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U. S. DEPARTMENT OF COMMERCE
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BUREAU OF PUBLIC ROADS
BERTRAM D. TALLAMY, Administrator
CHARLES D. CURTISS, Commissioner

Financial Planning for an Expanded Highway Program

BY THE DIVISION OF FINANCIAL AND ADMINISTRATIVE RESEARCH BUREAU OF PUBLIC ROADS

Reported [1] by G. P. St. CLAIR, Chief of Division, and THOMAS R. TODD, Transportation Economist

Of the nationwide estimate of $101 billion in immediate highway needs, $45 billion were found on the Federal-aid systems below the level of the Interstate; and $33 billion on roads and streets not eligible for Federal aid. Engineering plans to meet these needs must be matched by equally adequate financial plans. A successful financial plan should (1) provide for completion of the accelerated highway improvement program within the desired number of years; (2) take care of maintenance, administration, and other regular commitments of the highway department; (3) meet interest and principal charges on the debt, if any, incurred in financing the program; and (4) provide sufficient additional revenues to meet the gradually increasing needs for replacement and expansion in the years following completion of the program.

A technique for the examination of alternate financial plans, familiarly known as the "cut-and-fill" method, was applied to the needs of the Federal-aid systems (other than Interstate) as they might be found to exist in an average State. The indications are that substantial increases in the rates of State taxes for highways must be brought about if these systems are to be improved to adequacy within a reasonable number of years. Financing with current revenues only would require drastic tax increases during the period of the accelerated program, with the prospect of a considerable reduction after its close. By resort to bond issues such a program may be financed by a relatively moderate increase of tax rates extending over the entire period of the bond issue. Although the problem will be found different in each State and the decisions made will be governed by prevailing fiscal policy, the procedures for critical study of different financing proposals are applicable in all cases.

RECENT STUDIES of highway needs have supplied the figure of $101 billion as the investment necessary for an adequate road and street plant. Not unnaturally the spotlight has been thrown upon the Federal aspects of the problem, and especially upon the financial requirements of the National System of Interstate and Defense Highways. It is the purpose of this article to examine the needs of the highway systems below the Interstate level, in an effort to gauge the nature and magnitude of the financing problem as it would confront the average State.

Needs of the Several Road and Street Systems

In figure 1 a perspective is given on the nationwide highway problem as the estimates were worked out in the highway needs study of 1954. Highway systems are grouped into three classes: the Interstate system, other highways eligible for Federal aid, and non-Federal-aid highways, chiefly county and local roads and streets. Of the $101 billion ($100 billion in continental United States) in estimated 10-year needs, the Interstate system, as it was constituted in 1954, claims slightly less than a quarter. The recent addition of 2,300 miles in urban areas will probably raise the $23 billion estimate by $4 or $5 billion, part of which will be a net addition to the grand total. The needs of other Federal-aid highways total nearly $45 billion—not far from half; and those of non-Federal-aid roads and streets, $33 billion, or about one-third.

A facet of the problem that has perhaps received too little attention is that of the requirements for replacement and for increased highway capacity after the completion of the catch-up program of accelerated highway construction. Roads—even the best of them—neither endure nor remain adequate forever. Figure 1 shows by 5-year intervals the accrual of construction needs during the 20 years following the close of the projected 10-year improvement effort. Summation of the 5-year totals reveals that $114 billion in replacement and expansion needs will come due during this 20-year period—a total somewhat greater than the needed investment during the initial 10-year effort.

In figure 2 the needs of Federal-aid highways below the Interstate level are set forth for the primary rural system, for the secondary system, and for Federal-aid highways in urban areas. For the 10-year catch-up period the needs of the primary rural system are estimated at slightly less than $20 billion; those of the Federal-aid secondary system at about $15 billion; and the claims of the Federal-aid urban group are set at nearly $10 billion.

Here even more than in figure 1, the accruing needs after the close of the initial investment period compel attention. During the period 1965–84, Federal-aid primary rural roads (other than Interstate) will require expenditures of $25 billion for replacements and expansion, an amount exceeding the needs of the 10-year accelerated program by 25 percent. The urban routes, requiring as they do relatively large expenditures for the long-lived elements, right-of-way and structures, make relatively modest demands during the 20-year period; but the secondary system requires $21 billion, nearly 40 percent in excess of the outlay during the 10-year catch-up period.

The two sets of bars at the right of the graph give an indication of the accrual of highway needs in the two 5-year periods between 1985 and 1994. Although the values given do not have high standing as a forecast, it can be said that if normal expectancies with respect to needed replacement and needed additions to capacity come to pass, the highway needs during the fourth decade will be something like those shown in the chart. Long-term predictions such as this are useful in financial planning.

Figure 3 (p. 156) shows the needs accrual profiles for roads and streets not eligible for Federal aid, with a similar projection of the forecast to 1994. Here the ratios of replacement and expansion needs to those of the initial program are, relatively speaking, rather high. It is clear that on these lower highway systems the demand for a short-term catch-up program is less urgent than on the systems of greater traffic importance; but the need for a sustained effort over the long pull is plainly evident. This is especially true of the rural group, which includes some State highways, but mostly county and local roads. Replacement and expansion needs are very substantial even in the decade following the 10-year accelerated program. The extended forecast hints that needs in the fourth decade will be even greater than those of the first decade, or catch-up period.[2]

[1] This article was presented at the 35th Annual Meeting of the Highway Research Board, Washington, D. C., January 1956.

[2] A more thorough discussion of the estimated needs of the several road and street systems, as found in the study made pursuant to Section 13 of the Federal-Aid Highway Act of 1954, is given in the report, *Needs of the highway systems, 1955–84*, H. Doc. 120, 84th Cong., 1st sess.

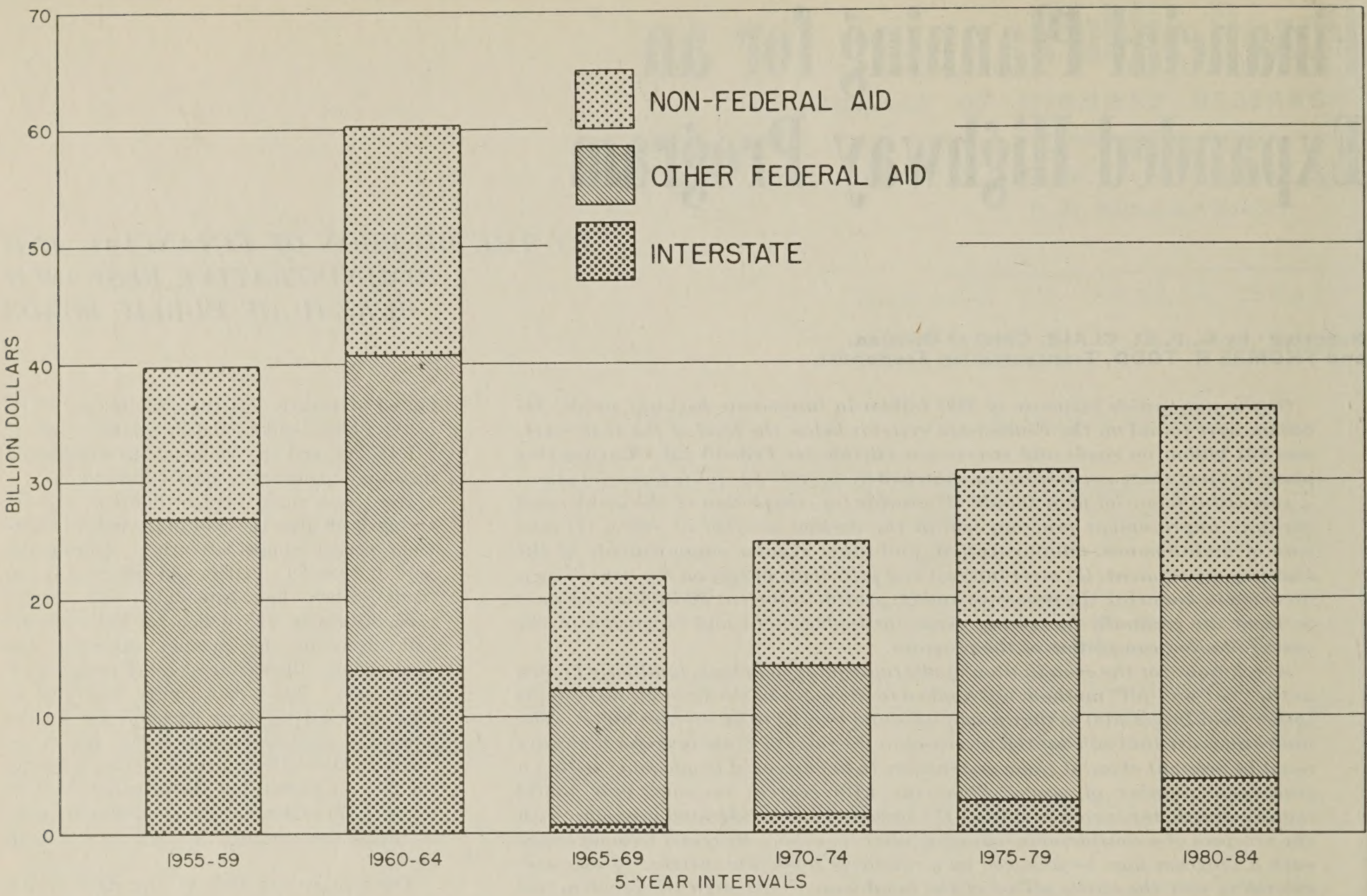

Figure 1.—Estimated highway needs of all roads and streets in the continental United States, 1955–84.

The data shown graphically in figures 1–3 are presented numerically in table 1.

Requirements of Financial Planning

These several needs profiles have been exhibited in order to underline the long-term character of the highway finance problem. In devising an accelerated program to satisfy immediate needs, no State can afford to neglect the accrual of further capital requirements in the years that follow. The task of financial planning, thus complicated by the necessity to peer into the future, is of equal difficulty and stature with that of engineering planning. An unusual combination of technical proficiencies, combining engineering, economics, and statistics, is needed for this work, both by the research and planning staffs of the highway departments and by the experts who may be called in as investigators or consultants.

A successful financial plan must meet four requisites: *First,* to provide for completion of the accelerated highway improvement program within the desired number of years; *second,* to take care of the expenses of maintenance, operation, administration, service of preexisting debt, and other regular commitments of the highway department; *third,* to meet interest and principal charges on the debt, if any, incurred in financing the new program; and *fourth,* to provide sufficient additional revenues to meet the gradually increasing needs for replacement and expansion in the years following completion of the program. The character of the plan best suited to a given situation is largely dependent on the relative magnitudes of the immediate highway needs and those that will accrue in later years. The alternatives range from current-revenue financing to a long-term bond-issue program.

The Cut-and-Fill Concept

A method of analysis designed to produce a plan meeting these requirements has become familiarly known as the cut-and-fill method. In schematic form the concept is illustrated by figure 4. The heavy curved line traces the profile of highway needs: First, those of the initial accelerated or catch-up period, 1956–65; and second, those of the ensuing three decades, during which the needs for replacement and upgrading or expansion of the system develop only gradually. It is evident that a needs profile of this shape lends itself readily to a system of financing whereby a large bond issue sold during the initial construction period can be retired during the ensuing period when replacement and expansion needs are at a minimum.

By inspection the year 1994 was taken as the limit of the bonding term, since the rate of increase of needs accruals begins to fall off at about that time. The heavy straight line represents the rate of revenue supply that will exactly balance needs at the year 1994; it subtends the same area as the profile of highway needs. The area above this line, lying between the years 1956 and 1965, represents bonds issued. The area, equal in size, lying below it and above the needs curve, and spanning the years 1966 to 1994, represents bonds retired. The representation is completed by computing interest at 2 percent in this example—the total revenue requirements of the program being traced by the broken line.

Although the solution is greatly oversimplified in figure 4, it will be observed that, granted the validity of the needs-accrual profile, the financing illustrated on the chart is entirely prudent, since the rate of increase of revenue supply is greater than the rate of increase of accruing needs at the year 1994.[3]

Application of Principle to Federal-Aid-System Needs

Application of the cut-and-fill principle to an actual situation requires a method of

[3] For somewhat similar treatments of bond-issue financing in relation to the accrual of highway needs, see *Supplemental bond financing for acceleration of the Ohio highway program,* by Bertram H. Lindman, Ohio Department of Highways, 1951; also *Economics of alternative highway programs,* by J. P. Buckley, Automotive Safety Foundation, Washington, D. C., June 1955.

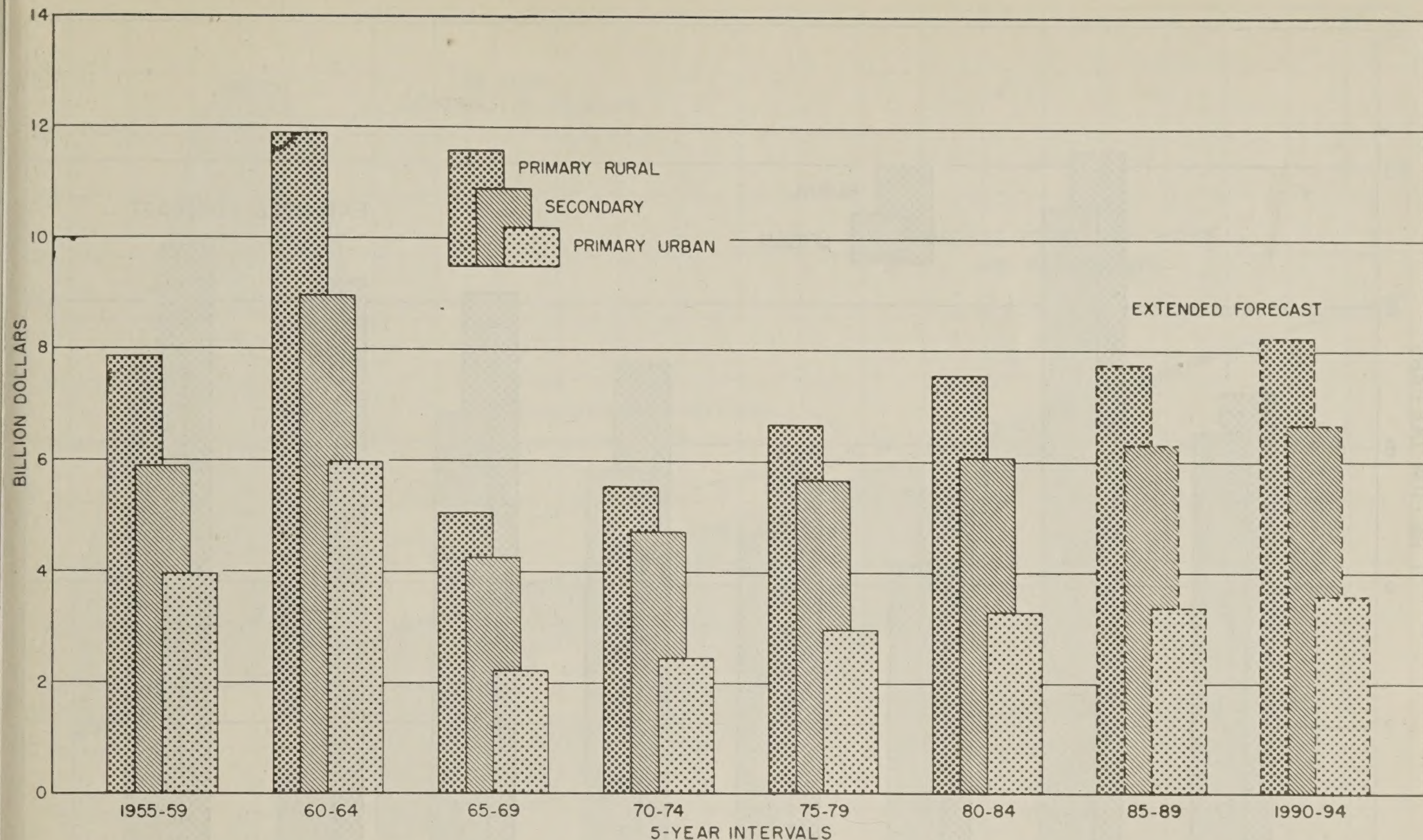

Figure 2.—Needs of the Federal-aid systems other than Interstate, with extended forecast to 1994.

successive approximations whereby the existing highway needs, the bond issue, and the required revenues are brought into a consistent relationship. The major ingredients are a long-term profile of highway needs and a forecast of available highway revenues at existing rates over the same period of years, both dependent for their validity upon an adequate forecast of travel volumes. The result is not a decision of policy, but in effect the determination of the maximum prudent bond issue and the minimum prudent increase in the level of highway taxes that will finance the needed improvement program.

To illustrate this method of analysis the needs of the Federal-aid systems (exclusive of the Interstate) in an average State have been taken. The dimensions of the problems are not dissimilar to those of the State highway system in such a State, since there are State highways not on the Federal-aid systems and,

Table 1.—Estimated highway needs [1] of all road and street systems in the continental United States, by 5-year intervals, 1955–94

Road system	Needs of 10-year catch-up period			Replacement and expansion needs following 10-year catch-up period						Grand total
	1955–59	1960–64	10-year total	1965–69	1970–74	1975–79	1980–84	1985–89	1990–94	
	Billion dollars	*Billion dollars*	*Billion dollars*	*Billion dollars*	*Billion dollars*	*Billion dollars*	*Billion dollars*	*Billion dollars*	*Billion dollars*	*Billion dollars*
Federal-aid systems:										
Interstate:										
Rural	5.0	7.5	12.5	0.4	0.9	1.4	2.4	3.4	3.8	24.8
Urban	4.2	6.5	10.7	.3	.7	1.3	2.2	2.9	3.1	21.2
Total	9.2	14.0	23.2	.7	1.6	2.7	4.6	6.3	6.9	46.0
Other Federal-aid highways:										
Primary:										
Rural	7.9	11.8	19.7	5.1	5.5	6.7	7.6	7.7	8.2	60.5
Urban	3.9	6.0	9.9	2.2	2.5	2.9	3.3	3.4	3.6	27.8
Subtotal	11.8	17.8	29.6	7.3	8.0	9.6	10.9	11.1	11.8	88.3
Secondary:										
On State highway systems	3.9	6.1	10.0	2.5	2.9	3.5	3.7	3.8	4.1	30.5
Not on State highway systems	2.0	2.9	4.9	1.7	1.8	2.2	2.4	2.5	2.6	18.1
Subtotal	5.9	9.0	14.9	4.2	4.7	5.7	6.1	6.3	6.7	48.6
Total, other Federal-aid highways	17.7	26.8	44.5	11.5	12.7	15.3	17.0	17.4	18.5	136.9
Total, all Federal-aid systems	26.9	40.8	67.7	12.2	14.3	18.0	21.6	23.7	25.4	182.9
Non-Federal-aid highways:										
Other State:										
Rural	1.5	2.2	3.7	1.1	1.1	1.4	1.6	1.7	1.7	12.3
Urban	.7	1.1	1.8	.4	.4	.4	.5	.5	.6	4.6
Subtotal	2.2	3.3	5.5	1.5	1.5	1.8	2.1	2.2	2.3	16.9
County and other local rural roads	5.3	7.9	13.2	4.3	4.8	5.8	6.5	6.7	7.1	48.4
Local urban streets	5.5	8.4	13.9	3.9	4.3	5.2	6.0	6.1	6.4	45.8
All non-Federal-aid highways:										
Rural	6.8	10.1	16.9	5.4	5.9	7.2	8.1	8.4	8.8	60.7
Urban	6.2	9.5	15.7	4.3	4.7	5.6	6.5	6.6	7.0	50.4
Total	13.0	19.6	32.6	9.7	10.6	12.8	14.6	15.0	15.8	111.1
Grand total, all roads and streets	39.9	60.4	100.3	21.9	24.9	30.8	36.2	38.7	41.2	294.0

[1] The estimates of highway needs presented in this table are also given, in somewhat more abbreviated form, in the report *Needs of the highway systems, 1955–84*, H. Doc. No. 120, 84th Cong., 1st sess., with the exception that the forecast of future needs is here extended through the year 1994.

