NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 42

INTERSTATE HIGHWAY MAINTENANCE REQUIREMENTS AND UNIT MAINTENANCE EXPENDITURE INDEX

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of an effectual dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

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FOREWORD

By Staff

Highway Research Board

There is a continuing need to provide better guides for estimating future highway maintenance requirements from the standpoint of both budgeting and projecting labor, equipment, and materials needs. This is particularly true as the Interstate System with its multiple traffic lanes, wider right-of-way, and numerous interchanges becomes a reality. The constant rise in traffic volume, increasing demands by the traveling public for improved traffic services, and recent emphasis on aesthetics of highways will also have an as yet not completely determined effect on future maintenance requirements. The information contained in this report should provide highway administrative and maintenance officials with valuable new tools for determining maintenance needs. It contains a procedure for estimating the long-range maintenance requirements for large segments of the Interstate System and several maintenance cost indexes that can be continuously updated.

The Highway Research Board Committee on Maintenance Costs, the Bureau of Public Roads, and several States have conducted research and analyzed historical records to develop relationships between maintenance costs and the various influencing factors. However, there still exists a need for additional information on which to base estimates of future maintenance requirements.

Bertram D. Tallamy Associates undertook a study of two independent but related phases of this problem, the results of which are reported herein. Part I of the report, "Interstate Highway Maintenance Requirements," deals with the development of a procedure for determining Interstate System needs on a quantitative basis. The indexes described in Part II, "Unit Maintenance Expenditure Index," were developed for rural primary, municipal extensions, and total mileage of State-administered highway systems, both nationwide and for five separate regions.

Early in the Interstate study, it was determined that existing information, available from maintenance departments of State highway organizations, was of little value for the development of the desired practical measurement system. As a result, a daily report procedure was inaugurated for the collection of original data on use of labor, equipment, and materials for each of seven maintenance activities from 28 test sections over a 12-month period. The test sections totaled 567 miles, were located in five States and were selected to accomodate a maximum number of variables influencing maintenance requirements.

A multiple linear regression analysis was used to determine a relationship between the physical, environmental, and traffic factors for the test sections and the maintenance requirements in terms of labor, equipment, and materials units. General regressional models were developed for each of the seven maintenance activities, each model predicting the requirement units to maintain adequately a one-mile section of four-lane divided highway, given various physical, environmental, and traffic parameters. Finally, factors were computed to convert the requirement units into appropriate labor hours, equipment hours, and material dollars for each of the seven activities. Supplemental field studies were also conducted on productivity, work efficiency, and maintenance adequacy.

It is recognized that the collection and analysis of data over a longer period of time and a larger and possibly more representative sample would provide a

more accurate method of predicting total maintenance requirements and a further breakdown of labor, equipment, and materials units by activities. However, the degree to which the general approach and the models developed during this project predict Interstate maintenance requirements can only be determined by actual field trial. It should be understood that these models are intended to apply to large segments of the Interstate System and not to local sections. The procedures detailed in the report, when applied to the completed 41,000-mile Interstate System predict an annual maintenance cost of $261,000,000 by 1975.

The 1947 Unit Maintenance Cost Index developed by the HRB Committee indicated what it would cost to perform a fixed quantity of maintenance the same way in any year based on changes in the cost of units of labor, equipment, and materials. The advantage of the Unit Maintenance Expenditure Index and related indexes, developed during Part II of this project, is that they reflect other factors influencing maintenance costs, including changes in work load, productivity, maintenance standards, and levels of service. In fact, the investigation shows that since 1956 less than 40% of the average annual increase in unit maintenance expenditures per mile of road resulted from unit cost increases in labor, equipment, and materials.

Additional research is recommended in the report to refine coefficients for the Interstate maintenance requirement models and to develop similar models for other highway systems and for regions influenced by unique factors. Recommendations are also included for continuous updating of the unit maintenance expenditure and related indexes developed during the study.

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ACKNOWLEDGMENTS

Sincere appreciation is expressed for the generous cooperation and assistance provided throughout the "Requirements" (Part I) portion of the study reported herein by the California Division of Highways under J. C. Womack and E. L. Tinney, Principal Highway Engineer, Maintenance, and his staff; the Florida State Road Department under J. W. Brown and Rolfe Mickler, Assistant State Highway Engineer (Maintenance), and his staff; the New York Department of Public Works under J. Burch McMorran and Lester H. Krick, General Supervisor of Highway Maintenance, and his staff; the Ohio Department of Highways under P. E. Masheter and E. K. Core, Deputy Director for Operations, and his staff; the Texas Highway Department under D. C. Greer and J. A. Waller, Chief Engineer of Maintenance Operations, and his staff; the New York Thruway Authority and C. H. Lang, Chief Engineer, and his staff; and the Ohio Turnpike Commission and E. W. Meeker, Chief Engineer, and his staff.

Appreciated also is the assistance and information offered in connection with the Part I studies by all of the State highway departments, the Bureau of Public Roads, and the Highway Research Board.

Grateful acknowledgment also is made to the Bureau of Public Roads, and in particular to the staff and employees of the Construction and Maintenance Division under M. B. Christenson and of the Highway Statistics Division under E. M. Cope, who made available much of the background data needed to develop the indexes presented in Part II of this report.

Appreciation is also expressed to the many State highway departments for their assistance in providing information. Special thanks are given to the Maintenance Division of the Virginia Department of Highways for the information used in the development of the traffic and maintenance cost relationships included in the report.

PART I

INTERSTATE HIGHWAY MAINTENANCE REQUIREMENTS

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PART I
INTERSTATE HIGHWAY MAINTENANCE REQUIREMENTS

SUMMARY

With the steadily rising cost of maintenance, the impact of the added maintenance burden created by the Interstate Highway System is of particular concern to highway officials. Recognizing this problem, the American Association of State Highway Officials, through the National Cooperative Highway Research Program, authorized this study aimed at development of Interstate Highway maintenance requirements.

Previous and current efforts related to the evaluation of maintenance requirements, productivity and procedures were reviewed through a literature search and discussions with representatives of highway organizations in each of the 49 States in which Interstate highways are located.

For purposes of this study, the definition of "maintenance" found in the *Manual of Uniform Highway Accounting Procedures,* published by AASHO in 1958, was used. This definition states: "Highway maintenance is the act of preserving and keeping a highway, including all its elements, in as nearly as practical its original as-constructed condition or its subsequently improved condition; and the operation of a highway facility and services incidental thereto, to provide safe, convenient and economical highway transportation." Thus, "maintenance" as referred to in this study does not include resurfacing or other major rehabilitation costs.

Although all States indicated acceptance of the definition of maintenance as stated in the AASHO Manual and 40 States indicated that they followed the AASHO cost accounting system, 22 of these States indicated significant local variations in the application of these accounts. Only 15 States indicated that separate crews were assigned exclusively to maintenance of Interstate sections.

In reviewing other maintenance requirements studies, 282 publications were searched and abstracted. The Highway Research Board's Maintenance Cost Committee has made the most numerous attempts to analyze historical records and to develop relationships between maintenance costs and the factors influencing these costs. Additional studies have been made by the highway departments of Arizona, Louisiana, Idaho, Virginia, Ohio, and Oklahoma.

Based on the information obtained in the interviews with State maintenance officials and in the review of prior studies, it was determined that existing maintenance cost data available from the State highway departments would be of little value in developing a practical measuring system of Interstate maintenance requirements. As a consequence, original, controlled data were obtained for the study. Because of the time and funding limitations on the project, the original data samples were somewhat limited. However, the control of the sample selection and the complete and accurate measure of maintenance expenditures generated a more reliable base for measuring maintenance requirements than was possible with the historical data available.

Five States—New York, Florida, Ohio, Texas and California—were selected for the intensive study and data collection phase. Twenty-eight test sections were selected within these States, to accommodate a maximum number of variables

affecting maintenance requirements on the Interstate System. Significant variables included in the test sections were terrain, urban and rural areas, regional characteristics, traffic, and climatic conditions. Test sections were screened to select those on which high-caliber maintenance was practiced and on which uniformity of characteristics and traffic flow were present.

A daily report procedure was inaugurated whereby maintenance section personnel reported labor, equipment and material expenditures in terms of quantities as well as dollars for each maintenance activity for each day. The daily report program was monitored by experienced field representatives, all former maintenance engineers, in each of the five test States.

Daily report data were checked, summarized, coded and recorded using data processing equipment. A summary compilation of the labor, equipment and materials expenditures for the 12-month observation period on the 28 test sections showed that 47.7% of the expenditures were made on traffic services, 24.1% on physical maintenance, and 28.2% on aesthetic controls including litter removal and vegetation control. In the physical maintenance accounts, pavement and shoulder surface maintenance expenditures represented only 15.3% of the total maintenance requirements. The distribution of total expenditures by labor, equipment and material showed that labor accounted for 49%, equipment 27%, and material 24%.

The data on the daily report forms and those obtained through inventories of the physical and environmental characteristics of the test sections were not sufficient to meet all of the objectives of the study. So that valid comparisons could be made among the test sections, data also were needed to show the level or standard of maintenance achieved on each test section; the comparative efficiency of crews; the procedures by which labor, equipment and materials were utilized in performing the work; and the quality and quantity of work performed. To meet these needs, special studies were undertaken. Special studies were made of snow and ice control activities also.

From these observations it was concluded that the differences in maintenance standards on the various test sections measured through the conditions surveys were too small to affect the relationship developed through the regression analyses and, therefore, did not need to be considered. Work efficiency also was not a factor in interpreting maintenance expenditures for the regression analyses and was not included in the mathematical models.

The observation of work procedures illustrated the many different successful methods employed by maintenance crews. The studies related to optimizing procedures demonstrated that there is seldom a single procedure for maintenance operation that is fully applicable to a number of different locations. Limitations related to design and operational characteristics of the highway, types of equipment available and a variety of other local factors influence procedures. Thus it was evident that efficient maintenance operations depend to a great degree on management factors, particularly the ability of first- and second-line supervisors responsible for the planning and application of the proper mix of men, equipment, materials and procedures to routine tasks and emergency requirements in the maintenance program.

For the development of a quantitative measure of Interstate maintenance requirements expressed in terms of labor, equipment and material units, it was necessary to explore the relationships between the work load being generated by each test section and the physical, environmental and traffic factors having a potential influ-

ence on the work load. This was done using a multiple linear regression analysis where the significance of each factor was evaluated. The factors affecting maintenance work load were then incorporated into general regression models which related these factors to a single maintenance requirement value representing the units of labor, equipment and material expended to maintain the Interstate test sections.

General regressional models were developed for seven different maintenance activity groups. Each model predicted the requirement units needed to maintain adequately a one-mile section of four-lane divided Interstate highway, given various physical, environmental and traffic parameters. Finally, factors were computed to convert the requirement units into appropriate labor hours, equipment hours, and material dollars for each of the seven models. The activity groupings and the requirements models for each are as follows:

Pavement and Shoulders

$$Y_P = 19.72\,X_1^2 + 13.72\,X_2 - 183$$

in which Y_P represents pavement and shoulder maintenance requirement units for a centerline mile of four-lane Interstate highway or its equivalent in interchanges or multilane pavements; X_1 is the surface age, in years (Test sections generally consisted of more than one construction section, some of which were built at different times. A composite age was calculated by summing the products of age times the mileage associated with that age and then dividing this total by the total mileage. On sections which had been resurfaced, age was defined as the lapse in time since the date of resurfacing.); and X_2 is the number of days when the maximum daily temperature was below 32 F.

Drainage and Erosion

$$Y_D = 4.13\,X_1 + 2.68\,X_2 + 73$$

in which Y_D is the drainage and erosion control maintenance requirement units for a centerline mile of Interstate highway; X_1 is a terrain factor showing the percentage of side slopes 2:1 or steeper; and X_2 is the annual average rainfall, in inches.

Vegetation Control

$$Y_{VR} = 97.52\,X_1 + 35.12\,X_2 + 0.00975\,X_3 - 744$$

$$Y_{VU} = 97.52\,X_1 + 35.12\,X_2 + 0.0195\,X_3 - 744$$

in which Y_{VR} is the vegetation control requirement units for a centerline mile of Interstate highway in a rural location; Y_{VU} is the vegetation control requirement units for a centerline mile of Interstate highway in an urban location; X_1 is the length of the mowing season, in months; X_2 is the precipitation during the mowing season, in inches; and X_3 is the average daily traffic volume.

Structures

$$Y_S = N_1(1.63\,X_1 + 28) + 1.80\,N_2\,A/f$$

in which Y_S is the maintenance requirement units for structures per centerline mile of Interstate highway; N_1 is the average number of structures per mile; X_1 is the number of days of snow cover; N_2 is the average number of painted steel structures per mile; A is the average deck area of an N_2-type structure, in square yards; and f is the number of years between repaintings.

Snow and Ice Control

$$Y_{IS} = 14.8\,X_1 - 37.5\,X_2 + 24.3\,X_3 + 51.0\,X_4$$

in which Y_{IS} is the snow and ice control maintenance requirement units for a four-lane mile of Interstate highway or its equivalent in interchanges or multilane pavements; X_1 is the average annual snowfall, in inches; X_2 is the number of days of snowfall (includes days when the U. S. Weather Bureau reports "trace" snowfall); X_3 is the number of days with snow cover on the ground; and X_4 is the number of days when the maximum daily temperature was below 32 F.

Traffic Control Facilities

$$Y_{TC} = 0.0321\,X_1 + 165$$

in which Y_{TC} is the maintenance requirement units for all traffic control facilities on a centerline mile of Interstate highway, except rest or service areas, weighing or inspection facilities, and the cost of electric power; and X_1 is the average daily traffic volume.

Litter Removal and Sweeping

$$Y_{LSR} = 0.0051\,X_1 + 5.09\,X_2 + 113$$

$$Y_{LSU} = 0.0051\,X_1 + 5.09\,X_2 + 893$$

in which Y_{LSR} is the maintenance requirement units for litter removal and sweeping for a centerline mile of rural Interstate highway; Y_{LSU} is the maintenance requirement units for litter removal and sweeping for a centerline mile of urban Interstate highway; X_1 is the average daily traffic volume; and X_2 is a terrain factor as percentage of side slopes 2:1 or steeper.

Each of the foregoing regression models produces requirement units. These units include comparable units of labor, equipment and material which can be converted back to quantities of each component in their original proportions. A study of the distribution of the labor, equipment and material expended for the seven different activity classifications showed that a wide variation existed between activities. Therefore, separate factors were required for the conversion of maintenance requirements into appropriate labor, equipment and material units for each activity classification. Tables were developed showing the average distribution of labor, equipment and material by percent for urban and rural areas for each of the activity classifications to permit direct conversion of the requirements units into appropriate units of labor, equipment and material.

The seven maintenance requirements models are applicable to the entire Interstate System but because of their wide application and the relatively small sample taken over a single year, there are accuracy limitations. In general, the models are best suited for predicting requirements for large segments of the Interstate system and should not be used for short sections where unique local factors have a major influence. The maintenance expenditures reported for the various test sections in this study varied from $1,000 to $13,000 per mile. The application of the models predicted requirements which resulted in an overall difference of only 0.85% from the actual reported expenditures. The requirement units do not include vegetation control requirements where special landscaping procedures are practiced nor do they cover the maintenance requirements for rest areas or for the cost of providing electric power for roadway illumination.

Based on the use of the models developed in this study, the Interstate System is estimated to require the annual expenditure of $261,000,000 in 1975, assuming its full completion and operation before that date. Pavement and shoulder maintenance, which currently represents only about 15% of the maintenance expenditures on the Interstate test sections, is estimated to represent almost 45% of the total maintenance requirements in 1975.

As a result of the study, it is recommended that (1) The AASHO chart of accounts be fully developed and adopted without modification for the recording of State highway maintenance expenditures; (2) a more extensive program of test section data collection and analysis be undertaken on a national level for a period of time sufficient to encompass fully the long-range influences on maintenance activities, and from such data refined coefficients be determined for national models and models developed for local systems responsive to unique, local factors; and (3) increased attention be given to a system approach to maintenance planning and programming.

CHAPTER ONE

INTRODUCTION, REVIEW OF OTHER STUDIES, AND CURRENT PRACTICES

The National System of Interstate and Defense Highways was created in 1944 and Federal funds for its accelerated construction were authorized in 1956. As amended, this authorization provided for the Federal government to provide a 90% share of the total construction cost over the years 1957-1972. By the end of 1966, approximately 23,500 miles of the Interstate System had been opened to traffic, of which 20,100 miles were built to full or acceptable Interstate standards.

The maintenance required for this new System is expected to be costly, and evidence to date thoroughly substantiates this premise. With the steadily rising cost of maintenance, the impact of the added maintenance burden created by the Interstate System is of particular concern to highway officials who are increasingly aware of the major financial burden that maintenance places on annual budgets. If the present trend continues, 15% of the State maintenance dollar will be spent on the 41,000-mile Interstate System, which will comprise only 5% of the State-administered highway mileage.

The increasing cost of maintenance is caused in part by the increasing volumes of traffic using the highways. Increasing traffic accelerates the wear and tear on the highway plant; it generates more litter; it causes more accident damage to signs, lights, fencing, guardrail and other appurtenances; it causes more interference with the performance of maintenance work; it requires more traffic services and disabled vehicle and accident assistance; and, additionally, higher traffic volumes often are accompanied by trends to higher levels or standards of maintenance. An inspection of factors influencing increases in maintenance expenditures * indicates that about 30% is directly attributable to increases in traffic.

At the same time, there is an increasing need to improve the efficiency and productivity of maintenance programs. Labor costs continue to climb and the economics of mechanization must be evaluated. New materials and techniques must be analyzed and employed where applicable. Highway design concepts are becoming more sophisticated and maintenance problems are growing proportionately. Additionally, safety and traffic congestion problems greatly limit the time when maintenance work can be achieved.

All of these influences are particularly true for the multilane Interstate facilities which are rapidly being added to the highway system. Today, most Interstate highways are relatively new; the full weight of the requirements to maintain the Interstate System at the high standard to which it was constructed have not been felt. However, they soon will be and reliable methods for measuring maintenance requirements and associated costs are needed. Without this information, it will not be possible to plan accurately or finance a sound and adequate program of maintenance for the Interstate System.

Anticipating this problem, the American Association of State Highway Officials, through the National Cooperative Highway Research Program, authorized this study. The study objectives, as given in the Project Statement, were to:

1. Develop one or more practicable measuring systems for use by individual States to determine Interstate highway

* "Unit Maintenance Expenditure Index." Part II of this report.

maintenance requirements (by type, magnitude, frequency, etc.) on a quantitative basis.

2. Develop a practical measuring system for relating utilization of men, equipment and material to production in maintenance operations.

3. Delineate methods (for using values derived by employment of these measuring systems) for optimizing efficiency in maintenance operations on Interstate highways.

4. Test methods developed in Item 3 on a selected sample of maintenance operations on Interstate highways in the three or four selected States.

A comprehensive and deliberate study was made of other previous and current efforts related to the measurement of maintenance requirements, productivity, and organizational efficiencies. This was accomplished by reviewing applicable published matter, and through discussion and interviews with representatives of highway and research organizations and industry who are knowledgeable in these areas. The state-of-the-art review revealed that the magnitude of previous efforts in the various study areas was considerable. It also was apparent that the scope of this undertaking was substantial. The limited depth to which the various areas delineated for study could be pursued required a balancing of the effort in proportion to each area's contribution to the primary study objective, which was the quantitative measure of maintenance requirements for the Interstate System.

Fundamental to the undertaking of this study was the adoption of a definition of "maintenance." To make the resulting data as applicable as possible to the budgeting and accounting systems of the States, the AASHO definition was adopted. This definition (*1*, Ch. 1, Sect. A) states that *highway maintenance is the act of preserving and keeping a highway, including all its elements, in as nearly as practicable its original as-constructed condition or its subsequently improved condition; and the operation of a highway facility, and services incidental thereto, to provide safe, convenient, and economical highway transportation.*

The definition is further clarified in the AASHO manual by a listing of the routine maintenance operations, replacements, and minor additions considered to be maintenance. Of special importance here is the fact that *resurfacing of more than ¾-in. thickness for a continuous length of 500 ft or more is not defined as maintenance.* Thus, major rehabilitation of pavements by conventional 2 to 3-in. thick resurfacing is considered to be a "betterment" and does not enter into the measurement of maintenance requirements as determined by this study. Essentially then, pavement maintenance provides those services needed to produce the optimum service life for the pavement structure. Graphically, this might be depicted as in Figure 1, which shows that proper maintenance expenditures will control the annual reduction of serviceability of the highway at an optimum rate. When the accumulated loss of serviceability reaches a minimum point, major rehabilitation—usually including bituminous resurfacing—is required. The rehabilitation work itself is not considered as maintenance, but the annual routine expenditures before and after rehabilitation are.

Before deciding on the approach to use in the development of the measure of maintenance requirements, time was spent reviewing the problem and the suitability of existing maintenance information available from the State highway departments. The visits to the State highway departments did not produce the raw data needed for the development of a measure of maintenance, but they did provide much valuable information and background for the project. The insight gained relating to existing State maintenance practices served as a guide in developing the format for the measurement of maintenance requirements. Before the study was completed, every State highway department, with the exception of Alaska, was visited. The extensive information obtained is included in Chapter Two.

REVIEW OF OTHER MAINTENANCE REQUIREMENT STUDIES

As a part of the literature search for this project, 282 publications of various types were reviewed and abstracted. Emphasis was placed on a review of articles and reports dealing with the measurement of maintenance requirements. All publications are listed in the bibliography which is a part of this report. A brief summary of the information published about prior requirements studies of interest in this project follows.

The Highway Research Board's Maintenance Cost Committee has made the earliest and most numerous attempts to analyze historical records and develop relationships between maintenance costs and the factors influencing these costs (*3-31*). In 1956 the Committee reported (*20*) on a study of 560 miles of roads of various surface types which showed relationships between surface maintenance costs and traffic, road thickness, and subgrade. The relationships were converted to curves, which could be used to predict surface maintenance costs for a given road. Procedures for using the relationships were illustrated, but no record was found indicating that the relationships were ever tested in practice.

The Arizona Highway Department has been collecting detailed maintenance cost data from highway control sections within the State for the past seven years (*32, 33, 34*). The department has tabulated the relationships of various maintenance account costs with variables such as surface type, age, width, elevation, terrain, and traffic volume, and with system classifications such as primary, secondary, rural, urban, etc. Recently, Arizona expanded the program to encompass the entire State mileage.

In one of the original attempts to develop a quantitative measure of maintenance requirements, the Louisiana Department of Highways developed a formula to predict maintenance costs on a per-mile basis (*35*). The development consisted of defining a "base mile" of concrete, bituminous, or aggregate surfaced road in terms of a fixed age, traffic volume, subgrade classification, and width. A section of road meeting the criteria was given a factor of 1 and a fixed annual per-mile maintenance cost. The maintenance cost varied for different sections of the State so that local cost factors were reflected. A schedule of values was determined for each of the components, age, traffic, subgrade

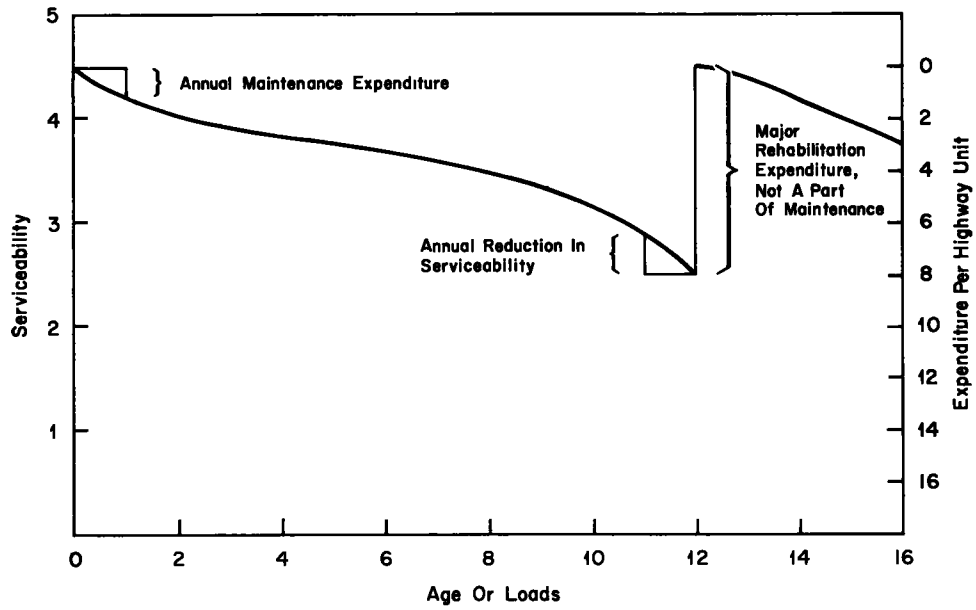

Figure 1. Typical performance curve, Interstate Highway section.

and width, to reflect increases in cost due to variations from the base-mile criteria. These schedules were generated by examining the maintenance cost on roads which were adequately maintained and were different from the base mile. Using trial-and-error techniques, factors were determined to reflect cost variations. With this information it became possible to examine any road, assign it appropriate modifying factors, and predict its future maintenance cost.

In 1963, Louisiana reported (*36, 37*) that it had developed a model which would quantitatively predict maintenance requirements for concrete roads in Louisiana. This model was developed from historical maintenance data and attempted to relate the effects of (1) traffic volume, (2) surface condition, (3) subsoil condition, (4) surface width, and (5) right-of-way on maintenance cost. The model predicted within 15% more than two-thirds of the historical maintenance costs used in the study.

A subsequent Louisiana study reported in 1965 (*38, 39*) followed the procedures outlined in the 1963 study, with attempts made to improve the quality of the input data. The same model and variables were used, but the factors used to reflect the variables were more sophisticated. Instead of using actual traffic volume, heavier vehicles were "converted" to equivalent passenger cars in a ratio reflecting the increased damage inflicted on the pavement surface by the heavier vehicles. Rather than the evaluation of surface conditions used in the first study, a rating form was devised which essentially followed the suggested criteria set forth in *HRB Special Report 30* (*2*, p. 30). The subsoil factor was reflected by using the Texas triaxial classifications. For the other two variables, surface and right-of-way width, actual values were used. One other modification related to the adequacy of maintenance; instead of relying on expenditures as an index of adequate maintenance, each test section was evaluated as to the adequacy of maintenance accomplishments. Any variation from a uniform adequacy standard was corrected by modifying existing costs to reflect any increases or decreases in labor, equipment and materials needed to make the maintenance accomplishments between sections comparable. In this manner the basic data reflected what should have been spent to maintain each section adequately, rather than what was actually spent.

Idaho made a maintenance cost study in 1965 (*40*) to determine the various factors influencing maintenance expenditures. The approach involved examination of various climatic, environmental and highway characteristics with historical maintenance cost using regression analyses. It was found that the most meaningful relationships were produced using climatic data which explained variations in snow removal and total routine maintenance expenditures.

In a recent study by Betz (*41*) directed towards establishing the importance of highway maintenance in the developing countries of the world, many of the previous attempts to formulate maintenance costs quantitatively were thoroughly examined. His review emphasized that most of the factors influencing maintenance cost were not independent variables. He stated that there were complex interrelationships between such factors as traffic, pavement design, base material, etc., and any attempt to relate any single variables to maintenance cost would prove impossible. Betz felt that the Louisiana State University approach was the most sophisticated that had been developed because it took into consideration the interrelationships between influencing factors, using multiple regression analyses of the variables. The resulting model adequately predicted maintenance in Louisiana, but Betz noted that "the equation is founded on Louisiana's local experience and the coefficients, therefore, cannot be used universally."

One of the most recent studies undertaken to improve

maintenance practices was the Virginia Maintenance Study (*42*). This research was undertaken in 1965 to "develop better ways and means to manage the function," by defining and quantifying highway maintenance work loads and procedures. The approach involved establishing activity definitions and corresponding measures of work accomplished. With the definitions, records could be obtained showing the actual effort expended in terms of labor, equipment and material to accomplish a measurable quantity of a specific activity. Further, this information was related to the management unit, road type, specific type of input (i.e., labor class, equipment type, kinds of material, etc.), along with the influences of the climate and geographic region.

Individual activities also were studied, using time and motion study techniques, to document the way in which different activities were undertaken so that improvements in procedures could be instituted.

The Virginia report also stressed the need for a competent administrative staff at all organizational levels to provide adequate planning and guidance for operational personnel.

An Ohio maintenance cost study initiated in 1961 is still in progress (*43*). The objective is to determine reliable unit maintenance costs and the major factors contributing to such costs so that maintenance requirements can be predicted from the known road elements. Further, Ohio hopes to identify the major factors that influence maintenance costs so that steps can be taken to reduce the influence of these factors to a minimum.

Initially Ohio established a number of test sections where cost data were collected on various maintenance activities. In a 1966 interim report (*44*) these various activity costs were compared with some of the potential influencing factors and confidence limits were determined for these various groupings. The variations were very wide, and it was concluded that the cost data were both unreliable and inadequate. To minimize these deficiencies the study procedures were changed and the number of reporting test sections was increased. Also, new maintenance adequacy evaluation procedures were initiated following a rating outline developed by the Oklahoma Department of Highways.

CURRENT STATE MAINTENANCE PRACTICES

In recognition of the shortcomings of information obtained by questionnaires mailed to the States, personal interviews were scheduled with administrative personnel involved in State highway maintenance in each of the 48 contiguous States and Hawaii. The officials of several of the toll road organizations, including those in Ohio, Illinois, Oklahoma, Pennsylvania, Indiana, and New York, also were interviewed. The interviews were based on a standard questionnaire, so that uniform information would be obtained.

Questions included in the interview were designed to provide information regarding the State practices and policies of administration, cost record keeping, and material and equipment management records.

The interviewers experienced full cooperation on the part of highway officials in every State. Interviews were supplemented by field trips over completed Interstate or toll road sections to view maintenance facilities, equipment, crews, and work accomplished.

Organization

In most States, the organization for maintenance follows a similar pattern. Titles vary considerably; however, functions vary little. A typical organization chart is shown in Figure 2.

The chief policy officer for the maintenance function is generally the maintenance engineer, serving as a staff officer to the chief highway engineer. It is his function, as a staff officer, to develop and recommend administrative control and policy. Line authority usually extends directly from the chief highway engineer to the division or district engineer and then to the division or district maintenance engineer.

To this level, the maintenance responsibility usually covers the entire State highway system, including Interstate highways. However, from this point down to the field operations there are many organizational variations. These variations stem from differences in legal assignment of responsibilities, from personnel policies, and from varying operating philosophies within the administrative organizations.

Regardless of titles, the field maintenance of State highways in the division or district is generally under the direction of an area maintenance supervisor who plans the maintenance activities in his area with the help of the crew foremen.

The foremen supervise groups of equipment operators and laborers who perform routine maintenance operations within a small area. Other foremen supervise crews responsible for specialized work requiring special equipment and skills, such as bridge and structure repairs, bituminous surface treatments or resurfacing, special drainage maintenance, etc.

It was reported that prison labor is used in seven States, although the extent of use varies from only one district in each of two States to Statewide use in several others. In all cases, highway maintenance funds, at rates varying from State to State, are used to pay for prison labor.

In 23 States the control of highway maintenance equipment is with the State maintenance engineer. A superintendent of equipment heads up the central garage facilities and equipment shops and is responsible to the State maintenance engineer. In each division or district there is a counterpart of the superintendent of equipment, who has jurisdiction over the garage facilities and equipment shops of the division or district (see Fig. 3). He is normally responsible to the division or district maintenance engineer. The acquisition, assignment and control of equipment is a function of the district maintenance engineer. Equipment requirements, specifications, requisitioning, and inspection upon delivery are under the control of the State maintenance engineer.

A second method, used in 21 States, provides for a separate equipment organization, headed by an equipment superintendent or similar title. In most cases, the equip-

ment division is established under the direct control of the head of the highway agency. In two instances, however, it is under a department outside of the highway agency.

In the early planning for maintenance of the Interstate highways, it was thought by some that it would be desirable and necessary to institute maintenance organizations separate from those for other State highways.

Although 41 States indicated that maintenance was carried on by a county or area.type of organization, 15 of the States also indicated that separate crews were assigned exclusively to the maintenance of the Interstate sections. Also, 12 reported equipment assigned exclusively to Interstate sections. Where Interstate maintenance is so separated, the States usually provide separate housing and storage yards for the Interstate maintenance sections. Special crews usually are moved in from the regular maintenance organization for work such as bridge painting, traffic line application, surface treatment, bituminous resurfacing, and other specialized projects.

