between 55 and 60 percent of the percent increase in fare. In other words, by reason of shrinkage in traffic because of passenger resistance to the fare increase and aside from traffic changes from economic or other causes, a 20 percent fare increase produces about 12 percent more passenger revenue, while a 30 percent fare increase produces about 17 percent more passenger revenue.

PASSENGER CAR TOLL INCREASES

Analysis of the before and after experience in a number of instances on bridge and tunnel facilities indicates that passenger car and, to a lesser extent, truck traffic are affected by a change in toll levels. In order to determine what has actually taken place when toll changes were inaugurated, requests for detailed information were sent to the agencies administering a number of bridge or tunnel facilities on which toll changes had been made. To permit the type of examination required it was necessary to obtain monthly data by class of vehicle for a period of at least three years in each instance. Adequate detail was obtained to make possible full analysis of toll changes on six facilities.

The passenger car toll increases that were studied in depth are given in Table 1. The first was the 25 percent increase in cash and commutation rates effective June 1953 on the Benjamin Franklin Bridge between Philadelphia and Camden. Table 1 also includes toll increases on the Delaware Memorial Bridge as well as on facilities in Nebraska, Michigan, Massachusetts, and Virginia. The increases in average tolls ranged from about 15 to nearly 87 percent.

TABLE 1

IMPACT OF TOLL INCREASES ON PASSENGER CAR TRAFFIC AND REVENUE

Facility	Toll Structure Before Increase				Effective Date of Increase	Toll Structure After Increase				Toll Increase (%)			Net Loss in Traffic (%)	Net Traffic Loss for Each 1% Increase in Toll (%)[a]
	Cash	Commutation		Average Toll		Cash	Commutation		Average Toll	Cash	Commutation Unit Rate	Average Toll		
		Package	Unit Rate				Package	Unit Rate						
Benjamin Franklin Bridge	$0.20	40 for $6.00	$0.15	$0.195	6/20/53	$0.25	40 for $7.50	$0.1875	$0.2436	25.0	25.0	24.9	3.4	0.14
Percent of traffic	89.96		10.04	100.00		89.76		10.24	100.00					
Delaware Memorial Bridge	$0.25	50 for $5.00	$0.10	$0.2359	7/1/63	$0.50	50 for $5.00	$0.10	$0.4409	100.0	None	86.9	6.1	0.07
Percent of traffic	89.95		9.11	100.00		84.20		11.72	100.00					
		10 for $2.00	$0.20 0.94%											
							20 for $4.00	$0.20 4.08%						
Leavenworth Centennial Bridge	$0.15	None	—	$0.1500	11/1/57	$0.25	15 for $2.25	$0.15	$0.2058	66.7	—	37.20	5.0	0.13
Percent of traffic	100.00			100.00		55.81		44.19	100.00					
Mackinac Bridge	3.25	None	—	$3.25	1/1/61	$3.50	None	—	$3.50	14.7	—	14.7	2.0	0.14
					5/1/61	$3.75	None	—	$3.75		(1961 over 1960)			
Mystic River Bridge	$0.15	—	$0.10	$0.1117	1/1/53	$0.25	—	$0.15	$0.1710	66.7	50.0	53.1	12.0	0.23
Percent of traffic	20.83		79.17	100.00		18.11		81.89	100.00					
Norfolk Elizabeth River Tunnel	$0.30	None	—	$0.3000	4/1/60	$0.40	None	—	$0.4000	33.3	—	33.3	9.5	0.29

[a]Average net traffic loss for each 1 percent toll increase was 0.17 percent.