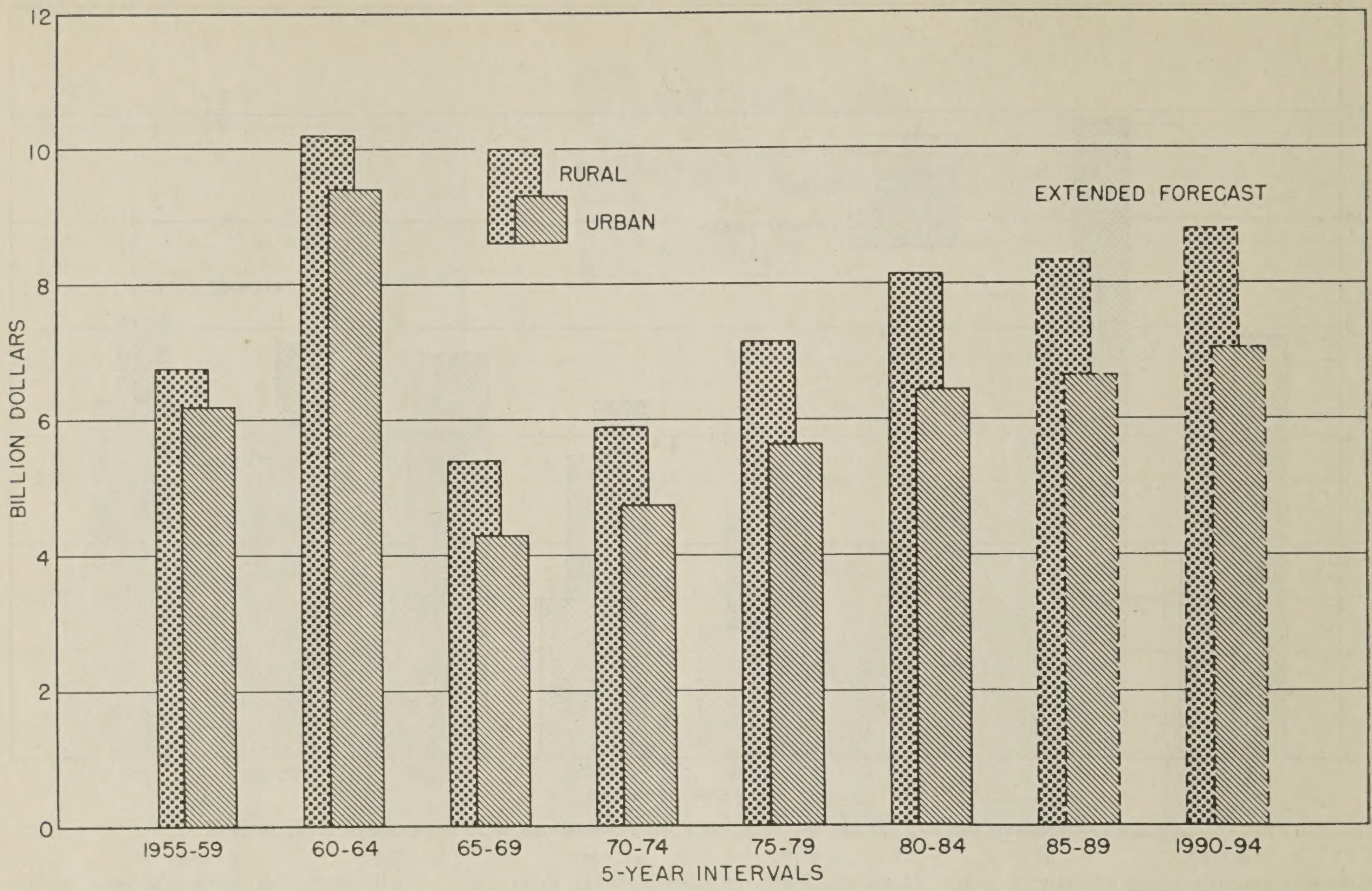

Figure 3.—Needs of road and street systems other than Federal-aid, with extended forecast to 1994.

conversely, Federal-aid secondary highways not on the State highway systems. For reduction to the scale of an average State, nationwide figures, in general, have been divided by 50.

Figure 5 depicts three alternative needs-accrual profile curves for the combined Federal-aid systems (primary rural, primary urban, and secondary) in an average State. Corresponding data are given in table 2. Since the year 1955 is behind us, the time period is taken as 1956–95. The original nationwide highway needs study was based on the assumption of a 10-year catch-up program. In this chart, however, the alternates of a 12-year and a 15-year program are also contemplated. In making the choice between them, a State would have to weigh the advantages of achieving adequacy at an early date against the difficulties in financing, in manpower, and in industrial and organizational capacity of a rapidly stepped-up program.

Because of the probability that a program to be legislated and put into motion in 1956 would have only a minor effect on construction expenditures in that year, the value $48.5 million, predicted on the basis of recent trends, was taken as the 1956 total for all three programs. In each case the expenditures of the catch-up program period have been scheduled so as to rise to a maximum and then recede toward the relatively low level of annual replacement and expansion requirements during the years immediately following the conclusion of the accelerated program.

The differences among the three initial programs are apparent: Average annual expenditures for the 10-, 12-, and 15-year catch-up programs are, respectively, $89, $81, and $73 million. Their cumulative totals, $893, $970, and $1,098 million, respectively, differ because of the accrual of further needs during the longer program periods. Beyond the year 1972 the differences in the accrual of needs are not great. For that reason, and to avoid confusion in the plotting, only the profile of needs for the period following the 12-year program is shown.

Revenues Predicted at Existing Rates

In table 3 and figure 6 we have the second major ingredient of the recipe—highway revenues available to the Federal-aid systems (exclusive of Interstate), as predicted at current tax rates. The left-hand panel shows them classified by source; the right-hand panel by object of expenditure. The predicted revenues rise from $51 million in 1956 to $76 million in 1975 and $100 million in 1995.

By far the largest proportion comes from State revenues—69 percent in 1956, rising to 78 percent in 1975, and 83 percent in 1995. In the year 1954, State government revenues for highways were derived 93 percent from road-user taxes, 4 percent from highway tolls, and 3 percent from general-fund appropriations and miscellaneous sources. For these calculations user-tax revenues were predicted on the basis of the forecasts of travel volume furnished by all States in the 1954 study, with adjustments for increases in user-tax rates since that time. To avoid a separate prediction of the future course of toll revenues, available to the lower Federal-aid systems chiefly from toll bridges, funds from this source as well as miscellaneous receipts were assumed to increase proportionately with user-tax revenues.

Increases in local road and street revenues were estimated by reference to recent trends and the predicted trends of general economic indexes.

In order to have an entirely neutral estimate of future Federal-aid receipts, it was assumed that the current annual authorizations of $315 million for the Federal-aid primary system, $210 million for the Federal-aid secondary system, and $175 million for Federal-aid highways in urban areas would be available in the future for the Federal-aid systems outside of Interstate. The annual total is $700 million or $14 million for the average State.

In the right-hand panel of figure 6, exactly the same revenues are subdivided by object of expenditure. The area shown at the top of the chart and diminishing with the years represents the service of highway debt contracted prior to the inception of the new

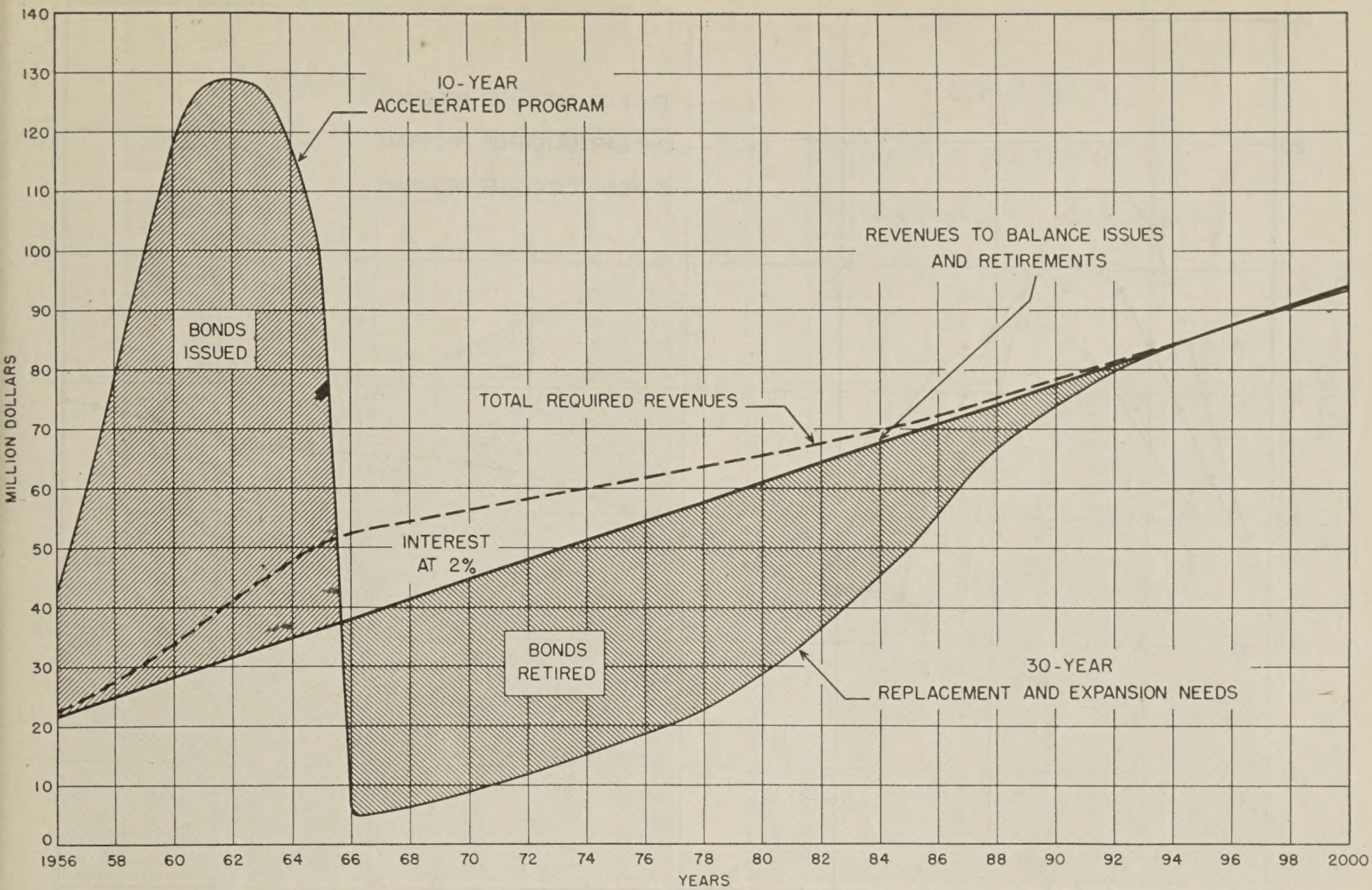

Figure 4.—Illustration of the cut-and-fill concept in financial planning for highways.

program. Beneath this, the predicted expenses of maintenance, operation, and administration are shown, and the net revenues available for capital outlay are given at the base of the chart.

The apparent dip in the trend of funds available for construction during the first few years results from an allowance for special administrative expenses, roughly proportional to capital outlays, during the period of accelerated construction activity. Ignoring this minor variation, it is found that funds available for construction increase from $31 million out of a total of $51 million, or 61 percent, in 1956; to $52 million out of $76 million, or 69 percent, in 1975; and to $74 million (and percent) out of $100 million in 1995. Involved in this trend is the assumption, not unreasonable but of course not inevitable, that the expenses of maintenance, operation, and administration will increase somewhat less rapidly than travel volumes and the revenues derived therefrom, thus gradually releasing a larger proportion for capital outlay.

Needs and Revenues Compared

A comparison of predicted capital needs with predicted revenues available for construction is given in table 4 and figure 7 (p. 160) for each of the three alternate catch-up periods, 10, 12, and 15 years, and for the ensuing decades. In the three upper panels of figure 7, values are expressed in millions of dollars. In the lower panels they are converted to equivalent amounts in cents per gallon of State motor-fuel tax. This procedure takes some liberties with the data, since motor-fuel taxes are only one (although the largest) of the sources from which the revenues of the Federal-aid systems are and will be derived. Equivalent cents per gallon has been found, however, to be the most convenient and most easily visualized unit by means of which predicted revenues may be compared with those required to finance a highway program. In actual practice the required increase in revenues may be distributed among various revenue sources, including increased motor-vehicle imposts, State general funds, highway tolls, local taxes, and Federal funds, as well as the State motor-fuel tax.

The conversion to equivalent cents per gallon was made by the use of a rate of motor-fuel consumption, applicable to all motor vehicles as a group, of 12.73 miles per gallon. On this basis the revenue produced by a tax of 1 cent per gallon is equivalent to about 0.79 mill per mile of travel. Estimates of total vehicle-miles in each year were based on the forecasts made in connection with the 1954 nationwide study of highway needs. No adjustment was made for increased travel volumes and consequent increased revenues resulting from earlier completion of the needed construction under the 10- and 12-year catch-up programs.

Table 2.—Estimated 10-, 12-, and 15-year catch-up programs for the combined Federal-aid systems (exclusive of Interstate) in an average State, with forecasts of needs through 1995

Time period	Estimated construction needs		
	10-year program	12-year program	15-year program
	Million dollars	*Million dollars*	*Million dollars*
1956	48.5	48.5	48.5
1957	60.4	57.2	52.8
1958	76.1	66.8	58.2
1959	91.9	77.4	64.7
1960	106.7	87.9	71.7
1961	112.7	96.6	79.3
1962	112.8	101.4	86.3
1963	107.9	101.3	90.1
1964	97.6	97.3	91.0
1965	78.2	90.4	89.8
1966	------	79.7	87.0
1967	------	66.0	83.0
1968	------	------	75.8
1969	------	------	66.3
1970	------	------	53.6
1975	56.6	56.2	55.8
1985	68.9	68.9	69.9
1995	77.4	77.1	76.6
Program totals:			
10-year, 1956–65	892.8	------	------
12-year, 1956–67	------	970.5	------
15-year, 1956–70	------	------	1,098.1
10-year, 1966–75	496.0	------	------
12-year, 1968–75	------	407.5	------
15-year, 1971–75	------	------	261.8
All programs, 1976–85	656.2	653.4	652.6
All programs, 1986–95	727.7	726.8	725.0
All programs, 1956–95	2,772.7	2,758.2	2,737.5

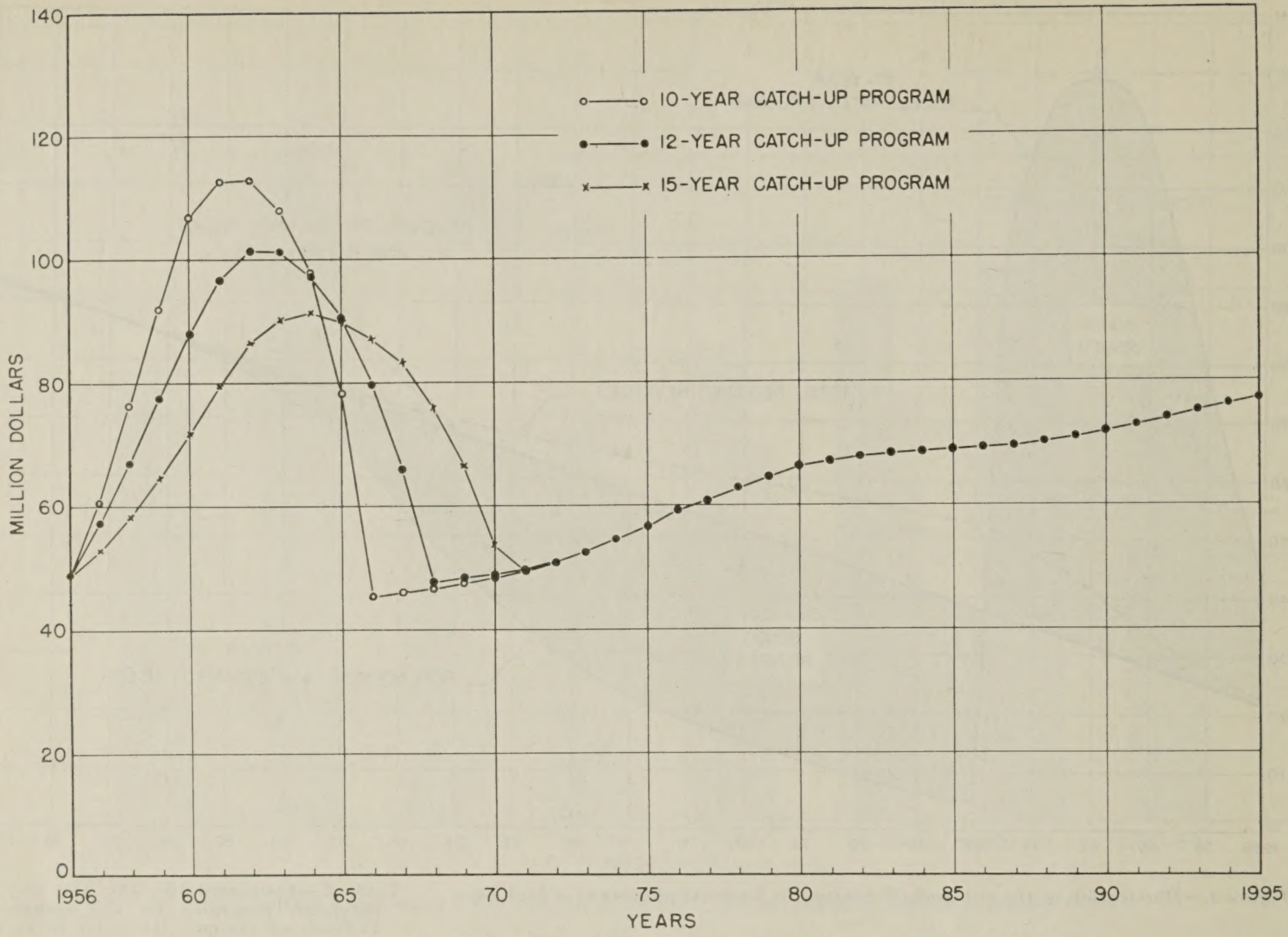

Figure 5.—Needs of the Federal-aid systems in an average State, exclusive of Interstate.

The range in values of annual travel volume in an average State and that of the corresponding yield of 1 cent per gallon State motor-fuel tax are illustrated as follows:

Year	*Annual vehicle-miles of travel*	*Annual yield of motor-fuel tax*
	Millions	*$1,000*
1956	12, 153	9, 547
1965	16, 071	12, 624
1975	20, 258	15, 913
1985	24, 609	19, 332
1995	28, 243	22, 186

The comparison of revenues with needs in figure 7 is presented in pairs of contiguous bars. Heavy dimension arrows indicate the excess of needs over revenues—the additional revenue required under the condition of current revenue financing. In the left-hand panels it is indicated that it would take $893 million or the equivalent of 8.0 cents per gallon of motor-fuel tax to pay the cost of the 10-year catch-up program in this average State. Revenues predicted at current tax rates amount to $344 million, the equivalent of 3.1 cents per gallon. It would take a raise in revenues equivalent to 4.9 cents per gallon to finance this program out of current income. After the close of the 10-year catch-up period, predicted revenues would be very nearly sufficient to meet the accrual of replacement and expansion needs.

A similar story is told in the center and right-hand panels. To meet the needs of the 12-year accelerated program in the years 1956–67 would require additional revenues equivalent to a motor-fuel tax of 4.0 cents per gallon. The 15-year program would require an increase equivalent to 3.0 cents per gallon, making the total requirement nearly double the amount of revenues predicted to be available for capital outlay during the period 1956–70.

This is the picture of current revenue financing, if the goal of producing an adequate highway plant in a reasonable time is to be achieved. It requires a formidable, although perhaps not unthinkable, increase in highway tax rates during the period of accelerated investment. There is a temptation, when confronted with a situation like this, to lower one's sights and decide to "make-do" with something less than adequacy in highway provision and service. Credit financing, however, offers an alternative by which the desired goal may be achieved without putting quite so much strain upon the pocket nerve of the user-taxpayer.

40-Year Bond-Issue Plan

Figure 8 portrays the results of a calculation designed to finance the 12-year catch-up program, plus accruing needs over the following 28 years, by means of a bond issue the total term of which would cover the entire 40-year period. For illustrative purposes the needs-accrual profile has been extended another 5 years. Only capital items relating to the 40-year period are shown, the costs of maintenance, administration, and service of preexisting debt having been deducted at the outset.

Bonds issued, indicated by the mountainous crosshatched area at the left of the chart, amount to $408 million out of a total 12-year investment of $970 million. The equal amount of bonds retired over the ensuing 28 years is shown in similar hatching with reversed slope. The light stippled area represents interest, computed at 2½ percent per year—a rate perhaps somewhere near a median for State issues that may include revenue and limited-obligation bonds as well as those backed by the faith and credit of the State. Total interest payments amount to $243 million over the 40-year period, an average of $6.1 million per year. Interest accounts for only 6.1 percent of the total revenues required for the entire period, or 8.1 percent of the money put into new capital outlay and interest.