Training

Training methods and programs are quite varied from State to State. They range from periodic and seasonal meetings at supervisory levels in some States to formal classroom lecture courses with field demonstrations in others. In many States, the training of supervisory personnel consists of periodic observation by a superior, supplemented by staff meetings for discussion of problems and policies. Training is supplemented in a few States by use of films showing equipment operation and items of preventive maintenance. Special training materials prepared by producers of petroleum products and equipment manufacturers are used in instructions on equipment at both field and supervisory levels.

In at least one State, formal training includes classroom lectures for supervisory personnel. Subjects studied include teaching methods, labor relations, motivation, communications, report writing, delegation of authority, etc. The courses are presented on a university campus, in a classroom, by university faculty members. The courses require three days for each group. The groups of 30 to 35 men are housed on campus for the training period.

Field forces are given in-service training in most States, usually in the form of one-day courses on seasonal operations supplemented by field demonstrations. Supervisors and foremen usually conduct meetings and lead the field demonstrations. Courses usually cover work reports, equipment use and care, characteristics of materials and their uses, public relations, and safe working practices.

Several of the States believe that the quality of maintenance can be improved by some form of competitive work incentives. One State has developed a highway section maintenance rating procedure by which it can indicate the quality of maintenance performed by groups of maintenance personnel under each supervisor. After the original rating was made known and suitable recognition was given for the best work performance, later ratings indicated the value of this incentive-creating competition, and subsequent ratings showed marked improvement in maintenance section ratings.

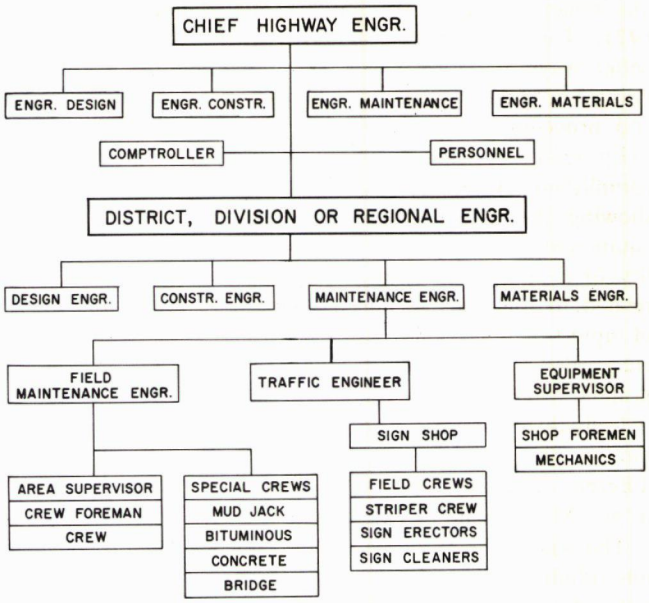

Figure 2. Typical organization chart.

Housing

Where Interstate maintenance is separate, maintenance buildings and storage areas usually are provided for each 25 to 30 centerline miles of highway. The areas, usually located near the Interstate route in the vicinity of an interchange, vary in size from 3 to 10 acres (see Fig. 4). The buildings are usually quite modest, but most have storage space for four or five trucks, a foreman's office, a room for tools and supplies, work area and hand tools for equipment adjustment, and toilet facilities. The buildings are usually metal or concrete block structures. Most facilities

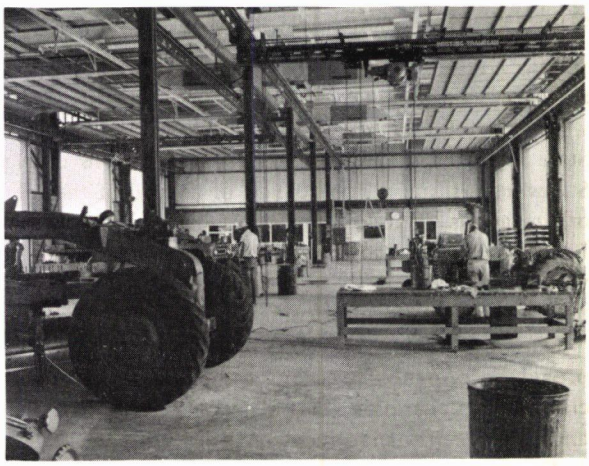

Figure 3. Typical district maintenance equipment repair shop (Dist. 6, Little Rock, Arkansas Highway Dept.)

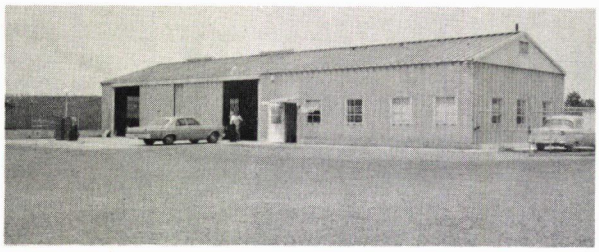

Figure 4. Typical maintenance garage and storage building serving 125 miles of State highway (north of Arkansas River from Little Rock).

are equipped with two-way radios. Principal materials stored in the yards include aggregate, chlorides, bituminous patch mixes, liquid asphalt, and replacement guardrail posts and beams and delineators (see Fig. 5). In addition, most yards have facilities for supplying gasoline to equipment units.

Equipment

In the northern portion of the United States, the number of equipment units varies with the intensity of snowfall and wind conditions experienced in that area. Exclusive of snow removal units, there is a practice of assigning one truck, usually in the 2½- to 3-ton class for each 40 lane-miles of highway and interchange maintained. A pickup truck usually is assigned for use of the foreman and for patrolling the section for emergency removal of debris from the traveled way or other emergency use.

Other routine maintenance equipment usually assigned to a typical 30-mile Interstate maintenance section includes one 15-ft and two 8-ft rotary tractor mowers, a front-end loader, a bituminous distributor, small bituminous mixers, and a portable roller.

The use of two-way radio communication in maintenance management is almost universal. Only two States indicated that radios were not in use in maintenance equipment.

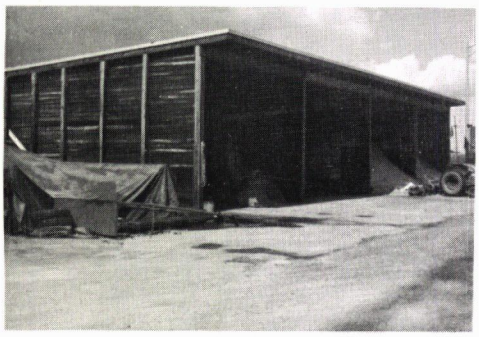

Figure 5. Typical salt storage building (Test Section 59, Ohio Turnpike at Elmore).

For replacement of equipment, two methods seemed to be most frequently employed. The first merely established a criterion of age or mileage, or both, for the several classes of trucks and passenger cars. The age and mileage factor varies from State to State, but is generally expressed in number of years in use or number of miles operated, whichever comes first.

The second method of determining time for disposal of cars and trucks is on the basis of age, mileage, condition, and expert opinion of the equipment personnel, or some combination of these factors. Cost records are generally consulted as a further basis of decision. In this method, a determination is made for each individual car or truck under consideration. The evaluation is done by personnel in the district or division and reviewed at the central office level.

The evaluation method for replacement of equipment is used quite generally for maintenance equipment other than passenger cars and trucks. However, there is great variation in the availability, accuracy, and use made of operating cost records for equipment. A number of States do not keep good usable records.

Equipment use on maintenance work generally is charged to the maintenance fund through a system of rental rates established on a Statewide basis. Rates are based on time used or miles operated. The items used in the makeup of rental rates usually include:

1. Depreciation.
2. Direct operating costs.
3. Direct repair costs.
4. Indirect repair costs.
5. Expendable parts costs.

Salvage value and other items, such as insurance premiums, also are given consideration in a few States.

There is much variation from State to State in the way in which rental time is determined. Time for which equipment charges may or may not be made include:

1. Equipment in preparation for work:
   (a) Cleaning, fueling, adjustments.
   (b) Moving to point of dispatch.
2. Equipment in transit from dispatch point to job site:
   (a) Short distances to job site.
   (b) Long distances to job site.
3. Operating time:
   (a) Field standby time between several jobs.
   (b) In transit from job site to job site.
4. Downtime for servicing or repair on the job:
   (a) Maintenance servicing.
   (b) Field repairs.

In a number of States, special maintenance equipment is designed, assembled, and placed in service by maintenance equipment shop personnel (see Fig. 6). Such inventiveness and originality is encouraged in most States. However, too often the development of useful devices is not passed on within the organization so that the improvement may receive the fullest use.

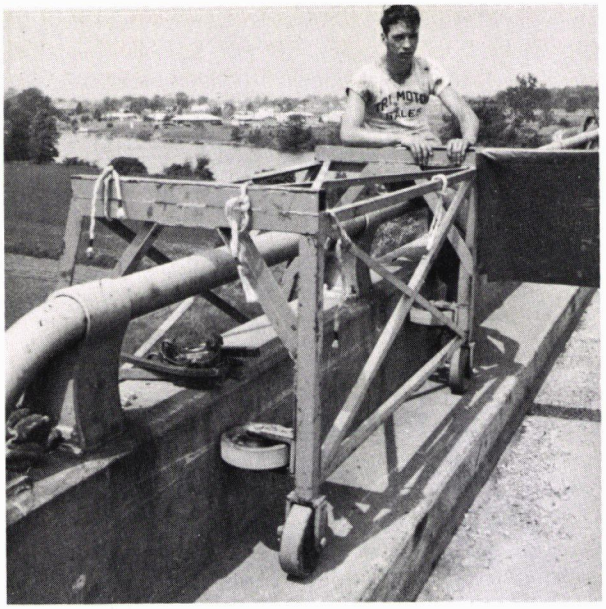

Figure 6. Rolling bridge-painting scaffold developed by maintenance personnel (Test Section 59, Ohio Turnpike).

Cost Accounting

Of serious concern to highway administrators for many years has been the lack of adequate and uniform information regarding the cost of highway maintenance within a State or between States.

Although all States accept the definition of maintenance as stated in the AASHO Manual, the variations in application of the definition are many.

Forty states indicated they follow the provisions of AASHO in their maintenance cost records. However, in further discussion there was evidence of variations and exceptions in 22 of these States sufficient to make it quite doubtful that cost records could be compared with costs of other States.

Among the variations and exceptions were the following. Whereas 37 States indicated their records show a breakdown in labor, equipment and materials by specific operations, this occurs frequently only in the daily or weekly crew work sheets. Summaries of these quantities usually are not developed for future use or study. Thirty States reported that material quantities and costs are charged to specific operations; 16 indicated no such record, even on the daily work sheets.

Forty-one States charge equipment costs to specific maintenance activities. Six States keep records of equipment as a total item of cost but do not distribute the costs to the maintenance operations in which the equipment is used. In one State, equipment use costs are not included in the published costs of highway maintenance; equipment costs are recorded under a Statewide equipment item and not distributed to the several highway functions.

Some of the increased maintenance costs are due to grade separations and interchange structures and have been a point of much discussion and study. However, only ten States keep separate costs of the maintenance of structures.

Separate costs for the maintenance of frontage roadways are kept by 18 States; the others include such costs with the mainline facility or have no service road maintenance responsibilities.

Six States routinely collect data on unit costs of maintenance activities from the field for a few selected operations such as bituminous seal coating or traffic line marking.

Maintenance costs are presently handled by data processing equipment in 44 States; 4 others indicated plans to convert to data processing.

The States handle the matter of overhead charges in a variety of ways. There are two types of overhead usually considered in maintenance accounts. One is generally termed "direct overhead" or "labor overhead." This includes costs for employees' vacations, sick leave, compensatory time off for overtime, Social Security, workmen's compensation and other payroll taxes, insurance, etc. Several States have developed a factor for direct overhead costs expressed in percent of labor costs. The factors vary from 19% to 25%. In some States this is added to and becomes a part of the labor cost recorded for maintenance accounts.

A second type of overhead includes the costs of supervisory personnel salaries, office and shop costs, office supplies, etc. These costs are generally collected in a separate account termed "overhead," "administration," or some similar designation. In most States, these costs are not prorated back to the control sections or other maintenance cost units.

Contract Work

All States indicated that they presently perform some part of their maintenance work by contract. The amount and

variety of work varies from State to State. One common type of contract maintenance work performed in most States is bridge painting. Others include surface treatment, painting of guardrail, and application of chemicals for vegetation control. Contract maintenance also is performed in one or more States for highway mowing, concrete pavement patching, bridge repairs, storage and shop building repairs, mudjacking of pavements, maintenance of traffic signals and lighting systems, maintenance of pumping stations, and application of traffic lines and markings.

CHAPTER TWO

DATA COLLECTION PROGRAM

Based on the information gained in the initial interviews with State maintenance officials and in the review of prior studies, it was determined that existing maintenance cost data available from the State highway departments would be of little value in developing a practical measuring system of Interstate maintenance requirements.

This was apparent for a number of reasons. Because the Interstate System is relatively new, only a limited quantity of information on maintenance costs was available. In many instances, Interstate costs were not separated from costs for other primary highways. The diversity of accounts and procedures used in reporting and recording maintenance expenditures almost precluded meaningful comparisons between States and often even between maintenance sections within a single State. Almost without exception, cost records did not reflect any measurement of the work accomplished by the expenditure and, generally, did not provide a breakdown of labor, equipment and material expenditures in a useful and meaningful manner.

In view of these major and significant limitations on existing data, the alternative of obtaining original, controlled data for the study was selected and the study procedures were designed accordingly.

Because of the time and funding limitations of the project, it was recognized that original data samples would be somewhat limited. However, it was felt that despite the limited sample the opportunity to control the sample selection and to obtain comprehensive and accurate measures of maintenance expenditures and maintenance activities would generate a more reliable base for measuring maintenance requirements than would historical data.

TEST SECTION SELECTION

To provide representation in the major geographic areas of the country, five States were selected for the intensive study and data collection phase. States were selected on the basis of the high caliber of current Interstate maintenance practices, the availability of a number of varied types of completed Interstate sections, the existence of State maintenance management and accounting systems which could accommodate a daily report system, and the willingness of the State officials to cooperate in the data collection program.

The States selected were: New York State in the Northeast, Florida in the Southeast, Ohio in the Midwest, Texas in the Southwest, and California in the West.

To provide local supervision of the data collection program, recently retired highway engineers, each with significant experience in highway maintenance, were retained as field representatives in each of the study States.

In consultation with the field representatives and with maintenance staff officials in the study States, six test sections were selected in each State. The test sections were selected to accommodate a maximum number of variables affecting maintenance requirements on the Interstate System. Variables considered in the selection of the test sections included:

1. Terrain. Sections representing each of the important types of terrain found in the State were included.
2. Urban and rural facilities. Typical urban and rural sections found in the State were included.
3. Regional characteristics. Where materials, personnel characteristics or other factors were distinguished by regions of the State, each region was represented by a test section.
4. Traffic density and volume. Heavy, moderate and light traffic sections were included.
5. Climate. Snow belts, rainy areas, deserts and other climatic areas were included.

Test sections were screened to select ones in which high-caliber maintenance practices were expected and in which traffic flow continuity and uniformity existed throughout the section length. A minimum age of three to five years was observed to eliminate those early post-construction inadequacies that might affect the first few years of maintenance requirements. Sections also were selected to be typical and representative rather than to reveal unique maintenance requirements. To the extent possible, test sections were selected where all maintenance work was done by the same crew and with the equipment and materials assigned exclusively to the test section. Where possible, the test section limits were made to coincide with existing State control section boundaries. Where no control sections were used in the State, AASHO's criteria for control section designation were used in establishing test section boundaries.

Based on the foregoing criteria, 30 sections were selected initially. A daily report system ultimately was established on 28 test sections to record maintenance expenditures throughout the field study phase of the project. Detailed descriptions of the test sections are given in Appendix A. The test section locations and project code numbers are given in Table 1 and shown in Figure 7.

TABLE 1
PROJECT CODE NUMBERS AND LOCATIONS OF TEST SECTIONS

TEST SECT. NO.	STATE	COUNTY	ROUTE
1	Calif.	Shasta	I-5
2	Calif.	Placer and Nevada	I-80
3	Calif.	Nevada and Sierra	I-80
4	Calif.	Alameda and Contra Costa	I-80
5	Calif.	Los Angeles	I-405
6	Calif.	San Bernardino	I-158
21	Fla.	Hamilton	I-75
22	Fla.	Hillsborough	I-4
23	Fla.	Osceola and Orange	I-4
24	Fla.	Duval	I-10, I-95
25	Fla.	Orange	I-4
26	Fla.	Dade	I-95
41	N.Y.	Oswego	I-81
42	N.Y.	Jefferson	I-81
43	N.Y.	Westchester	I-287
44	N.Y.	Albany and Saratoga	I-87
51	Ohio	Hancock	I-75
53	Ohio	Ashland	I-71
55	Ohio	Licking	I-70
56	Ohio	Franklin	I-71
58	Ohio	Portage	I-80[a]
59	Ohio	Ottawa and Sandusky	I-80[a]
64	Tex.	Oldham	I-40
68	Tex.	Howard	I-20
74	Tex.	Hayes	I-35
75	Tex.	Bexar	I-10
78	Tex.	Ellis	I-45
79	Tex.	Dallas	I-35E

[a] Ohio Turnpike.

DAILY REPORT DATA

The objective in developing the data collection program was to secure information which eventually could be related to the work load of maintenance being generated by the significant variables on the Interstate highways. Inasmuch as the daily information was to be recorded by local highway personnel, only a limited burden could be placed on these people. Therefore, the report form (Fig. 8) was keyed to producing a maximum amount of information with a minimum of effort.

A major requisite for the daily reports was to have uniform identification of the maintenance activities on all of the test sections. The accounts established by AASHO in the *Uniform Highway Accounting Manual* (*1*) were used in this study. However, the AASHO accounts permitted considerable leeway in interpretation for certain activities. To improve uniformity in identification, expanded definitions were established for every account, as given in Appendix B. A brief description of each activity was included on the daily report so that the final interpretation and classification of an activity could be made by the project staff to assure uniformity.

The daily reports were designed to show how much labor, equipment and material was expended for each activity each reporting day. The cost for each of these components was not considered adequate because this would not reveal the configuration of the components. Further, the unit costs of the labor and equipment components vary considerably between States. For these reasons, a schedule of classifications was developed for each of the three components—labor, equipment and material—and both the quantity and the unit cost for each component were obtained on the reports. The classifications used in the study are given in Table 2.

To distinguish between those activities which took place in a single location and those which occurred at more than one spot on the section, a starting and ending milepost for each activity was reported together with the number of the specific sites where work was done. The nature of the work site was identified so that main roadway work could be separated from work in rest areas, weighing stations, service roads, interchanges, and possibly off the right-of-way.

The Interstate route, control section number and test section number were all preprinted on the forms for each test section to eliminate the possibility of mixing daily reports. The instructions issued to field personnel for filling out the daily report forms are given in Appendix C.

Field Checks

The daily report forms were screened by the field representative in each of the five test States. The forms were checked for accurate activity identification and completeness. Regular personal contact was made with the test section personnel recording the daily report information. During these contacts, the reports were carefully reviewed with section personnel and any discrepancies were clarified. The field representatives forwarded the reviewed daily reports to the project central office at least monthly. As a further check, the reports were reviewed in the central office to insure a uniform interpretation of maintenance activities between reporting States. Questionable entries were referred back to the appropriate field representative for further clarification before final acceptance. Once the reported daily maintenance information was verified for accuracy and completeness, it was coded for data processing and transferred to data cards, as shown in Figure 9.

TEST SECTION INVENTORY

To provide a complete and accurate record of the quantity of the various components of each test section, detailed inventories were made by the field representatives and reported on the inventory form shown in Figure 10. Generally, the inventory provided information about the age of

Figure 7. Test section locations.

Test Section - Daily Report
Interstate Maintenance Study
NCHRP Project 14-1

Interstate Route No. 405

Control Section No. 701

Sheet 1 of 4

Date 13/32/66

Test Section No. 5

Account Number	Description of Operation	Location	Milepost Begin	Milepost End	Work Units
574	Sweeping	1	23.36	39.00	1
534	Guard Rail Repair	1	36.24	—	1
573	Litter Cleaning	1	23.36	39.00	1
	Crack Sealing	1	26.78	26.96	1
463	Cleaning for Drainage	1	35.85	36.72	1

Labor				Equipment					Material				
Class	Total hours	Hourly rate	Acct No.	Class	Equip. No.	Operating mi or time	Rental rate	Acct. No.	Class	Description	Quantity	Cost/Unit	Acct. No.
2	4	3.41	574	7	34.05	42	.20	574	10	Refuse (Sweepings)	1	$ 19.93	574
2	6	3.41	534	2	74.11	16	.16	534	10	Flex. Beam G/R (G)	1	12.33	534
									10	1 Wood Block 8"x8"x14" (13)	1	1.30	534
1	2	3.41	573	1	13.02	20	.06	573					
2	10	3.41	573	2	74.11	40	.16	573					
1	2	3.41	413	1	13.02	20	.06	413	4	Crack Seal Material	350#	.14	
2	8	3.41	413	2	74.08	19	.15	413					
3	16	3.41	413	8	496.14	7	3.50	413					
1	4	3.41	463	2	94.25	23	.25	463	10	Refuse (Litter)	2	1.25	463
3	8	3.41	463										

Completed by D.L.J. (Name), Hwy. Foreman (Title), Westwood (Office)

Bertram D. Tallamy Associates
Washington, D. C.

Figure 8. Daily report form.

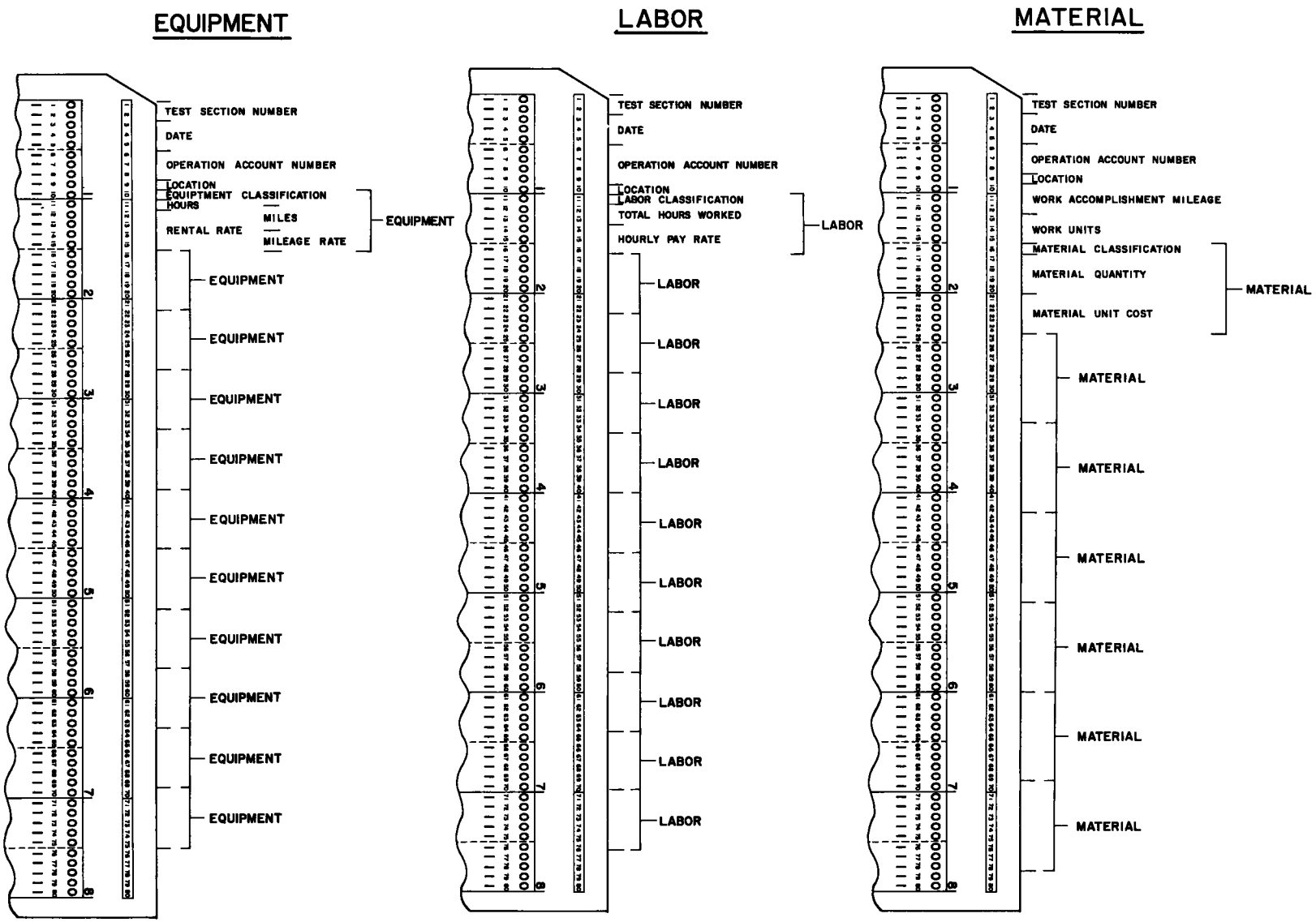

Figure 9. Data card format.

Interstate Route No. 40 State _____ County Old Europe

Control Section No. 72-12 Test Section No. 32

Centerline length, miles 33.6

Number 4 and location of contract sections by milepost

Begin	End	Year opened to traffic	Begin	End	Year opened to traffic
0.00	10.4	1960	5.8	24.3	1947
0.00	3.4	1951			
3.4	17.2	1957			

Environmental Data

Terrain

Flat ____ Rolling ✓ Hilly ____ Mountainous ____

Temperature.

Average annual low 61.2 °F

Average annual high 68.8 °F

Annual Average 65.0 °F

Weather:

Annual snowfall, inches 0.5

Snowfall frequency once every two years

Annual precipitation, inches 36

Design Characteristics

Mainline Pavement

☐ Bituminous ☒ Concrete Thickness, inches 8

Base thickness, inches 16 Subgrade Classification 4.0

Total width, feet 40 Total number of lanes 4

Shoulders.

Type outside Bit. treatment on flexible base

Type inside " " " " "

Width, outside 12 ft., inside 6 ft.; Thickness, ins. 4

Slopes and Unpaved Areas (side and median):

Slopes	Percent of total slopes and unpaved areas
2:1 or steeper	40
Flatter than 2:1	60

Drainage.

Total open ditching, miles 18.8

Catch basins and drop inlets, number 865

Culverts

Pipe	No	Total linear feet
Up to 36" diameter	42	5631
Over 36" diameter	14	1568
Box	1	105

Appurtenances.

Guardrail, total linear feet 72,948

Lighting units, number 2419

Major signs (more than one pole support), number 130

Minor signs, number 361

Delineators, number 814

Roadside rest

Pavement area, sq. ft. 48,600 Total area, acres 90

No		No	
0	Rest rooms w/running water	11	Picnic sites
0	Rest rooms w/o running water	0	Information booth
0	Wells	0	Other, _____

Walls.

Type of Construction	Length (ft)	Average ht (ft)	Cut or fill
Concrete	610	7	Fill
"	813	5	Cut

Interchanges

Location, milepost	Pavement, lane miles
12.6	4.1
13.5	0.8
14.1	1.3
17.2	.7

Traffic Data

ADT = Average daily traffic volume
30th = Thirtieth highest hour traffic volume
P = Passenger cars
B = Busses and light trucks
T = Heavy trucks

Year	ADT	30th	Percent P	Percent B	Percent T
1958	19010		78	12	10
1959	17900		79	12	9
1960	19050		75	10	15
1961	21220		76	10	14
1962	23830		78	8	14
1963	20530		76	11	13
1964	22150		81	11	8

Structures (Bridge)

Location (Milepost)	Type of Construction	Length	Width	Deck Surface Material	Crossing	Maintenance Jurisdiction
4.5	prestressed steel	502'	40'	steel	Little Valley	State Hwy. Dept.
9.7	conc box girder	140'	26'	prestressed conc.	No Name	" " "
11.6	8'x4'x Box 45° skew	105'	26'	fill	Frenchman's Bayou	" " "
12.2	cont. conc. slab unit.	114'	40'	conc.	Circumferential Expressway	" " "
12.3	steel I.B. spans	86'	40'	fill conc.	L.A.&N.Y.RR	" " "
12.3	steel I.B. spans	117'	40'	fill conc	West Ser. Road	" " "
12.6	steel girder spans	242'	48'	asphalt	Exit 14	" " "
2.7	36" RCCP	123'	40'	fill	Pedestrian Underpass	" " "
13.5	prestressed conc girder	129'	40'	conc.	S. Fork Overpass	" "
14.1	pre-stressed conc. beam	130'	40	conc.	N Fork Overpass	" " "
17.2	post-tensioned conc. girder	210'	40'	conc	Riverside Pkwy Under.	Dept. of Interior

Figure 10. Test section inventory form.

TABLE 2

CHART OF GENERAL CLASSIFICATIONS FOR DAILY REPORTS

Labor Classifications:

1. Supervisors
2. Heavy equipment operators
3. Light equipment operators
4. Skilled labor (electricians, carpenters, painters, plumbers, etc.)
5. Common labor

Equipment Classifications:

1. Cars and small trucks (¾-ton maximum)
2. Medium and large trucks
3. Graders, rollers, loaders, shovels, hoes and similar equipment
4. Major ice and snow control equipment (plows, hoppers, spreaders, blowers)
5. Major bituminous handling equipment
6. Tractor mowers
7. Major sweeping and cleaning equipment
8. Concrete mixers, air compressors, joint sealers, and similar equipment
9. Major pavement painting, signing or lighting service equipment
10. Other equipment

Material Classifications:	*Units*
1. Aggregate	Ton
2. Abrasive	Ton
3. Bituminous, mix	Ton
4. Bituminous, liquid	Gal
5. Cement	Sacks
6. Chlorides	Ton
7. Concrete (ready-mix)	Cu yd
8. Fertilizer and chemicals	Lb
9. Paint	Gal
10. Others	$

the test section, environmental characteristics, traffic data, and quantities for surfaces, structures, drainage, unpaved areas, appurtenances, and special facilities such as rest areas. Portions of the inventory data were obtained from construction plan and profile sheets; the remainder, by field inspection. The inventory data are summarized in Table 3.

In summary, the data collection program provided for the establishment of a daily report system on each of the 28 Interstate maintenance test sections and the recording of a comprehensive inventory record of the size or quantities of the physical components on each test section.

PROCESSING AND EVALUATION OF DAILY REPORT DATA

An IBM 360/40 data processing system was used to handle all the data compilation and summarization required for the project. This system, having 128,000 units of storage, proved more than adequate to handle all of the data processing needs of the project. IBM's Report Program Generator was used to program all of the compilations and summaries. Six different programs were developed to handle the daily report data. Two of these provided an edited version of each data record after it had been transferred from card to tape and sorted. The other four created various combinations of summary data. One of the earliest summaries provided for the actual breakdown of labor, equipment, and material by classification. These summaries were generated for each chart of account for monthly intervals and permitted a detailed examination of activity configurations. The monthly summaries also pinpointed extreme maintenance expenditures, frequently caused by unusual events such as earthquakes, floods, and other natural disasters.

Twelve-month summaries, by accounts, for the entire data collection program were also generated in the same format, as shown in Figure 11, which shows accounts 462, 463 and 464 for Test Section 59. Information relating to "mile sites" and "spot sites," intended to identify work configuration, and to the number of days during which work was performed for each account, is also shown in this summary.

Another summary compilation was developed to show the variations between labor, equipment and material totals by account. This summary * included both actual costs and adjusted costs, which reflect comparable expenditures between the various test sections (the development of factors to adjust actual costs is covered in Chapter Four). The adjusted costs were converted to total centerline-mile costs and to lane-mile costs and generated for both monthly and annual expenditures, the first being used to examine activity frequency and the latter to examine total distribution of expenditures for each of the activities.

Using these summaries, the adjusted expenditures for groups of activities were totaled by test section and plotted in bar graph form (Figs. 12, 13, and 14). Examination of these bar charts shows how widely expenditures varied between test sections for the various activity groups. In Figure 12 total maintenance expenditures are illustrated both with and without two of the major activities—ice and snow control and vegetation control. Ice and snow control and vegetation control account for more than 50% of all maintenance expenditures.