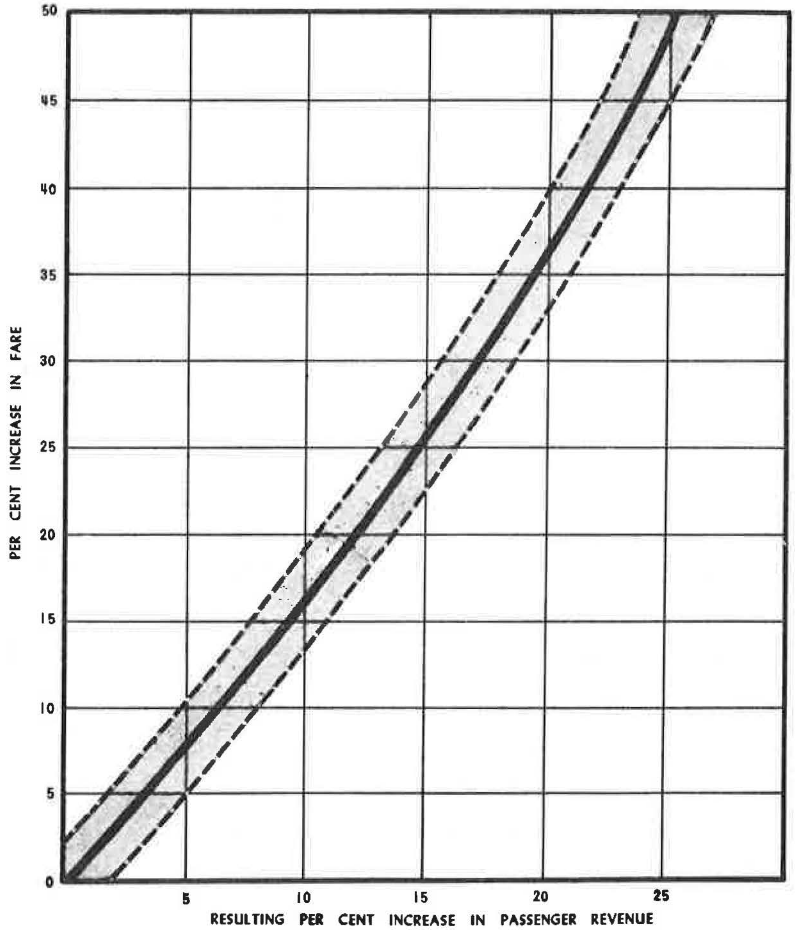


Figure 2. Percent increase in passenger revenue resulting from various amounts of fare increase.

Individual analyses of these toll changes and their impact were compiled as Appendixes A-1 through A-6.* Each briefly describes the facility, the toll structure before and after the change, and the monthly trend of traffic before the increase—for both individual months and cumulatively—computed for periods of one to 12 months, beginning with the month immediately preceding the increase and accumulating in reverse from that point. The next step in the analysis was a corresponding examination of the monthly trend after the toll increase, together with a calculation of the cumulative post-change trend. The before and after percentage trends were then compared for varying periods. Finally, the conclusions reached from the analysis were presented in each instance, culminating in a numerical expression of the percent net loss in traffic and the increase in revenues attributed specifically to the toll change.

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*Appendixes are not presented here but are available at cost of reproduction and handling from the Highway Research Board. When ordering, refer to XS-21, Highway Research Record 252.

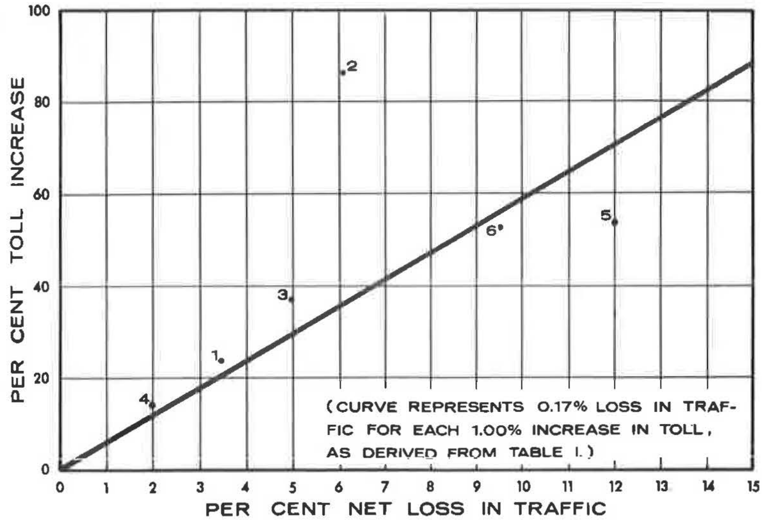

Figure 3. Shrinkage in passenger car traffic due to toll increases on bridge and tunnel facilities.

IMPACT OF PASSENGER CAR TOLL INCREASES ON TRAFFIC AND REVENUE

A summary of the findings resulting from the individual analyses of traffic is shown in Figure 3. In Table 1, the average tolls and percent toll increases are indicated, and the percent net loss in traffic resulting from each toll increase is given. The relationship of the traffic loss to the toll increase was computed in terms of the percent net traffic loss for each one percent increase in toll. These traffic shrinkage ratios may be compared with the Simpson and Curtin formula used in forecasting the effect of transit fare increases.

As noted earlier, the transit formula indicates a passenger loss of 0.33 percent for each 1 percent increase in fares. The impact of toll increases on bridge and tunnel traffic is considerably less than the normal impact on patronage of transit fare changes. The average shrinkage ratio among the six facilities in Table 1 is shown to be 0.17 percent for each 1 percent increase in average toll.