The massive area of heavy stipple at the base of the chart represents current revenues applied directly to construction. During the

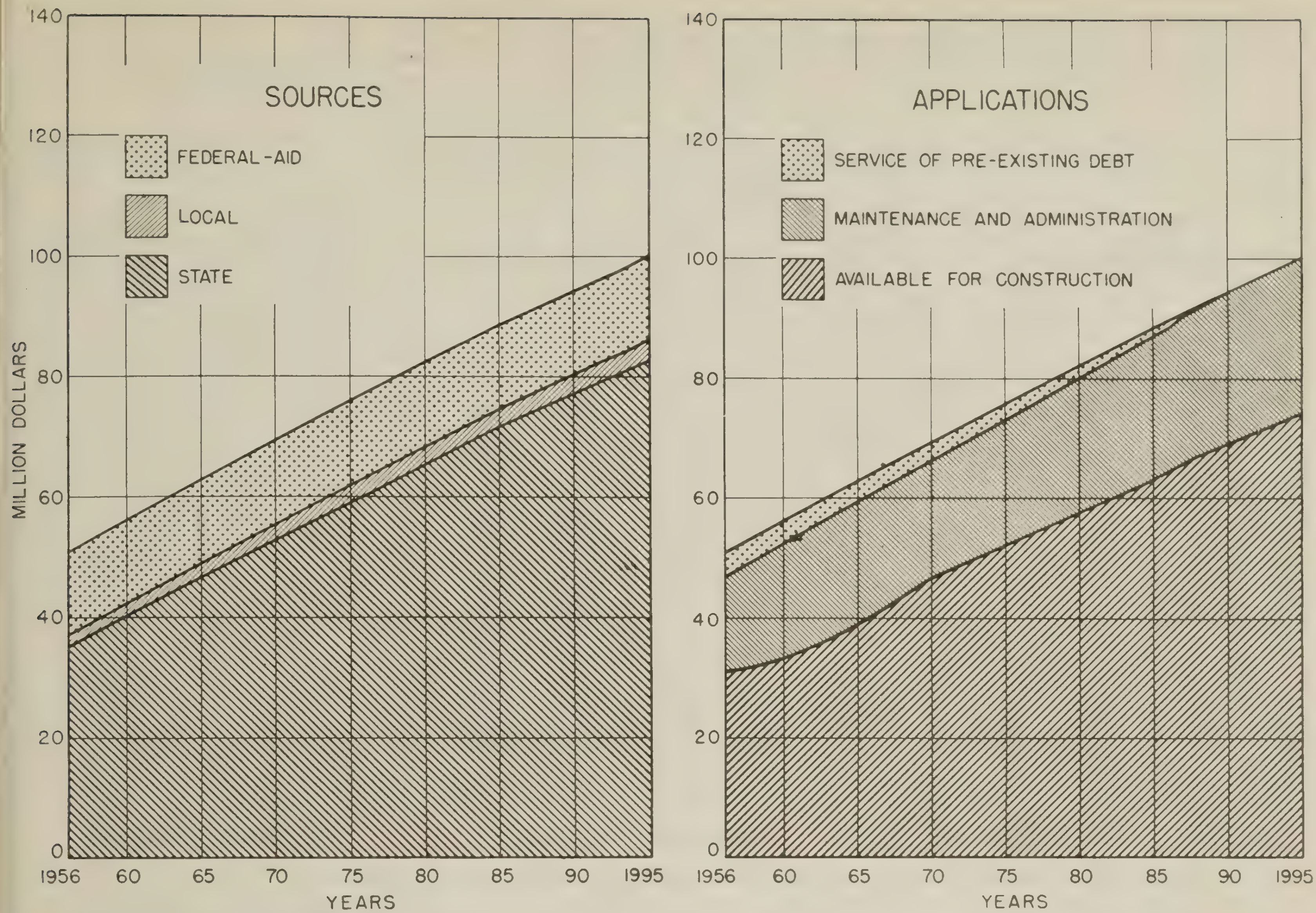

Figure 6.—Predicted revenues of an average State available for the Federal-aid systems, exclusive of Interstate.

nitial 12-year period direct capital outlays of $562 million account for 58 percent of the total capital investment in highways; bond issues for 42 percent. Since all capital outlays in the ensuing 28 years are made out of current revenues, it is clear that the bond issue, although large, plays only a fractional part in the total financial plan.

Table 3.—Predicted revenues of an average State, assuming the continuation of current rates of taxation, available for the combined Federal-aid systems (exclusive of Interstate) for the years 1956–95

Time period	Source of funds				Application of funds (12-year program)		
	Federal aid	State	Local	Total	Service of preexisting debt	Maintenance and administration	Revenue available for capital outlay
	Million dollars	*Million dollars*	*Million dollars*	*Million dollars*	*Million dollars*	*Million dollars*	*Million dollars*
1956	14.0	35.4	1.6	51.0	3.7	15.9	31.4
1957	14.0	36.7	1.6	52.3	4.0	16.6	31.7
1958	14.0	38.0	1.7	53.7	3.9	17.4	32.4
1959	14.0	39.3	1.7	55.0	3.8	18.3	32.9
1960	14.0	40.6	1.8	56.4	3.7	19.2	33.5
1961	14.0	41.9	1.8	57.7	3.7	19.9	34.1
1962	14.0	43.2	1.8	59.0	3.5	20.4	35.1
1963	14.0	44.4	1.9	60.3	3.4	20.7	36.2
1964	14.0	45.7	1.9	61.6	3.3	20.8	37.5
1965	14.0	46.9	2.0	62.9	3.3	20.6	39.0
1966	14.0	48.1	2.1	64.2	3.1	20.4	40.7
1967	14.0	49.3	2.1	65.4	3.0	19.9	42.5
1975	14.0	59.2	2.5	75.7	2.3	21.3	52.1
1985	14.0	72.1	2.9	89.0	1.6	23.9	63.5
1995	14.0	83.0	3.3	100.3	--------	26.0	74.3
Period totals:							
1956–67	168.0	509.5	22.0	699.5	42.4	230.1	427.0
1968–75	112.0	439.0	18.3	569.3	20.9	161.8	386.6
1976–85	140.0	663.1	26.9	830.0	19.1	228.7	582.2
1986–95	140.0	779.7	30.9	950.6	3.0	250.5	697.1
Cumulative total, 1956–95	560.0	2,391.3	98.1	3,049.4	85.4	871.1	2,092.9

Predicted revenues at current tax rates are shown by the heavy continuous line. The total revenues required to finance the program are traced by the heavy stepped line above the stippled area denoting interest. The area between these two revenue lines, denoted by the dimension lines at the right of the chart, represents the revenues required in excess of those predicted. Expressed in equivalent State motor-fuel tax, these additional required revenues amount to 1.415 cents per gallon in each year. Similar calculations made for the 10- and 15-year programs indicate additional revenue requirements equivalent to 1.47 and 1.34 cents per gallon, respectively. If, as seems not unlikely at the time of writing, new Federal-aid legislation should materially increase the authorizations for Federal-aid highways below the Interstate level, the necessity for increased State taxation to finance Federal-aid needs will be correspondingly reduced.

The calculation illustrated in figure 8 serves to demonstrate the manner in which a continuous and gradually increasing flow of revenues may be used to finance a construction program greatly accelerated in a short period of years, to be followed by a relatively moderate buildup of replacement and expan-

Table 4.—Comparison of available revenues with construction needs for the Federal-aid systems (excluding Interstate) in an average State, and the equivalent State motor-fuel tax required to meet those needs

Time period	Estimated construction needs and revenues					Equivalent State motor-fuel tax required to meet construction needs				
	Construction needs	Predicted revenues			Additional required revenues	Construction needs	Predicted revenues			Additional required revenues
		State and local funds	Federal-aid funds	Subtotal			State and local funds	Federal-aid funds	Subtotal	
	Million dollars	*Million dollars*	*Million dollars*	*Million dollars*	*Million dollars*	*Cents/gal.*	*Cents/gal.*	*Cents/gal.*	*Cents/gal.*	*Cents/gal.*
10-year catch-up program:										
1956–65	892.8	203.8	140.0	343.8	549.0	8.035	1.834	1.260	3.094	4.941
1966–75	496.0	329.8	140.0	469.8	26.2	3.438	2.286	.971	3.257	.181
1976–85	656.2	442.2	140.0	582.2	74.0	3.687	2.485	.787	3.272	.415
1986–95	727.7	557.1	140.0	697.1	30.6	3.488	2.670	.671	3.341	.147
Total, 1966–95	1,879.9	1,329.1	420.0	1,749.1	130.8	--------	--------	--------	--------	--------
Average, 1966–95	--------	--------	--------	--------	--------	3.541	2.504	.791	3.295	.246
Total, 1956–95	2,772.7	1,532.9	560.0	2,092.9	679.8	--------	--------	--------	--------	--------
Average, 1956–95	--------	--------	--------	--------	--------	4.319	2.388	.872	3.260	1.059
12-year catch-up program:										
1956–67	970.5	259.0	168.0	427.0	543.5	7.066	1.885	1.223	3.108	3.958
1968–75	407.5	274.6	112.0	386.6	20.9	3.452	2.326	.949	3.275	.177
1976–85	653.4	442.2	140.0	582.2	71.2	3.672	2.485	.787	3.272	.400
1986–95	726.8	557.1	140.0	697.1	29.7	3.483	2.670	.671	3.341	.142
Total, 1968–95	1,787.7	1,273.9	392.0	1,665.9	121.8	--------	--------	--------	--------	--------
Average, 1968–95	--------	--------	--------	--------	--------	3.367	2.400	.738	3.138	.229
Total, 1956–95	2,758.2	1,532.9	560.0	2,092.9	665.3	--------	--------	--------	--------	--------
Average, 1956–95	--------	--------	--------	--------	--------	4.296	2.388	.872	3.260	1.036
15-year catch-up program:										
1956–70	1,098.1	354.0	210.0	564.0	534.1	6.129	1.976	1.172	3.148	2.981
1971–75	261.8	179.6	70.0	249.6	12.2	3.435	2.357	.918	3.275	.160
1976–85	652.6	442.2	140.0	582.2	70.4	3.667	2.485	.787	3.272	.395
1986–95	725.0	557.1	140.0	697.1	27.9	3.474	2.670	.671	3.341	.133
Total, 1971–95	1,639.4	1,178.9	350.0	1,528.9	110.5	--------	--------	--------	--------	--------
Average, 1971–95	--------	--------	--------	--------	--------	3.088	2.221	.659	2.880	.208
Total, 1956–95	2,737.5	1,532.9	560.0	2,092.9	644.6	--------	--------	--------	--------	--------
Average, 1956–95	--------	--------	--------	--------	--------	4.264	2.388	.872	3.260	1.004

sion needs over a long period. The term of the bond-issue plan (40 years in total, although no bonds would be issued for more than 30) may arouse some objections. The two facts (1) that the financing takes care of all needs for initial construction, replacement, and upgrading during the 40-year period, and (2) that at the close of the period the rate of revenue supply is considerably in excess of the rate of accrual of needs, should be sufficient to quiet such fears. The excess of predicted revenues over predicted requirements may be regarded as a safeguard against unforeseen contingencies.

In a calculation of this sort, the length of

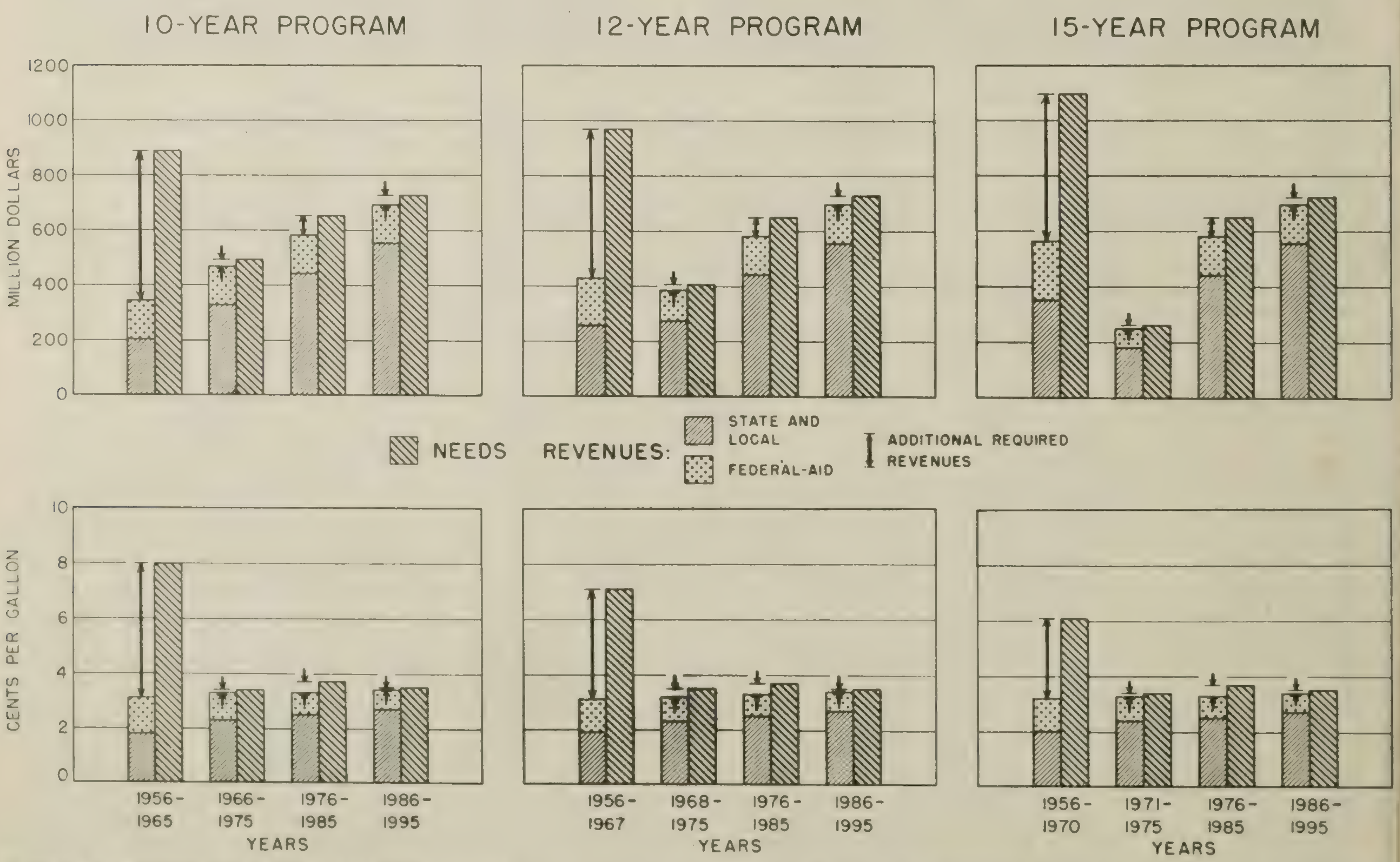

Figure 7.—Comparison of available revenues with construction needs for the Federal-aid systems (excluding Interstate) in an average State, and the equivalent State motor-fuel tax required to meet those needs.

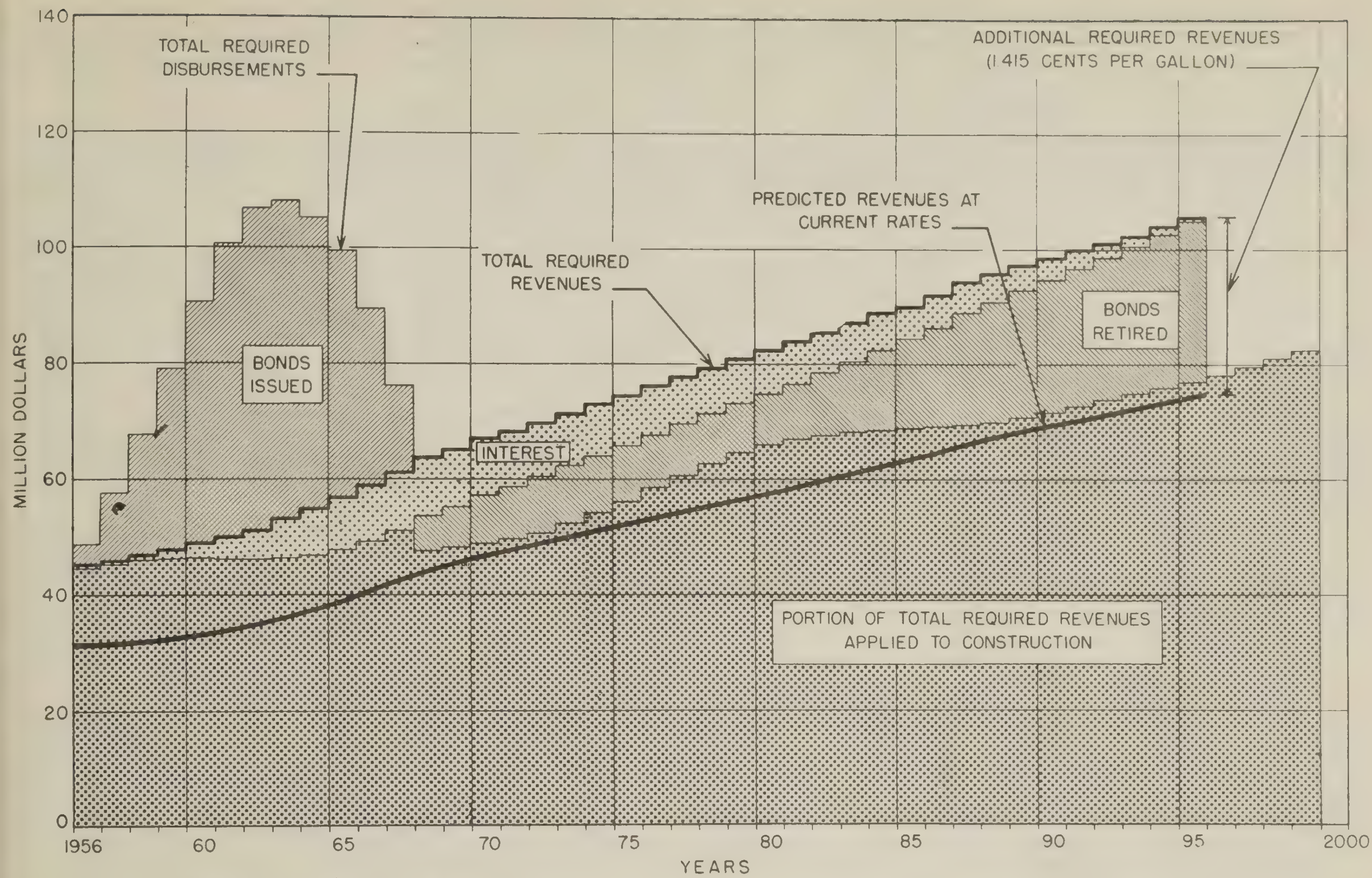

Figure 8.—Calculation of 40-year bond-financing plan for the Federal-aid systems, exclusive of Interstate.

the bonding term is contingent upon the composite life span of the highway investment in right-of-way, grading, surfacing, and structures. The results, therefore, tend to set bounds of prudence to (1) term of bond issue, (2) amount of bond issue, and (3) amount or rate of increase in supporting revenues, the limit in the latter case being minimum rather than maximum. In working out the financial plan for an individual State, consideration must be given to other factors, including the general financial situation in the State government, established public policy, and popular attitudes toward credit financing. Alternative plans, with varying terms of bond issue and varying levels of increased revenues, must necessarily be developed before a decision is reached.

Method of Calculation

The procedure in the cut-and-fill method of bond-issue calculation is one of successive approximations. Since the profile of needs and the schedule of predicted revenues are known, it is only necessary to determine the rate of *additional* revenue supply that will accomplish the desired financing in the chosen period of years. The estimated additional revenues can be expressed in terms of cents per vehicle-mile of travel, or as in figure 8, in equivalent cents per gallon of State motor-fuel tax. The first estimate, and the calculation based on it, may be wide of the mark; but repeated estimates will rapidly converge toward a rate of increased revenues that will just pay off the bond issue in the year selected as the final date of retirement.

The process of calculation is illustrated by table 5 which gives values for each year of the entire 40-year period. In order that the variation of the smaller items may be readily traced, values are given to the nearest thousand dollars. Essentially the computation consists of a year-by-year determination of the following quantities: Bonds to be issued or retired in the year; the amount of revenues directly applicable to construction; and the required interest payments.

The following formulas have been found useful in the calculations for the initial program period, or period of bond issuance. They are based on the assumptions that no bonds will be retired during the issuing period and that the bonds for each year are issued at the beginning of the year.

Let N = Highway needs of a given year.
D = Debt outstanding at end of preceding year.
B = Bonds issued in given year.
I = Total interest paid in year.
R = Total revenues available in year.

Then, if receipts and expenditures balance—

$$R+B=N+I$$
$$B=N-R+I$$

Let i = Annual rate of interest.

Then $$I=i(D+B)$$
$$=i(D+N-R+I)$$

Transposing,

$$I(1-i)=i(D+N-R)$$
$$I=\frac{i}{1-i}(D+N-R) \qquad (1)$$

Solving for B,

$$B=N-R+I$$
$$=N-R+\frac{i}{1-i}(D+N-R)$$
$$=\frac{N-R+iD}{1-i} \qquad (2)$$

These formulas may be readily adapted to varying circumstances of bond issuance and retirement.