In Figure 15, activities are grouped to show three major maintenance subdivisions: traffic services, with snow and ice control, rest areas, signs, and appurtenances, accounting for 47.7%; physical maintenance, with structures, drainage and surfaces, accounting for 24.1%; and aesthetics, with litter removal and vegetation control, accounting for 28.2%. Also of interest is the fact that only 15.3% of the expenditures were required for pavements and shoulders.

The distribution of total expenditures by labor, equipment and materials is also shown in Figure 15, where labor accounts for 49% of the total.

In Figure 16, the total expenditures by activity groups were divided between the rural and urban sections, with

* The summaries are not included herein, but are available on loan to qualified researchers by written request to the Program Director of NCHRP.

TEST SECTION 59 SPOT SITES- 14 MILES TOTAL- 50.5 SINGLE SITES- 14 TOTAL SITES- 41
CHART OF ACCOUNT 462 MILE SITES- 4 AVE MILES- 12.6 MULTI SITES- 4 AVERAGE PER DAY- 2.3

LABOR						EQUIPMENT				MATERIAL		COST SUMMARY
CLASS	HOURS	COST	PERCNT HOUR	PERCNT COST	CLASS	HOUR	MILES	COST	PERCNT	CLASS	COST	PERCNT	L.E.M.
					1	36		54.00	5.5	1	129.62	38.4	$2,497.77
1	13	37.44	2.8	3.2	2	199		553.50	56.7	2	.00		
					3	20		300.00	30.8	3	108.63	32.1	
2		.00			4			.00		4	.00		AVE DAILY
					5			.00		5	71.22	21.1	$138.77
3		.00			6			.00		6	.00		
					7			.00		7	.00		SITE AVE
4	448	1,146.84	97.2	96.8	8	30		68.00	7.0	8	.00		$60.92
					9			.00		9	.00		
5		.00			0			.00		0	28.52	8.4	WORK DAYS 18
	461	$1,184.28*	47.4			285		$975.50*	39.1		$337.99*	13.5	

TEST SECTION 59 SPOT SITES- 13 MILES TOTAL- 104.7 SINGLE SITES- 18 TOTAL SITES- 39
CHART OF ACCOUNT 463 MILE SITES- 12 AVE MILES- 8.7 MULTI SITES- 7 AVERAGE PER DAY- 1.6

LABOR						EQUIPMENT				MATERIAL		COST SUMMARY
CLASS	HOURS	COST	PERCNT HOUR	PERCNT COST	CLASS	HOUR	MILES	COST	PERCNT	CLASS	COST	PERCNT	L.E.M.
					1	49		73.50	13.9	1	20.60	39.6	$1,507.30
1	22	64.30	6.1	6.9	2	137		372.50	70.4	2	.00		
					3	4		18.00	3.4	3	7.20	13.9	
2		.00			4			.00		4	.00		AVE DAILY
					5			.00		5	.00		$60.29
3		.00			6	10		35.00	6.6	6	.00		
					7			.00		7	.00		SITE AVE
4	339	862.02	93.9	93.1	8	12		30.00	5.7	8	.00		$38.65
					9			.00		9	.00		
5		.00			0			.00		0	24.18	46.5	WORK DAYS 25
	361	$926.32*	61.5			212		$529.00*	35.1		$51.98*	3.4	

TEST SECTION 59 SPOT SITES- 18 MILES TOTAL- 1.3 SINGLE SITES- 18 TOTAL SITES- 22
CHART OF ACCOUNT 464 MILE SITES- 1 AVE MILES- 1.3 MULTI SITES- 1 AVERAGE PER DAY- 1.2

LABOR						EQUIPMENT				MATERIAL		COST SUMMARY
CLASS	HOURS	COST	PERCNT HOUR	PERCNT COST	CLASS	HOUR	MILES	COST	PERCNT	CLASS	COST	PERCNT	L.E.M.
					1	33		49.50	10.4	1	10.98	4.7	$1,602.14
1	51	146.88	14.6	16.5	2	137		343.50	72.3	2	.00		
					3			.00		3	.00		
2		.00			4			.00		4	.00		AVE DAILY
					5			.00		5	20.80	8.8	$84.32
3		.00			6	7		24.50	5.2	6	.00		
					7			.00		7	98.02	41.6	SITE AVE
4	298	744.74	85.4	83.5	8	23		57.50	12.1	8	.00		$72.82
					9			.00		9	.00		
5		.00			0			.00		0	105.72	44.9	WORK DAYS 19
	349	$891.62*	55.7			200		$475.00*	29.6		$235.52*	14.7	

Figure 11. Maintenance expenditure account summary (Nov. 1965 through Oct. 1966).

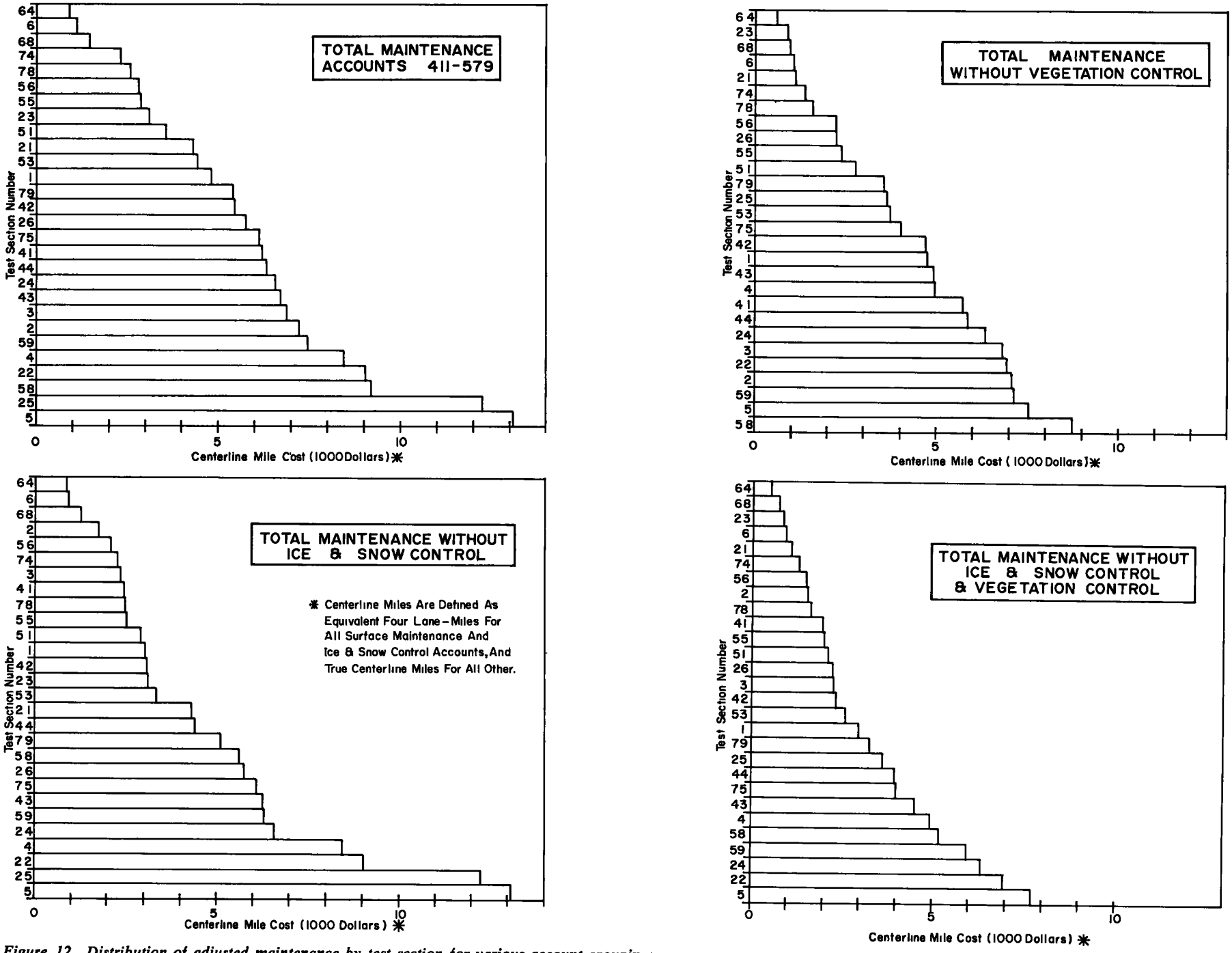

Figure 12. Distribution of adjusted maintenance by test section for various account groupings.

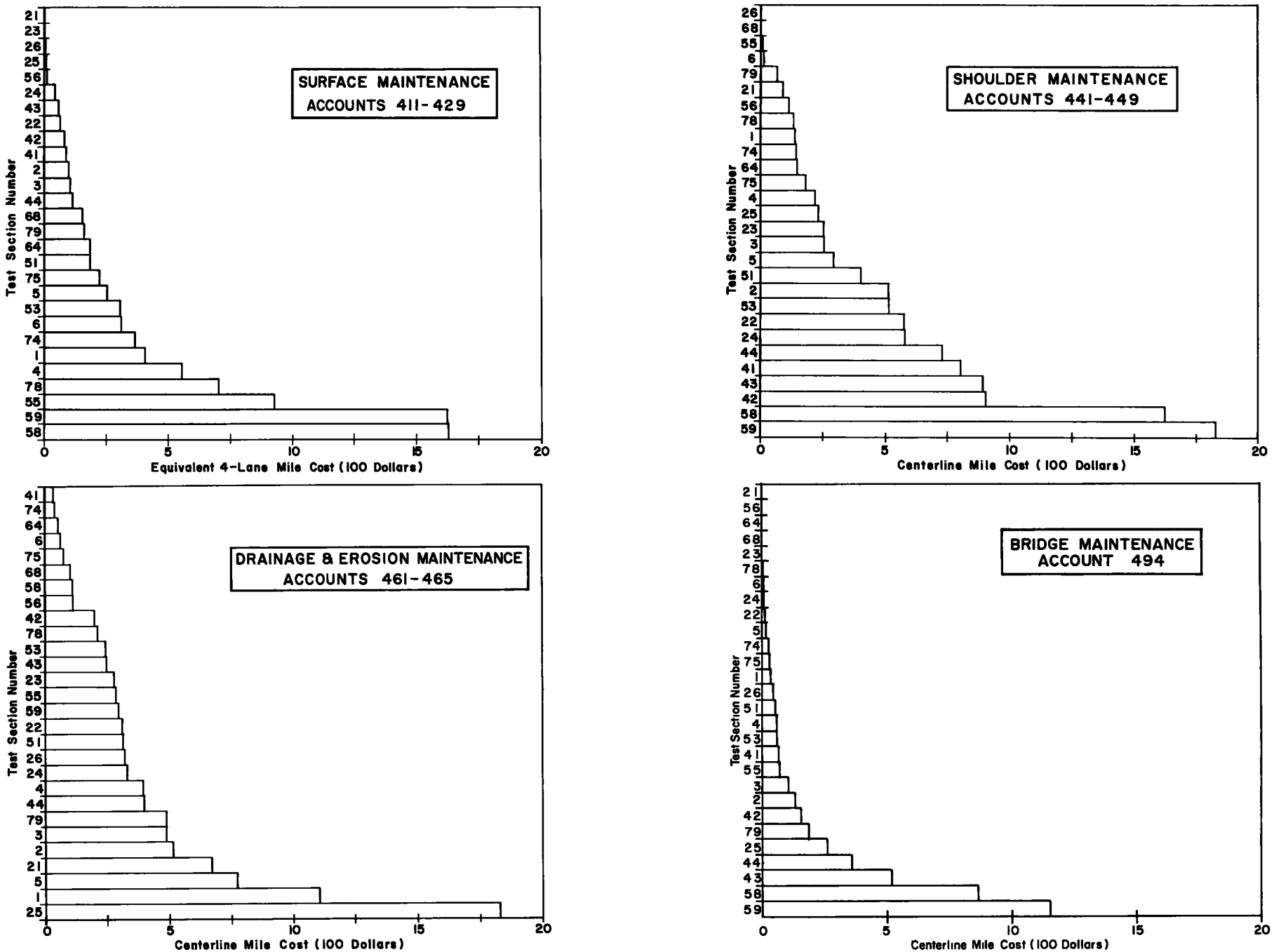

Figure 13. Distribution of adjusted maintenance by test section for various account groupings.

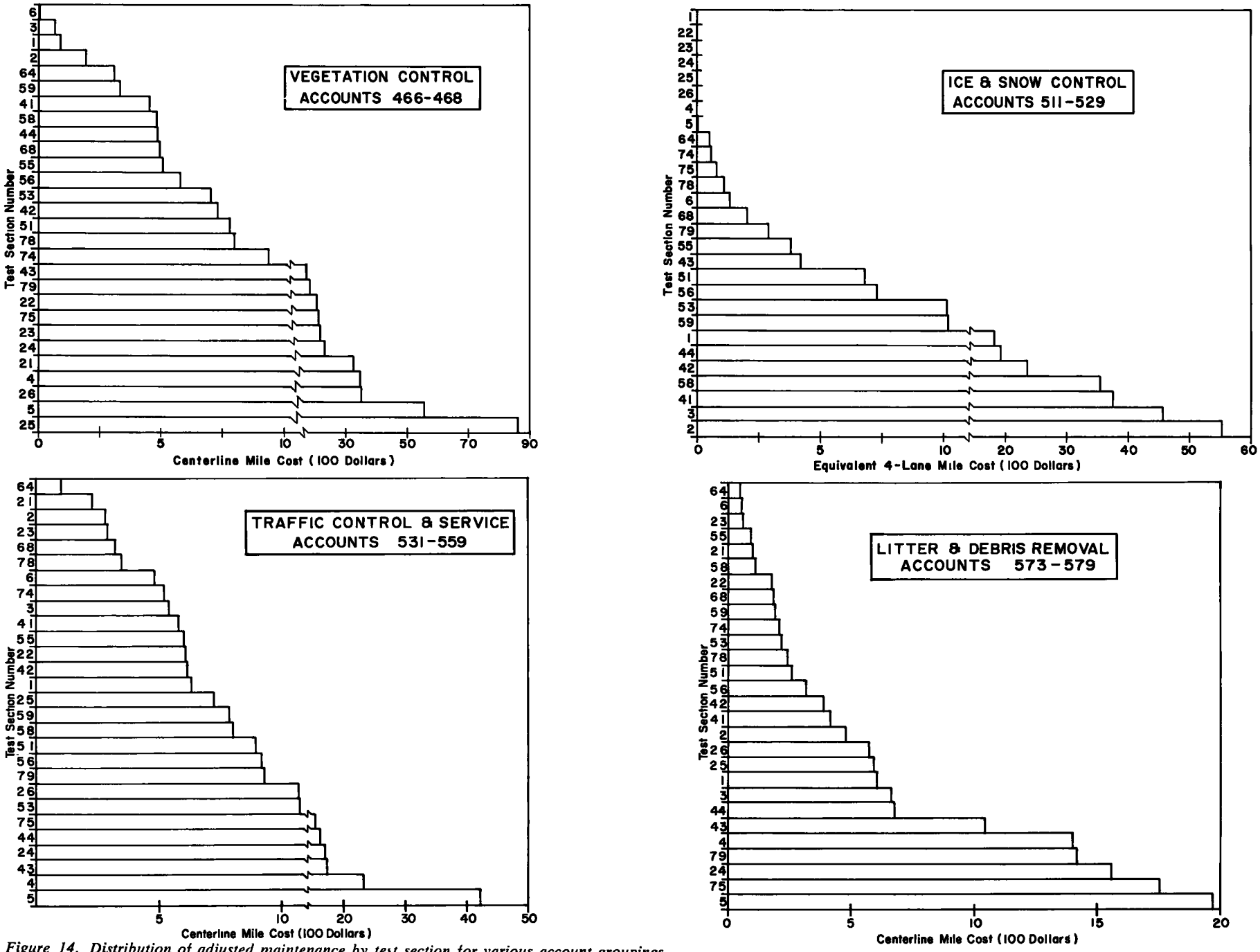

Figure 14. Distribution of adjusted maintenance by test section for various account groupings.

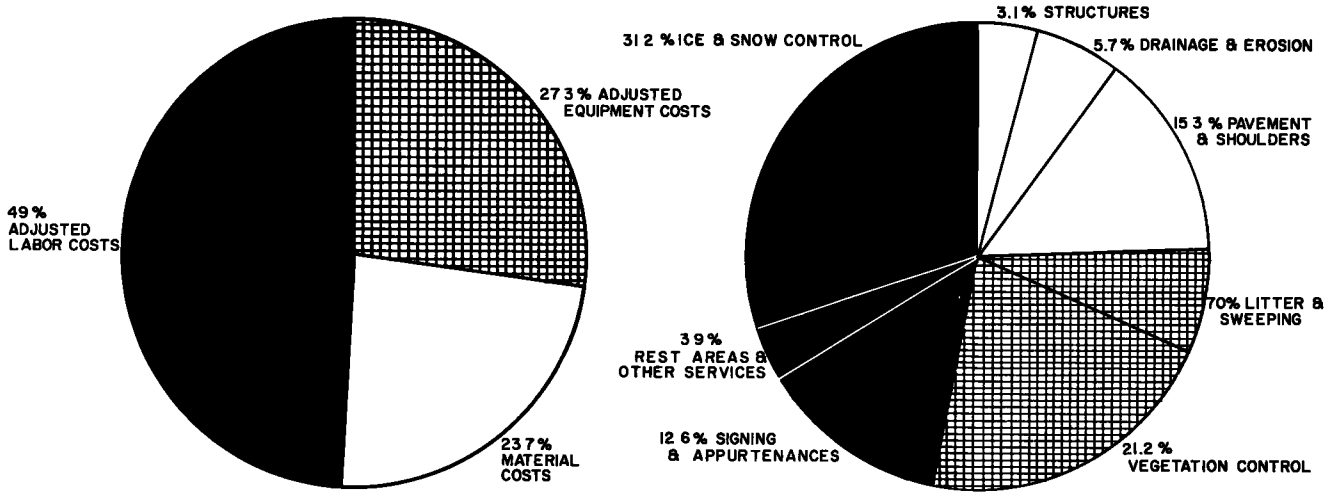

Figure 15. Distribution of adjusted maintenance expenditures for labor, equipment, and material, and various account groupings.

the percentage of each rural or urban group to the rural or urban total being shown. The significant difference between urban and rural for sign, appurtenance, litter and sweeping was later demonstrated in the model development. However, the apparent differences between urban and rural vegetation and ice and snow control are misleading because most of the urban test sections were located in areas where no snow removal was required and, conversely, where vegetation control requirements were high.

A summary of total test section expenditures is shown in Figure 17, in which most of the columns are self-evident. All of the top figures are actual costs, whereas the bottom figures show adjusted costs. It may be noted that material was not adjusted. The adjusted costs were converted to centerline-mile costs (ADJ MI COST) and to lane-mile costs (ADJ LM COST), which are shown as the top and bottom figures, respectively, in the last column. It can be seen that the centerline-mile costs varied from $904 to $13,470, whereas the lane-mile costs varied from $226 to $2,243 for the test sections.

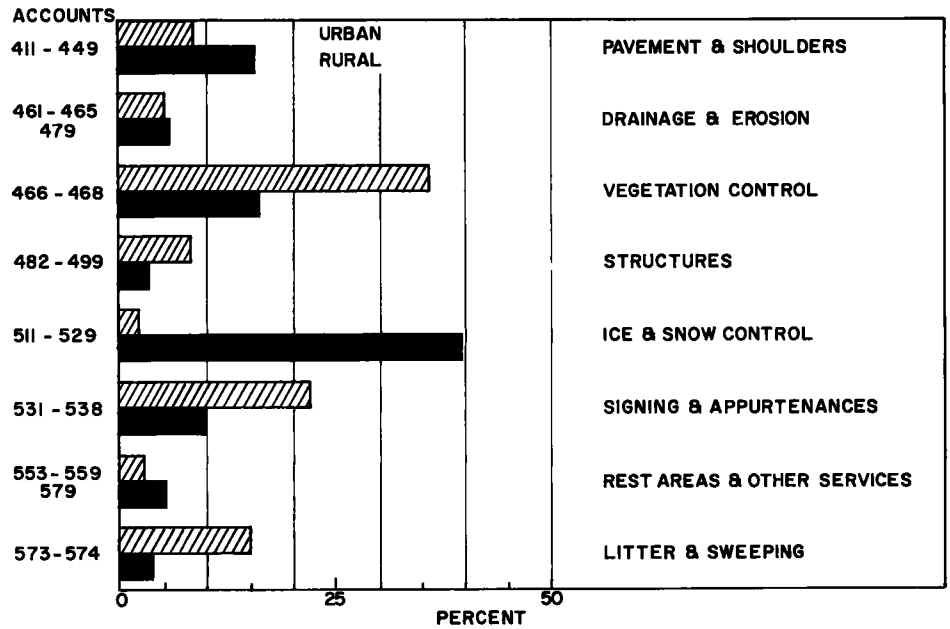

Figure 16. Distribution of adjusted maintenance expenditures for urban and rural test sections.

SECT	LABOR HOURS	EQUIP HOURS	EQUIP MILES	LABOR COSTS	EQUIP COSTS	MATERIAL COSTS	----PERCENT----- LAB.	EQP.	MAT.	ACTUAL COSTS ADJUST COSTS	ADJ MI COSTS ADJ LM COSTS
1	9,524	2,974	72,420	40,713.21	31,231.70	14,422.96	47.1	36.2	16.7	86,367.87	$5,293.92
				20,952.80	22,486.82		36.2	38.9	24.9	57,862.58	$1,102.77
2	26,625	9,047	168,719	94,551.30	95,729.87	29,829.19	43.0	43.5	13.6	220,110.36	$8,390.92
				58,575.00	68,925.50		37.2	43.8	19.0	157,329.69	$1,891.89
3	25,113	5,026	185,894	89,685.07	57,137.38	50,890.47	45.4	28.9	25.7	197,712.92	$7,305.46
				55,248.60	41,138.91		37.5	27.9	34.6	147,277.98	$1,739.64
4	44,949	4,609	143,551	182,655.00	38,670.14	43,303.18	69.0	14.6	16.4	264,628.32	$8,996.48
				98,887.80	27,842.50		58.2	16.4	25.5	170,033.48	$1,135.83
5	61,467	4,552	179,541	203,162.87	43,870.14	43,886.02	69.8	15.1	15.1	290,919.03	$13,471.86
				135,227.40	31,586.50		64.2	15.0	20.8	210,699.92	$1,384.54
6	9,307	960	78,939	34,006.40	11,625.77	23,678.82	49.1	16.8	34.2	69,310.99	$1,105.55
				20,475.40	8,370.55		39.0	15.9	45.1	52,524.77	$266.70
21	33,525	8,829	110,075	52,047.34	29,506.04	7,088.50	58.7	33.3	8.0	88,641.88	$4,320.60
				73,755.00	43,373.87		59.4	34.9	5.7	124,217.37	$1,012.37
22	18,821	8,896	45,674	30,127.37	14,225.06	9,057.30	56.4	26.6	17.0	53,409.73	$3,845.60
				41,406.20	20,910.83		58.0	29.3	12.7	71,374.33	$825.71
23	18,358	7,419	53,643	27,226.76	15,721.98	6,270.55	55.3	31.9	12.7	49,219.29	$3,085.78
				40,387.60	23,111.31		57.9	33.1	9.0	69,769.46	$581.17
24	22,282	4,782	28,000	34,292.46	8,174.04	5,635.72	71.3	17.0	11.7	48,102.22	$6,620.85
				49,020.40	12,015.83		73.5	18.0	8.5	66,671.95	$974.31
25	11,674	2,920	30,378	17,561.44	5,872.74	2,221.38	68.5	22.9	8.7	25,655.56	$12,260.77
				25,682.90	8,632.92		70.3	23.6	6.1	36,537.10	$1,439.60
26	10,805	1,609	19,792	14,863.09	4,869.16	5,624.11	58.6	19.2	22.2	25,356.36	$5,756.34
				23,771.00	7,157.66		65.0	19.6	15.4	36,552.77	$668.85
41	40,886	18,401		94,117.65	82,052.77	48,316.84	41.9	36.6	21.5	224,487.26	$6,543.75
				89,949.20	64,001.16		44.5	31.6	23.9	202,267.20	$1,532.79
42	39,971	18,202		90,468.76	53,030.10	28,447.43	52.6	30.8	16.5	171,946.29	$5,738.34
				87,936.20	41,363.47		55.7	26.2	18.0	157,747.10	$1,281.14
43	20,757	10,023		49,340.02	29,015.86	20,899.92	49.7	29.2	21.1	99,255.80	$8,668.39
				45,665.40	22,632.37		51.2	25.4	23.4	89,197.69	$1,167.97
44	38,366	17,377		90,799.35	52,690.01	38,847.70	49.8	28.9	21.3	182,337.06	$7,716.01
				84,405.20	41,098.20		51.4	25.0	23.6	164,351.10	$1,152.53
51	20,073	14,431		38,914.90	23,072.21	23,158.60	45.7	27.1	27.2	85,145.71	$3,610.13
				44,160.60	23,764.37		48.5	26.1	25.4	91,083.57	$866.47
53	14,986	9,746		30,418.62	19,518.75	18,959.05	44.2	28.3	27.5	68,896.42	$4,463.26
				32,973.60	20,104.31		45.8	27.9	26.3	72,036.96	$1,091.47
55	15,048	8,483		30,790.91	17,266.63	14,180.90	49.5	27.7	22.8	62,238.44	$2,974.00
				33,105.60	17,784.62		50.9	27.3	21.8	65,071.12	$695.06
56	10,252	7,791		20,078.06	12,491.92	5,775.64	52.4	32.6	15.1	38,345.62	$2,927.98
				22,554.40	12,866.67		54.7	31.2	14.0	41,196.71	$640.40
58	37,246	26,291		91,847.71	94,850.83	89,042.23	33.3	34.4	32.3	275,740.77	$9,046.46
				81,941.20	97,696.35		30.5	36.4	33.1	268,679.78	$2,243.86
59	37,474	21,029		94,541.33	61,680.70	74,027.47	41.1	26.8	32.2	230,249.50	$7,719.35
				82,442.80	63,531.12		37.5	28.9	33.6	220,001.39	$1,757.20
64	2,432	1,056	6,207	4,540.71	3,602.49	3,023.11	40.7	32.3	27.1	11,166.31	$904.06
				5,350.40	5,223.61		39.3	38.4	22.2	13,597.12	$226.02
68	11,153	2,010	54,705	18,366.57	7,920.58	13,326.36	46.4	20.0	33.6	39,613.51	$1,468.68
				24,536.60	11,484.84		49.7	23.3	27.0	49,347.80	$367.17
74	12,560	4,306	39,408	22,086.19	12,637.04	10,518.59	48.8	27.9	23.2	45,241.82	$2,324.04
				27,632.00	18,323.70		48.9	32.4	18.6	56,474.29	$581.01
75	16,399	2,535	37,164	26,521.28	11,362.94	16,062.12	49.2	21.1	29.8	53,946.34	$6,192.80
				36,077.80	16,476.26		52.6	24.0	23.4	68,616.18	$1,349.65
78	15,951	639	37,958	38,650.27	4,751.30	17,944.31	63.0	7.7	29.3	61,345.88	$2,560.94
				35,092.20	6,889.38		58.6	11.5	29.9	59,925.89	$640.23
79	20,022	1,416	67,785	42,739.43	9,355.35	16,400.85	62.4	13.7	23.9	68,495.63	$5,693.42
				44,048.40	13,565.25		59.5	18.3	22.2	74,014.50	$862.64

Figure 17. Summary of test section maintenance expenditures (Nov. 1965 through Oct. 1966).

TABLE 3

TEST SECTION CHARACTERISTICS

STATE	TEST SECT. NO.	LENGTH (MILES)	TERRAIN CLASSIFICATION	ROAD TYPE	NO. OF INTER-CHANGES	TRAFFIC VOLUME, ADT (1,000's)	AVERAGE MONTHLY TEMP. RANGE (°F)	'65-'66 WINTER SNOWFALL (IN.)	AVERAGE ANNUAL PRECIP. (IN.)
Calif.	1	10.93	Mountainous	Rural	7	5–6	24–85	86	48.91
	2	18.75	Mountainous	Rural	12	6–7	28–78	113	60.37
	3	20.16	Mountainous	Rural	6	6–7	28–78	140	26.93
	4	18.90	Rolling	Urban	22	65–70	38–74	—	22.38
	5	15.64	Rolling-hilly	Urban	22	130–140	43–75	—	12.63
	6	47.51	Flat-rolling	Rural	6	5–6	49–92	—	6.31
Fla.	21	28.75	Rolling	Rural	5	9–10	42–91	—	60.69
	22	18.56	Flat	Rural	10	14–15	52–91	—	56.31
	23	22.61	Flat	Rural	7	9–10	50–92	—	52.80
	24	10.07	Flat	Urban	16	50–55	45–92	—	53.36
	25	2.98	Flat	Urban	7	19–20	50–92	—	51.23
	26	6.35	Flat	Urban	12	85–90	58–92	—	46.26
N.Y.	41	30.91	Rolling	Rural	8	4–5	16–84	100	37.60
	42	27.49	Rolling	Rural	11	4–5	16–84	118	35.23
	43	10.29	Rolling	Urban	19	40–45	26–84	31	33.06
	44	21.30	Rolling	Rural	10	14–15	14–83	66	35.25
Ohio	51	25.23	Flat	Rural	5	7–8	26–71	7	37.48
	53	16.14	Rolling	Rural	1	11–12	25–70	21	38.16
	55	21.88	Rolling	Rural	5	10–11	31–77	18	36.67
	56	14.07	Flat	Rural	5	14–15	31–77	14	33.70
	58	29.70	Rolling	Rural	2	14–15	28–72	37	38.51
	59	28.50	Rolling	Rural	2	15–16	26–72	20	30.50
Tex.	64	15.04	Flat	Rural	1	4–5	21–92	9	19.67
	68	33.60	Flat-rolling	Rural	22	5–6	33–95	1	15.50
	74	24.30	Flat-rolling	Rural	15	9–10	40–95	4	32.81
	75	11.06	Flat-rolling	Urban	16	28–30	40–96	4	27.93
	78	23.40	Rolling	Rural	15	7–8	36–96	3	33.90
	79	13.10	Flat-rolling	Urban	24	22–24	36–96	6	34.55

CHAPTER THREE

SUPPLEMENTAL FIELD OBSERVATIONS

The data in the inventory reports and on the daily report forms were not sufficient to meet fully all of the objectives of the study. So that valid comparisons could be made among the test sections, data also were needed to show the level or standard of maintenance achieved on each test section; the comparative efficiency of crews; the methods by which labor, equipment and materials were utilized in performing the work; and the quality and quantity of work performed. To meet these needs, the following special studies were made: condition surveys; work time sampling; observation of work procedure; measurement of work accomplished; and snow removal observations.

SPECIAL STUDIES

Condition Surveys

Maintenance requirements are the function of a great number of factors, one of which is the standard or level of the maintenance which is sought. Standards depend largely on local interpretation of need normally modified to reflect available funds. The data collection program generated information showing how much maintenance work was done on the 28 test sections. Obviously, the data could not be compared directly if widely different standards of maintenance were being achieved.

AASHO's attempt to develop maintenance standards in finite terms has been unsuccessful, although they have published a number of maintenance guides. In explaining the inability to establish finite standards, AASHO has said that until maintenance organizations become more familiar with and adopt for standard use the present serviceability index (PSI) as developed in the AASHO Road Test or some other workable test, the determination of highway deficiencies and needs is not a mechanical process and, therefore, the standards published by AASHO are considered in the nature of guides.

For this study maintenance adequacy was evaluated by measuring periodically the work accomplished and the work required on each test section. To accomplish the evaluation, the condition survey form shown in Figure 18 was used. Field representatives conducted condition surveys on each of the test sections at the beginning of the report period and at about 4-month intervals during the course of the study.

Specifically, the maintenance condition survey was designed to provide information on (a) how much maintenance work was needed, (b) how much maintenance work was accomplished, and (c) how well the maintenance work was done on the test sections. Data were collected on the condition of pavements, shoulders, drainage systems, turf and plant materials, traffic control items, structures, and general appearance of the test sections. The definitions used in rating each of the items on the form are given in Appendix D.