The impact of bridge or tunnel toll increases on passenger car traffic is only about one-half as large as the drop in business resulting from a transit fare rise. Primarily because fewer acceptable alternatives are available, toll bridges are much less vulnerable to loss in patronage resulting from price increases than are local transit systems.

Available data indicate that each increase in bridge or tunnel tolls has a discernible effect on the trend of passenger car utilization of the facility. The result in each instance has been an increase in revenue which was something less than the percentage rise in the average toll.

The revenue results of the toll increases are given in Table 2. In four of the six instances, the revenue gain was in the range of 82 to 87 percent of the increase in average toll. In the other two instances, the revenue productivity was approximately two-thirds of the potential. In these six instances, the revenue gain ranged from 65 to 87 percent of the increase in revenue which would have been realized had there been no decline in patronage as a result of the higher toll.

APPLICATION OF FORMULA TO PASSENGER CAR TOLL STRUCTURE

Table 3 and Figure 4 illustrate the application of the shrinkage ratio and revenue productivity factors developed above. These hypothetical projections are based on an average present toll level of $0.24 for passenger cars on a cross-river facility.

TABLE 2

REVENUE PRODUCTIVITY OF TOLL INCREASES
(Passenger Car Toll Increases on Bridge and Tunnel Facilities)

Facility	Increase in Toll (¢)	Increase in Revenue (¢)[a]	Revenue Productivity: Percent of Potential Revenue Gain Realized
Benjamin Franklin Bridge	24.9	20.7	83
Delaware Memorial Bridge	86.9	75.5	87
Leavenworth Centennial Bridge	37.2	30.3	82
Mackinac Bridge	14.7	12.4	84
Mystic River Bridge	53.1	34.7	65
Norfolk Elizabeth River Tunnel	33.3	22.0	66

[a]Revenue increase realized after allowing for impact of toll change on traffic.

Table 3 gives the patronage and revenue effect of toll structures that would produce average tolls ranging from $0.25 to $0.45, listed by $0.01 increments. For example, a new toll structure yielding a $0.30 average rate, 25 percent above the present average toll, would result in a traffic decline of 4.3 percent. The resulting increase in revenue is estimated at 19.6 percent.

The revenue productivity, or the revenue increase expressed as a percentage of the increase in average toll in each instance, is given in Table 2. Using the 0.17 percent shrinkage ratio (Table 1), it is estimated that the productivity of a $0.01 increase in average toll above the present $0.24 level would be 83 percent. The revenue productivity progressively declines as higher toll structures are considered. At a $0.30 average toll, the productivity is estimated at 78.5 percent of the potential, declining to slightly over 75 percent at a $0.35 average toll, and to about 68 percent at a $0.45 average toll.

Figure 4 shows the relationship between toll increase and percent gain in revenues from the present $0.24 average toll level, based on a 0.17 percent loss ratio.

TABLE 3

NET TRAFFIC LOSS AND REVENUE PRODUCTIVITY FOR PASSENGER CARS
(On Basis of a Loss Ratio of 0.17 Percent)

Average Toll Under Future Toll Plan (cents)	Increase in Average Toll Above Percent Level of 24 Cents (¢)	Net Loss in Traffic Resulting From Toll Increase (¢)	Increase in Revenue (¢)	Revenue Increase as Percent of Toll Increase
25	4.2	0.7	3.5	83.0
26	8.3	1.4	6.8	82.0
27	12.5	2.1	10.1	81.0
28	16.7	2.8	13.4	80.5
29	20.8	3.5	16.6	79.8
30	25.0	4.3	19.6	78.5
31	29.2	5.0	22.7	77.9
32	33.3	5.7	25.8	77.3
33	37.5	6.4	28.7	76.6
34	41.7	7.1	31.6	75.9
35	45.8	7.8	34.5	75.2
36	50.0	8.5	37.3	74.5
37	54.2	9.2	40.0	73.8
38	58.3	9.9	42.7	73.1
39	62.5	10.6	45.3	72.5
40	66.7	11.3	47.8	71.8
41	70.8	12.0	50.3	71.1
42	75.0	12.8	52.6	70.1
43	79.2	13.5	55.0	69.5
44	83.3	14.2	57.3	68.8
45	87.5	14.9	59.6	68.1