Conclusion

Some of the alternatives that may be explored in the analysis leading to a financial plan have been outlined. Under conditions such as those depicted, current revenue financing requires drastic tax increases during the initial catch-up period, with only moderate rates in the ensuing decades. A long-term bonding plan may be financed with a relatively small increase in tax rates, sustained throughout the period. Intermediate choices are offered by bond issues of shorter term, requir-

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Table 5.—Calculation of a 40-year bond financing plan for combined Federal-aid systems (exclusive of Interstate) in an average State

Year	Required expenditures						Required revenues						Credit financing		
	Program needs and commitments				Interest on new financing at 2½ percent	Total	Amounts predicted at current tax rates				Additional required revenues [1]	Total	Bonds issued (Jan. 1)	Bonds retired (Dec. 31)	Bonds outstanding (Dec. 31)
	Capital outlay	Maintenance and administration	Service of debt outstanding at end of 1955	Total			Federal aid	State revenues	Local rural and urban revenues	Total					
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
1956	48,520	15,849	3,700	68,069	92	68,161	14,000	35,380	1,580	50,960	13,509	64,469	3,692		3,692
1957	57,160	16,627	3,980	77,767	389	78,156	14,000	36,660	1,620	52,280	14,003	66,283	11,873		15,565
1958	66,770	17,455	3,880	88,105	909	89,014	14,000	38,020	1,660	53,680	14,525	68,205	20,809		36,374
1959	77,350	18,353	3,840	99,543	1,688	101,231	14,000	39,340	1,720	55,060	15,022	70,082	31,149		67,523
1960	87,920	19,166	3,740	110,826	2,728	113,554	14,000	40,660	1,760	56,420	15,515	71,935	41,619		109,142
1961	96,560	19,902	3,720	120,182	3,991	124,173	14,000	41,900	1,800	57,700	15,980	73,680	50,493		159,635
1962	101,410	20,423	3,500	125,333	5,371	130,704	14,000	43,160	1,860	59,020	16,462	75,482	55,222		214,857
1963	101,320	20,692	3,400	125,412	6,743	132,155	14,000	44,440	1,900	60,340	16,943	77,283	54,872		269,729
1964	97,340	20,761	3,340	121,441	8,004	129,445	14,000	45,660	1,960	61,620	17,404	79,024	50,421		320,150
1965	90,450	20,620	3,240	114,310	9,070	123,380	14,000	46,880	1,980	62,860	17,863	80,723	42,657		362,807
1966	79,670	20,342	3,120	103,132	9,833	112,965	14,000	48,100	2,040	64,140	18,327	82,467	30,498		393,305
1967	65,990	19,916	2,980	88,886	10,204	99,090	14,000	49,340	2,080	65,420	18,793	84,213	14,877		408,182
Subtotal, 1956–67	970,460	230,106	42,440	1,243,006	59,022	1,302,028	168,000	509,540	21,960	699,500	194,346	893,846	408,182		
1968	47,600	19,229	2,920	69,749	10,204	79,953	14,000	50,560	2,140	66,700	19,257	85,957		6,004	402,178
1969	48,200	19,512	2,860	70,572	10,054	80,626	14,000	51,800	2,180	67,980	19,724	87,704		7,078	395,100
1970	48,900	19,779	2,620	71,299	9,877	81,176	14,000	53,040	2,220	69,260	20,189	89,449		8,273	386,827
1971	49,700	20,051	2,620	72,371	9,671	82,042	14,000	54,200	2,260	70,460	20,626	91,086		9,044	377,783
1972	50,600	20,307	2,700	73,607	9,445	83,052	14,000	55,460	2,300	71,760	21,088	92,848		9,796	367,987
1973	52,200	20,620	2,480	75,300	9,200	84,500	14,000	56,700	2,360	73,060	21,569	94,629		10,129	357,858
1974	54,100	20,949	2,400	77,449	8,946	86,395	14,000	57,980	2,400	74,380	22,054	96,434		10,039	347,819
1975	56,200	21,287	2,280	79,767	8,695	88,462	14,000	59,220	2,440	75,660	22,517	98,177		9,715	338,104
Subtotal, 1968–75	407,500	161,734	20,880	590,114	76,092	666,206	112,000	438,960	18,300	569,260	167,024	736,284		70,078	
1976	58,500	21,615	2,080	82,195	8,453	90,648	14,000	60,500	2,500	77,000	23,002	100,002		9,354	328,750
1977	60,700	21,938	2,000	84,638	8,219	92,857	14,000	61,800	2,540	78,340	23,488	101,828		8,971	319,779
1978	62,900	22,239	1,980	87,119	7,994	95,113	14,000	63,100	2,580	79,680	23,977	103,657		8,544	311,235
1979	64,700	22,541	1,940	89,181	7,781	96,962	14,000	64,420	2,620	81,040	24,464	105,504		8,542	302,693
1980	66,100	22,844	2,000	90,944	7,567	98,511	14,000	65,700	2,660	82,360	24,951	107,311		8,800	293,893
1981	67,000	23,079	2,040	92,119	7,347	99,466	14,000	66,960	2,720	83,680	25,428	109,108		9,642	284,251
1982	67,700	23,304	1,860	92,864	7,106	99,970	14,000	68,240	2,760	85,000	25,902	110,902		10,932	273,319
1983	68,300	23,524	1,840	93,664	6,833	100,497	14,000	69,500	2,800	86,300	26,377	112,677		12,180	261,139
1984	68,600	23,708	1,760	94,068	6,528	100,596	14,000	70,780	2,840	87,620	26,858	114,478		13,882	247,257
1985	68,900	23,870	1,640	94,410	6,181	100,591	14,000	72,100	2,860	88,960	27,355	116,315		15,724	231,533
Subtotal, 1976–85	653,400	228,662	19,140	901,202	74,009	975,211	140,000	663,100	26,880	829,980	251,802	1,081,782		106,571	
1986	69,200	24,054	1,340	94,594	5,788	100,382	14,000	72,940	2,940	89,880	27,660	117,540		17,158	214,375
1987	69,600	24,305	500	94,405	5,359	99,764	14,000	74,140	2,960	91,100	28,100	119,200		19,436	194,939
1988	70,100	24,541	440	95,081	4,873	99,954	14,000	75,300	3,000	92,300	28,539	120,839		20,885	174,054
1989	70,900	24,750	200	95,850	4,351	100,201	14,000	76,360	3,040	93,400	28,934	122,334		22,133	151,921
1990	71,800	24,964	180	96,944	3,798	100,742	14,000	77,440	3,060	94,500	29,330	123,830		23,088	128,833
1991	72,900	25,168	160	98,228	3,221	101,449	14,000	78,500	3,120	95,620	29,725	125,345		23,896	104,937
1992	74,000	25,371	100	99,471	2,624	102,095	14,000	79,560	3,140	96,700	30,120	126,820		24,725	80,212
1993	75,100	25,595		100,695	2,005	102,700	14,000	80,620	3,180	97,800	30,514	128,314		25,614	54,598
1994	76,100	25,794		101,894	1,365	103,259	14,000	81,800	3,240	99,040	30,954	129,994		26,735	27,863
1995	77,100	26,013		103,113	697	103,810	14,000	82,980	3,300	100,280	31,393	131,673		27,863	
Subtotal, 1986–95	726,800	250,555	2,920	980,275	34,081	1,014,356	140,000	779,640	30,980	950,620	295,269	1,245,889		231,533	
Grand total	2,758,160	871,057	85,380	3,714,597	243,204	3,957,801	560,000	2,391,240	98,120	3,049,360	908,441	3,957,801		408,182	

[1] Equivalent to 1.415 cents per gallon of State motor-fuel tax.

ing greater revenue increases at the outset but less total cost. The suitability of different solutions depends in large part upon the contour of the needs-accrual profile. If the immediate needs are large in comparison with those of the next two or three decades, a long-term bond issue such as that portrayed in figure 8 is a valid solution. If the immediate needs are only moderate in comparison with those of subsequent years, either current revenue or short-term bond-issue financing is indicated.

The necessity to pay interest makes all bond-issue financing of greater total cost to the State than financing with current funds. That the cost to the taxpayers may be less rather than more is sometimes overlooked. Those who contribute to the support of the highways have alternate uses for their money, yielding either profits or tangible satisfactions, which they must forego in part if increased taxes are paid. The extent of the sacrifice is best measured by the interest-earning power of the money if invested privately, which would generally be more than it would cost the State to borrow the same funds. Thus a bond issue may give highway users and other taxpayers a better bargain than a drastic raise in taxes to finance a current revenue plan.

Applications of Electrical Resistivity Measurements to Subsurface Investigations

BY THE DIVISION OF PHYSICAL RESEARCH
BUREAU OF PUBLIC ROADS

Reported [1] by R. WOODWARD MOORE, Head, Geophysical Explorations Unit

There has been a constantly growing trend towards the use of the earth-resistivity test on a wide variety of subsurface problems in many parts of the world. In this country the Bureau of Public Roads has been one of the pioneers in establishing the practical application of geophysical test procedures to highway construction problems. Use of the geophysical tests, the earth-resistivity test in particular, has increased rapidly during the past 10 years. At the present time 26 State highway departments have earth-resistivity equipment or have arrangements with other State agencies for cooperative resistivity work. Four States have refraction seismic equipment also. Ten other States and the Territory of Hawaii have indicated keen interest in their possible use of the resistivity test.

The work being done by the Bureau of Public Roads has been expanded during the past 2 years with the construction and purchase of 6 additional sets of resistivity equipment for use by its regional offices in this country, in the Philippines, and in Central America.

The fundamental principles of the earth-resistivity test are reviewed very briefly and a number of graphs are presented which show test data typical of that obtained in various parts of the United States and in Central America, together with correlating drill data. These tests involved such subsurface problems as bridge foundations, slope design for grading projects, landslide conditions and the location of materials of construction such as sand and gravel.

The geophysical tests are not intended to supplant conventional direct explorations by auger borings, the core drill or the test pit, although their elimination is possible in some instances. They are being recommended as valuable additional tools for use in making more complete subsurface surveys at less expense.

PERHAPS the first real attempt to correlate earth-resistivity test data with depths to underlying geologic layers was made by Messrs. Gish and Rooney about 30 years ago. Since that time there has been a constantly growing trend towards use of this relatively simple test procedure on a wide variety of subsurface problems in many parts of the world. Its use in mining exploration will be found in almost every country where mining properties exist. The same is true for areas throughout the world where underground water resources are being sought. Much of the ever-increasing store of literature dealing with the use of earth-resistivity apparatus describes its application to water supply problems. More recently the test procedure has been used in the search for uranium ores.

As is generally known, the Bureau of Public Roads has been one of the pioneers in seeking to establish the practical application of geophysical methods of test to highway construction problems. In this country during the past 10 years there has been a relatively rapid increase in the use of the earth-resistivity test, and to a lesser extent, the refraction seismic test on shallow subsurface explorations for highway and other engineering structures. Figure 1 shows the extent to which geophysical tests are being used currently in the 48 States.

As of January 1, 1957, 26 State highway departments had acquired earth-resistivity equipment or had arrangements with other State agencies for cooperative resistivity work. Four of these have refraction seismic equipment also. Two other States have made limited use of the geophysical tests in the past. At the present time, 10 additional States and the Territory of Hawaii have indicated an interest in the possibilities of the resistivity test in their subsurface exploration programs.

In furthering the interest in these economical exploration methods, the Bureau has made demonstration tests or conducted full-scale field studies in 33 of the 48 States, 4 of the 7 Central American countries, and in Hawaii. Such work on one project, a 19-mile section of the Baltimore-Washington Parkway in Maryland just north of the boundary of the District of Columbia, made possible a monetary savings on required quantities of sand and gravel sufficient to reimburse the Bureau for all of its expenditures for the geophysical research work since its inception in 1933.

In a further expansion of the work of the Bureau in this field, the Division of Physical Research recently built 6 additional sets of resistivity equipment, 5 of which were fur-

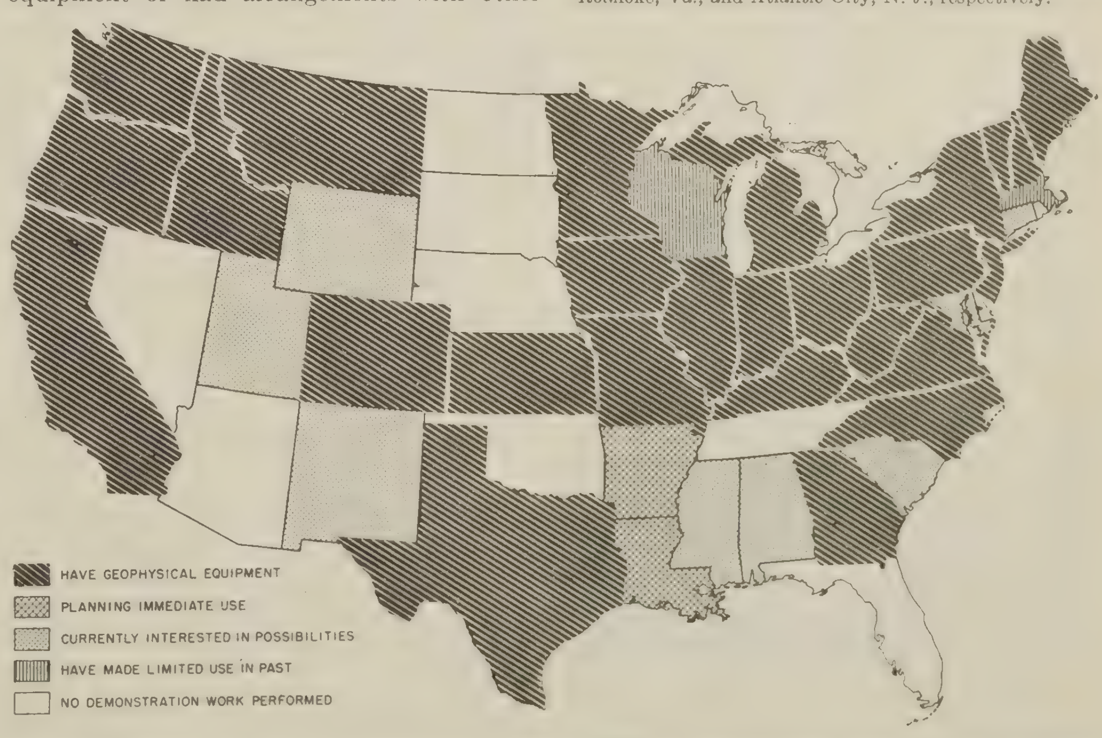

Figure 1.—Map showing current use (January 1957) of geophysical methods in highway construction.

[1] This article was presented at the 1956 annual meetings of the Southeastern Association of State Highway Officials and the American Association of State Highway Officials at Roanoke, Va., and Atlantic City, N. J., respectively.

Figure 2.—Earth-resistivity apparatus used by the Bureau of Public Roads in making subsurface explorations.

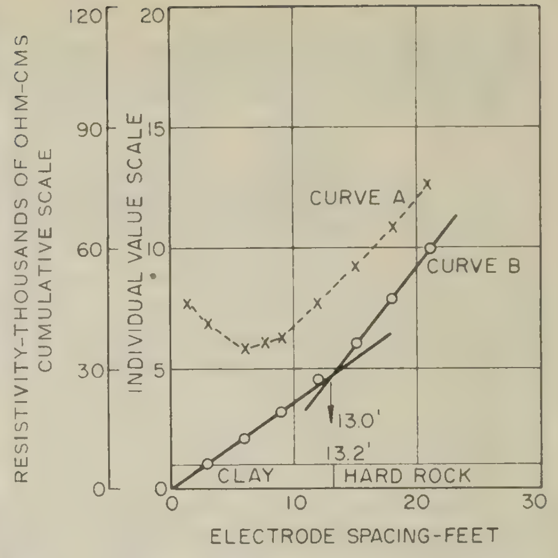

Figure 4.—Empirical method of analysis applied to resistivity curve for a clay stratum with underlying rock in the Washington, D. C., area.

nished to 3 of the Western Regional offices, the Philippine office, and the Inter-American Highway office. One additional, commercially built unit was purchased recently by the Region 15 office for use in its Saint Paul, Minn., District.

With this brief summary it is of interest to consider some of the results obtained thus far. The following discussion is limited to information from the Bureau's files, since a complete record of results obtained in the various States is not available.

Principles Underlying Test

Before presenting examples of the test results, however, a very brief discussion of the principles underlying the test procedure may be of interest. All surface and subsurface materials have, to some degree, the ability to conduct an electrical current. The moisture within the earth's materials and, more particularly, the impurities in this moisture provide an avenue for the current flow. It is natural, then, for the harder more dense rock layers, containing less moisture and perhaps less impurities than the clays and silty layers, to have high resistivity as compared with the resistivities usually found to be associated with the fine-grained clays or silty materials. Salt water is a very good conductor of current flow. Hence a geologic layer such as shale, clay, and so forth, laid down under marine action usually has a very low resistivity. Such materials can be located beneath weathered or leached-out materials overlying them.

Usually, any hard, dense layer of parent rock will have a resistivity which is different from its weathered components. Because of these and other individual characteristics, trial or calibration tests must be made over exposed or otherwise identifiable formations of each material, known to exist in the area of operations, to produce type curves needed in evaluating data obtained elsewhere in the area. Adequate calibration tests are essential to the successful use of the resistivity test. A knowledge of local geology also can be helpful to those making use of the test.

Figure 2 shows the resistivity apparatus used by the Bureau of Public Roads set up in a large cut made to carry the relocated Georgia Railroad around the Altoona Dam which was constructed some years ago. Using the Wenner 4-electrode system, the 4 electrodes are spaced equal distances apart, as shown in the photograph. The distance between the electrodes approximates the depth of soil involved. This is shown to better advantage in figure 3. Hemispherical zones are assumed around each current electrode. Every point on the surface of one of these hemispheres is at the same potential for a given flow of current from C_1 to C_2. The potential electrodes, P_1 and P_2, are placed where the two hemispheres intersect the ground surface, and a measured direct current of a few milliamperes strength is passed through the ground between the two outer electrodes. This produces a drop in potential between the hemispherical zones at C_1 and C_2 which is measured between the two inner electrodes. The resistivity for a centimeter cube of the material is computed and these values are used to plot a resistivity-depth curve such as that shown in figure 4. As previously indicated, the depth of material involved for a 3-foot electrode spacing is approximately 3 feet. By expanding the electrode system to larger separations, the test is carried deeper and any formation such as solid rock, having substantially higher resistivity than the surface layer, will be indicated by a rise in resistivity as shown in figure 4.

The dashed-line relation represents the computed resistivities; that is, actual values obtained in the field test. The circles and the

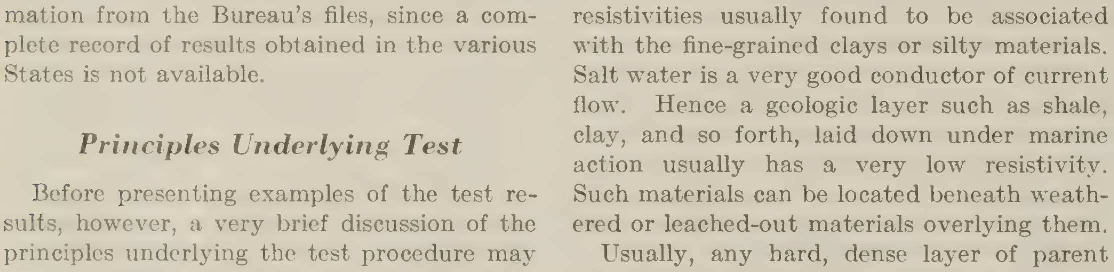

Figure 3.—Equipotential bowls assumed beneath current electrodes when making earth-resistivity tests.

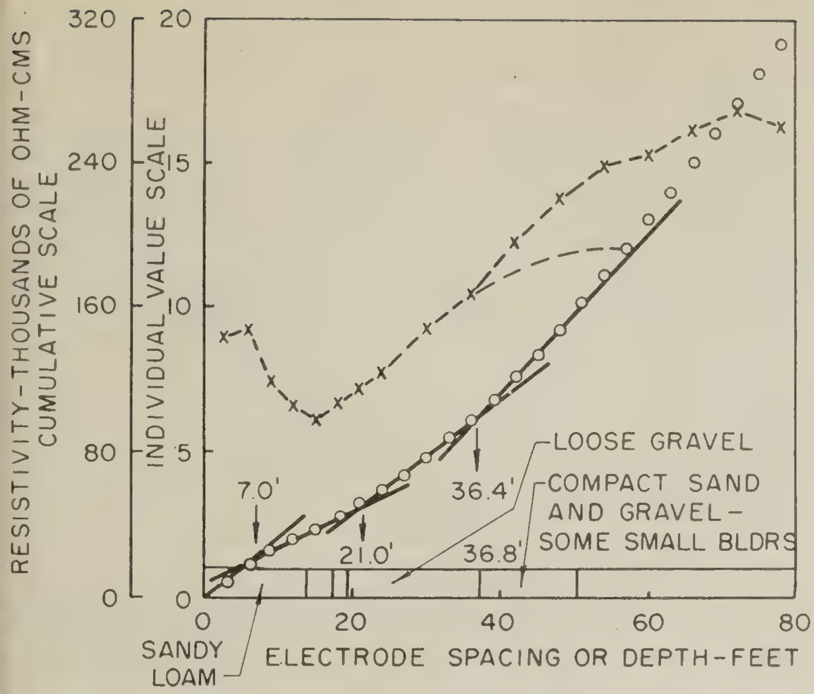

Figure 5.—Resistivity test made at the Fonseca River bridge site in northern Panama.