Work Time Sampling

As a means of measuring the relative efficiency of work crews on the various test sections, a sampling procedure was established to observe and record the percentage of time that crew members "worked" during the performance of a maintenance activity. For the purposes of this study, "work" was defined as that time during which an employee was actively engaged in the performance of his assigned task or necessarily engaged in travel to, from, or between tasks.

Minimum 4-hr observation periods were established, during which the field representative observed the crew and recorded the number of crew members "working" at each instant of observation. Twelve observations were made in each of 24 random time segments during the 4-hr period. The work time sampling form and instructions are shown in Figure 19.

The work time sampling technique was employed in preference to a basic time and motion study on this project for several reasons. First, the experienced engineers serving as field representatives were highly qualified to make the observations and judgments necessary to determine "work time." The resulting field reports were conclusive and did not require the additional exhaustive analysis that must follow time and motion study observations. The observation of a crew of several men could be accomplished readily by a single field observer, whereas time and motion study records would have required additional observers beyond the funding limitations of the project.

Observation of Work Procedures

To permit the delineation of methods for optimizing efficiency in maintenance operations, it was necessary to evaluate the procedures by which the various maintenance activities were accomplished on the test sections.

The observation of work procedures form (Fig. 20) provided detailed information regarding the configuration of a work crew by labor classifications, equipment used (including size or capacity) and the material used in an operation. It also permitted the recording of the precise procedure followed and recommendations for improving the operation or increasing its efficiency. Observations were made of the following activities:

1. Pavement, shoulder, and bridge deck patching (temporary or permanent).
2. Surface treatment of pavements or shoulders.
3. Litter removal.
4. Mowing.
5. Crack, joint, and edge joint sealing.
6. Mudjacking.
7. Edgeline and/or centerline pavement marking.

The form also was used to record data for observation of revised or optimized procedures when the field representative recommended a means of improving a previously observed procedure. The data recorded for the original procedures and the improved or optimized procedures were the basis for determining the value of the recommended optimization.

Measure of Work Accomplished

The measure of work accomplished form (Fig. 21) permitted the field representative, with the help of the crew foreman or supervisor, to make field measurements and record units of work completed. Date(s) for the performance of the work were also noted so that the measurements could be related to expenditures reported on the daily report forms and rates of productivity computed. The representative observing the finished work also placed a rating on the quality of the work and reported the number of sites involved in the quantity of work accomplished.

Snow Removal

Because snow and ice control represents such a major maintenance expense in the snow belt States, a special study procedure was used to evaluate the quantity and use of labor, equipment and materials for winter maintenance on the northern test sections. The survey form shown in Figure 22 was developed to obtain detailed information regarding pre-planning of crew configurations, equipment assignments, and the use of chemicals and abrasives under various storm conditions.

For recording information observed in specific storms, the snow and ice control procedures evaluation check list shown in Figure 23 was developed. This form provided for a detailed description of the storm and an evaluation of the procedures followed in combating that storm. Because of the difficulty in anticipating the arrival of snow storms and getting to the widespread test sections during snow and ice control activities, the number of storm observations accomplished was somewhat limited.

ANALYSIS OF SUPPLEMENTAL FIELD DATA

In addition to the data obtained through the daily reports from each of the test sections, much useful information about adequacy, procedures and productivity was obtained through data recorded and supplied by the field representatives on the forms previously described.

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Interstate Maintenance Study
TA 107-2 NCHRP 14-1

Interstate Route No. --- Date Dec 20, 1966
Control Section No. --- Test Section No. ---

Test Section
Maintenance Condition Survey
Record Form

Pavement Maintenance — Condition

Patching:

Number of sites requiring patching — Slight 0; Moderate 3; Severe 0

Number of sites having temporary patches in place — Good 0; Fair 0; Poor 1

Number of sites having permanent patches in place — Good 2; Fair 0; Poor 0

Joint & crack filling:

Percent of joints & cracks which are --- Adequate 99

The percent which require sealing in the following conditions — Slight 1%; Moderate 0; Severe 0

Mudjacking:

Number of sites which require mudjacking — Slight 0; Moderate 0; Severe 0

Number of sites which have been mudjacked — Good 0; Fair 0; Poor 0

Bituminous surface treatment:

Percent of surface area which is ------- Adequate 100

The percent which require surface treatment in the following conditions — Slight 0; Moderate 0; Severe 0

Shoulders

Number of sites which require patching — Slight 5%*; Moderate ___; Severe ___

*5% Entire Surf. Trt'd Shoulders Need Resurfacing

Number of sites which have patching in place — Good 3; Fair 0; Poor 0

Bituminous surface treatment:

Percent of area which is ---------- Adequate 98

The percent which require surface treatment in the following conditions — Slight 0; Moderate 2; Severe 0

Edge joint sealing:

Percent of edge joint which is -------- Adequate 100

The percent which require treatment in the following conditions — Slight 0; Moderate 0; Severe 0

Drainage Systems

Ditch cleaning:

Percent of total ditching length which is ---------- Adequate 99

The percent which require cleaning or reshaping in the following conditions — Slight 1; Moderate ___; Severe ___

Culverts, drainage walls, cribbing and riprap:

Number of culverts which need cleaning — Slight 2; Moderate ___; Severe ___

Number of structures which require repairs — Major 0; Minor 0

Slope repairs:

Percent of total slope area which is ---------- Adequate 92

The percent which require erosion repair in the following conditions — Slight 5; Moderate 3; Severe ___

Turf and Plant Maintenance

Describe briefly each of the turf and plant areas receiving a different maintenance treatment on the test section:

a. Roadway - Machine Mowing
b. Steep Slopes - Hand Labor & Hand Mowing
c. Road Side Ditches - Mowing, Hand Labor & Chemicals
d. Wooded or Outside R/W - No Mowing Req'd.
e. Median - Hand Mowing

	Classification a	b	c	d	e
What percent of the total area does each classification represent	70	15	8	2	5
At what annual frequency is each classification mowed	12	12	3	0	12
What is the maximum allowable growth in inches for each classification	10	10	X	X	10
At what annual frequency is each of the classifications fertilized	No Program - done only as needed. X	X	X	0	X
At what rate is each classification fertilized (lbs/acres)	400 lb/Ac if & when done X	X	X	0	X
At what annual frequency are herbicides used on the various classifications	No Program - Only as needed. X	X	X	0	X
At what rate are herbicides applied to the various classifications (pounds/acres)	20± lb/Ac, if done X	X	X	X	X
Is the general appearance of each of the classifications good, fair, or poor	G	G	G	G	G

Traffic Control:

Guardrail and barrier fence repair:

Percent of total guardrail and barrier fence which is ---------- Adequate 99

Percent which needs repair in the following conditions — Slight 1; Moderate ___; Severe ___

R/W fence repair:

Percent of r/w fence which is --------- Adequate 99.5

Percent which require repair in the following conditions — Slight 0.5; Moderate ___; Severe ___

Major traffic sign structures (more than single pole support):

Number of signs which need painting 0
Number of signs which need cleaning 0
Number of signs needing repair 0

Minor traffic signs (single pole support):

Percent of total minor signs which are ---------- Adequate 99

Percent which require cleaning, straightening or repair — Clean ___; Straighten 1; Repair ___

Delineators:

Percent of total delineators which are ---------- Adequate 92

Percent which require cleaning, straightening or repair — Clean ___; Straighten 6; Repair 2

Lighting:

Number of light units which require cleaning, straightening, painting or repair — Clean 0; Straighten 0; Paint 0; Repair 0

Structures

Retaining walls:

Number of retaining walls requiring repair — Major repair 0; Minor repair 0

Bridges:

Number of bridges which require painting — Major paint 0; Minor paint ___

Number of bridges requiring repair — Major repair 0; Minor repair ___

Cleaning and sweeping

Appearance of pavement areas — Good ✓; Fair ___; Poor ___

Appearance of unpaved right-of-way areas — Good ✓; Fair ___; Poor ___

Inspected by: [illegible]

Date. [illegible]

Figure 18. Condition survey form.

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TA 107-2, NCHRP 14-1
Work Time Sampling

Test Section Number ___ ___ ___ State ___ ___ ___

Date of Observation 9-7-66 By PB

Activity Being Observed Resurfacing Bridge Floor with Epoxy

Time of Sample														Work Units	Total Units
10:00 A.M.		8	8	8	7	7	7	9	9	8	7	7	7	92	120
10:05		6	6	7	7	7	7	6	6	6	6	7	7	78	120
10:12		10	10	10	10	9	9	10	10	10	10	10	10	118	120
10:38		8	8	9	8	8	7	7	7	10	10	10	10	102	120
11:07		8	8	7	6	6	7	8	7	9	9	10	10	95	120
11:10		8	8	9	9	8	8	8	7	7	7	8	8	95	120
11:22		8	8	7	7	8	8	6	6	6	8	8	7	87	120
11:29		7	7	7	8	8	8	7	7	7	8	8	8	90	120
11:46		8	8	7	7	7	8	8	8	7	7	8	8	91	120
11:55		7	7	7	6	6	8	8	9	9	9	9	9	93	120
~~2:00~~	12:30	3	3	3	4	4	3	3	7	7	7	4	4	52	96
2:22	12:45	7	7	7	7	7	7	6	6	6	6	7	7	80	96
2:34	1:04	8	8	8	8	8	8	8	8	8	8	8	8	96	96
2:36	1:06	6	6	7	8	8	6	6	8	8	8	8	8	87	96
2:50	1:20	6	6	6	6	7	7	4	4	4	6	6	6	68	96
2:53	1:23	8	8	8	7	7	7	7	7	8	8	6	6	87	96
2:55	1:25	7	7	7	7	7	7	7	7	7	7	7	7	84	96
3:00	1:30	7	7	7	7	5	5	5	7	7	7	7	7	78	96
3:02	1:32	8	8	8	7	7	6	6	5	8	8	7	8	86	96
3:05	1:35	8	8	8	8	8	8	7	7	8	8	8	8	94	96
3:14	1:44	6	6	6	8	8	8	5	5	5	7	7	6	77	96
3:17	1:47	6	6	8	8	8	7	7	7	7	6	6	6	82	96
3:19	1:49	4	4	6	6	6	8	8	8	6	6	5	5	72	96
3:34	2:04	6	6	7	7	7	6	6	6	8	8	6	6	79	96
3:46	2:16	6	6	4	4	5	8	8	8	6	6	7	7	72	96

Total 2135 2640

Efficiency = $\frac{WU}{Tot.}$ x 100 = 80.87 %

25 - 3/31/66

Area surfaced with expoxy material 273' x 12'. The surfacing was completed at 12:00 Noon, and one truck and two men were transferred to another job.

Figure 19. Work time sampling form.

Work Time Sampling Instructions

Work time sampling will be used to measure the efficiency of a crew as it is observed during a four-hour study period. This work time sampling will be conducted as follows: At the beginning of the work procedure study, the time will be noted and entered beside 0:00 on the time sampling form. Next, each of the 24 randomized time segments will be added to the beginning time. The resulting time sequence indicates when the observer should take each work time sample. Each sample will consist of twelve distinct observations of each member of the crew. These twelve instant observations should be taken over a one-minute interval. At the instant of the observation, each crew member will either be working or not working. The observer will note the number of crew members working for each instant observation and record this information on the time sampling form. The crew will then be observed again and the procedure repeated until all twelve observations have been made.

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Observation of Work Procedure

Test Section Number ____ State ____

Date of Observation 9-13-66 By ____

Activity Being Observed Shoulder Surface Treatment (Ramps Only)

Crew Member	Duties
1 Supervisor	
5 Heavy equipment operators	Operate 3 trucks, roller, spreader
3 Light equipment operators	2 light trucks & pickup
7 Laborers	

Equipment	Size or Capacity
Stone spreader	Tail-gate
Pneumatic-Tire Roller	10 ton
3 Trucks	8 ton
2 [illegible]	2½ ton
	½ ton

Material

Bituminous material 6TD
Limestone chips

Narrative Description of the Operation: On the previously swept shoulder (8' wide during observation period) bit. mat was applied from suppliers distributor, by spreader bar at the rate of 0.25 gal/sy. Limestone chips (¼") were then spread by tail-gate spreader at the rate of 20#/sy, rolled with the pneumatic-tire roller. One truck and three men followed, hand spreading the chips to insure complete and uniform coverage. The chips are rolled again to complete the work.

(over)

Quantity of Work Accomplished * Number of Sites ** See "Comments"
Quality of Work Accomplishment Good ____ Fair X Poor ____

26 - 3/31/66 * On ramp [illegible] shoulder was continuous for 3200'. [illegible] SY/HR. This would be reduced by 30% + on [illegible] due to moving of equipment & traffic

Figure 20. Observation of work procedures form.

Narrative Description of the Operation (Cont'd): ____

** NUMBER OF SITES
Each interchange can be counted as four sites. The material available indicates that three interchanges will be completed.

Comments for improving operation and efficiency If there were some way to supply a flexible amount of equipment, efficiency would be increased. The three heavy trucks on this work are the correct number for the "average" haul distance for chips. At the far end the operation will be delayed, waiting for material. All the closer locations, two (and occasionally all three) trucks will be waiting.

Observation of Work Procedure
Instructions

The narrative description of the observed operation should be as brief as possible and should mention all of the following items that are applicable: Instructing, assembling and transporting crew, equipment and materials to the work site. Any work zone set up including safety measures and traffic control. Worksite cleaning or preparation and material preparation, handling, placing, finishing, curing and protecting. Final clean up and moving of the operation to any new worksite. A final paragraph should be added offering your comments on means of improving the operation or increasing its efficiency.

Work procedure studies will be conducted on the following activities:

1. Pavement, shoulder or deck patching (temporary or permanent)
2. Surface treatment or seal coating of pavement or shoulders
3. Litter policing of the right-of-way area
4. Mowing
5. Joint, crack and edge joint sealing
6. Mudjacking
7. Edgeline and/or centerline pavement marking

Work procedures descriptions will be prepared without observation for the following, where a standard procedure is followed:

1. Draining, cleaning of ditches or culvert
2. Guardrail or median fence repairs
3. Cleaning, straightening and repair of signs and delineators
4. Cleaning, repair and relamping of roadway lighting

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Measure of Work Accomplished

Test Section Number ____ ____ State ____ ____

Date of Observation 9-7-66 By [illegible]

Reporting Period Examined 8-30-66 thru 8-31-66

Item	Accomplishment: Sites	Accomplishment:	Quantity	Rating*
411 Patching:			sq. yards	
413 ~~Joint and~~ Crackfilling:		800	lin. feet	Fair (Some Splash)
425 Bituminous Treatment:			sq. yards	
426 Resurfacing (bituminous):			sq. yards	
441 Patching (shoulders):			sq. yards	
443 Bituminous Resealing (shoulders):			sq. yards	
446 ~~449~~ Edge Joint Sealing:		16,300	lin. feet	Fair
467 Mowing **			acres	
494 Br. Deck Patching**			sq, yards	
531 Pavement Marking			line-miles	
573 Litter Removal (R/W)			cu. yds/acre	

Remarks: Work done on shoulder edge no. 2 lanes - where needed, not continuous, since all edges can not be done this season, only the most open joints are being filled.

* Rate quality of work as: Good, Fair or Poor
** Report only when this activity is separately shown on daily report form.

Figure 21. Measure of work accomplished form.

Condition Surveys

Condition surveys were made on each test section during the Fall of 1965, in the Spring of 1966, and again in the Fall of 1966 after the completion of most summer maintenance programs.

From the data obtained through the condition surveys, an adjectival and numerical rating was developed to express the relative level of maintenance accomplished on each of the test sections. Elements were weighted in this rating plan as follows:

Pavement	40 points
Shoulders	10 points
Drainage	25 points
Roadside	5 points
Traffic control facilities	10 points
Structures	10 points
Total	100 points

The information so developed indicated that 61% of the test sections rated 90 points or better, 82% rated 85 points or better, and only one section rated under 80 points.

It was concluded from the ratings that 23 of the 28 test sections were satisfactorily maintained, three sections were slightly less than satisfactory, and two sections needed slight improvement in the level of maintenance. Table 4 shows the rating of the maintenance level of each of the test sections, as achieved during the data collection program.

The ratings indicate the quality or completeness of the maintenance performance, and also reflect the quality of maintenance management, personnel and training, and the adequacy of funds to carry out the maintenance function. The principal purpose of the condition surveys, however, was to identify the maintenance standard of the test sections, measure the deviations of sections from the standard, and determine if the deviations would affect the maintenance model.

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Interstate Maintenance
IA 107-2 NCHRP 14 1

Snow and Ice Control Procedures

Survey Form

Test Section No — State — County —

Persons Interviewed — Title

— — — — Highway Superintendent

— — — Highway Foreman

Date March 16, 1966 Interviewer —

Snow and Ice Control Survey — Sheet 2 of 7

General

		Yes	No
1	Is an attempt made to keep the Test Section clear of ice and snow under all winter conditions (bare pavement)?	X	

2 How frequently can you cover the Test Section under a severe storm condition?

Plowing	Hourly
Spreading Chemicals	Every 2 hours
Spreading Abrasives	Every 2 hours

3 What arrangements are used for alerting maintenance personnel of impending storms? Most of crew lives at station - Alerted by F.M. radio from highway headquarters & by commercial radio weather reports

How long does it take to put crew on the job? 20-30 minutes

4 What agencies are used to forecast the weather? U.S. Weather Bureau

What is your most reliable source? The above

5 How many snow storms occur on an average each winter? 5

Procedures

		Yes	No
6	Are special plowing assignments made for interchange area?		X

Explanation
What? All interchanges are between I-15 and San Bernardino County roads. State crews plow ramps during routine snow removal from I-15.

Figure 22. Snow and ice control procedures form.

Yes No

7 When is snow removed from the shoulder area? As soon as traveled way is clear and conditions permit.

With what? 3 Cubic Yard trucks with type "B" push plows and motor graders.

8 When are chemicals applied to road surface? As soon as heavy snow fall lessens and during freezing rain or sleet.

9. What spreading patterns are used (width of spread) and what is the application rate?

Pattern	Rate	Material
24'-30'	½-2 tons/mi	Cinders
20'-30'	½-1 ton/mi	Salt

Note: Rate varies with conditions

10 Who patrols roads looking for hazardous conditions during winter months?

State Police	X
Foreman or Supervisor	X
Special Patrol Force	X (Crew assigned by Foreman)

		Yes	No
11	Are operational procedures and policies for bridge decks the same as the mainline?		X

If no, what do you do? Particular attention is given bridge decks during freezing rain and sleet.

Equipment

12 How many plows are available for use during snow storms?

Push plows	5
Rotaries	None

13 How many material spreader trucks are available for use during snow storms?

No of Trucks	Material Capacity	Type of Spreader
2	4 C.Y.	Swenson Chip Spreader
1	2 C.Y.	Tarco Salt Spreader

Snow and Ice Control Survey — Sheet 4 of 7

Yes No

14 How are plow blades set relative to pavement?

Location	Replacement Frequency
Above — inches	
Flush X	1-5 hours (Depending on ice or slush)

15 How many vehicles, in train, are used to plow roadway mainline and which direction does each vehicle plow the snow?

Number	Type Plow	Direction Median	Direction Shoulder
1	"B" Reversible	X	
1	"B" Fixed	X or	X
1	"B" Fixed		X
1	Motor Grader	X or	X

16 How many spare units of equipment (in event of breakdown) are available during a storm?

Equipment	Number	Owned/Rented
Trucks	2	X
Plows	None	
Spreaders	1	X
Loaders	1	X
Motor Grader	4	X

17 What lag time would there be between notification of need and availability of rental equipment for use on road? 4 hours

18 What type of equipment is used for loading materials into spreader trucks?

Equipment	Chemicals	Abrasives
Mechanical Loader		X
Conveyor		
Hopper		X
Manual Labor	X	

19 What is the normal plow truck speed? 20-25 mph

20 What is the normal spreader speed? 18 mph

Yes No

Materials

21 What materials are stored for use on Test Sections?

	Abrasives (Capacity)	Bulk Chemicals (Capacity)	Bag Chemicals (Capacity)
Open Bin	1000 C.Y.		
Shed			30 tons (1200 bags)
Hopper	40 C.Y.		
Other			

22 How accurately is the rate of application for materials controlled? Good — Fair X — Poor —

23 What types of chemicals or combinations are used and under what conditions?

Chemicals - Rate	Condition Temperature (Rising)	Condition Temperature (Falling)	Condition Other
Salt ½ to 1 ton/mi	X	X	Applied on glaze or pack and on wet pavement when temp is falling or predicted to fall.

24 Under what conditions are abrasives used on Test Section?

Abrasives - Type	Rate	Condition Temperature (Rising)	Condition Temperature (Falling)	Condition Other
Volcanic Cinders	½-2 C.Y. per mile	X	X	Applied on glaze or pack.

Snow and Ice Control Survey — Sheet 6 of 7

Yes No

25 Describe the procedure used for mixing chemical or abrasives if applicable Bagged salt is opened and dumped into 4 C.Y. trucks with Swenson spreaders. While loader is loading cinders - making a fair mix and spread when dump truck bed is raised & spreader operating.

		Yes	No
26	Is there a spring cleaning program to remove abrasive material from Test Section? Pavement is cleaned regularly since sand and dust accumulates from wind storms.		X

To what account is it charged? Street Sweeping. Since no differentiation can be made - a great deal of it blows off the road.

Labor

		Yes	No
27	Are crews given formal instruction sessions?	X	

At what intervals? New employees undergo training program and crews are advised of conditions and duties at start of shift

		Yes	No
28	Do personnel know in advance what their responsibilities will be during storm operations?	X	
29	Do you increase the length of shifts during storm periods?	X	

How long are shifts? 12 hrs and more if emergency exists

30 How many men work during each shift? 2-8 depending on conditions

		Yes	No
31	Are arrangements made to get additional men on the road during severe conditions?	X	

How long does call-out take? 1 hour from Baker, 2 hours from Barstow

32 What is the maximum number of hours personnel are permitted to work continuously? 24 in emergency

Note: (In my opinion this crew is undermanned during storms however snow storms seldom last more than 24 hours and it may not be economical to increase personnel at present.) R. I. N.

Snow and Ice Control Survey — Sheet 7 of 7

Others

33 How much snow fence is used on Test Section? (estimate)

Temporary (placed annually)	None linear feet
Permanent (plantings or permanently installed)	None linear feet

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Test Section ___ ___

County ___ ___
State ___ ___

Snow and Ice Control Procedures

Evaluation Check List

Observation time
from 8:00 hour 1-30-66 date
to 11:30 hour 1-30-66 date

Yes No

A Description of Storm

1. Give a brief description of the snow storm in terms of type of precipitation, wind direction and velocity. *Storm came from S.W. and was same storm reported on Test Section #2. Wind velocity variable 10-15 m.p.h. with some directional changes S.W. to S.E.*

2. What was the total snowfall during observation period? *4* inches

3. What was the total snowfall for the storm? *8-10* inches

4 What was the temperature range and direction during the observation period? *28-34*

B Condition of Test Section during storm

5. What was the maximum accumulation of snow on the Test Section pavement during the period of observation? *1-0* inches

6. What was the condition of the pavement during the period of observation? Show the percentage of time for the following conditions

Condition	Percent
Wet	*15*
Trace snow	*15*
Glazed	
Loose snow	
Packing snow	*70*
Packed snow	
Ice	
Mealy snow	

7 Was existing snow fence effectively eliminating drifting over roadway? *No Snow Fence* ___ ___

Sheet 2 of 4

Yes No

8. Indicate the number, extent and causes of snow drifts observed on the roadway and ramps during the snow storm. *No appreciable drifting, some snow swirls. However, other storms of more intense snowfall witnessed by the writer, have caused drifting during high winds, mostly at little used interchanges east of ---.*

9. Make a note of major operational delays caused by roadway obstructions or traffic jams and record the duration of the delay.

Delay	Duration	Cause
Traffic was slowed by the storm but no recordable delays occured.		

C. Evaluation of storm procedures

10. How many units of equipment are being "charged" to snow and ice control during the observed storm period?

	Number
Trucks, spreader	*2*
Trucks, plow	*3*
Rotary plows	*1*
Loaders	*1*
Motor graders	*2*
Other *Pickups*	*2*

11. Of the above charged units, what percent of observed time during the storm were they actually on the Test Section?

	Percent
Trucks, spreader	*50*
Trucks, plow	*90*
Rotary plows	*100 cleaning up reef.*
Loaders	*25*
Motor graders	*100 working with Rotary*
Other *Pickups*	*100*

Sheet 3 of 4

Yes No

12. How frequently do equipment operators take rest breaks? *2 or 3 times during shift, not counting time for meals.*
For approximately what duration? *10-15* minutes

13. Is replacement equipment available in case of equipment breakdowns during storm? *X* ___

Spreader trucks	
Plow trucks	*1*
Loaders	*1*
Trucks	*1*

14. When were spreaders initially loaded with material? *Prior to storm*

How is the material loaded and is the operation efficient? *By loaders and from hopper chutes. This is considered efficient. Bulk salt from elevated bin is handled efficiently. Material delivered by vendor in special trucks and blown by air pressure into storage bin.*

How could it be improved? *Construct a larger sand storage building with same type of conveyor system.*

15 How long does it take to load spreader trucks?

Capacity *4 C.Y.* Time *5 min. approx.*

16 Is spreading equipment standing idle waiting to be loaded? ___ *X*

If yes, how often? Frequently ___
Occasionally ___
Seldom ___

Sheet 4 of 4

Yes No

17. Was it necessary to mix materials during storm conditions? *X* ___

How often? *Each truck load*

Were there any delays in spreading materials due to mixing? ___ *X*

18. How is material usage estimated? *By truck measurement and converted to weight by previously determined factor.*

19 How effective was plowing operation? *Very effective*

20. Comment on plowing problems, if any, and on adequacy of equipment type, size and operation. *Traffic causes most of the problems along with wind and low visibility. More equipment is needed. A new stretch of highway has been added to the system and some of the equipment assigned to the --- area must be diverted until additional equipment is obtained. A Rotary from an abandoned missile site in Montana is on the way.*

Date: *1/30/1966* Report completed by: *R.N.*

Figure 23. Snow and ice control procedures evaluation check list.

TABLE 4

TEST SECTION RATINGS DETERMINED FROM CONDITION SURVEYS

TEST SECTION NO.	RATING	TEST SECTION NO.	RATING
1	87	43	82
2	83	44	79
3	85	51	90
4	83	53	88
5	90	55	80
6	93	56	97
21	97	58	85
22	96	59	89
23	94	64	99
24	98	68	98
25	97	74	93
26	98	75	98
41	96	78	98
42	96	79	98

Therefore, the ratings were used to adjust the maintenance expenditures on the test sections to provide equitable dependent variables in the multiple regression analyses. These trial adjustments changed the expenditure distribution by such a small amount that the resulting impact on the regression models proved insignificant. It was concluded that the differences in maintenance standards on the various test sections, measured through the condition surveys, were too small to affect the relationships developed through the regression analyses and, therefore, did not need to be considered.

Work Time Sampling

Information obtained from the work time sampling forms is recapitulated in Table 5. It will be noted that although there is variation in efficiency among the various maintenance activities there is little variation in the same activity, even in different test sections. Work efficiency, therefore, was not a factor in interpreting the maintenance expenditures for the regression analyses and was not included in the mathematical models.

Observation of Work Procedures and Measurement of Work Accomplished

Observations of work procedures were made on all test sections. These included observations on pavement and shoulder maintenance, litter cleanup, mowing, mudjacking, edge and joint sealing, guard fence painting, bridge deck repair, ditch cleaning, bituminous surface sealing, traffic line marking, and snow and ice control.

Sixty-six work procedures were studied. The studies were carried out as the work was performed in the regularly planned schedule of the highway agency. In several test sections, some of the operations were not performed during the season of 1966. Therefore, observations of all of these procedures were not possible on all test sections.

TABLE 5

WORK EFFICIENCY

TEST SITE	REPORT DATE	OPERATION	EFFICIENCY (%)
22	7/7/66	Steep slope mowing	89.3
23	6/23/66	Machine mowing	91.2
24	9/14/66	Mowing, small machine	89.6
24	8/18/66	Mowing, machine	90.4
25	7/19/66	Mowing, small machine	93.7
53	5/24/66	Mowing	94.4
56	5/26/66	Mowing	97.8
58	5/4/66	Mowing	94.1
59	5/9/66	Mowing	90.8
74	6/15/66	Mowing	94.3
74	9/23/66	Mowing	91.8
75	9/22/66	Mowing	88.9
75	4/20/66	Mowing	78.8
78	6/21/66	Mowing	89.7
78	6/21/66	Mowing	89.8
26	6/27/66	Mowing and litter clean up	86.3
56	4/22/66	Litter removal	83.1
1	7/6/66	Pavement patching AC over PCC	79.0
2	6/13/66	AC patching on settled PCC	76.2
4	5/19/66	AC patching	59.4
5	7/27/66	AC patch	74.5
21	7/12/66	Patching (shoulders)	89.1
22	7/12/66	Paved shoulder patching	79.5
2	6/21/66	Bridge deck repair (494)	78.3
3	6/14/66	Edge joint filling	78.6
6	8/30/66	Sealing (425)	64.5
59	6/29/66	Sealing bituminous shoulder	81.5
74	4/20/66	Placing AC level-up	77.8
79	—	Repairs to PCC floor (494)	68.5
2	5/18/66	Centerline pavement marking	86.5
23	6/22/66	Centerline painting	88.5
26	8/22/66	Centerline painting	82.6
74	9/23/66	Placing center stripe	87.9
79	9/7/66	Resurfacing bridge	80.9

The observations demonstrated the many different successful methods employed by maintenance crews and the versatility and ingenuity of those planning maintenance work. Most of the procedures were well planned, within the limitations which affected the planning. The studies with a view to improving or optimizing the procedures pinpointed the fact that for a maintenance operation there is seldom a single optimized procedure that is fully applicable at a great number of locations. Limitations are related to the design and operational characteristics of the highway, the types of equipment available and a variety of other local factors.

Although it was not the purpose of this study to make management analyses, it was evident that efficient maintenance operations depended to a great degree on management factors. This is particularly true in budgeting and in personnel management. Policies on recruitment, training

and pay establish to a significant degree the caliber of the maintenance staff. Budgets and policies on equipment acquisition, maintenance and replacement have an important bearing on the manner in which work is performed. The management and leadership ability of first- and second-line supervisors is probably the single most important element in efficient, productive maintenance programs. A foreman who anticipates and plans the proper mix of men, equipment, materials and procedures for each task several days in advance, yet is flexible enough to alter the plans as emergencies require, is, perhaps, the greatest influence in determining efficiency and productivity.

Productivity

The development of "a practicable measuring system for relating utilization of men, equipment, and material to production in maintenance operations" was only partially successful. Maintenance activities that are of a repetitive nature using standard production techniques can be anticipated and planned well in advance and work units can be measured easily. However, it is often advantageous to perform these activities by contract rather than by maintenance crews.

Those maintenance activities that are of a routine nature, that can be anticipated but whose timing, location and quantity cannot be measured or specified, are not truly comparable. However, the information developed in the study on productivity, as outlined in the following paragraphs, can be of considerable value to maintenance engineers. Table 6 gives a range of productivity for those maintenance activities that were measured.

Optimized methods and techniques were devised and tested in a limited number of cases. The productivity results are included in the following paragraphs and a discussion of the procedures and techniques is given in Appendix E.

PATCHING, CONCRETE

Partial-depth pavement patching techniques vary greatly, particularly in the use of materials. On the other hand, the technique for making full-depth concrete patches appears to be well standardized. The area to be replaced is usually sawed, broken with a small hammer, and cleaned out. Then the subbase is leveled and compacted, dowels are placed in the old pavement, and the concrete is placed from a ready-mix truck. Table 7 gives productivity data gathered from test sections 58 and 59, where full-depth concrete repairs were being made.

Figure 24 indicates that there is a relationship between man-hours per square yard and square yards per patch, as given by

$$\text{Man-hr/sq yd} = (-0.1 \text{ sq yd/patch}) + 7.9 \qquad (1)$$

In an attempt to optimize the procedure, one repair job (the last in Table 7) was organized so that a specially trained crew performed each of the separate functions rather than have the entire crew participate in all the functions. As indicated in Table 7 and Figure 24, productivity was increased. More concrete was placed per man-hour without a relative increase in equipment or material costs. From a practical point of view, however, the emplaced concrete was more costly, inasmuch as additional personnel had to be imported from an adjacent section with attendant increased overhead costs because of overtime and travel.