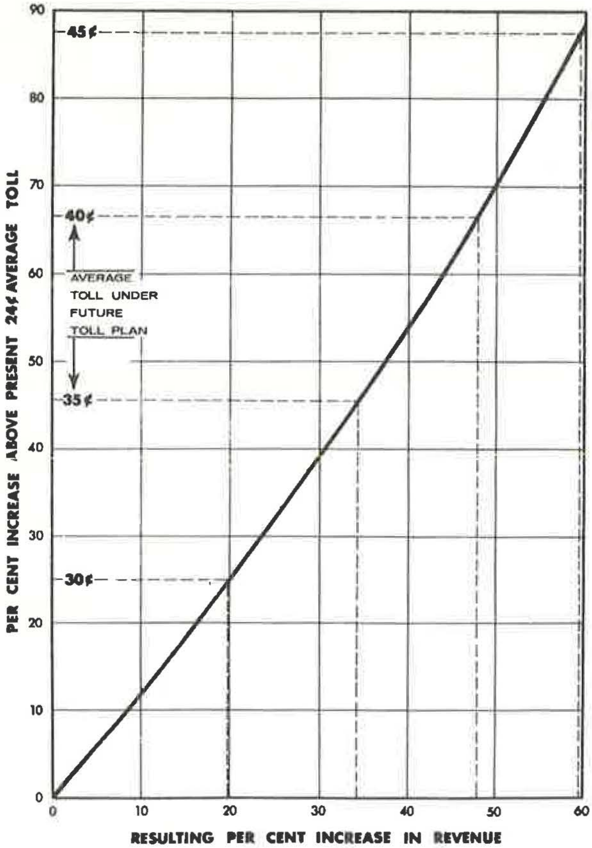

Figure 4. Percent increase in passenger car toll revenues resulting from various amounts of toll increase.

TOLL IMPACT ON FACILITY VULNERABLE TO COMPETITION

Special consideration has been given to the impact on traffic of a toll change on a cross-river facility running parallel to a bridge or tunnel having a much lower toll structure. Widening the toll differential by increasing the already higher tolls on the former can be expected to have a greater impact on traffic than the standard previously established. As a result, it is necessary to use a larger resistance factor in predicting the impact of a toll increase.

A reasonable factor to apply to a facility vulnerable to competition from a bridge or tunnel with a lower average toll level is 0.22 percent for each 1 percent increase in average toll, as opposed to a factor of 0.17 percent on other facilities. While this difference is necessarily a matter of judgment, it should be pointed out that the data in Table 1 (and presented elsewhere in Appendix A-5) lend support to this figure. The Mystic River Bridge in Boston experienced a resistance loss of 0.23 percent from the toll increase analyzed in this study, compared to an average shrinkage ratio of 0.17 percent for all of the experiences examined. The Mystic River Bridge is subject to competition both from the tunnels downstream and from the free bridges upstream from the Mystic River facility. The availability of alternative facilities in this instance resulted in a higher-than-average resistance to the toll increase.

TOLL INCREASES FOR TRUCKS AND TRACTOR-TRAILER COMBINATIONS

Information was obtained and analyzed with respect to truck toll changes on the same six facilities that were dealt with for passenger cars in the preceding section. The toll increases for trucks on these facilities (Table 4) ranged from slightly less than 10 percent on the Mackinac Bridge in Michigan to nearly 60 percent on the Leavenworth Centennial Bridge in Kansas. Table 4 gives the average toll before and after the change, as well as the percent increase in the average truck toll.

Experience indicates that the impact of toll increases on traffic is less for trucks than for passenger cars. In three of the six instances studied, there was no discernible loss of traffic by reason of truck toll increases ranging from approximately 10 to more than 23 percent (Table 4). In the three other instances examined, the net traffic loss for each 1 percent increase in toll ranged from 0.12 to 0.37 percent. The average net traffic loss for each 1 percent rise in toll was 0.13 percent.

In terms of revenue productivity, three of the six instances of truck toll increases resulted in 100 percent productivity—there was no reduction in traffic by reason of the toll increase (Table 5). In the other three instances, revenue productivity ranged from 51 to 81 percent. For the six facilities together, the average revenue productivity was 84 percent.

TABLE 4

IMPACT OF TOLL INCREASES ON TRUCK TRAFFIC

Facility	Average Toll		Toll Increase (%)	Net Loss in Traffic (%)	Net Traffic Loss for Each 1% Increase in Toll (%)[a]
	Before Increase	After Increase			
Benjamin Franklin Bridge	$0.679	$0.817	20.3	5.3	0.26
Delaware Memorial Bridge	1.051	1.296	23.3	None	None
Leavenworth Centennial Bridge	0.276	0.4390	59.1	6.9	0.12
Mackinac Bridge	7.46	8.19	9.8	None	None
Mystic River Bridge	0.297	0.341	14.8	None	None
Norfolk Elizabeth River Tunnel	0.316	0.421	33.3	12.2	0.37

[a]Average net traffic loss for each 1 percent increase was 0.13 percent.