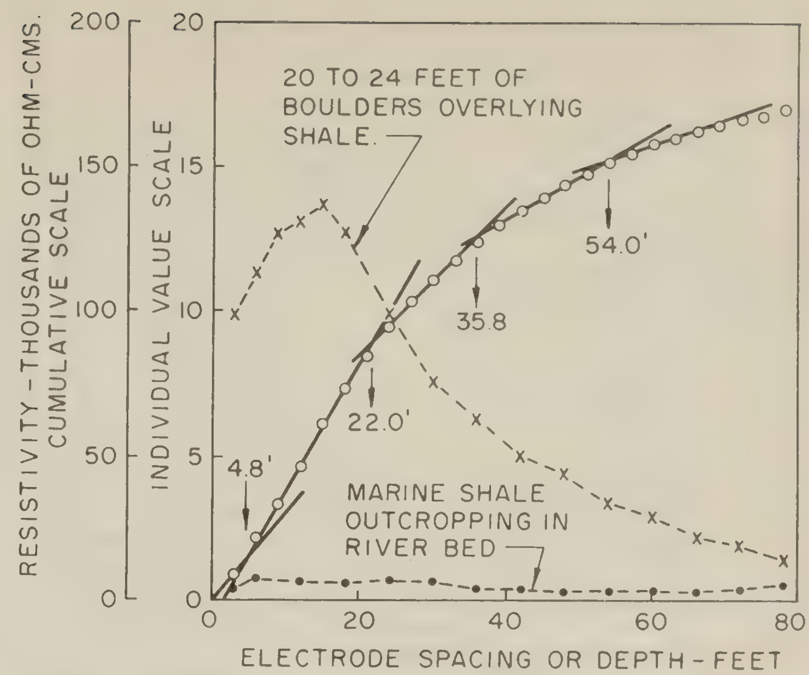

Figure 7.—Resistivity test made at the Corredores River bridge site in southern Costa Rica.

straight-line relations were plotted from computed cumulative values of resistivity. By using a constant increment of electrode spacing of 3 feet, each successive value of resistivity obtained as the electrode separations are increased is added to the summation of all preceding resistivity values to obtain a new point for plotting the cumulative resistivity relation. Drawing the straight lines as shown, their intersection has been found to approximate the depth at which the change in the underlying formation occurs. This empirical procedure, developed by the Bureau of Public Roads, has been used with considerable success in interpreting resistivity data obtained in the field and predicting depths to subsurface geologic formations of interest to the highway engineer.

Much has been written about the analysis of earth-resistivity data. Many of the published reports deal with theoretical procedures based on ideal surface and subsurface layers that are seldom found in field studies. For the convenience of those wishing to pursue the subject further, a brief reference list is given on page 169.

Figure 6.—Surface conditions existing in a mangrove swamp in northern Panama.

Without further consideration of the theoretical aspects, the following paragraphs discuss the results of earth-resistivity tests made in widely scattered areas but selected as typical of the many individual tests involved.

Tests Made on Inter-American Highway

Panama

Resistivity tests made at a bridge site on the Inter-American Highway in northern Panama produced data typified by those shown in figure 5. This test not only located sand, gravel, and boulders where it had been found by a boring but it also showed a change to the more compact material found 15.4 feet below by the boring. The curving dashed line breaking off to the right at an electrode spacing of 36.0 feet shows the shape the field curve would have assumed had the more compact layer not been present. Elsewhere in this area it was necessary to test for another bridge site on an alternate route. Figure 6 shows the almost impossible surface conditions existing in a mangrove swamp. Yet, a 30-minute test located a change to a higher resistivity material 34.0 feet below the surface. It was recommended that a sounding rod be used to confirm the indications of the test. The rod penetrated to within about 1 foot of the depth which the test had indicated. This was a case where the only two practicable methods of test were used, the sounding rod and the portable resistivity apparatus.

Costa Rica

In the jungles of southern Costa Rica nine tests were made in less than a day to explore the foundation conditions for the possible site of a large bridge over the Corredores River. Figure 7 shows data for 2 of the 9 tests. The upper curve was obtained over a 20- to 24-foot-thick boulder deposit resting on shale of marine origin. The lower curve represents data obtained for calibration purposes directly on an exposure of the shale bed The strong downtrend obtained in all of the curves was interpreted as indicative of the influence of the underlying low resistivity shale bed. Figure 8 shows the calibration test in progress with the boulder bed in the background. It should be emphasized again that trial or calibration tests made over exposed materials, rock, shale, soil, and so forth, are essential as criteria for properly evaluating resistivity data in each area where a survey is to be made. At this bridge site a single drill hole made on the most accessible bank, when considered in conjunction with the resistivity data, served to prove the entire river crossing. A final site selected for the bridge was some distance downstream from this location at a point where the river channel was narrower. However, much costly and unnecessary drilling was eliminated by the resistivity survey made at this location.

Figure 8.—Resistivity calibration test over marine shale underlying gravel-boulder bed along the Corredores River in southern Costa Rica.

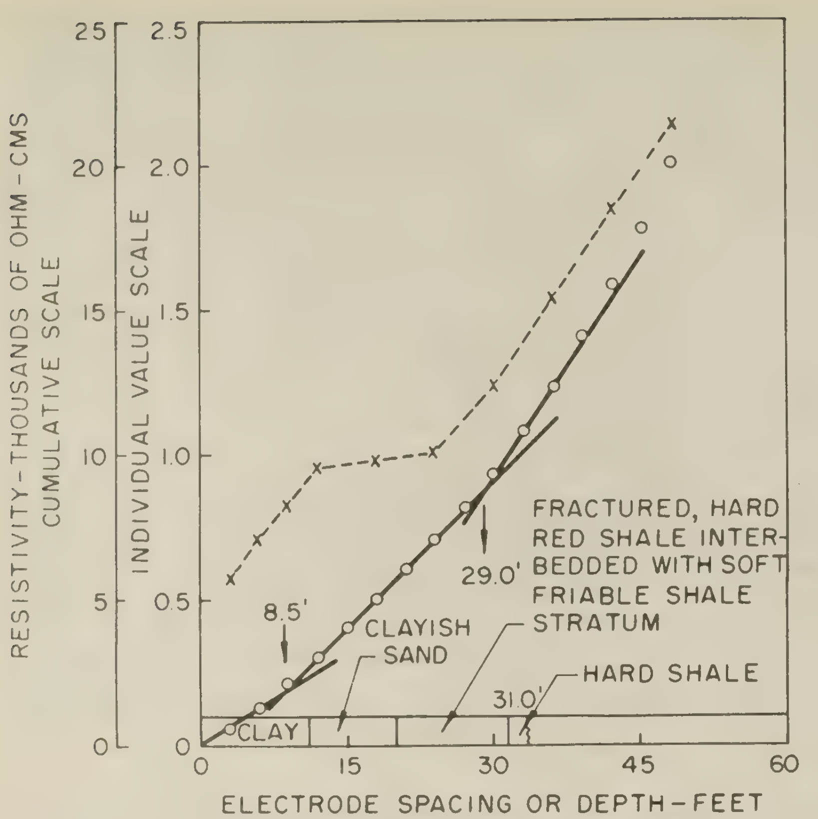

Figure 9.—Resistivity test made at the Limon River bridge site in Nicaragua.

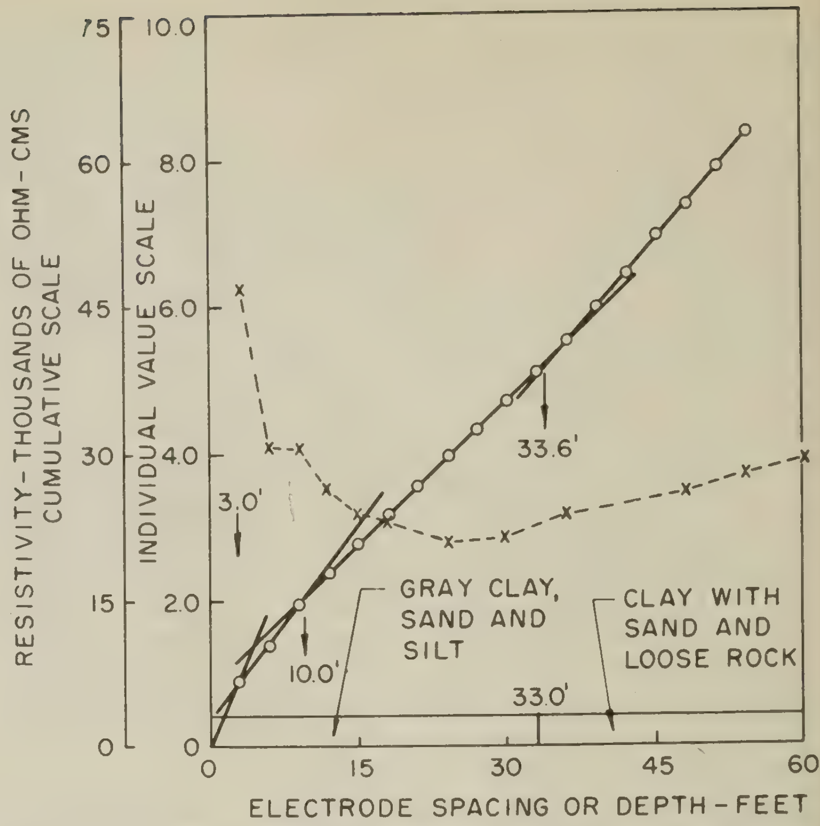

Figure 10.—Resistivity test made at the Rosario River bridge site in Guatemala.

Nicaragua

In Nicaragua the resistivity test was used successfully at the crossing of the Limon River, as shown by the data in figure 9. The strong, definite increase in resistivity at a depth of 29.0 feet was conclusive evidence of a major change in the underlying formation. Since salt-laden materials were involved, the interpretation was that the sharp rise in resistivity resulted from the influence of a more compact, impervious stratum such as the hard shale which had been located at substantially the same elevation by a test boring.

Guatemala

Figure 10 shows data from a test made near Champerico on the Pacific coast of Guatemala. The rise in resistivity indicates a change at a depth comparable to that at which the drill encountered a significant change in the substrata. Here again, since the materials involved were saturated with salt water, the increased resistivity can be interpreted as the influence of a more dense, less permeable stratum likely to have better foundation characteristics.

Slope Design Investigations

In slope design it is essential to know the character of the materials present in the proposed cuts. Lower unit bid prices for unclassified excavation result when earth slopes predominate in the plans and specifications. Accurate information regarding the materials will tend to prevent claims for underrun or overrun items. In a recent case, a bill of nearly $19,000 was paid a contractor as compensation for anticipated profits because final estimate rock quantities underran the contract item by more than 25 percent.

North Carolina

Figure 11 shows resistivity data from a test on a slope design investigation in the western part of North Carolina. The rising trend at a depth of 37.6 feet was indicative of a solid granite bedrock, the lower resistivity, although 150 times as high as a solid rock tested in Kansas, represented a weathered layer easily removed by rooter and self-loading scraper, which required a 1-to-1 slope. Such a test can be made in a matter of 12 to 15 minutes. When such marked differences exist between the resistivities of hard and soft materials in a given area, and they often do, the operator can predict the presence or absence of solid rock at a particular depth within 3 or 4 minutes after completing the test.

Idaho

Landslides plague the highway engineer in many areas. Disturbing Nature's slopes often can be disastrous. The earth-resistivity test can be of considerable help in preliminary explorations to locate possible sliding surfaces or to delineate existing failure zones. Figure 12 shows 3 of 6 sections prepared from investigations made on 6 separate slide areas along the Priest River in northern Idaho. The work was done in 2 days. While the hardpan and less pervious layers inferred from the

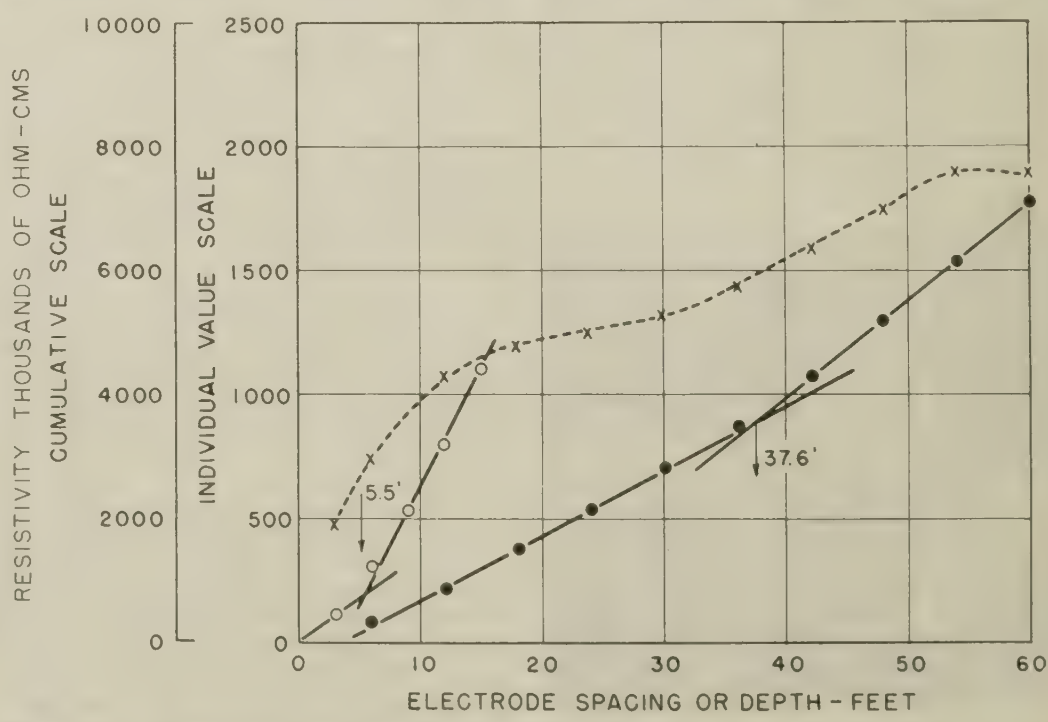

Figure 11.—Resistivity test made on the Blue Ridge Parkway in North Carolina. Test discloses presence of granite rock beneath weathered granite.

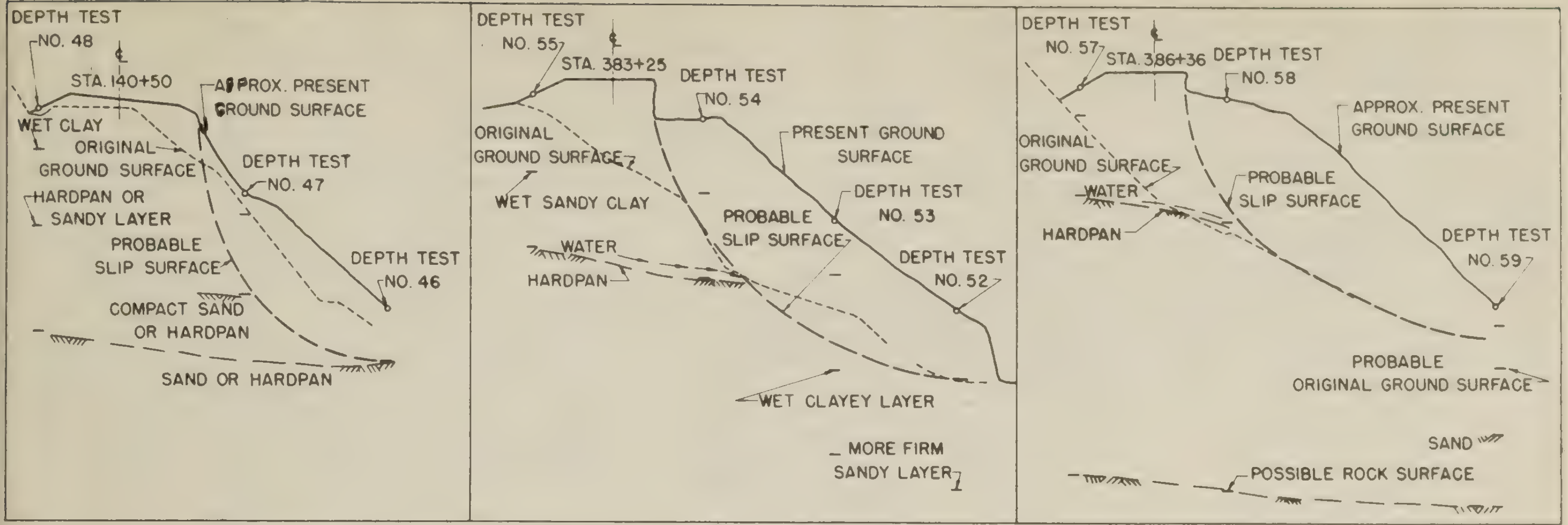

Figure 12.—Sections plotted from earth-resistivity data obtained at three locations along the Priest River in northern Idaho, showing probable slip surface upon which fill material is moving.

resistivity data should not be accepted until confirmed by boring or test pit at one or more points, the preliminary information shown should be of considerable value in locating sites for direct exploration and in laying out drainage operations so as to achieve maximum interception of water percolating through to saturate the fill material and initiate the failures as indicated.

Locating Sand and Gravel Deposits

Mention was made of the successful use of the test procedure in locating sand and gravel. By keeping the electrode system at a constant spacing, say 30 feet or any depth critical to the problem under study, it is possible to make a rapid survey of large areas to locate buried rock or lenses of sand, gravel, special clays, and so forth. Such materials may be in demand for local construction work. Figure 13 shows data from two such constant-depth resistivity traverses made over a deposit of sand and gravel (upper curve) and over a clay formation (lower curve). In this test procedure the electrodes are shifted as a group for successive readings of resistivity as the test progresses along a given line. Any significant change in the materials within the 30-foot depth below the surface is usually indicated by corresponding changes in the measured resistivity values. Any material surrounded and covered by a material of substantially different resistivity characteristics can be located and outlined with regard to its lateral limits by this type of test.

Figure 14 shows a resistivity contour map prepared from data obtained from several constant-depth traverses. The area involved contains large amounts of granular material suitable for stabilizing plastic clay soils before placing a pavement. A comparatively few borings served to prove the existence and identify the character of the granular material in the formation. This material was found within the right-of-way limits near the middle of a section of the Baltimore-Washington Parkway on which large quantities of granular material were needed. Although this particular deposit of granular material was not excavated due to the retention of this area for esthetic and other reasons, large savings in hauling costs in excess of $100,000 were possible elsewhere in the 19-mile project.

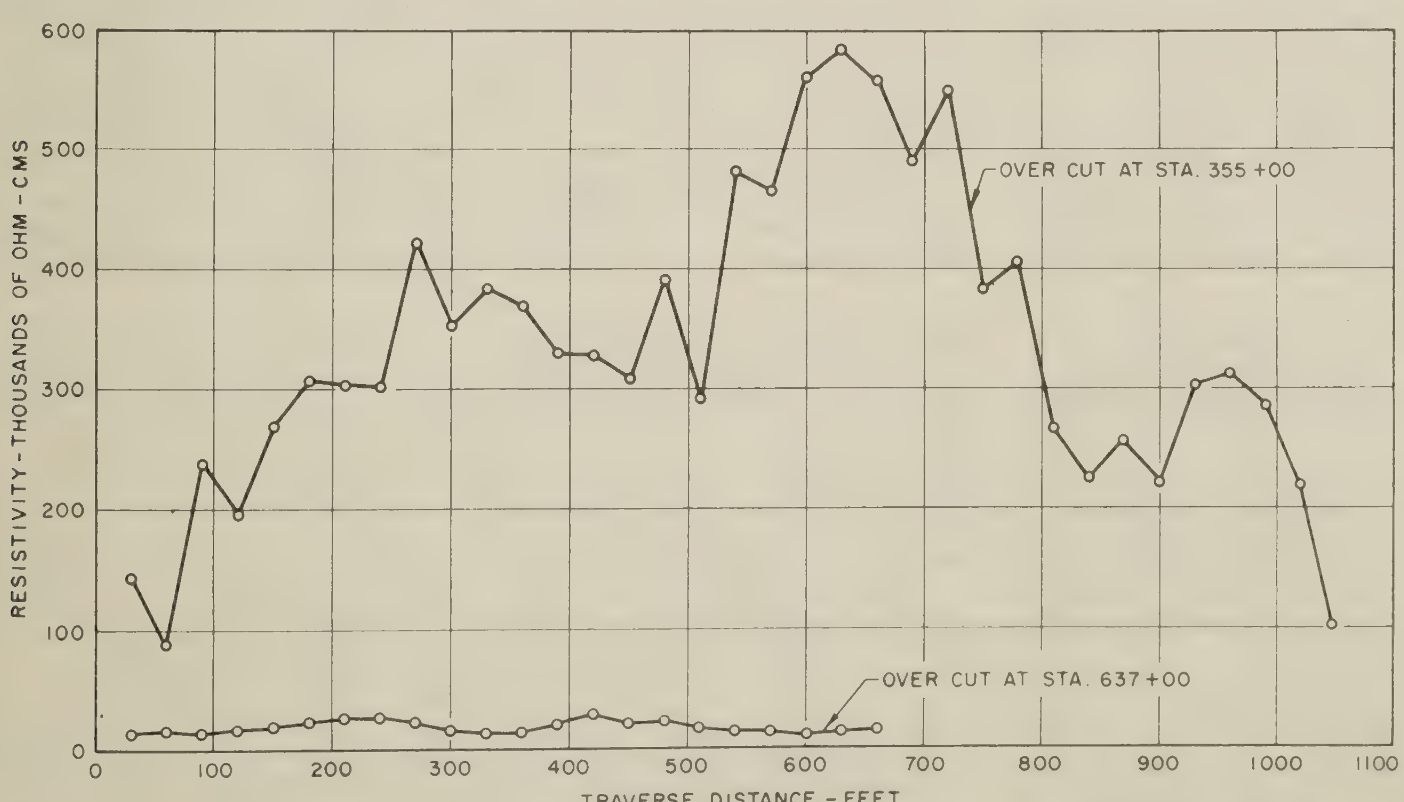

Figure 13.—Constant-depth resistivity traverses over a sand and gravel deposit (upper curve) and over a clay formation (lower curve) in the area of the Baltimore-Washington Parkway. Electrode spacing or depth was 30 feet.