PATCHING, ASPHALTIC

Table 8 gives the available data on the productivity of asphaltic patching. Repair of portland cement concrete and bituminous pavements with bituminous materials varies from small hand-placed cold patches to complete resurfacing with asphaltic concrete for the full width of the roadway. Spreading is done by hand, by motor grader, by spreader box, or by paving machine. Tack and seal coats are spread for smaller areas by hand-held pressurized sprays and for larger areas by truck-mounted distributor bars.

CRACK FILLING

Joints and cracks in the pavement are usually cleaned by compressed air and then filled from a hand-guided nozzle

TABLE 6

SUMMARY OF PRODUCTIVITY STUDY RESULTS

ACCOUNT AND ACTIVITY	NO. OF OBSERVATIONS	RANGE OF PRODUCTIVITY	PRODUCTIVITY OF OPTIMIZED PROCEDURE
411 Patching, concrete	8	3.17 to 7.71 mh/sq yd	3.18 mh/sq yd
411 Patching, asphalt	13	1.00 to 27.10 sq yd/mh	16.2 sq yd/mh
413 Crack filling	5	56.20 to 116.80 ft/mh	
441 Shoulder patching	7	0.93 to 19.50 sq yd/mh	
443 Shoulder resealing	7	25.50 to 397.00 sq yd/mh	78 sq yd/mh(wedge)
446 Edge joint sealing	10	53.00 to 552.00 ft/mh	543 ft/mh
467 Machine mowing	31	0.18 to 4.45 mh/acre	0.354 mh/acre
494 Bridge deck patching	6	2.78 to 16.00 mh/sq yd	
531 Pavement marking	9	1.22 to 7.65 mh/mile	
573 Litter removal	24	0.058 to 5.29 mh/acre	0.194 mh/acre

TABLE 7

CONCRETE PATCHING

TEST SECTION	DAYS INVOLVED	NO. OF PATCHES	AREA (SQ YD)	LABOR (MAN-HR)	COST ($) EQUIP.	COST ($) MAT.	MAN-HR/ SQ YD
58	10	7	144	793	1479	819	5.51
58	14	7	343	1088	2076	2287	3.17
58	4	2	80	293	721	529	3.67
58	6	5	73	450	1226	539	6.16
58 [a]	13	11	152	1174	3205	1729	7.72
59 [a]	5	4	51	293	571	464	5.76
59 [a]	16	11	159	1068	1553	2630	6.72
59 [b]	1	4	78	247	447	643	3.17

[a] Data modified. [b] Optimized.

with rubberized asphalt under pressure. To permit traffic to traverse the pavement immediately after repair, a paper strip or cement powder is placed over the sealant to prevent it from being pulled out by car tires before it is cured. The cover eventually wears off. Table 9 summarizes the information available on this type of repair.

SHOULDER PATCHING AND RESEALING

Types of shoulder repair range from edge joint sealing and shoulder buildup to spot patching and resealing of the entire shoulder. Small patches are usually hand-placed cold mix; larger ones may be hot-mix or cold-mix machine-placed or penetration patches. As necessary, surface treatment is included for the full width of the shoulder.

In one State, edge joint sealing was done by cleaning the crack with compressed air and pouring heated asphalt with hand-held cornucopias. When a small wheel was fixed to the metal cornucopia so that it could be wheeled along the edge of the pavement, productivity increased from 181 ft/mh to 445 ft/mh.

On one test section, the edge joint was opened by a small plow wheel, called a coulter, fastened to a motor grader. The grader was followed by a distributor applying an 8-in. wide prime coat of RS2 followed by a chip spreader box and steel mesh drag. Compaction was obtained from the tires of following trucks. Production by this method was 550 ft/man-hour.

Where the shoulder had dropped away from the pavement, the normal repair technique was to spray a prime coat followed by either a hot or cold plant mix of the proper depth covered with chips and rolled, usually by steel-wheel rollers. An optimized technique used a spreader box for the plant mix and chips in lieu of hand placement.

Although it is not practical to compare the productivity of one type of treatment with another, Tables 10 and 11 indicate a range of productivity measured in man-hours for various bituminous shoulder repairs. Because of different reporting methods, productivity in Table 11 is indicated in either lineal feet or square yards.

TABLE 8

ASPHALTIC PATCHING

TEST SECTION	DAYS INVOLVED	AREA OF PATCHING (SQ YD)	LABOR (MAN-HR)	SQ YD/MH
1	13	2300	495	4.7
1	1	560	40	14.0
2 [a]	1	40	24	1.7
2	1	112	56	2.0
3	4	2488	194	12.8
4	1	1300	48	27.1
5	2	610	95	6.4
5	3	470	114	4.1
55 [b]	1	16	16	1.0
78	1	1100	81	13.6
78	1	1600	153	10.5
3 [c]	1	530	46	11.5
3 [d]	1	356	22	16.2

[a] Hand patches. [b] Small cold-mix hand patches. [c] Road grader used. [d] Optimized; Layton paver used.

TABLE 9

JOINT AND CRACK FILLING

TEST SECTION	DAYS INVOLVED	LENGTH (FT)	LABOR (MAN-HR)	FT/MH
3	2	800	10	80
4	3	6970	112	62
4	3	11400	120	95
58	7	44762	383	117
59	10	21764	388	56

MACHINE MOWING

The rotary mower is the principal type of equipment used. These range in size from the hand-guided 21-in. mower to the 80-in. diameter jeep- or tractor-drawn variety. Three of

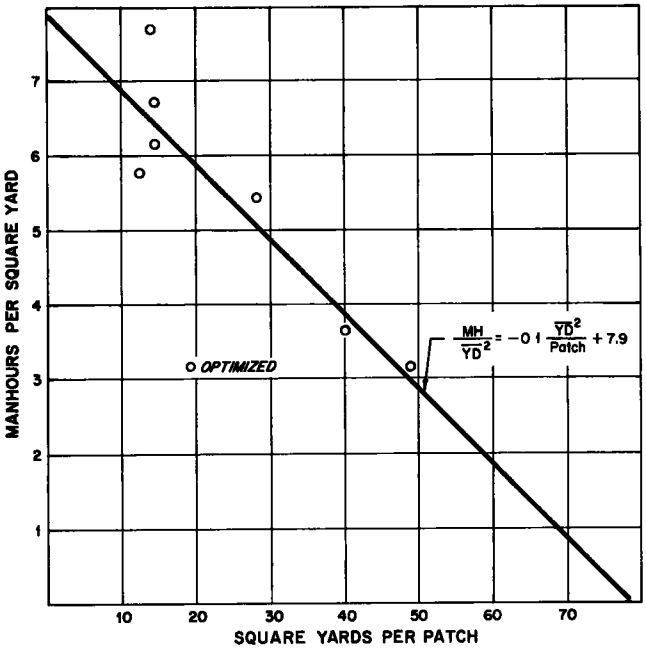


Figure 24. Concrete patch productivity.

the large rotary mowers towed by a tractor with a delta bar can cut a swath 15 ft wide. In some States rotary mower units mounted on hydraulic arms suspended from trucks or heavy tractors are used to trim slopes too steep to be negotiated by tractors. Small hand-controlled rotaries are sometimes used in small tight areas inaccessible to prime movers and under and around obstacles such as guardrails and delineators. The reel mowers and the hydraulically driven sickle bars are used less frequently because of their greater mechanical complexity. Also, the reel mowers are difficult to operate in even moderately high growth and require a more rigid adherence to cutting schedules.

Productivity for machine mowing varied from 0.18 to 4.45 man-hr per acre of turf cut. The greatest productivity occurred in those test sections with flat grassy areas with little or no plantings, and the least productivity in highly landscaped urban areas. Steep (2:1 or greater) slope mowing with rotaries was also on the lower end of the production scale. Table 12 indicates the measured range in productivity for machine mowing. Data on hand mowing were eliminated from the table. In the one optimized procedure noted, a 15-ft rotary was used in lieu of an 80-in. rotary.

BRIDGE DECK PATCHING

The technique for the repair of bridge decks is similar to that for pavement repair and varies from full-depth concrete patches through the various types of bituminous repairs to the use of epoxy cements. Table 13 summarizes data for this activity.

PAVEMENT MARKING

Normally, traffic line marking of highways is done by special crews from maintenance headquarters trained for this purpose. Table 14 contains productivity data on pavement marking. They compare favorably with the data contained in *Highway Research Board Circular 478* of August 1962.

LITTER REMOVAL

Litter pick-up and disposal requires constant attention from most maintenance crews. No effective mechanical device has yet been developed to pick up trash from turf and planted areas; consequently, hand labor is universally used. Frequency varies from State to State and from section to section, depending primarily on requirements, with urban sections getting more attention than rural. Usual procedures are for a flatbed or dump truck to proceed along one side of the right-of-way with one or more laborers carrying burlap bags walking along to pick up the trash, depositing it in the bags and then dumping it in the truck. For safety, crews do not usually crisscross the traveled way. In most instances a crew of two or three men is responsible for the section and must travel the length of the section several times for full coverage. In an optimized procedure two

TABLE 10

PATCHING SHOULDERS

TEST SECTION	DAYS INVOLVED	AREA (SQ YD)	LABOR (MAN-HR)	SQ YD/MH	REMARKS
21	2	280	128	2.19	200 patches; double surface treatment; kettle-heated asphalt.
22	2	230	66	3.49	Cold-mix patches over cold tack coat.
22	1	836	57	14.65	Penetration patches.
23	1	30	32	0.94	Cold-mix patches.
23	1	75	56	1.34	Cold-mix; prison labor.
51	2	1400	72	19.50	Seal treatment.
58	1	2346	292	8.04	Seal treatment.

TABLE 11

SHOULDER EDGE TREATMENT

TEST SECTION	DAYS INVOLVED	LINEAL FEET	LABOR (MAN-HR)	FT/MH	REMARKS
2	3	7000	131	53	Wedge seal.
3	7	42400	296	143	Air compressors and hand cornucopias.
3	2	16300	89	183	Air compressors and hand cornucopias.
3	1	5808	32	181	Air compressors and hand cornucopias.
5	2	23971	54	443	Air compressors and wheeled cornucopias.
55	2	61776	112	552	Coulter-cut groove, sealed, chipped.
58	8	54912	405	135	Technique undetermined.
59	4	55968	169	331	Technique undetermined.
59	2	92928	190	488	8-in. wedge.
59	1	21648	40	541	Optimized wedge buildup.
		SQ YD		SQ YD/MH	
53	1	5475	52	105	Edge resealing.
53	5	48400	122	397	Edge resealing.
55	5	14667	164	89	Edge resealing.
58	6	23763	303	78	Wedge seal; optimized.
59	4	52800	1109	48	Raising and sealing outside 5 ft; tack coat and penetration.
59	1	46464	284	163	Seal coat 8 ft wide.
59	17	30888	1210	26	Shoulder built up and then seal coated.

TABLE 12

PRODUCTIVITY MEASUREMENTS FOR MACHINE MOWING

TEST SECTION	DAYS INVOLVED	AREA (ACRES)	LABOR (MAN-HR)	MAN-HR/ ACRE
2	4	20	28	1.40
4	2	9.0	20	2.20
4	2	8.5	20	2.35
5	2	3.6	16	4.45
21	9	347	240	0.69
21	1	20	24	1.20
22	6	109	93	0.86
23	5	480	280	0.58
23	2	113	48	0.43
23 [a]	1	36	24	0.68
23 [b]	1	68	24	0.35
26	8	63	102	1.62
26 [c]	2	3.2	30	9.38
26	1	14	18	1.29
26	7	63	100	1.59
26	6	63	77	1.20
41	5	160	184	1.15
51	6	175	322	1.84
51	23	800	1048	1.31
53	1	59	24	0.41
55	9	500	416	0.83
56	12	279	606	2.17
56	10	80	296	3.70
58	2	260	48	0.18
58	3	203	56	0.27
59	1	86	17	0.20
59	6	224	142	0.64
74	10	281	360	1.28
74	1	20	32	1.63
74	1	41	40	0.98
78	12	505	1348	2.67

[a] Before optimization. [b] After optimization. [c] Steep slope mowing.

men each were used on the two shoulders and the median under one truck driver-foreman in one sweep down the section, with the results indicated in Table 15.

In most States, the full length of a section is given light coverage once or twice a week, with truck stops being made at only the more unsightly accumulations of debris. Complete ground coverage varies, but usually is not more frequent than once per month. The most thorough coverage occurs when policing is done in conjunction with mowing, particularly on those sections that require a considerable amount of hand mowing to supplement machine mowing.

In some States, maintenance crews are charged with removing accumulated litter, debris, and garbage from rest and service areas. Where this requirement exists, service must be at least twice weekly. In some States, landscape crews are charged with this responsibility. Debris is usually

TABLE 13

STRUCTURE MAINTENANCE

TEST SECTION	DAYS INVOLVED	AREA (SQ YD)	LABOR (MAN-HR)	MH/SQ YD
3 [a]	1	2	28	14.00
51 [b]	6	20	320	16.00
58 [b]	5	45	219	4.87
58 [b]	13	545	1518	2.78
58 [b]	11	144	752	5.22
59 [c]	6	44	185	4.20

[a] Epoxy cement. [b] Partial-depth concrete patches. [c] Thin concrete patches.

TABLE 14

PAVEMENT MARKING

TEST SECTION	DAYS INVOLVED	LINE (MILES)	LABOR (MAN-HR)	MH/MILE	REMARKS
2	3	29.7	114	3.8	Asphalt raised stripe.
4	1	16	104	6.5	White paint stripe.
4	1	18.6	56	3.0	Yellow paint stripe.
4	1	0.3	34	113.1	Thermo-plastic painted gores.
23	1	16.4	20	1.2	Dashed black and white stripe.
26	4	60.7	464	7.7	Dashed black and white centerline; night operation.
58	1	120	161	1.3	Double-line centerline.
59	1	58	72	1.2	Double-line centerline.

TABLE 15

PRODUCTIVITY MEASUREMENTS FOR LITTER REMOVAL PROGRAMS

TEST SECTION	DAYS INVOLVED	LITTER (CU YD)	ACRES COVERED	LABOR (MAN-HR)	MH/ACRE	REMARKS
1	1	8	26	8	0.31	
1	15	49	390	59	0.15	
2	1	10	44	52	1.19	
3	1	5	24	3	0.12	
4	3	20	8.9	47	5.29	
4	3	16	55	48	0.87	
5	1	8	18	95	5.28	
5	15	48	320	534	1.67	
21	1	10	650	64	0.10	
21	1	0.75	72	25	0.35	Before optimization.
21	1	0.5	72	14	0.19	Optimized.
22	1	4.0	20	16	0.80	Before optimization.
22	1	6.0	45	28	0.62	Optimized.
22	1	5	165	33	0.20	
22	1	5	130	41	0.31	
25	1	2	65	16	0.25	Quick cleanup.
25	1	1.5	65	16	0.25	Quick cleanup.
26	6	5	24	77	3.21	
41	1	25	730	64	0.09	Quick cleanup.
42	2	3.6	650	64	0.10	Quick cleanup.
44	1	12.5	500	24	0.06	Quick cleanup.
59	[a]	275	1155	278	0.24	A good average.
59	[a]	155.1	970	220	0.23	A good average.

[a] One month.

disposed of in sanitary fills or incinerators of neighboring communities, where a service charge per yard or truck load is imposed in some cases.

The amount of debris collected has little bearing on productivity figures. Varying standards of cleanliness are interpreted by different foremen from section to section and State to State. The difficulty of measuring with any degree of accuracy the small quantities of litter involved, make small variations in estimating affect productivity figures unduly.

The best measure of the productivity of litter removal appears to be man-hours per acre of area cleaned. Even on a man-hour per acre basis, productivity ranged from a low of 0.064 on Test Section 44 to a high of 5.29 on Test Section 4. The two orders of magnitude difference can be explained in part by the difference between a spot cleanup by truck, and a complete coverage on foot.

Table 15 summarizes information on litter removal.

Except for urban areas, records indicate that paved areas usually are not cleaned with mobile power brushes. Normal precipitation usually provides sufficient cleaning action in those areas. In urban areas, mobile power brushes gen-

erally are used to clean gutters and curbed sections, bridge decks and other surfaces where debris lodges. No record of power sweeper productivity was taken.

MUDJACKING

There were five observations of mudjacking operations, three in Ohio and two in California. The techniques and procedures in both States were typical and roughly the same. Ohio employed a cement-limestone slurry and California a cement-loam slurry.

The observations were insufficient to draw any definite relationships on productivity. However, Ohio's operation varied from 2.47 to 3.01 man-hr per square yard and California's from 0.4 to 0.48 man-hr per square yard.

CHAPTER FOUR

DEVELOPMENT OF MAINTENANCE REQUIREMENTS

For the development of a quantitative measure of Interstate maintenance requirements, expressed in terms of the labor, equipment and material units, it was necessary to explore the relationship between the work load being generated by each test section and the various physical, environmental and traffic factors having a potential influence on the work load. This was done using a multiple linear regression analysis where the significance of each factor was evaluated. The factors significantly affecting the maintenance work load were then incorporated into general regression models which related these factors to a single maintenance requirements value. This value represented the units of labor, equipment and material which were expended in an efficient and productive manner to maintain adequately the various Interstate test sections.

General regression models were developed for seven different maintenance activity groups. Each model predicted the requirement units needed to maintain adequately a one-mile section of four-lane divided Interstate highway, given various physical, environmental and traffic parameters. Finally, factors were computed to convert the requirements units into appropriate labor hours, equipment hours and material dollars for each of the seven models.

MAINTENANCE WORK LOAD

The maintenance work load on a section of highway refers to all those conditions which generate a need for maintenance activities. Work load includes conditions on a section of highway which affect its appearance (e.g., litter, weeds, unmowed areas); which affect, directly or indirectly, its physical integrity (e.g., pavement breaks, open joints, blocked drainage); or reduce its capacity for service (e.g., snow or ice, worn pavement markings).

In some instances, work load can be measured in terms of the amount of work needed to correct a roadway deficiency (e.g., yards of patching, lineal feet of joint sealing, acres of mowing). In other instances, the appropriate measure will be the labor, equipment and material units needed to remedy a deficient condition, such as litter and snow and ice control. However, most of the work load being generated by a section of highway will fall somewhere between these two categories; i.e., the number of units such as signs or the amount of work such as linear feet of guardrail might be known but the combination of labor, equipment and material needed to correct the situation will vary widely, being a function of the location, access and configuration of the work load.

This suggests that the best measure of work load is the labor, equipment and material investment rather than a quantitative measure of the work. An evaluation of work load in labor, equipment and material units more readily accommodates the widely divergent job sizes and procedures associated with each of the maintenance activities. Of course, built into the reported labor, equipment and material expenditures are potential crew inefficiencies, low production procedures, and variations in the adequacy of accomplishment. These elements need to be considered and evaluated before expenditures can be used as a measure of the work load being generated by each of the test sections.

In most instances, the procedures used for similar activities reflected the needs and the availability of resources in the various locations. That a different procedure, usually involving different equipment, might improve certain operations in selected areas was obvious. But the warrants for recommending such changes usually could not be developed, considering the total requirements peculiar to the specific locations and the associated physical, environmental and traffic factors affecting these locations.

Therefore, it was concluded that the reported investment in labor, equipment and material on the test sections was an appropriate measure of requirements without any productivity adjustment. This investment reflected variations in productivity which existed and would continue to exist because of the conditions under which maintenance is performed in various locations.

As noted previously, the percentage value for working time varies considerably for different types of activity, but remains fairly constant, even on different sections, for a given activity. As a consequence, it was determined that

there was no need to correct the reported expenditures for variations in crew efficiency.

Prior to establishing the test sections, it was recognized that the standards could vary unduly. One of the selection criteria for the test sections was that a uniformly high standard of maintenance should be practiced. Consequently, no modification of the reported expenditures was made for standards. Rather, the requirements models predict the standards which were being practiced on the sections.

MAINTENANCE REQUIREMENT UNITS

The models which were developed to predict maintenance requirements on the Interstate System are based on data obtained from the collection program undertaken as part of this study. The data were adjusted to produce comparable units of labor, equipment and material for the various test sections; i.e., the units reflect values of equal magnitude. Therefore, the requirement units being predicted by the regression models generate comparable units of labor, equipment and material. For the sake of convention these units can be interpreted as dollars and in the models reflect a composite labor rate of $2.20 per unit, a composite equipment rental rate of $2.72 per unit, and material at $1.00 per unit.

COMPOSITE LABOR RATE

Information available in the 1965 Progress Report of HRB-AASHO Joint Committee on Maintenance Personnel permitted a composite maintenance labor rate to be developed for each of the test States. These values were determined by dividing the total salaries paid to all labor having a maintenance job classification by the associated number of laborers. An hourly wage was calculated by dividing the average annual wage per man by an assumed 2,080 working hours per year. The following composite hourly wages determined for each of the test States were averaged to produce a $2.20 value used to convert maintenance labor hours into requirement units:

California	$3.17
Florida	1.64
New York	2.25
Ohio	1.96
Texas	1.98
Avg.	(11.00/5) = $2.20

EQUIPMENT RENTAL RATE

It was recognized that the cost expended on equipment for the various reported activities could not be used in a direct comparison without an adjustment. First, the charges for equipment vary considerably between States; second, there are different types and different uses of equipment for similar maintenance activities.

The data available from the daily report forms divided equipment into ten classifications. The unit cost was multiplied by a usage weighting factor for each classification. The sum of these products was averaged for each test State and then averaged for the five test States. The ratio of each State's average to the five-State average produced a weighting factor for equipment, referred to as the unit cost factor. As an alternate, another weighting factor was computed using only the first three equipment classifications. This factor was referred to as the rental rate factor. These two factors were averaged to produce each State's equipment adjustment factor. The calculation of these adjustments, shown in Appendix F, resulted in the following values:

STATE	UNIT COST FACTOR	RENTAL RATE FACTOR	EQUIPMENT ADJUSTMENT FACTOR
Calif.	1.55	1.23	1.39
Fla.	0.56	0.81	0.68
N.Y.	1.14	1.43	1.28
Ohio	0.98	0.96	0.97
Tex.	0.74	0.63	0.69

The five-State average weighted unit cost was $3.17 and the five-State average rental rate was $2.26. The average of these is $2.72, which reflects the composite hourly rate of all equipment used in the development of the adjusted activity expenditures.

MATERIALS

The units used in reporting material quantities varied considerably; therefore, the only values which permitted comparison between test sections were dollars of material. Inasmuch as different materials were used for similar purposes on the different sections, it was impractical to attempt to factor the dollars of materials used to reflect variations in unit costs of specific materials. Further, there was no indication that such a factoring was needed. Therefore, the dollars expended for materials on the various sections were assumed to be comparable, and the dollars of materials were equated directly to material requirement units.

PHYSICAL, ENVIRONMENTAL AND TRAFFIC VARIABLES

Many factors influenced the requirements for specific maintenance activities on the test sections. These factors had to be incorporated in the method developed to measure maintenance requirement units. Also, the influencing factors were interrelated, so that a single factor could not be treated as an independent variable. The major factors influencing highway maintenance fell into the following three broad categories:

1. Roadway.
2. Traffic.
3. Environment.

The roadway characteristics encompass those factors established during design and construction and include the following:

1. Pavement type and width.
2. Shoulder type and width.
3. Base and subgrade type and depth.

4. Turfed and landscaped areas.
5. Geometrics and interchanges.
6. Drainage facilities.

Traffic characteristics include both vehicles and the controls established to serve the vehicles, as follows:

1. Traffic volume and type.
2. Traffic control facilities.
3. Rest and weighing areas.

The environmental factors to be considered include:

1. Terrain.
2. Temperature.
3. Precipitation.
4. Population density and characteristics.

Roadway, traffic, and environmental factors were assigned a finite measure and analyzed with respect to maintenance costs using multiple regression techniques.

INVENTORY DATA

Most of the roadway, traffic, and environmental data needed for each of the test sections were available from the test section inventory. The inventories were obtained by the staff field engineers from construction plans and measurements made directly on the test sections. Most of the weather information was obtained from records provided by the U. S. Weather Bureau. All of this information is tabulated in Appendix G.

REGRESSION ANALYSIS

Multiple linear regressions were used in analyzing the relationships between test section expenditures and the variables peculiar to each of the test sections. The regressions were performed using the IBM 360/40 data processing system and programs available in the IBM 360 system scientific subroutine package using the FORTRAN language. Four subroutines were needed to perform a multiple regression analysis. The information developed by this analysis is shown in Appendix H, where the results for the seven activity groups for which regression models were developed are presented.

In developing the regression models, an attempt was made to limit the number of independent variables to a minimum. In some instances variables were eliminated which improved the multiple correlation and the standard error value. However, the improvement was slight, and considering the sample size available for the development of the regression models it seemed unwise to include variables having only a marginal effect.

TOTAL MAINTENANCE EXPENDITURES

The first approach taken in the development of a maintenance regression model was to examine the total maintenance units expended on each test section in regression analyses. The expenditures represented the dependent variables, while the varying physical, environmental, and operational factors peculiar to each section were the independent variables. The results showed little relationship between any of the variables. Next, activities which were known to be major contributors to the total expenditures (first, snow and ice control, then mowing, and finally both) were subtracted from the totals and again regression analyses were made to find meaningful relationships. The results proved no better, so the attempt to develop a maintenance model for gross expenditures was abandoned.

As an alternate approach the activities were divided into groups which reasonably could be expected to be influenced by the same factors. The results of this grouping created the following activity classifications:

1. Pavement and shoulders.
2. Erosion and drainage.
3. Vegetation control.
4. Structures.
5. Snow and ice control.
6. Traffic control and service facilities.
7. Litter and sweeping.

Regression analyses again were made, this time using only those variables which might reasonably alter the expenditures for each of the seven activity groupings.

PAVEMENT AND SHOULDERS

The adjusted maintenance expenditures for the centerline-mile equivalent of four lane-miles of pavement were added to the adjusted shoulder maintenance expenditures per centerline mile of highway to provide the magnitude of the pavement and shoulder dependent variables in the multiple regression analysis.

The independent variables examined in the analysis were as follows:

1. Age in years.
2. Age^2.
3. Age^3.
4. Average daily traffic volume (ADT).
5. Commercial ADT (CADT).
6. $\sqrt{ADT}$.
7. $\sqrt{CADT}$.
8. $Age^2 \times \sqrt{CADT}$.
9. $(Age^2 \times \sqrt{CADT})/2$.
10. $(Age^2 \times 0.85\sqrt{CADT})/2$.
11. Annual average precipitation.
12. Terrain factor, as percentage of side slopes 2:1 or steeper.
13. Snowfall, in inches.
14. Number of days of snowfall.
15. Average annual temperature.
16. Number of days of snow cover.
17. Number of days when maximum temperature was below 32 F.
18. Urban or rural location.

Original analyses were made treating pavement and shoulders separately. Compensating effects were revealed, so it was decided to combine pavement and shoulders into a single classification.

The final regression model includes terms to reflect the

effects of age and climatic conditions on maintenance requirements.

A factor for subgrade, which has been present in some previous evaluations of surface maintenance, is not included in the model. The uniformly high design standards for the Interstate System tend to eliminate the effects of variations in subgrades for all but the most severe conditions. Although two of the test sections included in this study had poor subgrades and high surface maintenance costs, subgrade was not identifiable as a significant factor in the regression. It is suggested, however, that the predicted surface maintenance requirement units might well be substantially increased if poor subgrades are known to be a factor in the surface maintenance expenditures for a specific section or system of Interstate highways.

Because of the limited age of the Interstate System at the time of this study, the ultimate effect of age on pavement maintenance (not resurfacing) may not have been fully revealed by the test section data. However, the regression analyses, using data from test sections ranging up to ten years in age, showed the square of the surface age in years to be a significant factor.

The final regression model for pavement and shoulders was

$$Y_P = 19.72\,X_1^2 + 13.72\,X_2 - 183 \qquad (2)$$

in which

Y_P = Pavement and shoulder maintenance requirement units for a centerline mile of four-lane highway or its equivalent in interchanges or multilane pavements;

X_1 = Surface age, in years (The test sections generally consisted of more than one construction section, some of which were built at different times. A composite age was calculated by summing the products of age times the mileage associated with that age and then dividing this total by the total mileage. On sections which had been resurfaced, age was defined as the lapse in time since the date of resurfacing.); and

X_2 = Number of days when the maximum daily temperature was below 32 F.

The solution of this model is shown in nomograph form in Figure 25.

DRAINAGE AND EROSION CONTROL

The adjusted expenditures per centerline mile were used as the dependent variables in the development of the drainage and erosion model. The following independent variables were considered:

1. Terrain factor, in terms of percentage of side slopes 2:1 or steeper.
2. Miles of open ditches.
3. Culvert pipe inventory factor.
4. Annual average precipitation, in inches.
5. Urban or rural location.
6. Annual average temperature.
7. Age, in years.
8. Snowfall, in inches.

The percentage of 2:1 or steeper slopes and the annual precipitation produced the best multiple correlation. None of the other variables made a substantial contribution to the regression model. The multiple correlation coefficient of 0.808 (Table H-2) was the lowest of all the regression models. However, this activity grouping was responsible for the smallest expenditures on the test section, so limited accuracy attributed to this regression model will not have any great impact on the total maintenance requirement being predicted for the Interstate System.

The regression model developed for drainage and erosion control was

$$Y_D = 4.13\,X_1 + 2.68\,X_2 + 73 \qquad (3)$$

in which

Y_D = Drainage and erosion control maintenance requirement units for a centerline mile of Interstate highway;

X_1 = Terrain factor showing the percentage of side slopes 2:1 or steeper; and

X_2 = Annual average rainfall, in inches.

A nomograph solution for the regression model is shown in Figure 26.

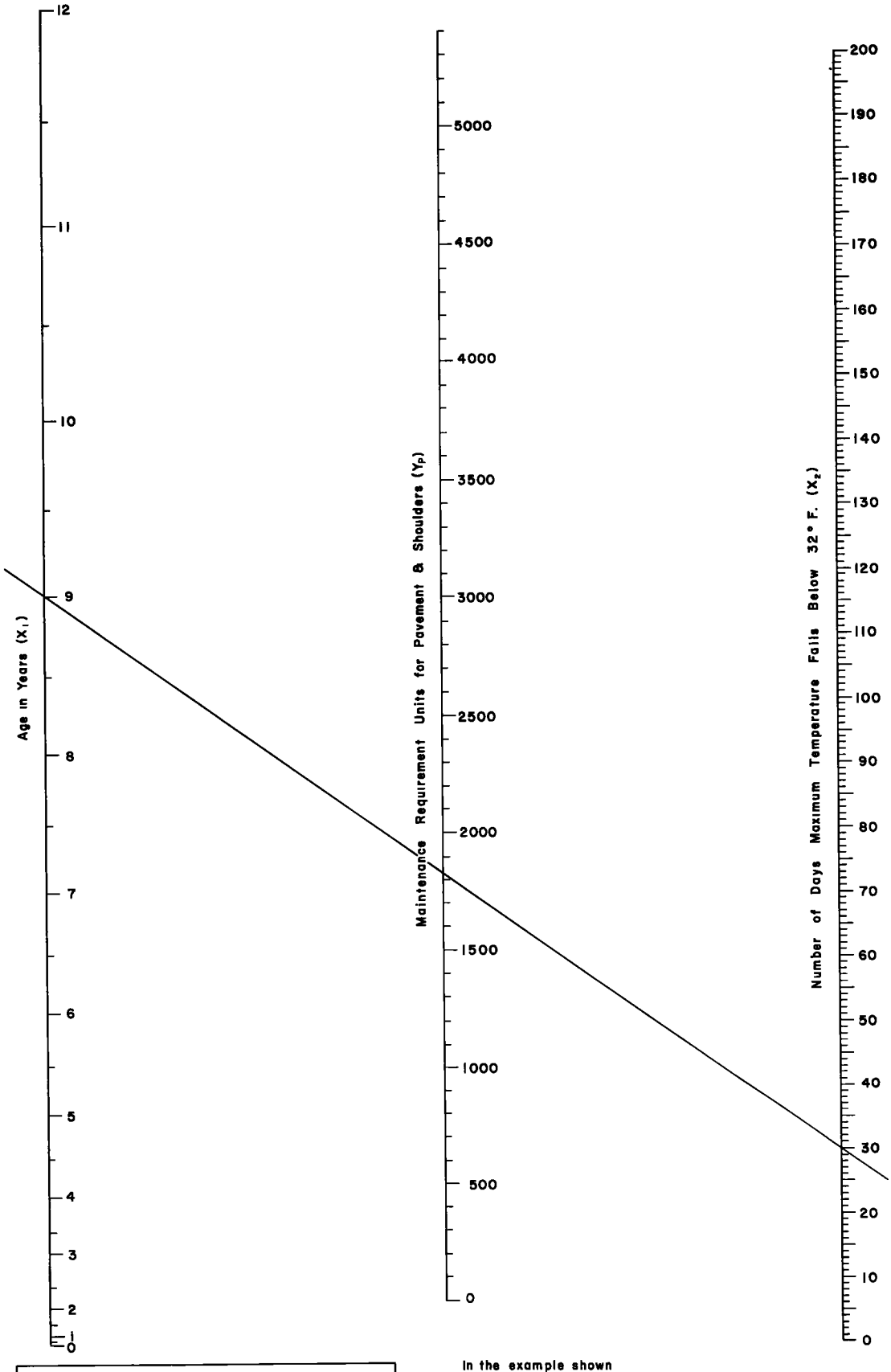
VEGETATION CONTROL

The adjusted maintenance expenditures for a centerline mile of vegetation control were used as the dependent variables in a regression with the following independent variables:

1. Urban or rural location (UR).
2. Mowing season, in months.
3. Mowing season precipitation.
4. Annual average precipitation.
5. Terrain factor, in terms of percentage of side slopes 2:1 or steeper.
6. Average daily traffic volume (ADT).
7. ADT × UR.
8. Average width of right-of-way, in feet.
9. Mowing area, in acres.
10. Concentrated mowing area, in acres.
11. Annual average temperature.
12. Average temperature during the mowing season.