TABLE 5

REVENUE PRODUCTIVITY OF TOLL INCREASES FOR TRUCKS

Facility	Increase in Toll (%)	Increase in Revenue (%)	Revenue Productivity: Percent of Potential Revenue Gain Realized
Benjamin Franklin Bridge	20.3	13.9	69
Delaware Memorial Bridge	23.3	23.3	100
Leavenworth Centennial Bridge	59.1	48.1	81
Mackinac Bridge	9.8	9.8	100
Mystic River Bridge	14.8	14.8	100
Norfolk Elizabeth River Tunnel	33.3	17.1	51

TABLE 6

NET TRAFFIC LOSS AND REVENUE PRODUCTIVITY FOR TRUCKS

Average Toll Under Future Toll Plan	Increase in Average Toll Above Present Level of $1.14 (%)	Net Loss in Traffic Resulting From Toll Increase (%)	Increase in Revenue (%)	Revenue Increase as Percent of Toll Increase
$1.20	5.26	0.68	4.54	86.3
1.25	9.65	1.25	8.28	85.8
1.30	14.04	1.83	11.95	85.1
1.35	18.42	2.39	15.59	84.6
1.40	22.81	2.97	19.16	84.0
1.45	27.19	3.53	22.70	83.5
1.50	31.58	4.11	26.18	82.9

Application of Formula to Truck Toll Structures

To illustrate the traffic and revenue resulting from application of a 0.13 percent loss ratio when truck toll levels are increased, a table was prepared presenting a series of hypothetical toll structures. Table 6 lists average truck tolls ranging from $1.20 to $1.50 in relation to an assumed present average of $1.14. Under a future plan that would raise the average toll from $1.14 to $1.25, an increase of 9.65 percent, the resulting net loss in traffic was estimated at 1.25 percent and the increase in revenue was projected at 8.28 percent. The revenue increase, therefore, was approximately 86 percent of the theoretical potential or the amount that would be realized if there were no loss in truck traffic as the result of the toll change. In the range of toll

TABLE 7

IMPACT OF TOLL DECREASES FOR PASSENGER CARS AND TRUCKS

Facility	Date of Change	Vehicle Type	Toll			Net Change Resulting From Toll Decrease (%)	
			Before	After	Decrease (%)	Traffic	Revenue[c]
Delaware Memorial Bridge	6/1/58	All pass. cars	$0.686[a]	$0.457[a]	33.4	11.7	25.6
Delaware Memorial Bridge	6/1/58	2-axle trucks	1.00[b]	0.75[b]	25.0	11.4	16.5
Delaware Memorial Bridge	6/1/58	3-axle trucks	1.50[b]	1.00[b]	33.3	14.3	23.8
Delaware Memorial Bridge	6/1/58	4-axle trucks	2.00[b]	1.50[b]	25.0	13.7	14.7
Thousand Island Bridge	3/1/56	All pass. cars	0.932[a]	0.738[a]	20.8	10.5	12.5
James River Bridge	4/1/64	All pass. cars	0.764[a]	0.662[a]	13.4	9.6	5.0
George P. Coleman Memorial Bridge	4/1/64	All pass. cars	0.684[a]	0.626[a]	8.5	None	8.5
Sunshine Skyway Bridge	12/1/58	All pass. cars	1.75[b]	1.00[b]	42.9	44.9	17.2
Sunshine Skyway Bridge	4/1/66	All pass. cars	1.00[b]	0.50[b]	50.0	26.3	36.9

[a]Average toll. [b]Cash toll. [c]Denotes decrease.

increases up to an average of $1.50, the revenue productivity of truck toll changes was estimated at 83 to 86 percent of the theoretical potential.

The revenue productivity of a truck toll increase was somewhat higher than that anticipated from passenger car toll changes, as can be seen by comparing Table 6 with Table 3, a similar analysis for passenger car toll increases.

The reasons for the higher productivity of truck toll increases are evident. Trucks are engaged in business or commercial activity and are on essential trips. Toll charges are a business expense and, in the aggregate, represent such a small proportion of trip cost that a toll change does not have a major effect on demand.

Impact of Toll Decreases

Information was obtained concerning nine instances in which bridge or tunnel tolls were reduced (Table 7). Six of these toll decreases were for passenger cars, the remaining three for trucks.

The toll decreases ranged from 8.5 to 50 percent. In eight of the nine instances, there was some increase in traffic after the toll reductions were made effective. In all cases, the increase in traffic was not nearly adequate to offset the decrease in rate of toll, with the result that reductions in revenue ranged from 5 to 37 percent.