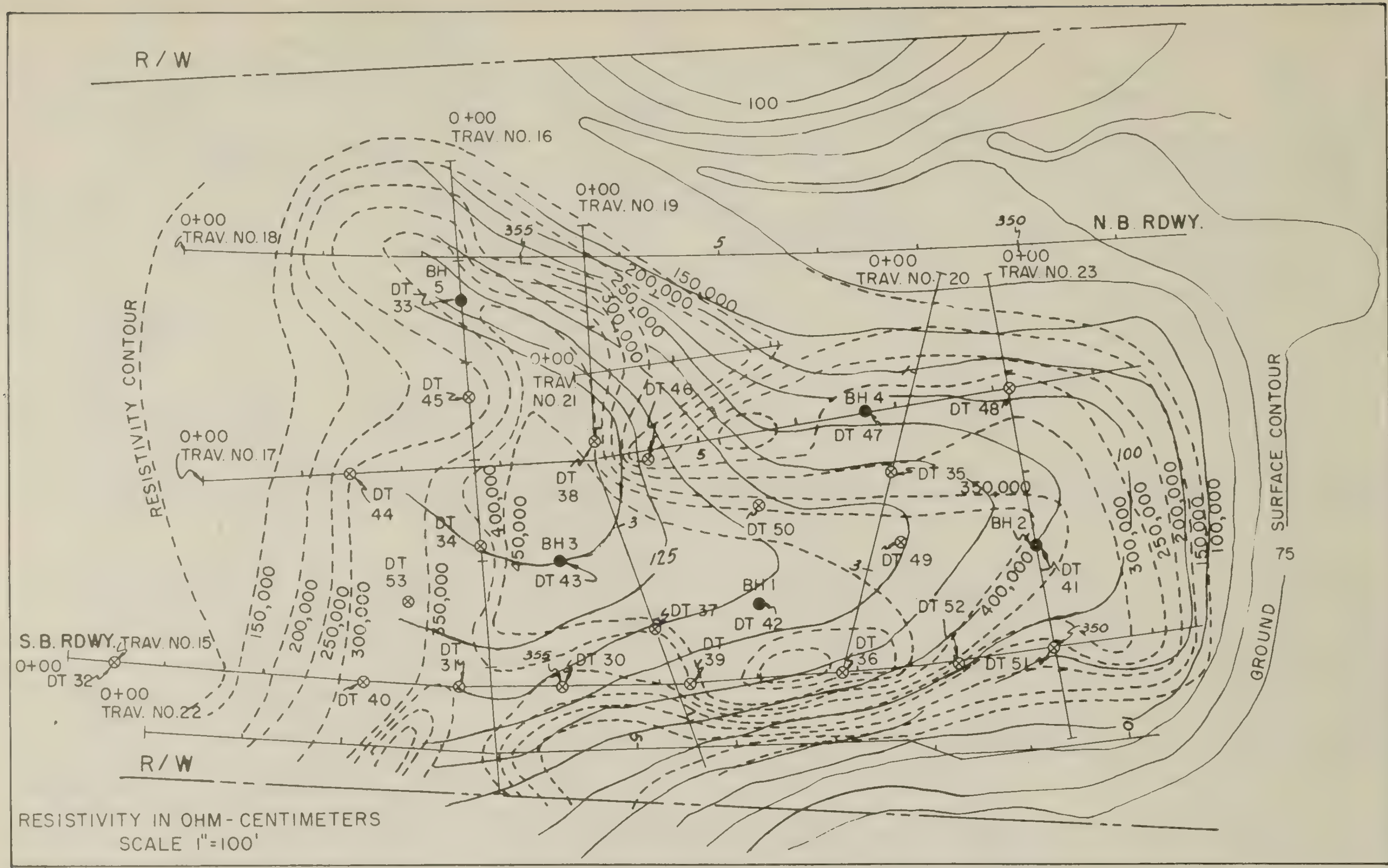

Figure 14.—Resistivity contour map showing sand and gravel deposit within the right-of-way limits of a section of the Baltimore-Washington Parkway.

Benefits of Resistivity Tests

Figure 15 contains data which emphasize the practical application of the resistivity test to three differing subsurface problems. In the left-hand graph the resistivity test has produced a reliable indication of ledge rock at a depth where solid material was encountered by a sounding rod. The sounding rod can be stopped by a boulder or a thin layer of hard material and its use alone may lead to erroneous conclusions. If used in conjunction with the resistivity test, this cannot happen. The strong uptrend in the resistivity curve is conclusive evidence of a definite change in the substrata. The continuing trend upward indicates a thickness of at least 20.0 feet for the underlying formation.

In the middle graph, the resistivity test showed evidence of a low resistivity layer about 3 feet below the deepest boring that had been made in foundation investigations for the structure. This material could be a plastic clay formation likely to allow serious settlement or it could be a fairly dense marine clay with good support for piling. A resistivity survey prior to the boring tests could have dictated the depths to which borings should be carried to obtain samples of the low resistivity layer from which its foundation characteristics might have been established.

Again, in the third graph, good foundation material, waste slag, found near the surface

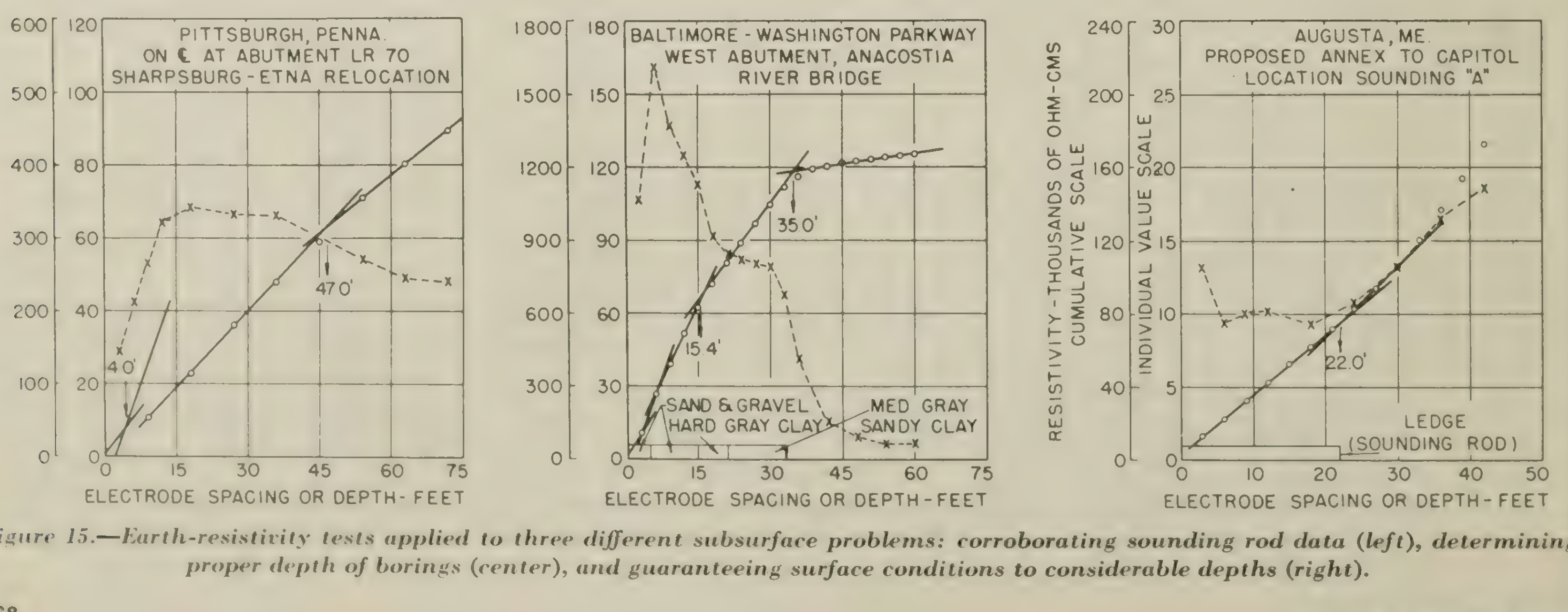

Figure 15.—Earth-resistivity tests applied to three different subsurface problems: corroborating sounding rod data (left), determining proper depth of borings (center), and guaranteeing surface conditions to considerable depths (right).

could be guaranteed to depths sufficiently great to provide ample support for almost any type of structure. The resistivity test indicated that the old slag dump present at this test location had a thickness of at least 40 feet. At a location only a few hundred feet away, at a proposed pier location, this material was only 13 feet thick. Thus we see that the resistivity test can provide good preliminary information and, working with the sounding rod, drill or auger, also be instrumental in obtaining more complete information regarding the subsurface materials at a given structure site.

Many more instances could be cited in which the earth-resistivity test has produced very useful results. Although it is not applicable to all combinations of surface and subsurface materials, its successful applications will far outnumber its unsuccessful applications.[2] Often, savings on a single construction project resulting from a thorough resistivity survey are sufficient to pay for the initial cost of suitable equipment as well as several years of fieldwork. The Turkish Department of Highways effected an estimated savings of $200,000 on its first application of the test to the location of sand and gravel. In the work of the Bureau, similar savings have been made possible on the same field problem. As the various agencies now using the earth-resistivity test in this country publish accounts of their experience, other worthwhile savings will no doubt be reported. With a wider and more complete report of the results obtained by those making use of the test, the earth-resistivity test procedure will become more fully established and its possibilities more fully realized by engineers concerned with a study of the subsurface materials.

[2] There have been a few instances where the resistivity test was inconclusive. Conditions in which the surface layer and the underlying layer have little or no contrast in resistivity have nullified test results. Metal structures such as pipe lines, electric conduits, railroad rails, etc., can cause current to leave the normal path and produce unsatisfactory test results.

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A Study of Factors Related to Urban Travel

BY THE DIVISION OF HIGHWAY TRANSPORT RESEARCH
BUREAU OF PUBLIC ROADS

Reported by WILLIAM L. MERTZ, Highway Transport Research Engineer, and LAMELLE B. HAMNER, Statistical Assistant

This study was undertaken to determine the effect of automobile ownership, population density, distance from the central business district, and income per household on the number of vehicular trips residents made in Washington, D. C., on an average weekday in 1948.

It was found that the use of all four variables combined did not produce a significant increase in the accuracy of predicting trips over that which was obtained using automobile ownership and population density combined. Furthermore, automobile ownership was found to be the most reliable single predictor with very little additional accuracy gained by combining it with population density.

THERE are many factors that affect the number of daily trips made by residents of an urban area. It is extremely difficult to find objective measures of any phenomenon that involve the psychology of a large group of people but some inferences may be drawn. It seems quite logical to assume that the number of automobiles owned per dwelling unit by the residents of an urban area is closely related to the number of trips made by the residents of that area. Many more possible factors come to mind. What for instance is the effect of net density of population, distance from the central business district, and income per household on the number of daily trips? There are other factors, too, that may have a bearing on the question.

This report presents the results of an analysis of the effect of automobile ownership, distance from the central business district, income per household, and net population density (population per net residential acre) on the number and frequency of vehicular trips made by residents by all modes of travel.[1] These factors were selected because it has been possible to establish measures that are free from personal bias and because it seems that they constitute a quite logical premise on which to begin an analysis of total number of trips made by the residents of urban areas.

Sources of Information

This analysis was based on travel data obtained from the Washington, D. C., metropolitan area traffic study made in 1948, but was limited to the District of Columbia, because reliable data on income and population density were not readily available for the rest of the Washington metropolitan area.

The income information was obtained from a study made by the Washington Board of Trade.[2] The average gross income per household was estimated for each census tract on the basis of rentals and home values reported in the 1950 Census of Housing. This method, although not a direct measure of income, was the best available information on this subject.

Population data were obtained from the 1948 metropolitan area traffic study and converted to population per net residential acre on the basis of factors used by the Department of Research and Statistics, United Community Services, Washington, D. C. The residential acreage was based on the July 1948 areas used for residences. All other land uses such as streets, parks, commercial and industrial areas were excluded. Land occupied by the United States Soldiers Home and St. Elizabeths Hospital was also excluded.

Data relative to automobile ownership and distance from the central business district were obtained from the 1948 Washington, D. C., metropolitan area transportation survey. Census tracts were utilized for this study since population density and income data were reported only by those areas. The 1948 transportation trip data, though summarized by census tracts, did not separate trips by the various modes of travel, thus preventing in this study a separate analysis of either of the two primary vehicular modes of travel.

Correlation of Trips and Automobile Ownership

For each census tract the average number of residents' trips per dwelling was correlated with the average number of automobiles owned per dwelling. The data are presented in figure 1. A very definite relation is indicated but since the points are somewhat scattered, the principle of least squares was used to fit a line through the plotted points of the trip averages. This is known as a regression line. The equation of this line is $X_1 = 2.88 + 4.60X_2$ where X_1 is residents' trips per dwelling unit and X_2 is automobile ownership per dwelling unit. The correlation coefficient is $+0.827$.

Since correlation coefficients range from 0.00 when there is no correlation between two variables to ± 1.00 for perfect correlation, they serve as a measure of the strength of association between the variables. For a perfect correlation, every plotted point would fall exactly on the regression line, and for a condition with no correlation the scatter of points would have a round pattern with the highest density at the center. The resulting regression line would be horizontal showing no change of the dependent variable on the

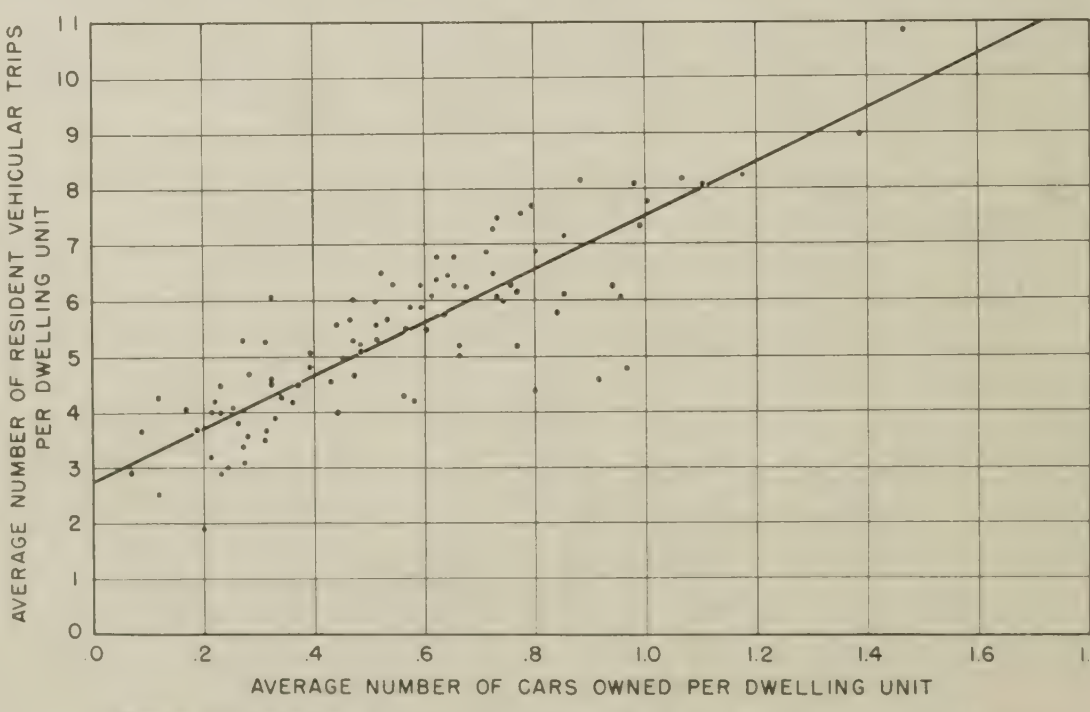

Figure 1.—Relation of resident vehicular trips to automobile ownership.

[1] All modes of travel refers to residents' trips within the metropolitan area by various forms of transportation. It does not include trips by taxi and truck operators in the course of their daily work.

[2] *Number of households and average income per household in the District of Columbia, 1949–1954,* by the Economic Development Department, Washington Board of Trade, June 1954.

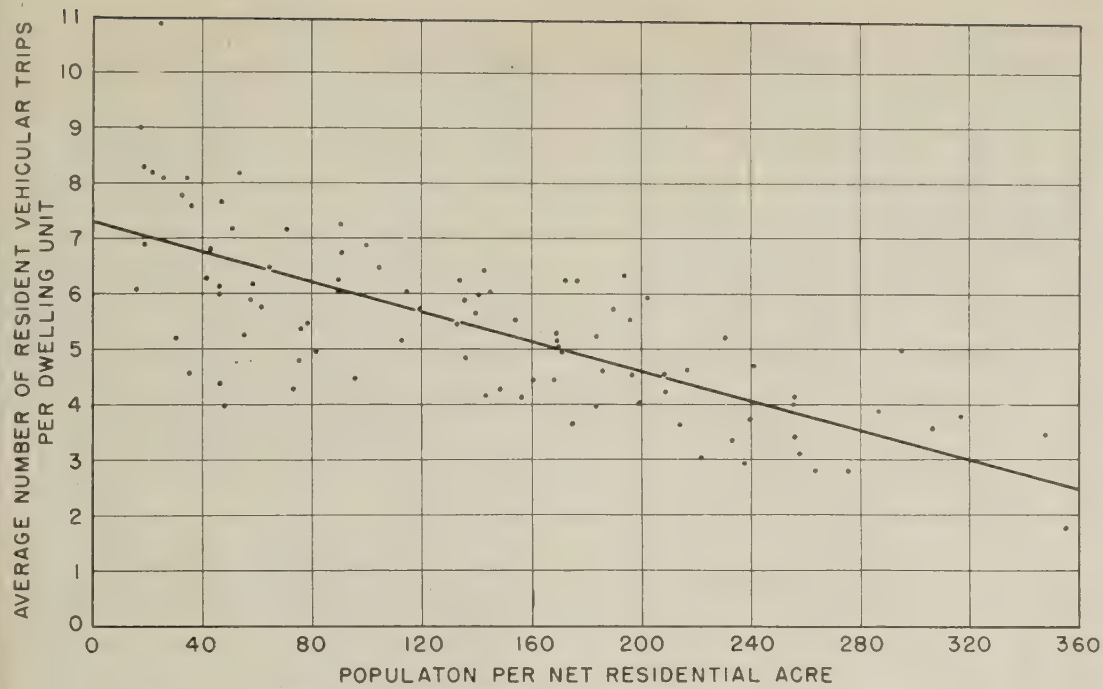

Figure 2.—Relation of resident vehicular trips to population density.

vertical axis with a change in the independent variable on the horizontal axis. Another interpretation of the coefficient of correlation is that its square multiplied by 100 is the percentage of the total variation in trips that can be explained by variation in automobile ownership or any other factor being studied, such as income, population density, or distance. Conversely, the quantity 1 minus the square multiplied by 100 is the percentage of variation left unexplained or due to other causes.

The square root of the average of the variation left unexplained is the standard error of estimate and for the data plotted in figure 1 (relation of resident trips to car ownership), it is 0.89 trip per dwelling unit. This means that approximately two-thirds of all the plotted points are within 0.89 trip above or below the line, thus furnishing a measure of the reliability of estimates of trips from cars owned per dwelling. This also means that for the whole population it is probable that estimates of residents' trips per dwelling unit in each census tract in Washington, D. C., would be within ± 0.89 trip of the true value in two-thirds of the cases when using average automobile ownership per dwelling unit per census tract as the predicting variable.