The significant variables were found to be the length of the mowing season, the precipitation during the mowing season, and a factor to reflect whether the highway was in a rural or urban location. The average daily traffic values explained the variations in vegetation control expenditures better than an arbitrary urban-rural factor, but the product of the two proved even more significant. Therefore, the product of the average daily traffic volume and urban (with a factor of 2) or rural (with a factor of 1) was used as a variable in the regression analysis.

Excluded from the regression analyses were the California test sections where vegetation control was a highly specialized project in the heavily landscaped and irrigated urban sections, and largely nonexistent in the rock-sloped mountain and arid desert sections. Therefore, the resulting model does not attempt to measure vegetation control requirements for such specialized conditions.



Regression Model for Concrete Pavement & Shoulders

$Y_P = 1972X_1^2 + 1372X_2 - 183$

In the example shown

$X_1 = 9$ $X_2 = 30$

Therefore

Maintenance Requirement Units = 1826

Figure 25. Nomograph to solve regression model for pavement and shoulders.

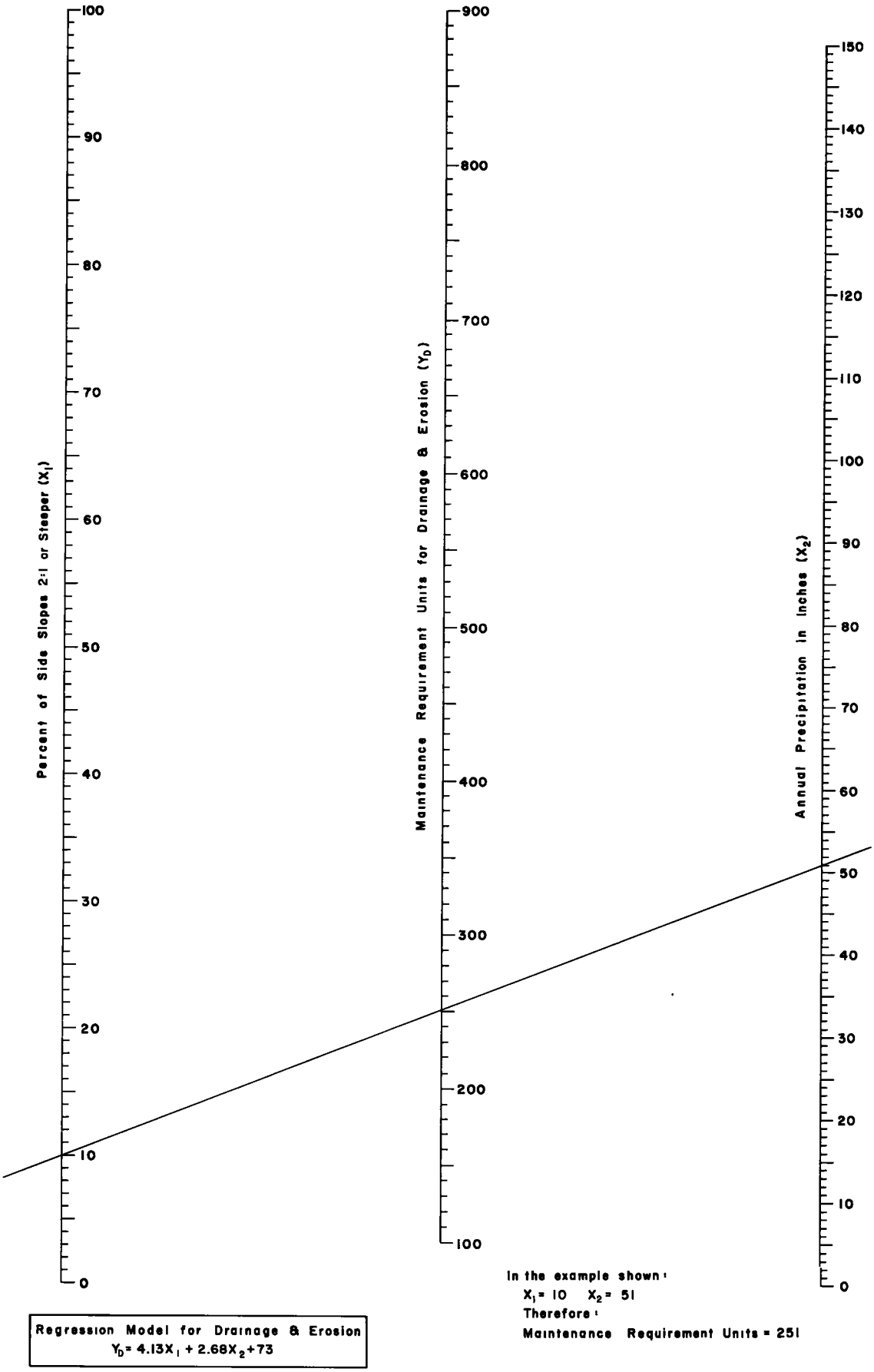


Figure 26. Nomograph to solve regression model for drainage and erosion.

Included in the vegetation control requirements model are those requirements for mowing; weed control (mechanical and/or chemical); reseeding; resodding; fertilizing; brush cutting; replacement of trees, shrubs, or other damaged or destroyed vegetation; and those other routine activities normally attributed to the maintenance and upkeep of vegetative cover within the highway right-of-way, in those regions of the country where climatic and environmental conditions permit the growing of vegetation within the right-of-way without highly specialized irrigation or other artificial growing conditions.

The regression model developed for vegetation control was

$$Y_{VR} = 97.52\,X_1 + 35.12\,X_2 + 0.00975\,X_3 - 744 \quad (4)$$

$$Y_{VU} = 97.52\,X_1 + 35.12\,X_2 + 0.0195\,X_3 - 744 \quad (5)$$

in which

Y_{VR} = Vegetation control requirement units for a centerline mile of Interstate highway in a rural location;
Y_{VU} = Vegetation control requirement units for a centerline mile of Interstate highway in an urban location;
X_1 = Length of mowing season, in months;
X_2 = Precipitation during mowing season, in inches; and
X_3 = Average daily traffic volume.

A nomograph solution for the regression model is shown in Figure 27.

STRUCTURES

Structures were examined using as dependent variables the total, centerline-mile, and per-structure adjusted expenditures. The following independent variables were used in the regression:

1. Age.
2. Age^2.
3. Age^3.
4. Average daily traffic volume.
5. Snowfall.
6. Snowfall × Age.
7. Days of snowfall.
8. Days of snow cover.
9. Days when maximum temperature was below 32 F.
10. Number of structures.

No meaningful relationships were found, probably because the expenditures for structure maintenance varied unduly, reflecting different maintenance responsibilities, structure construction, and cyclic requirements on the various test sections. A careful study of the expenditure data permitted the elimination of cyclic painting, which was made a separate part of the model. The remaining expenditures per mile were then divided by the number of structures per mile to produce the single-structure expenditure for each test section. These values were examined in a regression analysis with the previously mentioned variables.

The only variables which proved to be significant were those related to weather, and they were complementary. Days of snow cover proved the most significant, so it was used in the final regression model for structure maintenance, as follows:

$$Y_S = N_1(1.63\,X_1 + 28) + 1.80(N_2A)/f \quad (6)$$

in which

Y_S = Maintenance requirement units for structures per centerline-mile of Interstate highways;
N_1 = Average number of structures per mile;
N_2 = Average number of painted steel structures per mile;
X_1 = Number of days of snow cover;
A = Average deck area of an N_2-type structure, in square yards; and
f = Number of years between repaintings.

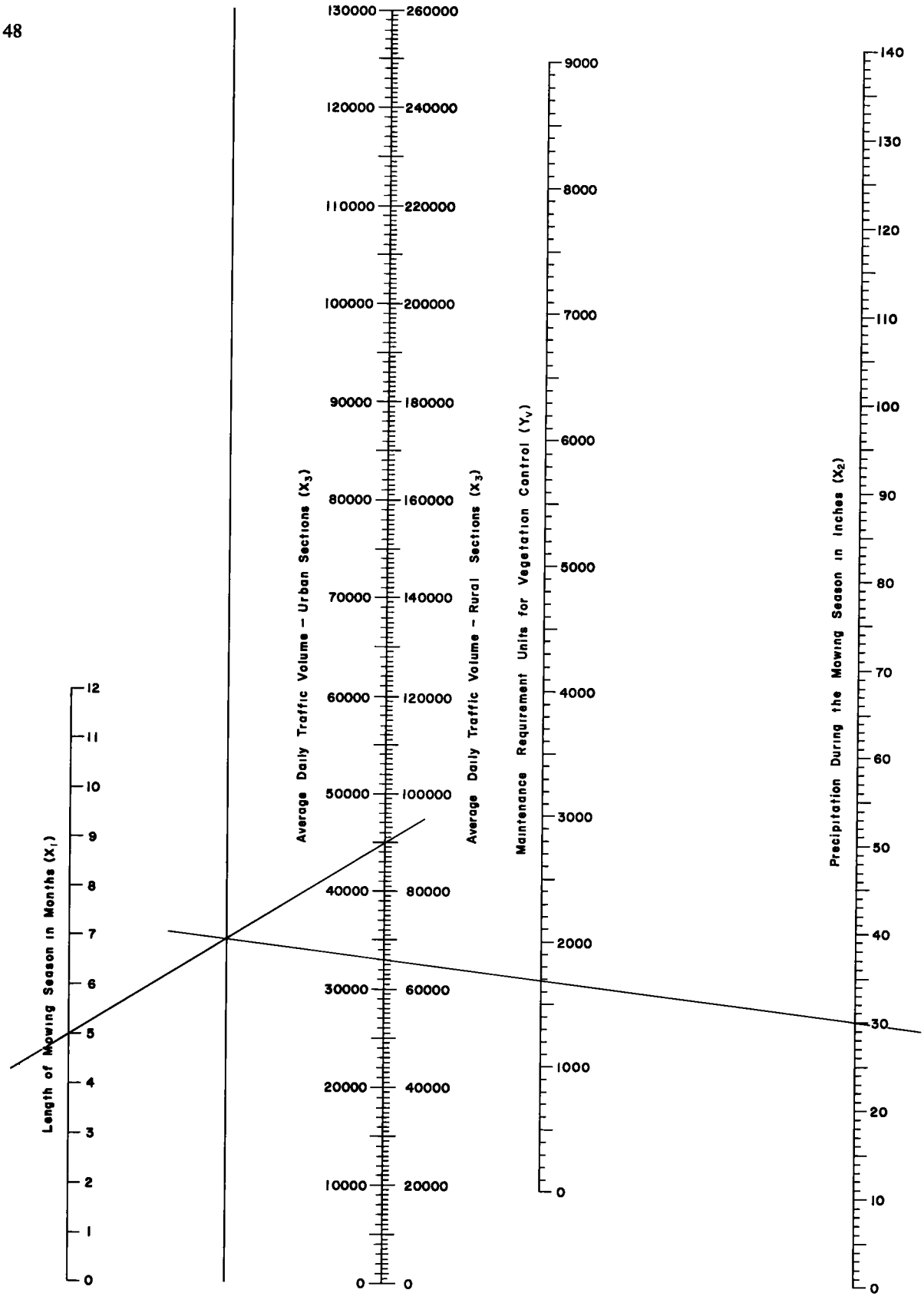
A nomograph to solve the structure model is shown in Figure 28.

SNOW AND ICE CONTROL

The adjusted snow and ice control expenditures for the centerline-mile equivalent of four lane-miles were used as the dependent variable in the evaluation of snow and ice control requirements. The following independent variables, regressed against the dependent expenditures, resulted in variables 3, 4, 5, and 8 being selected for the final regression model:

1. Average annual precipitation.
2. Precipitation from November-April.
3. Snowfall, in inches.
4. Days of snowfall.
5. Days of snow cover.
6. Average annual temperature.
7. Average temperature (November-April).
8. Number of days when maximum temperature is below 32 F.
9. Number of days when minimum temperature is below 32 F.
10. Number of days when minimum temperature is below 0 F.
11. Urban and rural location.
12. Average daily traffic volume.
13. Average mean maximum temperature.
14. Annual mean minimum temperature.
15. Terrain factor.

The multiple correlation value was quite good (0.975) and was the best of all the correlation values derived from the various models of maintenance requirements. The range of expenditures used for the dependent variables varied from 0 to 5,500 units per four lane-miles. The standard error of the estimate was 372 units, meaning that with 95% confidence the model predicts snow and ice removal requirements within 744 units per four lane-miles. An examination of the residual values (difference between given and predicted requirement units) revealed that all values but one fell within the confidence limits predicted. The exception was Test Section 58, which during the observation period received only one-half the normal snowfall for that area. The fact that more expenditures were reported than the model would predict could have been



Regression Model for Urban Vegetation Control

$Y_{VU} = 98.52X_1 + 35.12X_2 + .0195X_3 - 744$

Regression Model for Rural Vegetation Control

$Y_{VR} = 98.52X_1 + 35.12X_2 + .00975X_3 - 744$

In the example shown:

$X_1 = 5$ $X_3 = 45000$

$X_2 = 30$

Therefore:

Maintenance Requirement Units = 1680

Figure 27. Nomograph to solve regression model for vegetation control.

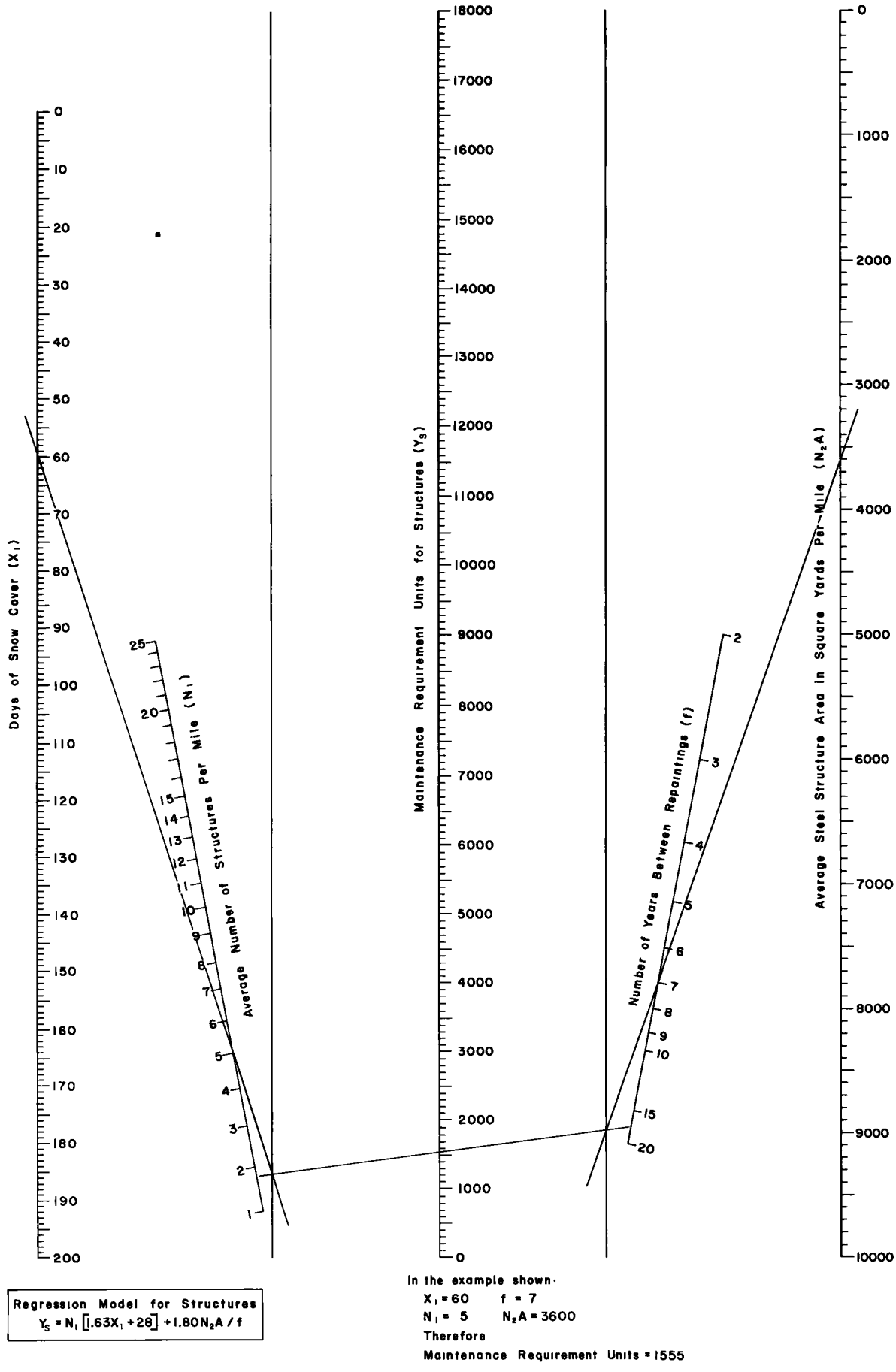


Figure 28. Nomograph to solve regression model for structures.

the result of the fact that many built-in expenses were geared to handle twice the snowfall actually experienced.

The final regression model for snow and ice control was

$$Y_{IS} = 14.8\,X_1 - 37.5\,X_2 + 24.3\,X_3 + 51.0\,X_4 \quad (7)$$

in which

Y_{IS} = Snow and ice control maintenance requirement units for four lane-miles of Interstate highway or its equivalent in interchanges or multilane pavements;
X_1 = Average annual snowfall, in inches;
X_2 = Number of days of snowfall (including days of "trace" snowfall);
X_3 = Number of days with snow cover on the ground; and
X_4 = Number of days when maximum daily temperature was below 32 F.

An intercept value of 26, which was calculated in the multiple regression, was considered insignificant and therefore was not included in the model because the standard error of the estimate was 372. The solution of the snow and ice control model is presented in nomograph form in Figure 29.

TRAFFIC CONTROL FACILITIES

Prior to developing a single model for traffic control facilities, separate regressions were made comparing expenditures for guardrail, signs, and lighting, with the following applicable independent variables:

1. Average daily traffic volume.
2. Guardrail inventory factor.
3. Lighting inventory factor.
4. Sign inventory factor.
5. Urban or rural location.
6. Age, in years.

The only variable having any relation to expenditures for all three activities was traffic volume. Therefore it was concluded that the inventory factors would not contribute to the final model.

The adjusted expenditures for a centerline-mile of roadway for all traffic control activities, except rest or service areas, were the dependent variables in a regression with the following independent variables used to develop a model:

1. Urban or rural location (UR).
2. Average daily traffic volume (ADT).
3. Age.
4. Age^2.
5. $ADT^2/100$.
6. Terrain, as a percentage of side slopes 2:1 or steeper.
7. Snowfall, in inches.
8. ADT × UR.

Traffic proved to be the most significant variable. The UR factor was significant but contributed so little to the model that it was not used.

The regression model developed for traffic control facilities was

$$Y_{TC} = 0.0321\,X_1 + 165 \quad (8)$$

in which

Y_{TC} = Maintenance requirement units for all traffic control facilities on a centerline-mile of Interstate highway except rest or service areas and weighing or inspection facilities and except for the cost of electric power; and
X_1 = Average daily traffic volume.

A conversion scale to solve the traffic control facility model is shown in Figure 30.

LITTER REMOVAL AND SWEEPING

The adjusted expenditures per centerline-mile for litter removal, pavement sweeping and account 579 (which covers picking up debris, rock, dead animals, etc.) were used as the dependent variables in a regression analysis with the following independent variables:

1. Average daily traffic volume (ADT).
2. Urban or rural location (UR).
3. Terrain factor, in terms of percentage of side slopes 2:1 or steeper.
4. Terrain factor, in terms of percentage of side slopes being rock cuts.
5. ADT × UR.

All of the variables except the terrain-rock factor proved significant. The correlation where UR and ADT were treated separately proved the best, so the resulting regression model for litter removal and sweeping was

$$Y_{LSR} = 0.0051\,X_1 + 5.09\,X_2 + 113 \quad (9)$$

$$Y_{LSU} = 0.0051\,X_1 + 5.09\,X_2 + 893 \quad (10)$$

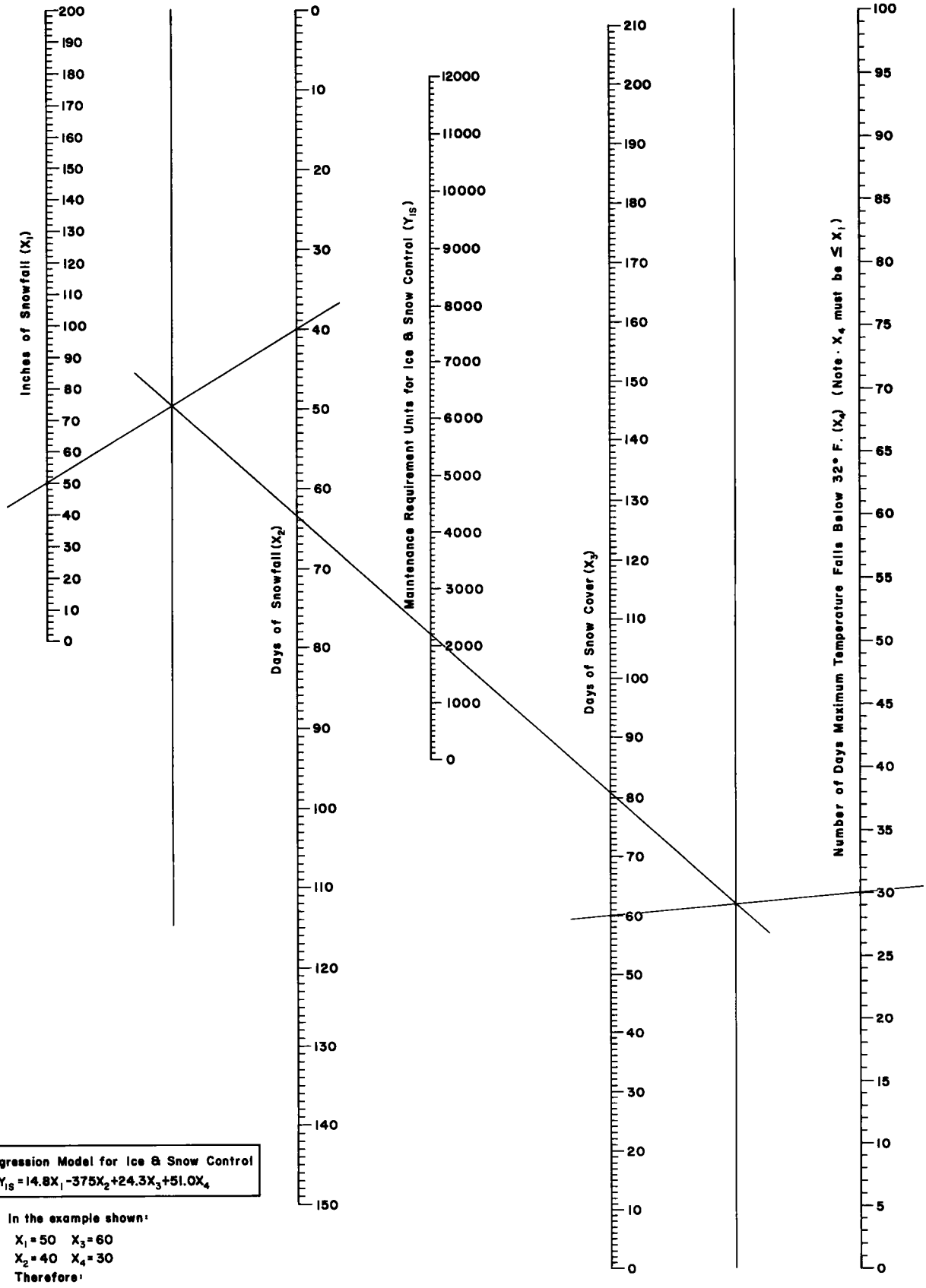
in which

Y_{LSR} = Maintenance requirement units for litter removal and sweeping for a centerline-mile of rural Interstate highway;
Y_{LSU} = Maintenance requirement units for litter removal and sweeping for a centerline-mile of urban Interstate highway;
X_1 = Average daily traffic (ADT); and
X_2 = Terrain factor, as percentage of side slopes 2:1 or steeper.

The solution for the model for litter removal and sweeping is shown in Figure 31.

REQUIREMENT UNITS CONVERSION INTO UNITS OF LABOR, EQUIPMENT AND MATERIAL

Each of the seven regression models produce requirement units. These units include comparable units of labor, equipment, and material which can be converted back to quantities of each component in their original proportions. A study of the distribution of labor, equipment and material expended for the seven different activity classifications showed that a wide variation existed between activities. Therefore, separate factors were required for the conversion of maintenance requirements into appropriate labor, equipment and material units for each activity classification.



Regression Model for Ice & Snow Control

$$Y_{IS} = 14.8X_1 - 375X_2 + 24.3X_3 + 51.0X_4$$

In the example shown:

$X_1 = 50$ $X_3 = 60$

$X_2 = 40$ $X_4 = 30$

Therefore:

Maintenance Requirement Units = 2200

Figure 29. Nomograph to solve regression model for snow and ice control.

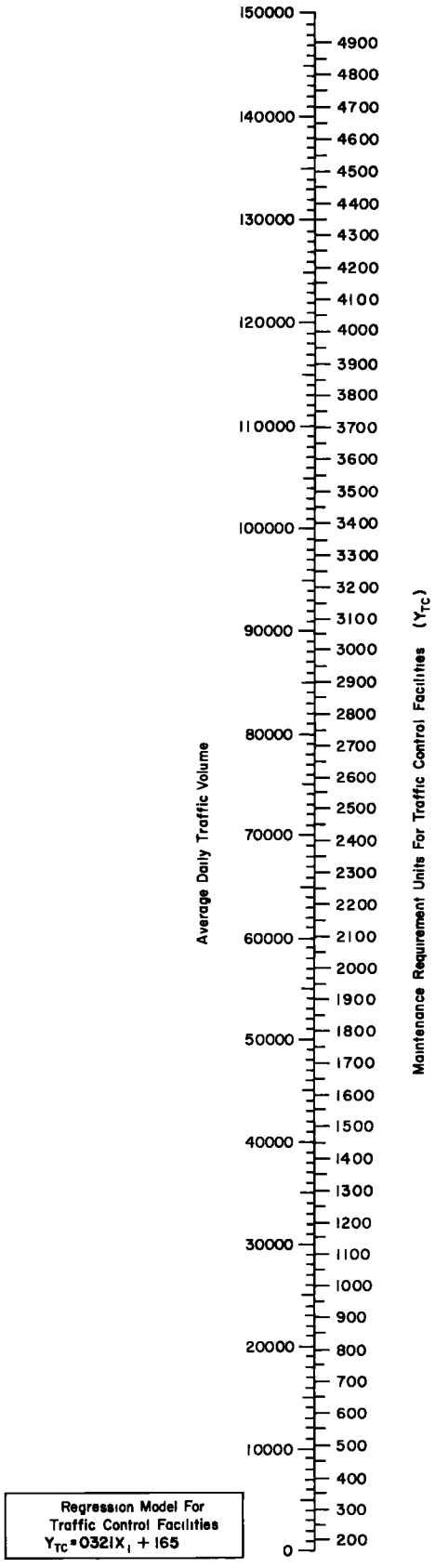


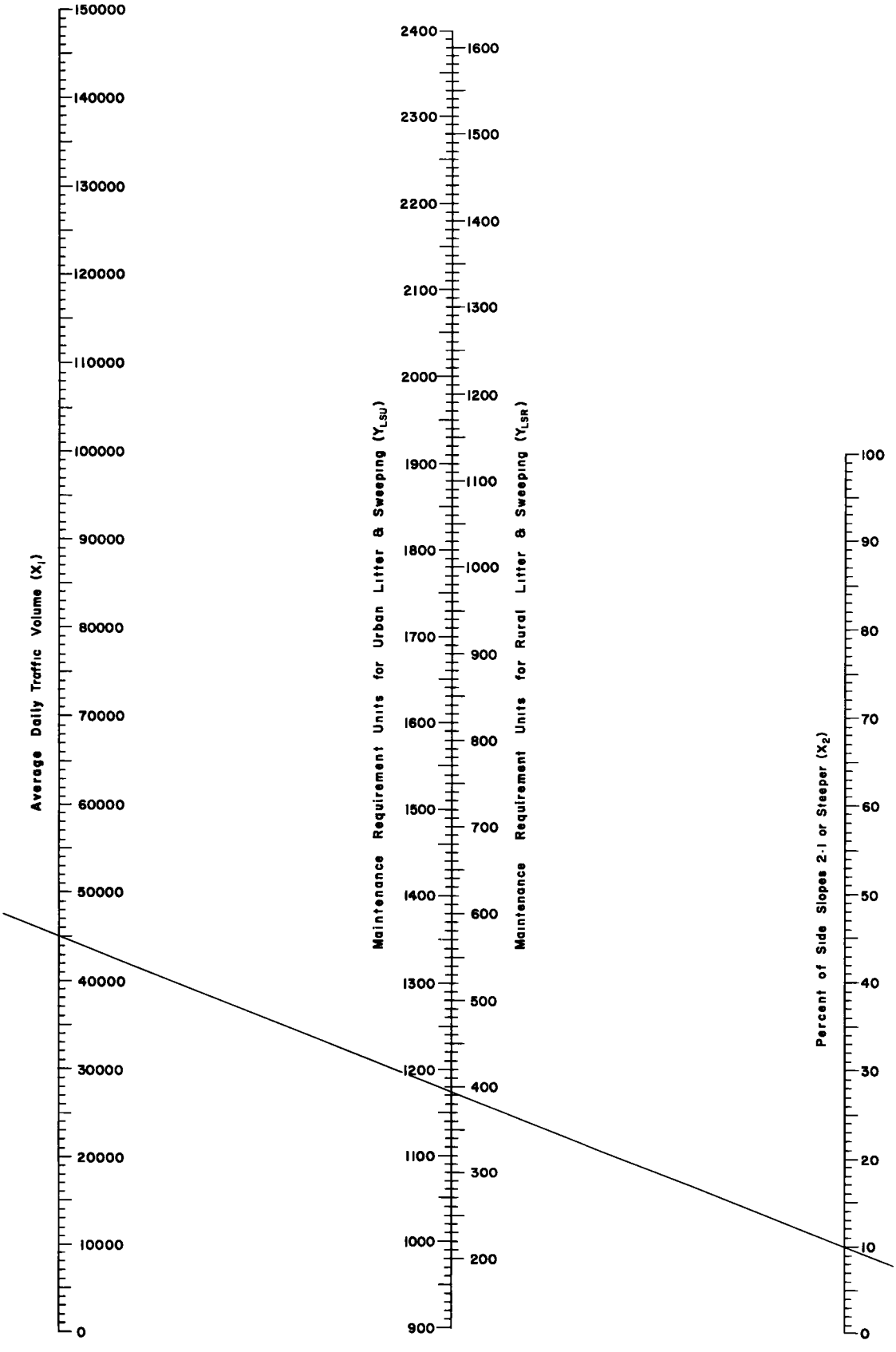
Figure 30. Conversion scale to solve regression model for traffic control facilities.