Relation of Trips to Population, Distance, and Income

The same analysis as illustrated in figures 2–4 was made for population density, distance from the central business district, and income per household. It is significant to note that trips decrease as population density increases. For comparison, the pertinent measures for each relation are presented in table 1. Notice that as the correlation coefficients decrease the errors of estimate increase. This is the usual case in regression analysis.

It would appear from the evidence thus far obtained that each of the four factors influence the number of trips made by residents in an urban area. However, this does not furnish any information about the interdependence of the variables. For example, how much does automobile ownership depend on income, population density, and distance from the city center? Further, does population density depend on income? Obviously, a high correlation would be obtained between population density and distance from the central business district. Intercorrelation among the variables used as predictors clouds the issue considerably. At this point in the investigation it is not known whether trips are a function of all of these variables working independently, or whether they are interacting together and in effect overlapping. Therefore, correlation coefficients were computed to give a perspective of their interaction. They are presented in table 2.

As was suspected, there is a high correlation between distance and population density and substantial correlations among all combinations of factors. To qualify technically as truly independent variables, all of the values in the table other than those shown in italics would have to be zero or so nearly so that the association could be ascribable to chance.

All of these variables were analyzed to produce one multiple regression equation [3] as follows:

$$X_1 = a + b_{12.345}X_2 + b_{13.245}X_3 + b_{14.235}X_4 + b_{15.234}X_5$$

Where:

X_1 = Residents' trips per dwelling unit.
X_2 = Automobile ownership per dwelling unit.
X_3 = Population density.
X_4 = Distance from the central business district.
X_5 = Income per household (index).
a = Intercept on the X_1 axis.
b = Multiple regression coefficient (similar to slope on a two-variable problem).

This technique requires the simultaneous solution of five equations to determine the five unknown quantities in the equation. It also makes possible the measurement of the relative importance of each variable when the effect of all the others acting simultaneously is taken into account. With the coefficients determined, the multiple regression equation is $X_1 = 4.33 + 3.89X_2 - 0.005X_3 - 0.128X_4 - 0.0120X_5$.

At first inspection it would appear that automobile ownership is the most important predictor of trips since it has the highest coefficient, and population density the least important, but comparison of the coefficients directly is not possible because of the different units of measurement of each of the independent variables. Beta coefficients that are

[3] Example: $b_{12.345}$ should be read as "multiple regression coefficient of variables 1 and 2 with variables 3, 4, and 5 held constant.

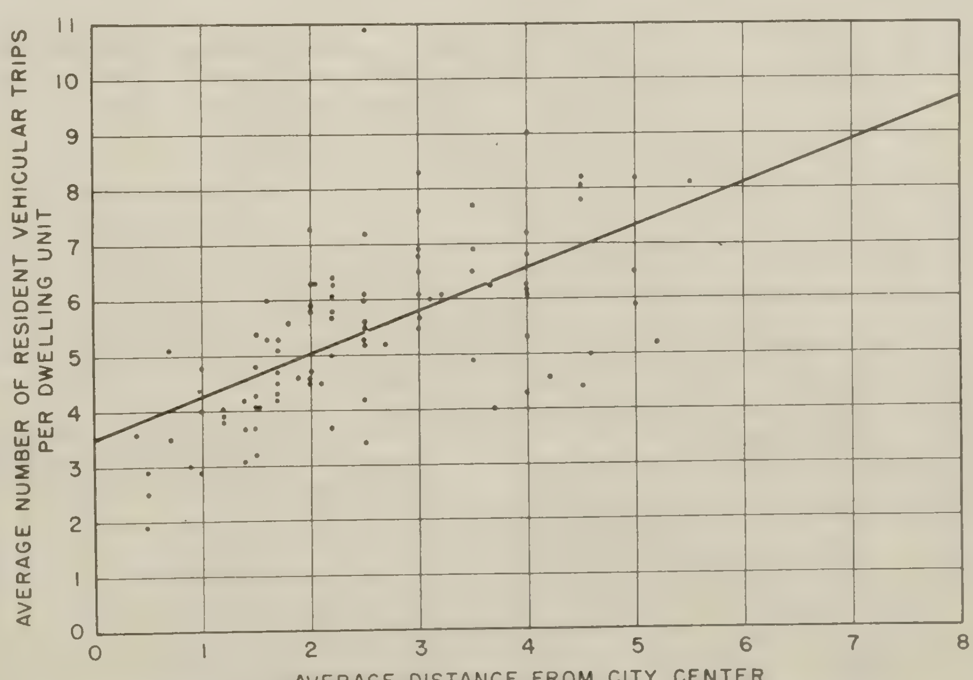

Figure 3.—Relation of resident vehicular trips to distance of residence from the central business district.

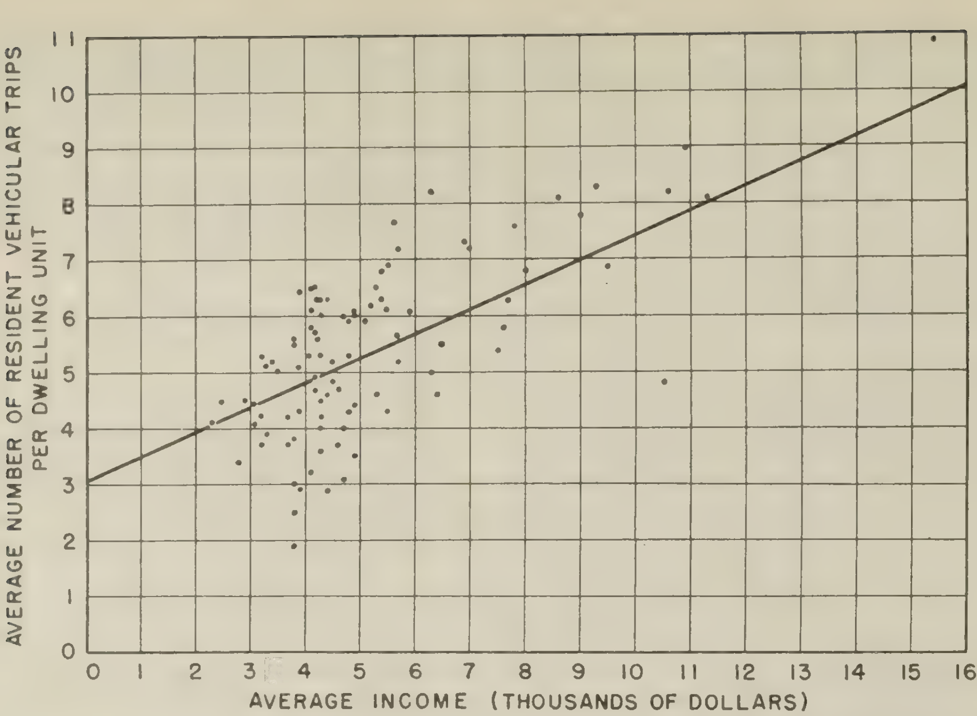

Figure 4.—Relation of resident vehicular trips to average income per household.

independent of units of measurement were computed to overcome this difficulty, thus permitting comparison in the same fashion as correlation coefficients.

Variable	*Beta coefficients*
Automobile ownership per dwelling unit	0.700
Net population density	.265
Distance from central business district	.099
Income per household	.018

Significance of Variables

The order of importance of the independent variables is now known, and the next step is to determine how much influence each has to the whole. The coefficient of multiple correlation of the four variables is 0.837 and the standard error of estimate is 0.87 trip. These are the indicators of the predictive reliability of all of the variables working together. Referring to table 1, it can be seen that automobile ownership alone had a correlation coefficient of +0.827 and a standard error of estimate of 0.89—almost as good as all variables taken together.

Another factor that casts doubt on the added value of population density, distance, and income as predictors of trips when used in conjunction with automobile ownership is that in the original two-variable analyses, all the regression coefficients (slopes) were positive with the exception of trips versus population density as would be expected; but in the multiple regression equation, all of the regression coefficients turned negative except automobile ownership. Such behavior is often the case when the net relation between two variables is very minor and the sample measure is easily tipped positively or negatively by chance variation.

A technique known as "analysis or partition of the variance" was employed to estimate the significance of the contribution of each of the independent variables. As stated before, the square of a correlation coefficient multiplied by 100 is the percentage of the variation in the dependent variable that can be explained by one or more independent variables. This concept is a valuable tool for further insight into the problem.

Since automobile ownership was the strongest independent variable, the variation attributable to it was taken out of the total variation in trips and tested against values in probability tables to determine whether it was significant or whether it could be due to chance.

If a coin were tossed a great many times, it would be expected that during very nearly one-half of the tosses the coin would fall heads and one-half tails. Actually, this means that the odds or probability on any given toss of the coin is one-half for a head and one-half for a tail. If two coins were tossed at a time, there would be four equally likely possibilities on any given toss. First, coin A may be heads and coin B tails; second, coin A may be tails and coin B heads; third, both coins may be heads; and fourth, both coins may be tails. Since there are four possible combinations in which the two coins may fall, the probability of both coins being heads is one-fourth, or the coin tosser may expect both to fall heads in approximately 25 percent of the tosses if chance were the only factor operating. The more times the coins were tossed, the greater the possibility of attaining the ideal. If both coins were actually heads in 50 percent of the tosses, the evidence would be very strong that chance was not the sole determinant and that some other influence was causing the difference in results.

The technique used in this investigation of factors affecting trips is merely an extension of the coin-tossing principle. It was decided to reject the possibility that a measure of variation differed from the value that would have been obtained had chance been the only factor operating if the odds were 99 to 1 against chance. In the area between 99 to 1 and 95 to 5, the results were classified as questionable or doubtful. If the odds are less than 95 to 5, the possibility of chance factors yielding such values for the measures of variation has been accepted and the variable has been rejected as not contributing anything significant to the problem.

In comparison to the coin-tossing experiment the standards selected are quite conservative. They are satisfactory for anyone willing to be wrong one time out of one hundred. These statements apply only to the data in hand. No inferences are made about the reliability of the sampling methods or the possible bias due to averaging the data on a census tract basis. This topic is discussed later in the article.

The increment of variation accounted for by the addition of population density, when the effect of automobile ownership is taken into account and held constant, was next de-

Table 1.—Correlation of residents' daily trips with selected variables, as measured by a study of 95 census tracts in Washington, D. C., on an average weekday in 1948

Independent variables	Trips per dwelling unit (dependent variable)		Predicting equation
	Correlation coefficient	Standard error of estimate	
Automobile ownership	+0.827	0.89	$X_1=2.88+4.60X_2$
Population density	−.718	1.10	$X_1=7.22-0.013X_3$
Income	+.655	1.20	$X_1=3.07+0.44X_5$
Distance from central business district	+.575	1.30	$X_1=3.55+0.74X_4$

Table 2.—Degree of correlation between the several variables, as measured by a study of 95 census tracts in Washington, D. C., on an average weekday in 1948

Variables	Correlation coefficients of each variable to all other variables				
	Trips per dwelling unit	Automobile ownership	Population density	Income per household	Distance from central business district
Trips per dwelling unit	----------	*+0.827*	*−0.718*	*+0.655*	*+0.575*
Automobile ownership	*+0.827*	----------	−.780	+.786	+.662
Population density	*−.718*	−.780	----------	−.631	−.825
Income per household	*+.655*	+.786	−.631	----------	+.448
Distance from central business district	*+.575*	+.662	−.825	+.448	----------

Table 3.—Source and amount of variation in trips per dwelling unit, as measured by a study of 95 census tracts in Washington, D. C., on an average weekday in 1948

Source of variation in trips per dwelling unit	Amount of variation in trips per dwelling unit	
	Automobile ownership data available	Automobile ownership data not available
Gross amount explained by—	*Percent*	*Percent*
Automobile ownership	68.34	----------
Population density	----------	51.55
Increment explained by—		
Income with population density held constant	----------	14.00
Population density with automobile ownership held constant	4.29	----------
Distance with automobile ownership and population density held constant	.94	----------
Distance with population density and income held constant	----------	.04
Income with automobile ownership, population density, and distance held constant	.04	----------
Residual, unexplained	26.39	34.41
Total	100.00	100.00

termined and tested for significant difference from the value that would have been obtained if chance were the only factor operating. Then the increment due to distance from the central business district with the effect of both automobile ownership and population density held constant was tested for significance. This procedure was repeated for income with all other factors held constant. The analysis shows that automobile ownership alone is definitely significant. When the effect of automobile ownership is taken out, the increment added by population density is of doubtful significance. This means that the odds were about 95 to 5 that the additional variation accounted for could have been chance variation. The increments of distance and income did not prove to be significant, as indicated in the first column of table 3, and are probably due to chance variation only.

Since the increment of variation in trips explained by population density is of doubtful significance, but not weak enough to reject according to the standards set, a multiple regression equation including it with automobile ownership was developed to compare with the equation using ownership alone. This multiple regression equation, $X_1=3.80+3.79X_2-0.0033X_3$, is shown graphically in figure 5. The multiple correlation coefficient is 0.835 and the standard error of estimate is 0.87 trip. This may be compared with the results of using automobile ownership as the only predictor of trips ($X_1=2.88+4.60X_2$). In the latter instance, the correlation coefficient is $+0.827$ and the standard error of estimate is 0.89 trip. It can be seen from a comparison of the correlation coefficients and standard errors of estimate that population density adds very little to the predictive accuracy.

For cases where automobile ownership data are not available, the next best combination was determined. The order of importance of the independent variables, as reported in the second column of table 3, was found to be (1) population density, (2) income, and (3) distance from the central business district.

In this analysis, both population density and income were found to be significant and distance, not significant. The multiple regression equation for this combination, shown graphically in figure 6, is $X_1=5.49-0.0089X_3+0.227X_5$. The multiple correlation coefficient is 0.764 and the standard error of estimate is 1.02 trips. If population density alone is used as the predictor the regression equation is $X_1=7.22-0.013X_3$. The correlation coefficient is -0.718 and the standard error of estimate is 1.10 trips.

Each succeeding combination of independent variables used thus far has resulted in a decrease in the correlation coefficients and an increase in the standard errors. Table 4 shows all significant combinations in descending order of predictive accuracy.

As previously mentioned, data were available from the 1948 metropolitan area traffic survey on residents' trips and automobile ownership for the entire Washington, D. C., metropolitan area, but similar data on income and population density were unavailable for the suburban areas at the time of the study. The linear regression equation for trips and car ownership for the entire area in 1948 is $X_1=2.80+4.45X_2$, whereas for the District of Columbia, the equation is $X_1=2.88+4.60X_2$. The standard errors of estimate for the entire

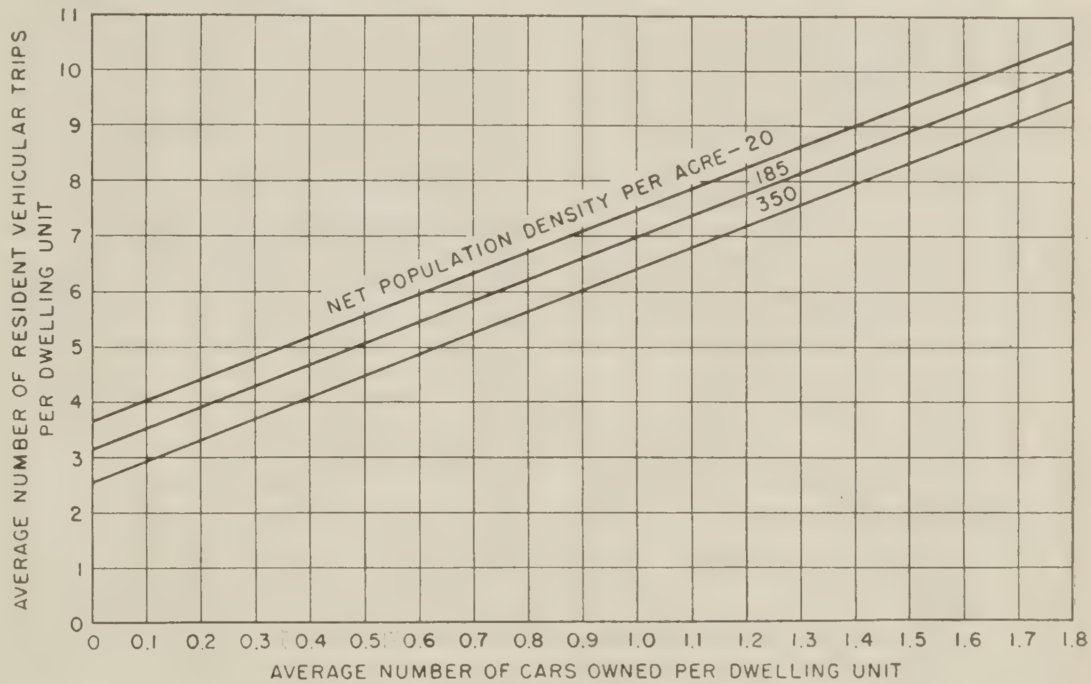

Figure 5.—Relation of resident vehicular trips to automobile ownership and population density.

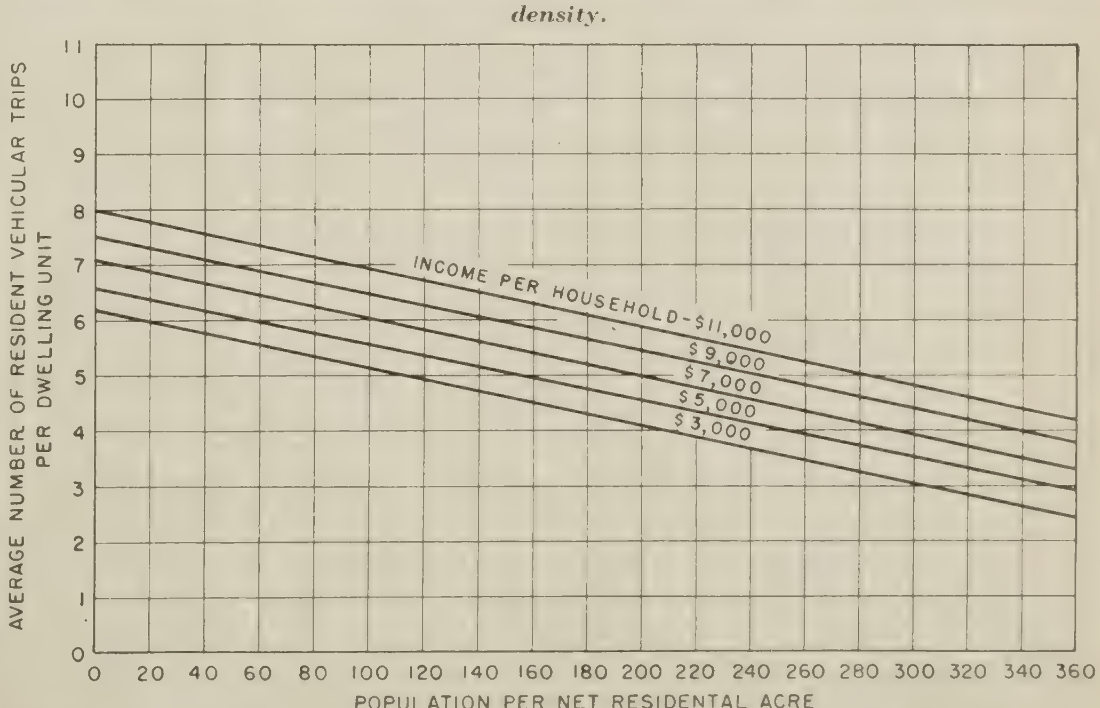

Figure 6.—Relation of resident vehicular trips to population density and average income per household.

Table 4.—Correlation of residents' daily trips per dwelling unit with various combinations of independent variables, as measured by a study of 95 census tracts in Washington, D. C., on an average weekday in 1948

Independent variables	Trips per dwelling unit (dependent variable)		Predicting equation
	Correlation coefficient	Standard error of estimate	
Automobile ownership and population density	0.835	0.87	$X_1=3.80+3.79X_2-0.0033X_3$
Automobile ownership	+.827	.89	$X_1=2.88+4.60X_2$
Population density and income	.764	1.02	$X_1=5.49-0.0089X_3+0.227X_5$
Population density	−.718	1.10	$X_1=7.22-0.013X_3$
Income	+.655	1.20	$X_1=3.07+0.44X_5$
Distance from central business district	+.575	1.30	$X_1=3.55+0.74X_4$

area and the District of Columbia are 0.91 and 0.89 trip per dwelling unit and the correlation coefficients are +0.815 and +0.827, respectively.

Factors Affecting Study

The methods presented here provide a means of evaluating very complex collections of data without personal bias. It should be pointed out, however, that the selection of the grouping units has a very definite effect on any statistical study. It is proper to form groupings whenever the individual units within a group are more nearly like each other with respect to the factors under consideration than they are like the units in any other group. Insofar as this is done effectively, just thus far is the analysis of the relation of variation between groups made more precise. In this study the interest is in the relation of number of trips to economic, geographic, and demographic factors. Census tracts establish groupings on the basis of these and other factors. Other groupings that may be more or less effective in attaining this purpose may lead to conclusions differing somewhat from those obtained in this study.