The distribution of LEM for each activity classification for each test section was examined using multiple linear regression analyses. The percentage of labor, equipment and material on each of the test sections for each activity was treated as the dependent variable, while the various factors delineated previously for each activity classification were used as independent variables. The expenditures for each activity also were included as independent variables in the regression analysis. Only urban and rural locations significantly affected the distribution. Therefore, the average distributions of labor, equipment and material by percentages were figured separately for urban and rural areas for each of the activity classifications. The results are shown in the distribution table in Figure 32. This figure permits direct conversion of the total requirements units into appropriate units of labor, equipment and material. Material converts directly to dollars, whereas equipment and labor are converted to hours using the 2.72 and 2.20 composite values previously mentioned.

USE OF MODELS TO PREDICT REQUIREMENTS

Seven different models were developed to predict maintenance requirements on Interstate highways. Each model generates the requirement units which can be associated with the group of activities represented by that model. In the following example, presented to illustrate the determination of maintenance requirements, only the pavement and shoulder model has been used, and requirements for surface and shoulder maintenance determined. To get total maintenance requirements, the requirements determined by each of the seven models (if they were in fact all applicable for a given Interstate highway segment or system) would be added together.

Example:	Pavement and Shoulder Requirements
Given:	A 200-mile, urban, Interstate highway system with four 12-ft lanes (or its equivalent in terms of multilanes and interchanges).
Step One:	From the pavement and shoulder nomograph (Fig. 25) find the variables needed to predict pavement and shoulder requirement units. These will be pavement age and number of days when maximum temperature was below 32 F.
Assume:	*9*-year pavement age. *30* days when maximum temperature is below 32 F.
Step Two:	Go back to nomograph (Fig. 25) with variables and find the annual requirement units for pavement and shoulder maintenance. Answer: *1,826 units.*
Step Three:	Go to the table in Figure 32 and get the distribution of labor, equipment and material for pavement and shoulder.
Find:	Labor: *60%* Equipment: *19%* Material: *21%*
Step Four:	Use the nomograph (Fig. 32) and convert the LEM percentages of requirement units into dollars and composite hours.

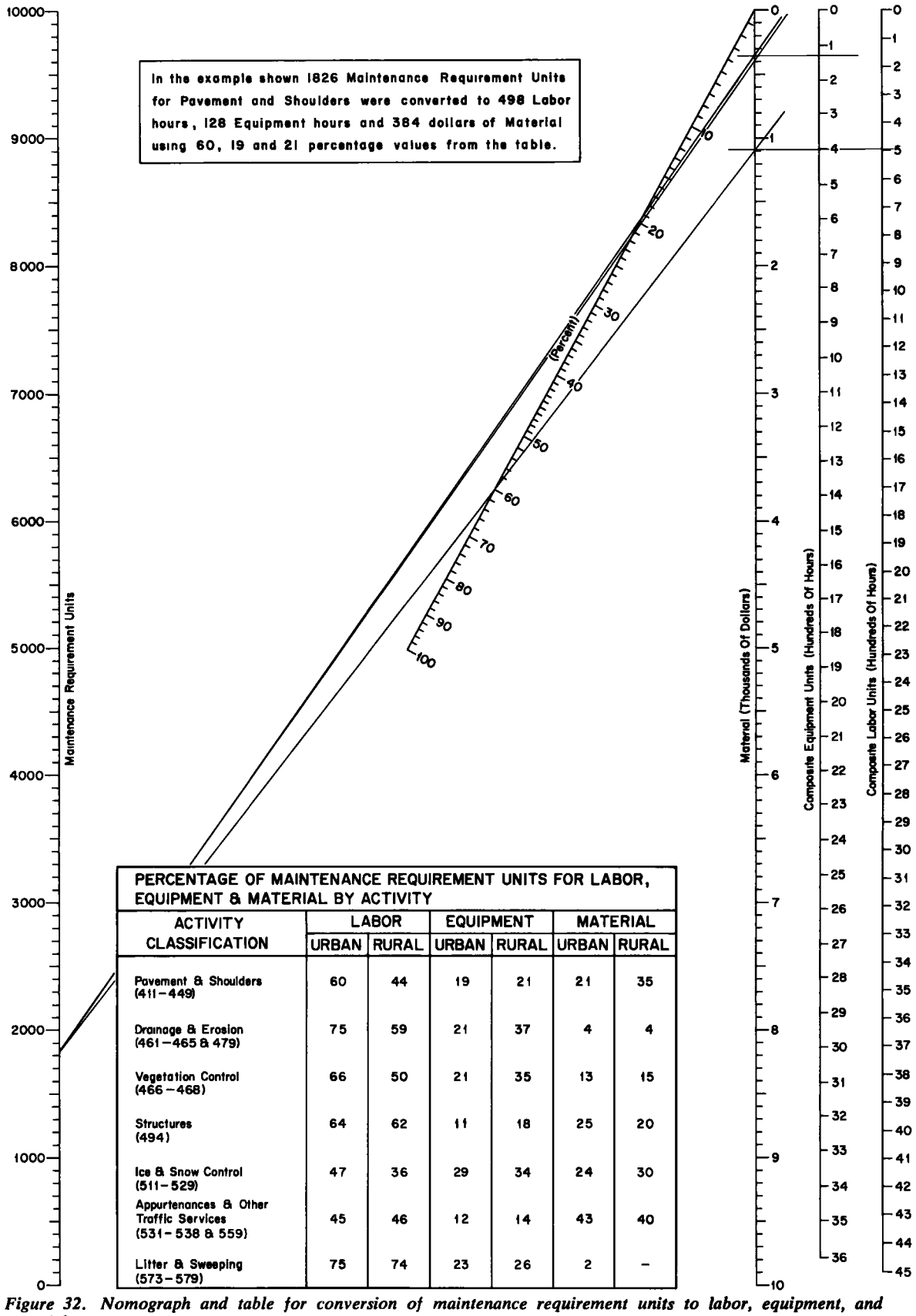


Regression Model for Urban Litter & Sweeping
$Y_{LSU} = .0051X_1 + 5.09X_2 + 893$

Regression Model for Rural Litter & Sweeping
$Y_{LSR} = 0051X_1 + 5.09X_2 + 113$

In the example shown:
$X_1 = 45000$ $X_2 = 10$
Therefore:
Maintenance Requirement Units = 1173

Figure 31. Nomograph to solve regression model for litter removal and sweeping.



PERCENTAGE OF MAINTENANCE REQUIREMENT UNITS FOR LABOR, EQUIPMENT & MATERIAL BY ACTIVITY

ACTIVITY CLASSIFICATION	LABOR		EQUIPMENT		MATERIAL	
	URBAN	RURAL	URBAN	RURAL	URBAN	RURAL
Pavement & Shoulders (411–449)	60	44	19	21	21	35
Drainage & Erosion (461–465 & 479)	75	59	21	37	4	4
Vegetation Control (466–468)	66	50	21	35	13	15
Structures (494)	64	62	11	18	25	20
Ice & Snow Control (511–529)	47	36	29	34	24	30
Appurtenances & Other Traffic Services (531–538 & 559)	45	46	12	14	43	40
Litter & Sweeping (573–579)	75	74	23	26	2	–

Figure 32. Nomograph and table for conversion of maintenance requirement units to labor, equipment, and materials.

Find: Labor hours: *498*
Equipment hours: *128*
Material cost: *$384*

Material is converted directly to dollars. However, labor and equipment are in terms of composite hours. The composite wage rate for labor hour and the composite rental rate to be applied to equipment hours must be determined for the particular location of the Interstate system. The development of a composite labor rate and a composite equipment rental rate are illustrated in Appendix I. Assume the following values apply to this sample:

Composite labor wage: $2.05/hr
Composite equipment rental rate: $2.50/hr

Step Five: Convert labor hours and equipment hours to dollars:

498 × $2.05 = $1,021
128 × $2.50 = $ 320

Step Six: Total the labor, equipment and material cost and multiply by the mileage to get the total annual cost to maintain pavement and shoulders on the Interstate System:

Labor	$1,021
Equipment	320
Material	384
Total	$1,725 × 200 = $345,000

SUMMARY

The seven maintenance requirement models developed in this chapter were based on accurate and comprehensive data developed during the study. Further, the models are universal and therefore are applicable to the entire Interstate System. Because they have such wide application, and because a relatively small sample taken over a single year was used to generate the models, there will be accuracy limitations.

In general, the models are best suited for predicting requirements for large segments of the Interstate System and should not be used for short sections where unique local factors have a major influence.

It should be noted that the models predict only the direct labor, equipment and materials required for Interstate maintenance. No provision is made here for the so-called overhead items, such as administration, supervision, engineering, housing, and other service requirements. Because no State highway department administered its Interstate maintenance program as a completely separate function, no assignment of overhead requirements was considered meaningful except through a prorationing of overhead on a mileage or direct labor basis, as practiced by individual States. Therefore, for total requirements for maintenance of a Statewide Interstate system, a percentage value as experienced by the particular organization in question must be added for overhead.

TABLE 16

COMPARISON OF MAINTENANCE REQUIREMENTS PREDICTED BY MODELS WITH REPORTED EXPENDITURES ON TEST SECTIONS

ACTIVITY GROUP	REPORTED EXPENDITURES [a] ($)	PREDICTED REQUIREMENTS ($)
Pavement and shoulders	496,000	488,000
Drainage and erosion control	147,000	133,000
Vegetation control	473,000	469,000
Structures	108,000	125,000
Snow and ice control	749,000	725,000
Traffic control facilities	379,000	388,000
Litter removal and sweeping	238,000	240,000
Total	2,590,000	2,568,000

[a] Adjusted.

The maintenance expenditures reported for the various test sections in this study varied from $1,000 to $13,000 per mile. Table 16 indicates how closely the model predicted requirements compared with the actual adjusted expenditures reported for each section.

The error by activity varied from 2,000 units for litter to 17,000 units on structures, the latter representing about 16% for the structures and 0.6% of total requirements. Some of the activities are compensating, which resulted in an overall difference for all activities of 22,000 units (or 0.85% error) between reported and predicted. These requirement units do not include actual or predicted vegetation control requirement units in California, where special landscaping is practiced. Also, no costs are summarized for rest or service area facilities. These facilities varied widely in design, from a few picnic tables in some instances to water, toilets, tables, and information booths in others. The adjusted maintenance expenditures ranged from $1,000 to $7,000 per rest area site. Also, Table 16 does not include the cost of electric power for roadway, area, or sign lighting, which may represent a significant item in urban areas.

CHAPTER FIVE

CONCLUSIONS, APPLICATIONS, AND RECOMMENDATIONS

During the two-year period of this study personal visits were made to each of the 49 States in which segments of the Interstate System are located. Continuing studies were made in five States on 28 representative sections of the Interstate System. Several significant conclusions were developed through this intensive and extended study of Interstate maintenance requirements.

ACCOUNTING

The review of prior reports and other literature on maintenance requirement studies, as well as the State questionnaire survey, revealed that most historical records of State highway maintenance costs are of little or no value in comparative analysis, or as a means of measuring productivity on State maintenance programs. In part this is attributable to the fact that only token acceptance has been given to the AASHO accounting standards by the States, no one of which has adopted the standards without some local modification. Further, the AASHO *Manual of Uniform Highway Accounting Procedures* (*1*) includes a listing of titles for maintenance accounts but does not include detailed definitions of the charges to be made under each account. This prevents a fully uniform interpretation of the account codes, even if the States elected to adopt them without modification.

ORGANIZATION

Although full separation of the Interstate System maintenance organization from other State highway maintenance does not appear to be necessary or practical in most States, there are warrants for a clear separation of maintenance responsibilities between the Interstate System and other State highways, at least at the field crew level. Unless such a separation is implemented there is a real danger that Interstate System maintenance standards in some locations will fall to a level wholly inadequate to protect the major investment in these highways or to serve effectively and safely the heavy, high-speed traffic volumes which are and will increasingly use the Interstate highways.

REQUIREMENTS

The daily report data, although limited in sample size, did permit meaningful relationships to be developed between design, environmental and operational characteristics of Interstate highways and maintenance requirements on those highways. Because of the limited study period, adjustments had to be made for cyclic maintenance not properly revealed during the 12-month observation period. The models developed from the multiple regression analyses, which are responsive to wide variations encountered in the test sections distributed throughout the nation, are better suited to the determination of requirements for significant segments of the Interstate System than for short individual sections of Interstate highway.

Based on the use of the models developed in this study, the Interstate System is estimated to require the annual expenditure of $261,000,000 in 1975, assuming its full completion and operation before that date. Table 17 shows the breakdown of these estimated requirements by seven maintenance activity groups.

It should be noted that the 1975 estimates given in Table 17 are exclusive of the maintenance costs of rest areas, special right-of-way landscaping, or electric power for highway facility illumination. In the distribution of estimated costs by activity groups, it is interesting to note that pavement and shoulder maintenance, which currently represents only about 15% of the maintenance expenditures on the Interstate test sections, is estimated to represent almost 45% of the total maintenance requirements in 1975. This increase in the pavement and shoulder portion of the total maintenance requirements is the result of the influence of age in the pavement and shoulder requirements model. Age was not a significant factor in the other models and these activity groups maintain about the same relationship to each other in 1975 as revealed by the current test section expenditures. A brief discussion of the factors used in preparing the 1975 estimate is offered in Appendix J.

PROCEDURES

The supplemental observations made as a part of the study effectively established the relative adequacy of maintenance on the test sections and the efficiency of the test section maintenance crews. Thus, adequacy and efficiency factors did not prove to be significant in the regression analyses.

TABLE 17

1975 MAINTENANCE REQUIREMENTS FOR THE NATIONAL SYSTEM OF INTERSTATE HIGHWAYS

ACTIVITY GROUP	COST ($ MILLION)	(%)
Pavement and shoulders	116.9	44.7
Drainage and erosion	19.0	7.3
Vegetation control	21.2	8.1
Structures	13.4	5.1
Snow and ice control	57.1	21.9
Traffic service facilities	22.1	8.5
Litter removal and sweeping	11.3	4.4
Total	261.0	100.0

The procedures and productivity studies served to demonstrate the variety of methods and range of productivity in performing maintenance work, largely due to the unique characteristics of each maintenance section. These studies documented the fact that maintenance efficiency is largely the function of the system rather than of isolated activities and can best be achieved through systems analyses and management of the entire maintenance program.

RECOMMENDATIONS

In consideration of the foregoing factors, the following recommendations are offered:

1. The chart of accounts for maintenance activities in the AASHO *Manual of Uniform Highway Accounting Procedures* (*1*) should be fully developed, with complete and comprehensive definitions prepared for each account. Upon completion and adoption of the expanded chart of accounts by AASHO, every effort should be made to bring about the acceptance of this accounting procedure for the recording of individual State highway maintenance expenditures without local modification.

2. To realize the full potential of the concepts and relationships developed in this study, a comparable but more extensive program of test section data collection and analysis should be undertaken on a national level for a period of time sufficient to encompass fully the cyclic maintenance activities, seasonal requirements, budget variations, and other long-range influences on maintenance activities. From such data, refined coefficients can be determined for the national models and models can be developed for local systems which are responsive to unique local factors.

3. Increased attention should be given to a system approach to maintenance planning and programming, with both routine annual and special long-range requirements determined and accommodated in funding and managing the maintenance program for the Interstate System.

Implementation of the foregoing recommendations will assist in the realization of optimum maintenance programs for the safeguarding of the major investment in Interstate highways and the realization of the full potential for safety and utility of this system to the traveling public.

PART II

UNIT MAINTENANCE EXPENDITURE INDEX

CONTENTS

PART II
UNIT MAINTENANCE EXPENDITURE INDEX

SUMMARY

A unit maintenance cost index is useful to a highway administrator or engineer in evaluating past and predicting future highway maintenance cost trends. A knowledge of such trends has particular value in anticipating future maintenance budgetary requirements.

The 1947 Unit Maintenance Cost Index, which was developed by the Maintenance Cost Committee of the Highway Research Board in 1947, is considered outdated. Further, there is some question concerning its merit in meeting the current needs of highway administrators and engineers. For these reasons, this study was undertaken to develop a new index which would reflect the cost associated with advances in highway engineering technology and which would be in a form suitable for continuous updating.

The 1947 Unit Maintenance Cost Index, based on the changing cost of fixed units of labor, equipment, material, and overhead, shows what it costs to perform a fixed quantity of maintenance the same way in any year. For budgetary purposes, this answers only part of the need. There are also changes in maintenance work loads and in the way maintenance work is done. To predict accurately future budgetary requirements, these items also must be considered. This might be done with a composite index developed from individual indexes showing maintenance cost trends associated with variations in standards, operational efficiency, work load, unit cost, and highway design.

However, the most practical index to be developed by this study was a Unit Maintenance Expenditure Index. This Index, using 1957-1959 costs as a base and a centerline-mile of highway as a unit, encompasses all factors influencing maintenance costs. Thus, changes in labor, equipment, and material costs are reflected, together with increases in productivity of crews and equipment, changes in work load per unit (mile) of highway, and changes in standards of maintenance or levels of service. With the 1957-1959 base equated to 100, the Unit Maintenance Expenditure Index has climbed at a relatively uniform rate to 140 in 1965. The data to compute the 1966 index value are not yet available, but based on a projection of the trend since 1957 it is estimated to be about 146.

Expenditure indexes also were developed for five different regions of the country which were representative of areas where major variations in ice and snow and vegetation control might be expected. Further, separate expenditure indexes were developed for two classifications of the State-administered highway systems: rural primary highways and municipal extension highways, as classified by the Bureau of Public Roads.

To supplement the expenditure indexes, individual labor, equipment, and material cost indexes were developed, as well as a composite of the three. The Unit LEM Cost Index can be used to eliminate the effect of changing costs in the expenditure index trend. This permits an inspection of the separate influence of changes in productivity, work load, standards, and services on maintenance expenditures regardless of changes in price paid for labor, equipment, and materials. For example,

the average annual increase in the Unit Maintenance Expenditure Index was 5.4% for the period 1956 through 1965, whereas the Unit LEM Cost Index trend was 2.1%. This means that there was an average annual increase of 3.3% in maintenance expenditures per mile of highway not resulting from unit cost increases in labor, equipment, or materials.

Another supplemental index which was developed was the Unit Traffic-Related Expenditure Index. This was the result of an analysis of maintenance control section expenditures obtained from the Virginia Highway Department. The traffic index showed that the increase in maintenance costs associated with traffic averaged 1.6% per year for the period 1955 through 1964.

CHAPTER SIX

INTRODUCTION

One of the most effective tools available to administrators and engineers for monitoring and evaluating cost trends is the unit cost index. The apparent rapid increase in highway maintenance costs and the significant increase in highway maintenance expenditures which have occurred in recent years make the need for an up-to-date, clearly understood index of great value in planning and programming highway maintenance.

In recognition of this need the American Association of State Highway Officials (AASHO), through the National Cooperative Highway Research Program, established the study for which this report is offered. The study had as its objective to develop a unit maintenance cost containing within its framework a technique which will permit its continuous updating.

HISTORICAL DEVELOPMENT OF MAINTENANCE COST STUDIES

During the late 1920's and early 1930's the Maintenance Committee of the Highway Research Board (HRB) explored different areas of maintenance cost and discussed the ramifications of obtaining these costs and assessing their potential value (*5*). It was believed that valid cost information could be used to estimate future expenditures, evaluate the efficiency of existing work, evaluate the economics of the expenditures, create a history of the economic life of roads, and solve particular maintenance problems.

Maintenance Cost Committee of HRB

By 1930 the Bureau of Public Roads (BPR) had established a staff section to study maintenance costs, and by 1933 a subcommittee for maintenance costs had been established by the HRB (*6*). An initial undertaking of the Maintenance Cost Committee was to attempt to secure uniform maintenance cost data from the States. This was necessary because each State had its own particular system for defining and recording cost information. Therefore, a form was devised by the Cost Committee in 1933 to overcome this problem. This was Form M-1 (Fig. 33), which was supplied and distributed to the State highway departments by the BPR. To secure uniformity, each State was requested to select approximately 20 representative control sections, each section being composed of a single type of pavement and cross section. Form M-1, which provided for standard classifications of maintenance operations, was used to report annual maintenance costs on each control section.

There was hope that the information as reported annually on Form M-1 would permit an equitable comparison between similar maintenance operations from different areas and States. Maintenance engineers from the BPR made field inspections of the sections being reported on the form, and evaluated the quality of maintenance being performed for later correlation with the reported cost data.

As the information reported on Form M-1 was received by the Maintenance Cost Committee, attempts were made to account for such variables as budget limitations, unit cost variations, traffic, climate, maintenance standards, and pavement width. Also, it was noted that maintenance operations frequently were deferred for a number of years and then essentially completed during a single year. It was necessary to prorate these periodic maintenance expenditures before including them in yearly maintenance cost records for the sections.

The data reported provided for an annual cost breakdown of labor, equipment, material, and overhead for 1,233 sections of highway totaling 18,718 miles from 47 States. By 1937, the M-1 reports had been completed by 30 States for three years, 11 States for two years and 6 States for one year (*6*). In many cases, there were omissions which

B. P. R. Maintenance Section Cost Form M-1 (Revised)

REPORT OF ANNUAL COST OF GENERAL HIGHWAY MAINTENANCE ON SECTIONS SELECTED FOR SPECIAL COST STUDY

State _____ Report for year ending _____

Section number _____ Location _____ Type surfacing in code _____ Length _____ Width _____ Thickness _____ Year built _____

Type shoulders _____ Width shoulders _____ Type shoulder treatment _____ Shoulder width treated _____

Traffic count: Trucks _____ Cars _____ Estimated future life of surfacing _____ Federal-aid projects included _____ Maintenance quality rating (B. P. R.) _____

Additional description of section _____

DEFINITION OF MAINTENANCE.—Highway maintenance is the preserving and keeping of each type of roadway, roadside, structure, and facility as nearly as possible in its original condition as constructed or as subsequently improved, and the operation of highway facilities and services to provide satisfactory and safe highway transportation. Maintenance does not include reconstruction or additions and betterments.

ANNUAL MAINTENANCE COSTS

(Subdivision by operations optional but desirable if kept by the State)

MAIN CLASSIFICATIONS	1	2	3	4	5	6	OTHER STATE CLASSIFICATIONS			TOTALS	LABOR	MATERIALS	EQUIPMENT
SURFACE-ROUTINE	Patching	Dragging, etc	Joints and cracks										
SURFACE-SPECIAL	Dust palliatives	Replacements	Reprocessing	Bit. treatment	Mud-jacking	Traffic protection							
SHOULDERS AND APPROACHES	Patching, etc.	Reseeding, resodding	Ribbon bit. tr	Retreatments									
ROADSIDE AND DRAINAGE	Cuts, fills, washouts	Drainage channels	Roadside cleaning	Roadside development	Misc structures								
TRAFFIC SERVICES	Signs, etc	Surface markings	Guard rail	Lighting, electricity	Comfort stns. etc.	Detours							
SNOW, ICE, AND SAND CONTROL	Snow fence	Snow removal	Sanding	Opening waterways	Sand drifts								
STRUCTURES (Over 20 ft.)													
EXTRAORDINARY REPAIRS													
GENERAL EXPENSE	Office	Field supervision											
									GRAND TOTALS,				

GENERAL QUESTIONS

1 ARE ALL RECONSTRUCTION CHARGES EXCLUDED FROM ABOVE COSTS? _____

2. WHICH OF THE ABOVE COSTS WERE OBTAINED BY PRORATING? _____

3. ARE FIELD AND OFFICE OVERHEAD COSTS INCLUDED IN ABOVE COSTS? _____

4 ARE ALL EQUIPMENT DEPRECIATION, OPERATING, AND OVERHEAD COSTS INCLUDED? _____

METHOD OF CALCULATING EQUIPMENT DEPRECIATION _____

LIST MAJOR EQUIPMENT USED ON SECTION, WITH DEPRECIATION RATES _____

AVERAGE COST OF MAJOR LABOR ITEMS _____

AVERAGE COST OF MAJOR MATERIAL ITEMS _____

ORIGINAL CONSTRUCTION COST		RECONSTRUCTION COSTS SINCE CONSTRUCTION	ADDITION AND BETTERMENT CHARGES (Also first surface treatment)	REMARKS AS TO UNUSUAL CONDITIONS AFFECTING MAINTENANCE COSTS (TOPOGRAPHY, INADEQUATE DESIGN, SOIL, TRAFFIC WEIGHT, CLIMATE, EXTRAORDINARY EMERGENCY WORK, EXCESSIVE HAUL AFFECTING TRANSPORTATION COSTS, ETC.)
Total	Surface			

Additional pertinent information:

U. S. GOVERNMENT PRINTING OFFICE 5—10602

Figure 33. Bureau of Public Roads Form M-1, used to report maintenance costs and quantities.

required revisions. Correspondence and conferences with the States remedied many of these inadequacies.

The Maintenance Cost Committee prepared summary tabulations of the reported costs for the 17th Annual Meeting of the HRB. Large variations in the cost per mile for comparable operations were apparent. However, the Committee felt that the collection period was too short to permit representative cost figures to be presented. Another report (*7*) was prepared for the 18th Annual Meeting; by then a fair estimate of the breakdown of maintenance costs into components of labor, equipment, materials, and overhead was being generated from the data.

In 1939, road surface costs were analyzed for the southwest central States (*8*). The total annual surface costs for different types of roads were calculated by adding average annual surface maintenance costs and an annual construction charge based on the life of the surface as reported from actual field inspections. Data taken from three different surface types were used to calculate linear regression lines comparing costs and traffic volumes.

Costs were collected continually for the next few years and in 1942 the Maintenance Cost Committee issued another report (*9*), this time comparing overall maintenance expenditures. A composite maintenance cost, reflecting the cost to maintain a mile of highway was computed. It was based on breakdown of labor, equipment, materials, and overhead for the elements of surface, shoulders, roadside, and traffic services. Most of the information used for the composite value was obtained from the M-1 forms; in some cases the information required modification to eliminate construction and betterment items that were included with maintenance. There were price fluctuations between years, so all costs were converted to a 1925-1929 highway cost base. This was done using a table titled "Highway Surface Price Index—Period 1925 to 1929." No information could be found relating to how the Index table was derived. An Index factor of 100.00 represented the 1925-1929 base year and the actual costs reported for the study years between 1935 and 1940 were all corrected by the appropriate index values before any averaging or comparisons were made between costs. The averages eventually generated were compared by similar topographic and climatic regions. This permitted a better evaluation of such variables as traffic, pavement width, and maintenance quality relative to total cost.

At the 25th Annual Meeting of the HRB the Committee gave and published the first cost report since 1942 (*11*). This report outlined attempts made to get unit costs on specific maintenance operations so that maintenance practices could be evaluated on a comparative basis. It was hoped that this would permit a basis for selecting the most efficient maintenance methods. However, comparisons could not be made because of the lack of uniformity between measuring units. No attempt was made to compare total maintenance costs because it was recognized that only partial highway maintenance was accomplished during the war years.

In 1946 the Committee attempted to compare the quality of maintenance then being accomplished with the prewar year, 1941. To effectively accomplish this task it was necessary to make the comparison using equal dollar values. This required determining the percentage increases for each of the cost factors—labor, equipment, material, and overhead—using the M-1 reports. For materials, the 1941 unit cost of each subfactor such as asphalt, or stone, was compared with the unit cost of the same item on the same section in 1945 (Table 18.) Using the average of the percentage cost increase of all such subfactors, the percentage cost increase for materials could be determined.

Labor rates for the different classifications, common labor, operators, patrolman, etc., from 28 States were examined and an average rate was determined. For example, the range in 1941 for common labor varied from $0.20 to $0.70 per hour and the average was taken at $0.45 per hour. A comparable average in 1945 was $0.65 per hour. The composite labor cost was determined to have risen 42 percent between 1941 and 1945. A similar procedure was followed in developing the equipment and overhead increases. The distribution of labor, equipment, material, and overhead costs, which were reported in 1942 to be 45, 25, 21, and 9 percent, respectively, then were used to compute a composite cost of maintenance in 1941 and 1945, and to show an increase of 35 percent during that period.