In all preceding analyses, emphasis was given to the relations of values of averages per dwelling unit per census tract. Had the interest been in studying the relation of values per dwelling unit, the measures of such a relation would have been smaller and the scatter greater than those obtained in this study, because the effect of many of the factors that were extraneous to this study could not have been eliminated partially or altogether by grouping. Likewise, it would have been even more difficult to study the relation of values for each dwelling unit rather than the relation of averages.

Comparison With More Recent Data

Preliminary results of an analysis of a 1955 followup traffic study strengthen the findings of the present study, as they apply to the relation between trips and automobile ownership per dwelling unit. The correlation coefficients and standard errors of estimate for 1948 were +0.827 and 0.89, respectively, as compared with +0.844 and 0.71 for 1955. The conclusion may be drawn that automobile ownership per dwelling unit is a good indicator for predicting the number of resident vehicular trips.

The application of the 1948 equation, $X_1=2.88+4.60X_2$ (X_1 represents trips per dwelling unit, and X_2, automobile ownership per dwelling), for estimating 1955 trips resulted in an across-the-board overestimate. This was primarily due to a change in procedure as to what constitutes a dwelling unit; the more recent study accounted for a greater number of dwelling units, such as roominghouses, military installations, and so forth, than did the earlier study.

Behavior of Riveted Connections in Truss-Type Members

Digest of a report [1] by E. CHESSON, JR., Research Associate in Civil Engineering, and W. H. MUNSE, Research Professor of Civil Engineering, University of Illinois

THIS article reports on a part of the cooperative research of the Bureau of Public Roads, Illinois Division of Highways, University of Illinois, and the Research Council on Riveted and Bolted Structural Joints.

Full-size tests under tensile loading were made on 16 specimens representing 8 variations of commonly used types of truss joints. There were two arrangements of laced-angle members and two of plate-and-angle members. Each was riveted to a pair of ½-inch gusset plates at each end which, in turn, were welded to large loading plates mounted in the testing machine. Rivet patterns represented common practice in joint design including an alternative pattern for one member. Three of the joint designs were tested with drilled holes and with punched holes.

By means of electric strain gages attached to the steel, the strains in different parts of the members were measured as the load was applied in increments up to failure. These tests, with mechanical dials and a whitewash coating to aid visual observation, revealed the distribution of load, points of weakness and initial failure, and the general nature of failure. The data were studied in relation to the tension, shear, bearing ratio, and theoretical joint efficiency.

Test loads ranged from 439,000 to 1,235,000 pounds depending upon the design of members. Tests of duplicate members agreed very well; in four cases the differences ranged from 1 to 2.4 percent, and in four cases from 6 to 8 percent. Several clear-cut indications are reported in the concluding remarks that follow.

Conclusions

1. Adherence to current design stresses does not necessarily insure a balanced design (i. e., a design in which, at ultimate, the member is likely to fail in either shear or tension); shear failures may be expected in long truss-type joints of "balanced design."

2. Large connections should be proportioned so that the distribution of rivets in a joint is similar to the distribution of areas connected by the rivets.

3. Members with drilled holes in the connections are more susceptible to shear failures than are similar punched specimens. In addition, the shear strength of the drilled member can be expected to be slightly smaller than that of the punched member.

4. Punched and drilled truss-type members of the same joint pattern and of ⅜- to ½-inch thick material may be expected to have approximately the same efficiency. This may be different for thicker materials or for loading conditions differing from these tests.

5. The use of lacing bars in tension members provides a secondary loading which may reduce the strength of the members. To reduce the likelihood of tensile failures at the lacing rivets, the edge distances at these rivets should be made as large as possible and the lacing bars as small as feasible.

6. Of the several design rules considered, the A. R. E. A. net-section rule appears to give the best agreement with the test efficiencies of these truss-type members.

7. In view of the lack of complete agreement between theoretical and test efficiencies and the unpredictable variations in the materials, it is doubted that complicated formulae for the design of tension members are justified. Because of the simplicity of application and our familiarity with the currently specified rule, it would seem desirable to retain the present net-section rule as a basis for design but to institute a suitable upper limit on efficiency or effective net section. Such a procedure would correct the most serious deficiency of the current specifications for tension members and would provide, for riveted connections, a predicted or theoretical efficiency which does not differ greatly from the test efficiency.

[1] Proceedings of the American Society of Civil Engineers, Paper No. 1150, Journal of the Structural Division, Jan. 1957.

Annual Report of the Bureau of Public Roads, Fiscal Year 1956

The Annual Report of the Bureau of Public Roads for fiscal year 1956 is now available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 25 cents a copy.

The report covers a wide range of engineering, administrative, and research activities in the highway field. During the fiscal year, progress was notable because improvements of Federal-aid highways and of highways in general reached new high levels and also by reason of the action of the Federal Government in assuring completion of a 41,000-mile National System of Interstate and Defense Highways in the following 13 to 15 years.

The Federal-Aid Highway Act of 1956, approved June 29, 1956, authorized the greatest long-range roadbuilding program ever undertaken. It authorizes a total amount of $24,825 million for the Interstate System for the period beginning July 1, 1956, and ending June 30, 1969.

The $875 million provided by the Federal-Aid Highway Act of 1954 for fiscal year 1956, an increase of $300 million over the previous fiscal year, gave added momentum to the Federal-aid highway program. The apportionment of $875 million authorized for fiscal 1957 was made on August 9, 1955. This authorization and remaining balances of prior authorizations, together with State and local matching funds, financed the program carried forward during the year. Additional 1957 funds totaling $1,125 million, provided by the Federal-Aid Highway Act of 1956, were apportioned June 29, 1956.

During the fiscal year 1956, $687 million of Federal funds were used in the improvement of 23,828 miles of highways with a total cost of $1,306 million. Included were 6,673 miles of highways and 1,290 bridges on the Federal-aid primary highway system outside of cities, 957 miles of highways and 599 bridges on urban portions of the primary system, 15,289 miles of roads and 1,886 bridges on secondary roads, and 909 miles of highways in National parks, forests, parkways, and on flood-relief projects. Railway-highway grade crossings were eliminated at 212 locations, 27 inadequate structures were reconstructed, and 305 crossings were protected by installation of appropriate safety devices.

In addition to a discussion of new highway legislation, other subjects covered in this report which were not found in the previous edition include highway design standards, survey of right-of-way practices and procedures, roadside improvement, and organization and training.

The report notes that improvement of major urban highways was of increasing concern to State highway departments. Programs were approved during the year which included projects in urban areas for a total estimated cost of $555 million, the Federal contribution being approximately $290 million. Work completed during the year cost $434 million for 957 miles, of which the Federal contribution was $217 million. Planning and initiation of construction of expressways in urban areas was stimulated by recent emphasis given to the Interstate System.

In the field of research, the annual report covers Bureau studies of highway finance, highway transport, and the array of physical problems that are associated with highways.

Reviewing other significant developments, the report points out that the year will be significant in highway history because it marks the end of discussion of what should be done to create an adequate system of main highways to serve the Nation and the adoption of a firm policy that will result in creation of such a system in 13 to 15 years.

Lost Production in Highway Construction: A Motion Picture

The Bureau of Public Roads, U. S. Department of Commerce, recently announced the release of a new motion picture *Lost production in highway construction.* The film, based on extensive studies conducted by the Bureau, examines minor delays that affect production rates of key units of highway construction equipment, including power shovels, scrapers, hot-mix bituminous plants, and pavers.

As stressed in this motion picture, most minor delays in highway construction jobs are timed in seconds; but the seconds add rapidly into hours and lost dollars for the contractor, and higher roadbuilding costs to the public. Minor delays cannot be eliminated completely, but greater efficiency by the contractors will mean that roads will be put into service sooner and at lower cost. Contrasts in operation practices shown in the motion picture are very revealing.

The motion picture is a 16-mm. sound and color film with a running time of 30 minutes. Prints may be borrowed for showings by any responsible organization by request addressed to Visual Education, Bureau of Public Roads, Washington 25, D. C. There is no charge except for the express or postage fees. Requests for the film should be sent well in advance of the desired showing and alternate dates for showing should be given if possible. Prompt return after each showing is necessary, so that all requested bookings may be fulfilled without delay.

Highway Statistics, 1955

The Bureau's HIGHWAY STATISTICS, 1955, the eleventh of the bulletin series presenting annual statistical and analytical tables of general interest on the subjects of motor fuel, motor vehicles, highway-user taxation, financing of highways, and highway mileage is now available.

The 174-page publication may be purchased from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at $1.00 a copy. The series of annual bulletins that are available from the Superintendent of Documents are indicated on the inside back cover of Public Roads.

U. S. GOVERNMENT PRINTING OFFICE: 1957

A list of the more important articles in PUBLIC ROADS may be obtained upon request addressed to Bureau of Public Roads Washington 25, D. C.

PUBLICATIONS of the Bureau of Public Roads

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

ANNUAL REPORTS

Work of the Public Roads Administration:

1941, 15 cents.	1948, 20 cents.
1942, 10 cents.	1949, 25 cents.

Public Roads Administration Annual Reports:

1943; 1944; 1945; 1946; 1947.

(*Free from Bureau of Public Roads*)

Annual Reports of the Bureau of Public Roads:

1950, 25 cents.	1953 (out of print).	1956, 25 cents.
1951, 35 cents.	1954 (out of print).	
1952, 25 cents.	1955, 25 cents.	

PUBLICATIONS

Bibliography of Highway Planning Reports (1950). 30 cents.
Braking Performance of Motor Vehicles (1954). 55 cents.
Construction of Private Driveways, No. 272MP (1937). 15 cents.
Criteria for Prestressed Concrete Bridges (1954). 15 cents.
Design Capacity Charts for Signalized Street and Highway Intersections (reprint from PUBLIC ROADS, Feb. 1951). 25 cents.
Electrical Equipment on Movable Bridges, No. 265T (1931). 40 cents.
Factual Discussion of Motortruck Operation, Regulation, and Taxation (1951). 30 cents.
Federal Legislation and Regulations Relating to Highway Construction (1948). Out of print.
Financing of Highways by Counties and Local Rural Governments: 1931–41, 45 cents; 1942–51, 75 cents.
General Location of the National System of Interstate Highways, Including All Additional Routes at Urban Areas Designated in September 1955. 55 cents.
Highway Bond Calculations (1936). 10 cents.
Highway Bridge Location, No. 1486D (1927). 15 cents.
Highway Capacity Manual (1950). $1.00.
Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.
Highway Practice in the United States of America (1949). 75 cents.
Highway Statistics (annual):

1945 (out of print).	1949, 55 cents.	1953, $1.00.
1946, 50 cents.	1950 (out of print).	1954, 75 cents.
1947, 45 cents.	1951, 60 cents.	1955, $1.00.
1948, 65 cents.	1952, 75 cents.	

Highway Statistics, Summary to 1945. 40 cents.
Highways in the United States, *nontechnical* (1954). 20 cents.
Highways of History (1939). 25 cents.
Identification of Rock Types (reprint from PUBLIC ROADS, June 1950). 15 cents.
Interregional Highways, House Document No. 379 (1944). 75 cents.
Legal Aspects of Controlling Highway Access (1945). 15 cents.
Local Rural Road Problem (1950). 20 cents.
Manual on Uniform Traffic Control Devices for Streets and Highways (1948) (*including 1954 revisions supplement*). $1.25.
Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate*, 15 cents.

PUBLICATIONS (Continued)

Mathematical Theory of Vibration in Suspension Bridges (1950). $1.25.
Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.
Opportunities in the Bureau of Public Roads for Young Engineers (1955). 25 cents.
Parking Guide for Cities (1956). 55 cents.
Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft (1943). $2.00.
Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents.
Public Control of Highway Access and Roadside Development (1947). 35 cents.
Public Land Acquisition for Highway Purposes (1943). 10 cents.
Public Utility Relocation Incident to Highway Improvement, House Document No. 127 (1955). 25 cents.
Results of Physical Tests of Road-Building Aggregate (1953). $1.00.
Roadside Improvement, No. 191MP (1934). 10 cents.
Selected Bibliography on Highway Finance (1951). 60 cents.
Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways, 1956: a reference guide outline. 55 cents.
Specifications for Construction of Roads and Bridges in National Forests and National Parks, FP–41 (1948). $1.50.
Standard Plans for Highway Bridge Superstructures (1956). $1.75.
Taxation of Motor Vehicles in 1932. 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces (1943). 10 cents.
Transition Curves for Highways (1940). $1.75.

MAPS

State Transportation Map series (available for 39 States). Uniform sheets 26 by 36 inches, scale 1 inch equals 4 miles. Shows in colors Federal-aid and State highways with surface types, principal connecting roads, railroads, airports, waterways, National and State forests, parks, and other reservations. Prices and number of sheets for each State vary—see Superintendent of Documents price list 53.
United States System of Numbered Highways. 28 by 42 inches, scale 1 inch equals 78 miles. 20 cents.

Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.

Bibliography on Automobile Parking in the United States (1946).
Bibliography on Highway Lighting (1937).
Bibliography on Highway Safety (1938).
Bibliography on Land Acquisition for Public Roads (1947).
Bibliography on Roadside Control (1949).
Express Highways in the United States: a Bibliography (1945).
Indexes to PUBLIC ROADS, volumes 17–19 and 23.
Title Sheets for PUBLIC ROADS, volumes 24–28.

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STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF FEBRUARY 28, 1957

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			CONTRACTS ADVERTISED CONSTRUCTION NOT STARTED			PROJECTS UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$29,258	$32,513	$25,863	264.4	$13,039	$8,418	120.1	$67,073	$39,874	832.0	$112,625	$74,155	1,216.5
Arizona	17,372	19,144	16,643	175.7	3,317	2,489	40.8	18,170	14,747	94.5	40,631	33,879	311.0
Arkansas	39,278	20,263	11,586	419.6	10,071	5,303	101.8	31,382	19,336	375.4	61,716	36,225	896.8
California	35,476	62,241	42,533	212.0	16,683	10,884	28.9	391,948	181,257	291.6	470,872	234,674	532.5
Colorado	32,733	19,397	13,342	149.4	5,542	3,363	48.6	30,929	21,594	170.3	55,868	38,299	368.3
Connecticut	39,159	13,198	8,169	7.6	9,677	8,123	10.3	9,622	4,843	16.1	32,497	21,135	34.0
Delaware	18,743	3,760	1,880	32.7	1,436	739	18.8	14,738	8,159	47.8	19,934	10,778	99.3
Florida	34,115	26,929	20,461	234.7	11,083	5,860	44.2	52,906	30,004	333.2	90,918	56,325	612.1
Georgia	65,305	33,818	18,444	415.7	8,389	4,078	53.4	84,409	48,705	788.2	126,616	71,227	1,257.3
Idaho	36,095	2,152	1,325	33.4	4,388	2,971	38.8	11,838	7,832	144.9	18,378	12,128	217.1
Illinois	36,361	89,656	66,031	627.3	44,277	30,744	107.4	145,285	101,933	583.7	279,218	198,708	1,318.4
Indiana	93,097	28,902	15,357	116.5	8,755	4,814	60.9	36,710	21,416	138.0	74,367	41,587	315.4
Iowa	9,246	65,454	47,908	1,109.1	26,591	17,975	280.1	32,928	21,896	676.2	124,973	87,779	2,065.4
Kansas	15,803	51,699	42,260	845.4	6,263	3,288	108.7	41,285	24,394	1,102.0	99,247	69,942	2,056.1
Kentucky	59,851	8,273	5,494	151.2	542	296	1.3	42,340	26,212	307.5	51,155	32,002	460.0
Louisiana	43,357	41,220	19,561	155.8	9,750	5,088	47.3	39,569	21,919	208.7	90,539	46,568	411.8
Maine	26,462	9,154	4,863	64.9	971	639	5.8	18,990	9,858	119.2	29,115	15,360	189.9
Maryland	7,863	27,669	16,667	69.8	16,312	12,608	20.5	50,342	31,867	146.2	94,323	61,142	236.5
Massachusetts	41,383	36,963	22,346	29.8	37,743	23,082	26.3	54,607	30,321	49.9	129,313	75,749	106.0
Michigan	54,031	74,143	55,001	453.0	37,298	22,331	70.3	66,033	40,003	279.5	177,474	117,335	802.8
Minnesota	36,254	27,897	20,686	640.6	9,841	6,142	113.0	58,964	39,295	731.7	96,702	66,123	1,485.3
Mississippi	12,284	51,946	38,183	788.3	14,331	11,190	128.0	31,378	17,999	574.5	97,655	67,372	1,490.8
Missouri	48,144	35,310	21,282	1,044.8	26,698	21,467	78.7	88,674	51,384	1,064.3	150,682	94,133	2,187.8
Montana	40,878	9,951	6,192	178.3	4,605	2,764	62.2	44,895	32,258	415.9	59,451	41,214	656.4
Nebraska	43,665	23,763	14,361	404.3	8,960	5,216	117.2	25,426	14,665	774.5	58,149	34,242	1,296.0
Nevada	35,656	4,550	3,798	119.6	1,941	1,673	6.0	11,404	9,621	134.7	17,895	15,092	260.3
New Hampshire	16,027	8,364	5,646	33.2	1,156	635	5.1	14,150	8,500	58.6	23,670	14,781	96.9
New Jersey	82,424	19,897	9,948	81.2	6,107	3,356	5.1	34,393	17,345	35.8	60,397	30,649	122.1
New Mexico	12,058	12,939	10,469	78.0	13,045	10,786	76.6	23,986	18,242	197.6	49,970	39,497	352.2
New York	132,775	51,553	32,099	129.9	78,390	50,846	61.6	308,147	172,168	353.2	438,090	255,113	544.7
North Carolina	66,488	35,887	23,143	440.9	13,788	7,169	117.5	54,397	27,495	657.8	104,072	57,807	1,216.2
North Dakota	18,269	25,481	19,111	1,282.7	8,957	6,628	153.9	17,420	9,624	818.4	51,858	35,363	2,255.0
Ohio	51,377	76,054	54,018	149.7	34,098	24,354	62.7	138,692	89,958	179.0	248,844	168,330	391.4
Oklahoma	32,072	46,256	31,264	469.8	15,922	9,330	121.7	47,048	26,875	419.0	109,226	67,469	1,010.5
Oregon	28,619	7,780	6,125	50.1	5,196	4,539	26.7	34,246	23,758	185.3	47,222	34,422	262.1
Pennsylvania	87,578	110,026	69,395	115.9	84,867	57,562	84.5	118,905	62,730	323.9	313,798	189,687	524.3
Rhode Island	5,010	10,625	8,198	14.9	2,773	2,496	.1	30,355	19,035	24.0	43,753	29,729	39.0
South Carolina	37,025	26,452	17,155	565.6	4,264	2,866	8.7	30,148	16,650	562.2	60,864	36,671	1,136.5
South Dakota	12,729	39,005	28,969	755.4	3,765	2,173	135.6	20,682	13,000	600.1	63,452	44,142	1,491.1
Tennessee	47,089	23,110	11,373	471.4	15,573	7,916	44.4	83,788	50,696	528.1	122,471	69,985	1,043.9
Texas	131,393	18,129	10,543	168.9	62,382	42,073	456.4	146,102	86,946	1,551.6	226,613	139,562	2,176.9
Utah	19,746	15,909	13,482	150.7	3,442	2,694	28.2	10,349	7,847	148.3	29,700	24,023	327.2
Vermont	12,848	7,753	5,388	37.9	1,276	718	4.0	13,773	8,926	59.3	22,802	15,032	101.2
Virginia	59,672	26,103	16,122	158.7	6,371	3,556	15.9	40,750	21,782	360.9	73,224	41,460	535.5
Washington	47,104	9,472	6,538	183.5	7,350	4,981	36.5	35,972	21,525	255.2	52,794	33,044	475.2
West Virginia	32,262	28,970	19,905	59.5	5,715	2,919	22.4	27,104	14,619	72.4	61,789	37,443	154.3
Wisconsin	63,521	15,935	9,109	214.0	10,736	5,546	61.3	56,978	34,360	314.9	83,649	49,015	590.2
Wyoming	3,377	27,245	22,444	238.7	5,882	4,416	59.6	24,115	17,924	270.3	57,242	44,784	568.6
Hawaii	6,599	2,082	1,041	8.8	3,324	1,659	5.1	4,741	2,247	8.3	10,147	4,947	22.2
District of Columbia	18,259	14,051	9,695	7.6	637	335	.5	9,850	7,430	.1	24,538	17,460	8.2
Puerto Rico	11,741	5,183	2,078	14.8	-	-	-	19,054	9,206	62.7	24,237	11,284	77.5
Alaska	15,074	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	2,003,005	1,484,226	1,003,494	14,625.7	733,519	481,098	3,333.5	2,846,990	1,660,280	18,447.5	5,064,735	3,144,872	36,406.7