Development of 1947 Unit Maintenance Cost Index

In 1947 the Maintenance Cost Committee noted that the cost of maintaining and operating the national system of highways had risen to an all-time high. The previous year's comparison between 1941 and 1945 was not considered detailed enough to compare the increase fully. Therefore, a comprehensive study of the unit costs of the components, labor, equipment, material, and overhead was undertaken to determine the year by year increases. The conclusion of

TABLE 18

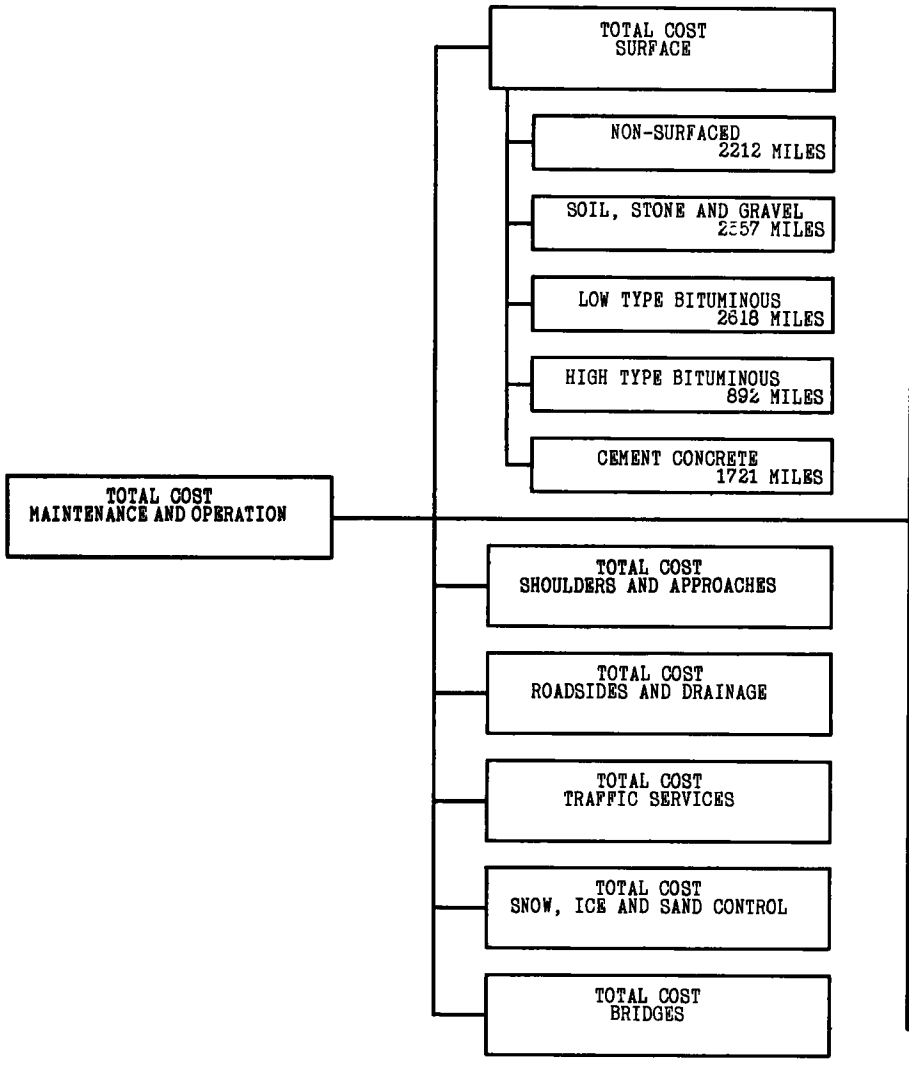
UNIT PRICE INCREASES [a, b]

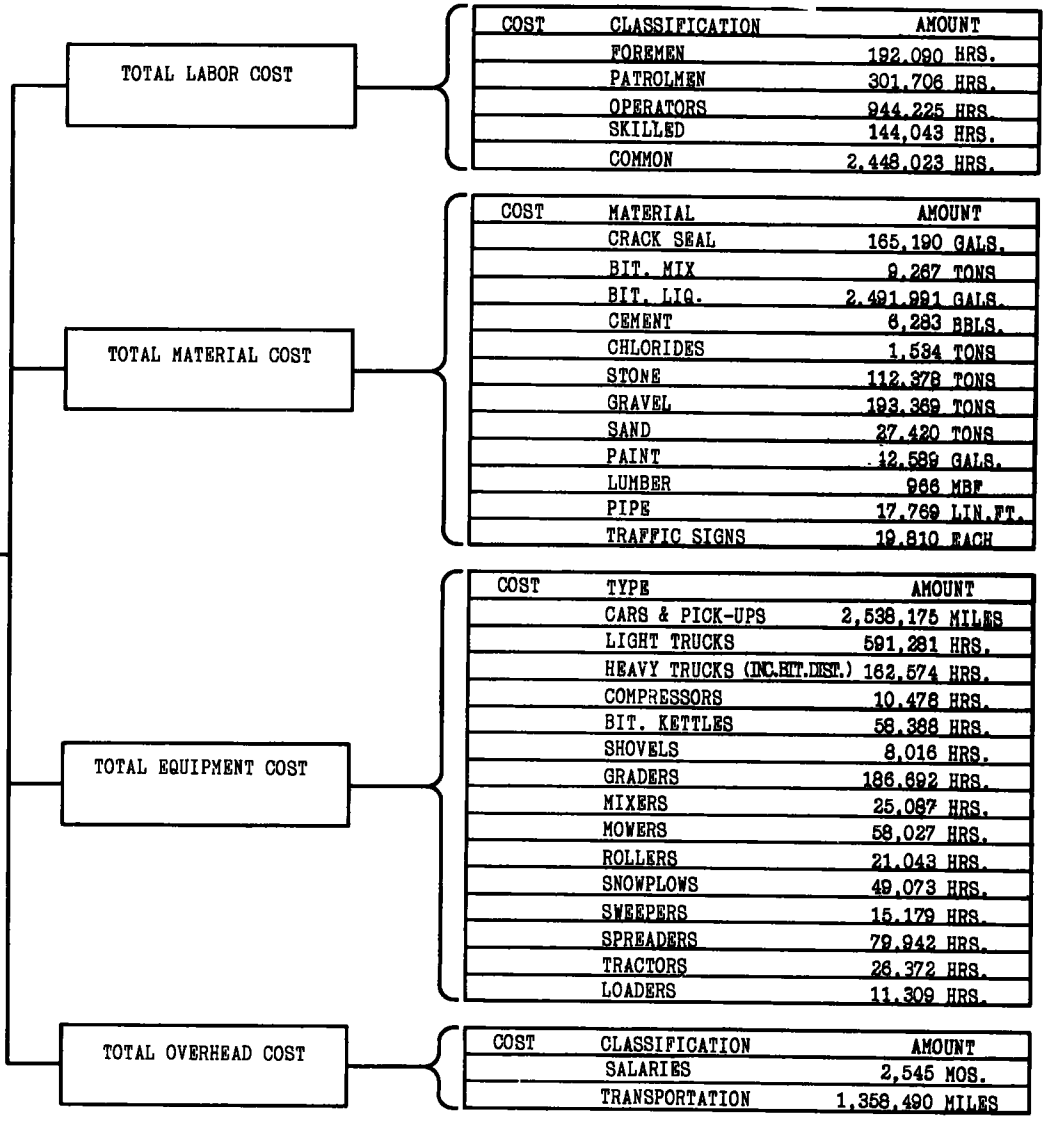
MATERIAL	UNIT	PRICE ($) 1941	PRICE ($) 1945	COST INCREASE (%)
Joint filler	Gal	0.0894	0.1111	24
	Gal	0.1400	0.1550	11
	Ton	19.00	20.75	11
Premix	Ton	3.00	3.50	17
	Ton	4.00	5.00	25
	Ton	5.25	7.50	42
R. C. asph.	Gal	0.0524	0.0653	25
	Gal	0.0560	0.0800	43
	Gal	0.0900	0.1200	33
	Gal	0.1200	0.1300	8
Stone	Ton	1.50	1.75	17
	Ton	1.75	1.85	6
	Ton	2.30	2.50	8
	Ton	3.00	4.00	33

[a] From 1946 Progress Report of Committee on Highway Maintenance Costs and Operating Methods (*11*).

[b] These examples of unit costs are not intended to be average for any particular State. They are actual costs of the items as reported on one particular cost section in 1941 and 1945. Therefore, they are not influenced by different lengths of haul or other variable factors.

ANNUAL COST
HIGHWAY MAINTENANCE AND OPERATION
COMPOSITE 10,000 MILES





TOTAL LABOR COST

COST	CLASSIFICATION	AMOUNT
	FOREMEN	192,090 HRS.
	PATROLMEN	301,706 HRS.
	OPERATORS	944,225 HRS.
	SKILLED	144,043 HRS.
	COMMON	2,448,023 HRS.

TOTAL MATERIAL COST

COST	MATERIAL	AMOUNT
	CRACK SEAL	165,190 GALS.
	BIT. MIX	9,267 TONS
	BIT. LIQ.	2,491,991 GALS.
	CEMENT	6,283 BBLS.
	CHLORIDES	1,534 TONS
	STONE	112,378 TONS
	GRAVEL	193,369 TONS
	SAND	27,420 TONS
	PAINT	12,589 GALS.
	LUMBER	966 MBF
	PIPE	17,769 LIN.FT.
	TRAFFIC SIGNS	19,810 EACH

TOTAL EQUIPMENT COST

COST	TYPE	AMOUNT
	CARS & PICK-UPS	2,538,175 MILES
	LIGHT TRUCKS	591,281 HRS.
	HEAVY TRUCKS (INC.HIT.DIST.)	162,574 HRS.
	COMPRESSORS	10,478 HRS.
	BIT. KETTLES	58,388 HRS.
	SHOVELS	8,016 HRS.
	GRADERS	186,692 HRS.
	MIXERS	25,087 HRS.
	MOWERS	58,027 HRS.
	ROLLERS	21,043 HRS.
	SNOWPLOWS	49,073 HRS.
	SWEEPERS	15,179 HRS.
	SPREADERS	79,942 HRS.
	TRACTORS	26,372 HRS.
	LOADERS	11,309 HRS.

TOTAL OVERHEAD COST

COST	CLASSIFICATION	AMOUNT
	SALARIES	2,545 MOS.
	TRANSPORTATION	1,358,490 MILES

Figure 34. Computation form used by Bureau of Public Roads to determine value for 1947 Unit Maintenance Cost Index.

this study (*12*) was that the best basis for measuring changing unit costs for labor, equipment, material, and overhead would be to compare the costs each year of maintaining a hypothetical 10,000 miles of highways composed of the same percentage of each different surface type as existed on the State highways of the nation in 1947. To determine the cost of maintaining the 10,000 miles, it was necessary to determine the amount of labor, equipment, material, and overhead required for its maintenance. This was done by breaking the 10,000 miles into five surface types or classes of highways. Maintenance was broken into six general maintenance operations and these in turn were divided into 34 components of labor, equipment, material, and overhead (see Fig. 34). The quantity of these components needed to perform each operation on each surface type was determined primarily from data contained in annual reports of the various State highway departments, supplemented by any other information available, including the M-1 reports.

The labor, equipment, and material requirements varied for the different classes of highways, but the same distribution of labor, equipment, material, and overhead existed for all operations except those dealing with surfaces. Therefore, all operations except those dealing with surface maintenance were combined for all classes of highways.

The unit cost for each of the 34 items was determined from the M-1 forms and information contained in the State's annual reports and, for 1947, from special supplementary reports submitted by the States. A national composite unit cost was determined for each of the 34 items by appropriately weighting the unit costs reported by each of the States. For example, the classification of foreman was assigned a different number of hours for each State. The number of hours assigned reflected each State's weight relative to total expenditure for maintenance in the entire country. These hours were multiplied by the foreman unit cost in each State. The resulting values were summarized for all States and then divided by the total hours for all States to get a national unit cost for foremen. The national unit cost for each of the remaining 33 items was determined in a similar manner. The year 1935 was established as the base year and the total cost associated with labor, equipment, material, and overhead for 1935 was equated to 100.00. An index for subsequent years was determined by multiplying the yearly national unit price by the quantities determined for each of 34 items making up the 10,000-mile base system. The dollar value determined for each of the components and for the total of labor, equipment, material, and overhead was divided by the dollars determined for the same component and total in 1935 and then multiplied by 100.

The base quantities for the foregoing outlined Unit Maintenance Cost Index are fixed. That is, varying unit costs are applied to fixed quantities of labor, equipment, material, and an overhead factor to reflect the changes. Therefore, the index permits a yearly comparison of the costs of performing identical quantities of work in exactly the same way as they were performed in 1947, and thus reflects the varying buying power of the dollar. It does not reflect any variations in maintenance work loads or accomplishments. It does not reflect any improvements in maintenance efficiency or technological know-how. It does not include the use of new materials or types of equipment or changes in the skills or composition of labor crews. Thus it does not permit a true evaluation of the changes in the cost of maintaining a unit of highway. However, this index is still a useful tool. It can be applied to yearly maintenance costs to permit a more meaningful comparison between these costs. For example, it may cost $10 to accomplish ten units of maintenance one year, but $20 in some later year. These costs cannot be equitably compared without some knowledge of the buying value of the dollar in each of the years. The 1947 Unit Maintenance Cost Index provides this dollar comparison.

Assume that the 1947 Unit Maintenance Cost Index = 100 when $10 buys ten units of maintenance. If a later year's Index is 150, then (10 is to 100 as X is to 150) $15 buys the same quantity of maintenance in the later year as $10 did in 1947. If ten maintenance units are being accomplished in exactly the same way in both years, $15 should complete the work in the later year. However, if they cost $20, or $5 more than the equitable comparison predicted, this would indicate a change in efficiency, productivity, work load, or perhaps a change in the level or standard of maintenance achieved.

CHAPTER SEVEN

DEVELOPMENT OF PROPOSED UNIT MAINTENANCE EXPENDITURE INDEX

REVIEW OF TYPES OF INDEX NUMBERS

An index number is a statistical measure employed to show overall changes in groups of data such as prices, costs, quantities. Such a number can be used to develop trends which are useful for making future predictions or historical comparisons between data.

The actual use made of an index number governs the method and data used in its construction. However, the limited availability of source data or the practicality of

collecting data can play a major role in the selection of both methods used in its development and types of data to be used.

The use of a maximum amount of information tends to insure more valid index numbers and also provide smooth trend lines, although an equally desirable alternative is to use a small quality sample of very representative data. Both approaches produce good results when properly applied.

An important part of an index number is the selection of a base period. This is the reference period which is equated to 100. All index numbers are computed relative to this base period. Two criteria are normally employed when selecting a base period. First, it should not be too far removed from the present and, second, it should be a normal period rather than one which contains extremes.

The U. S. Department of Commerce currently uses a 1957-1959 base year period for most of its index numbers. For that reason, the indexes developed for this report are based on the same 1957-1959 period.

There are three distinct types of index numbers which can be used for comparison and to show trends in highway maintenance. Following Neter's (*46*) definitions, they are: price indexes, quantity indexes, and value indexes.

In a *price index,* the quantity of individual items or groups of these items is held constant. An appropriate unit cost is applied to each item or unit and then a total cost is determined for a given period. The index is determined by dividing this cost by a base period cost. Regardless of the base period, the index for the base period is 100 by definition so the final quotient must be multiplied by 100. For example, let q be the number of units consumed or quantity consumed of any item, p_n the item unit price or cost for a given period, and p_0 the item unit price or cost for the base period. Then $p_0\,q$ is the base period cost and $p_n\,q$ is a given period cost, and

$$\text{price index} = \frac{p_n\,q}{p_0\,q} \times 100 \qquad (11)$$

By this definition the 1947 Unit Maintenance Cost Index is actually a price index.

For the *quantity index,* a constant unit price cost is determined for an item or group of items. An appropriate quantity is determined for each item for both a base period and any other period. The sum of the products of quantities times the unit prices for all items during a given period is divided by the comparable product for the base period and multiplied by 100.

The *value index* is the total dollar expenditure for an item or group of items in any period divided by the total dollar expenditure for the same item or group in a base period and multiplied by 100. This index reflects both quantity and unit price changes.

ANALYSIS OF PROJECT OBJECTIVES AND APPROACHES

With the foregoing background in mind, the problem statement and research objectives for this project were critically evaluated. The problem was stated: "The Highway Research Board in 1947 developed a Unit Maintenance Cost Index. A need exists for a suitable new index which reflects unit maintenance costs associated with advances in highway engineering technology."

The objective was to "develop a Unit Maintenance Cost Index containing within its framework a technique which will permit its continuous updating." These statements were not interpreted as a mandate to develop a modernized duplicate of the 1947 Index. For that reason, it seemed approprate first to determine the potential usefulness of an index to highway organizations, before attempting to develop a new one.

This project was a part of an overall study wherein the principal effort was being devoted to the development of Interstate maintenance requirements (see Part I herein). In conjunction with the requirements study, each of the State highway departments was visited and interviews were conducted concerning organizations and maintenance practices. Among the items discussed was the use of the 1947 Unit Maintenance Cost Index. In some States no use was being made of the Index and in a few it was being misused. However, it was possible to get a clear concensus of the desired use of an index—to show a need and justification for increases in maintenance budgets. In fact, the 1947 Unit Maintenance Cost Index, which shows how the cost of a fixed quantity of labor, equipment, material, and overhead varies from year to year, was developed for this express purpose. It failed because the quantity, quality, and methods of performing maintenance are not static but dynamic, continually changing due to greater volumes of traffic, improved technology, and higher levels of service to the highway users.

It would be useful to have a maintenance index similar to the present construction price index, where annual cost variations for such items as roadway excavation, surfacing, and structures can be compared. However, this type of index requires a knowledge of the amount of work accomplished for a given maintenance expenditure; i.e., yards of patching, acres of mowing, lineal feet of joint sealing, etc. Few, if any, State highway departments keep such records, and for many maintenance activities there is no convenient way for actually measuring the work accomplished. For this reason, it would be extremely difficult to produce a maintenance price (or cost) index similar to the present highway construction price index. Similarly, a quantity index would be impossible to develop without a measure of maintenance work accomplished. A value index, then, was the type most suited to maintenance work and this was the type developed.

Two alternative approaches were considered in the development of the value index, the first being based on expenditures on selected control sections and the second on total maintenance expenditures for the national system of State highways. In both cases, it was recognized that the reported expenditures would not reflect only maintenance requirements (i.e., what "should have been" spent, based on some standard or norm). Obviously, budget and policy factors influence expenditures. Expenditures for maintenance also reflect variations in highway design; maintenance technology, standards, and work loads; and the costs of labor, equipment, and materials. All of these factors should be considered when assessing present or predicting future

maintenance budgetary requirements. Therefore, a maintenance index based on expenditures can be a useful tool for budgeting and managing maintenance programs.

The use of control sections was considered first and the accounting practices of the States were reviewed. Those having inadequate records were eliminated as potential sources of control sections. The remaining States were screened further, both by telephone and by personal calls, until it became apparent that there was a general lack of available control section maintenance cost data. Where information was present, it was not in a form which permitted its ready extraction, a condition which might have made it difficult to secure such information for future updating of the index.

For these reasons, the index as developed is based on highway information currently being provided to the Bureau of Public Roads by each of the States. This information is presented annually in *Highway Statistics,* a publication of the Bureau of Public Roads, U. S. Department of Commerce. The 1947 Unit Maintenance Cost Index is included in this publication, so the new index, which has been developed by this project using the information available in *Highway Statistics,* might appropriately be updated annually by the Bureau and included in future editions of *Highway Statistics* as a replacement for the 1947 Index.

INDEX DEVELOPMENT

The indexes developed for this report have been identified as Unit Maintenance Expenditure Indexes (UME Indexes). This designation will clearly and quickly differentiate them from the 1947 Unit Maintenance Cost Index. Further, the use of the term "expenditure" in the index title accurately identifies the basis for its computation.

Three separate indexes have been developed, as follows:

1. A Total System Index reflecting changes in unit maintenance expenditures for the national system of all State-administered highways and streets.
2. A Primary Rural System Index reflecting changes in unit maintenance expenditures for the rural portion of the State primary highway system.
3. A Municipal Extension System Index reflecting changes in unit maintenance expenditures for the extensions of State routes into or through municipalities.

Selection of Geographic Regions

There are wide differences in maintenance requirements and practices across the country and many are occasioned by different geographic factors. It would be difficult to isolate all of the characteristics causing variations in maintenance requirements, but two major activities which are extremely sensitive to geographic environment are vegetation control and ice and snow removal. To accommodate the major variations experienced for these two maintenance activities, the country was divided into five geographic regions and regional indexes were computed to supplement the national indexes. This division was based on precipitation data available from the U.S. Weather Bureau and on an evaluation of the per-mile expenditures reported annually in *Highway Statistics* for ice and snow removal. Although there are variations within regions, each does reflect major differences in ice and snow removal and vegetation control practices. The five regions are shown in Figure 35.

Total System Index

All of the index values used in this report were developed using a 1957-1959 base year period. The 1957-1959 maintenance disbursements for "State-administered State highways" as reported in Table SF-4(A) of *Highway Statistics* were averaged for each of the 48 contiguous States. This produced a base year average annual maintenance expenditure for each State (Table K-1). The base year period (1957-1959) mileage as reported in Table SM-1(A), was also averaged for each of the continental States. This produced a base year average mileage for each State (Table K-1). By definition, the base year index is 100, so the base year cost was set equal to 100. To determine a maintenance index value for a given year required that the year's cost be divided by its comparable yearly mileage. This produced an annual unit mile maintenance expenditure. This value was multiplied by the base year mileage to produce the year's index cost, which was then divided by the base year's cost and multiplied by 100 to get each index number. Using this procedure, an index value can be developed by State, by region, or for the entire country, depending on the cost and mileage groupings used.

The maintenance index values developed for five regions and for the total system are given in Table 19. The corresponding curves showing trends are shown in Figures 36 and 37.

Primary Rural System Index

The Bureau of Public Roads *Instruction Manual for the Compilation and Reporting of Highway Mileage* defines the State Primary System as follows:

> This system is comprised of roads officially designated in some States as the "primary system," or as the "State Highway System" or similar designation in others. In the absence of such a "designated" principal system, the term shall be construed to mean the "system of State highways" in its entirety. However, if the system of State highways is subdivided into roads of primary and secondary importance, this in effect creates separate primary and secondary systems, and they should be reported separately where records permit.

The rural portion of the State Primary System was used to create this index. Only States having continuity in both reported mileage and maintenance expenditures for their rural primary system were included in this index. The procedure for developing the index was exactly like that for the Total System Index. Table K-2 gives base year expenditures and mileage for the rural primary system. The index values are given in Table 20 and are shown graphically in Figures 38 and 39.

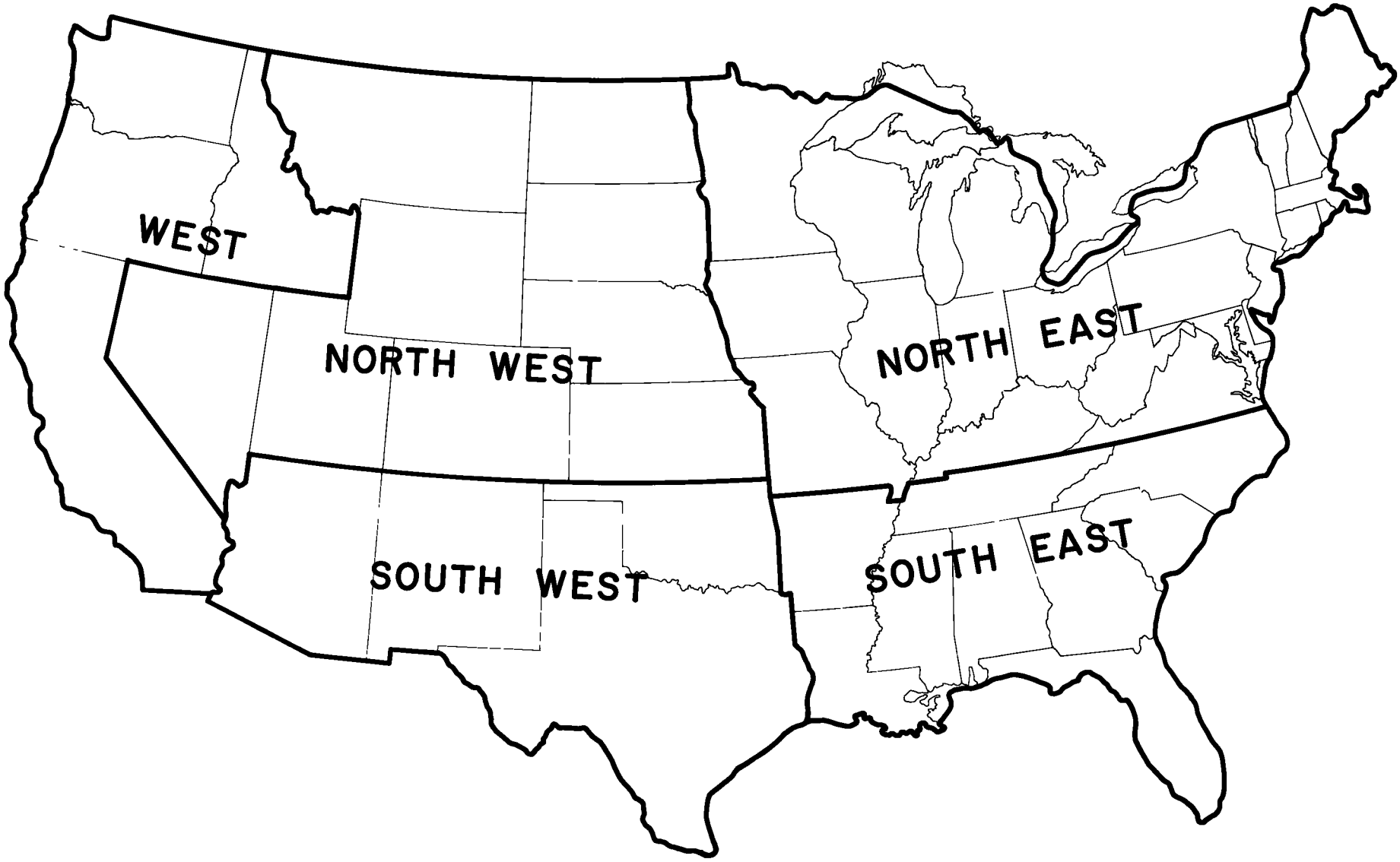


Figure 35. Subdivision of States for regional indexes.

TABLE 19

UNIT MAINTENANCE EXPENDITURE TOTAL SYSTEM INDEX
(1957-1959 BASE PERIOD = 100)

YEAR	INDEX VALUE					
	SOUTHEAST	SOUTHWEST	WEST	NORTHWEST	NORTHEAST	NATIONAL
1956	95.92	88.52	90.39	92.78	89.45	91.33
1957	95.41	96.72	97.72	92.63	94.57	95.65
1958	97.59	100.90	99.39	101.46	102.63	101.90
1959	106.61	101.97	102.69	105.84	102.77	104.19
1960	115.74	108.72	102.38	111.67	102.68	112.57
1961	116.20	108.72	108.26	115.42	115.64	115.16
1962	116.76	112.08	117.31	120.24	124.70	121.99
1963	120.10	115.92	124.73	126.12	126.76	125.18
1964	133.05	121.22	127.65	124.94	133.81	132.17
1965	141.41	128.02	145.53	134.28	141.14	139.91

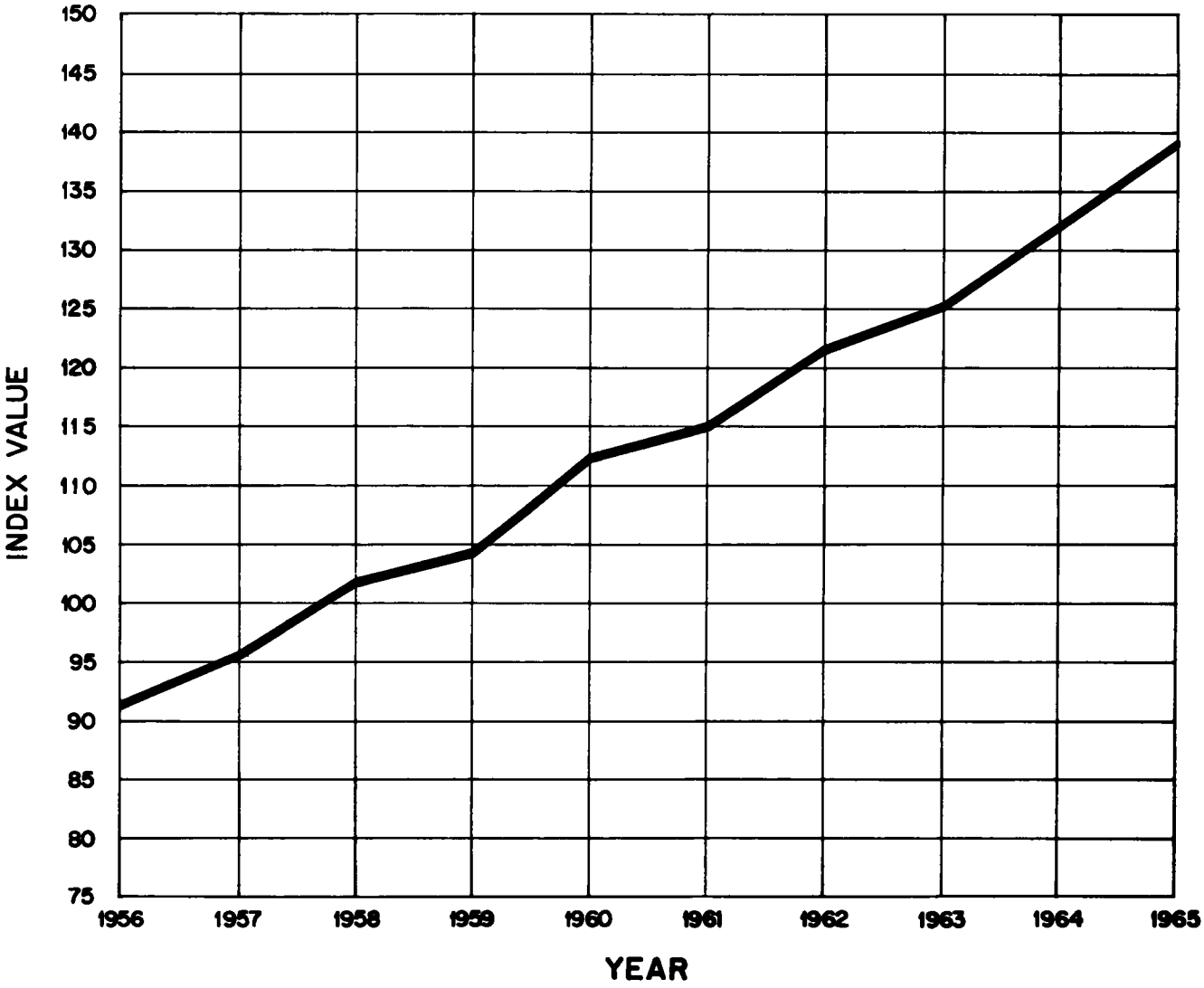


Figure 36. Unit Maintenance Expenditure Index for the total system of State-administered highways in the United States.

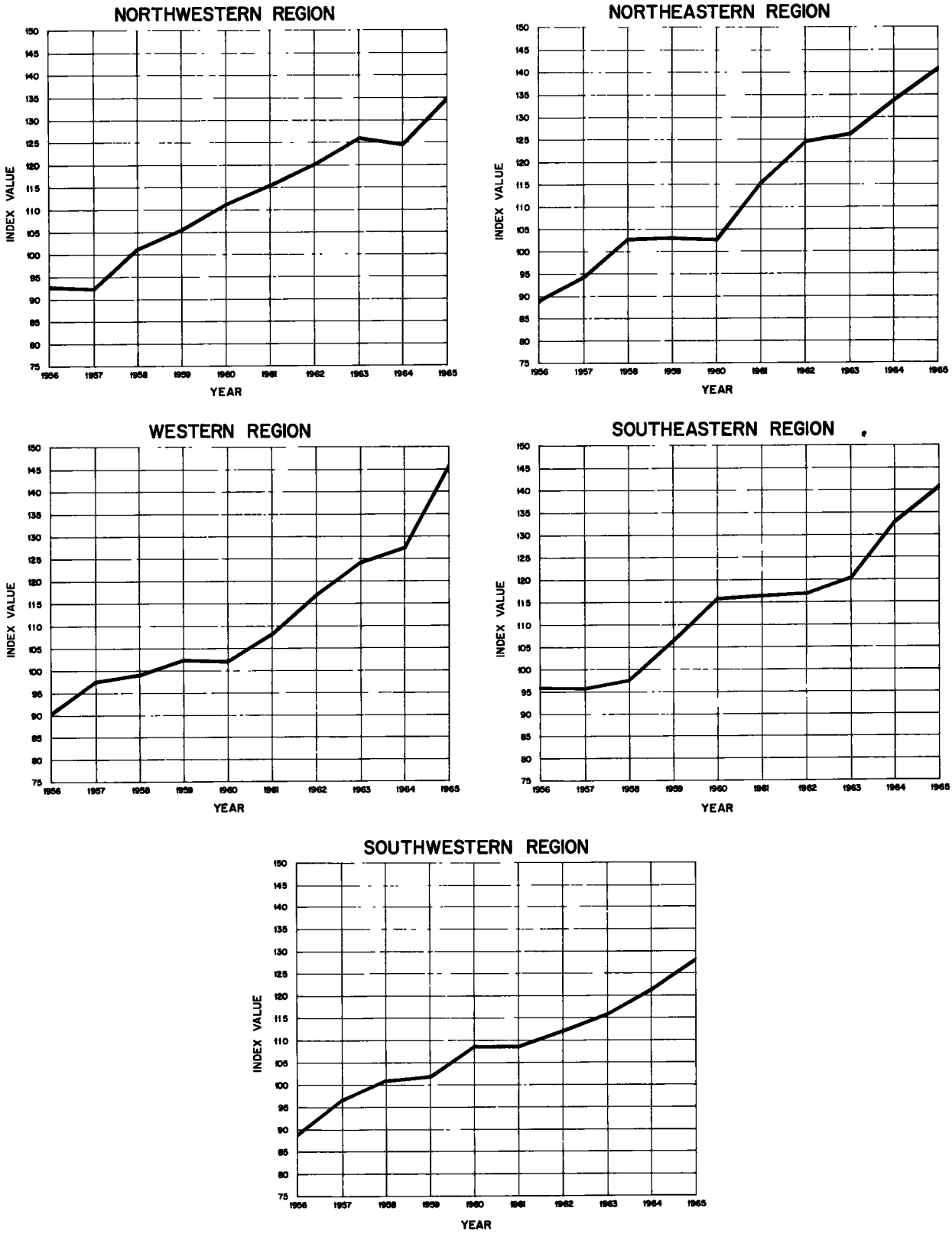


Figure 37. Unit Maintenance Expenditure Index for the total system of State-administered highways, by region.

TABLE 20

UNIT MAINTENANCE EXPENDITURE PRIMARY RURAL SYSTEM INDEX

YEAR	INDEX VALUE					
	SOUTHEAST	SOUTHWEST	WEST	NORTHWEST	NORTHEAST	NATIONAL
1956	96.89	86.61	89.17	94.21	90.63	90.08
1957	99.03	96.32	98.37	92.37	92.95	94.65
1958	100.20	102.65	99.35	101.22	103.18	102.12
1959	101.26	101.05	102.92	105.98	102.20	102.30
1960	111.89	108.47	105.18	111.98	106.37	107.78
1961	111.68	107.68	110.70	115.65	108.73	109.80
1962	116.26	108.41	117.56	120.23	117.06	116.48
1963	124.95	114.30	118.05	123.44	117.46	118.70
1964	141.05	118.42	121.13	123.93	123.69	125.26
1965	144.51	125.92	133.14	131.48	139.28	136.32

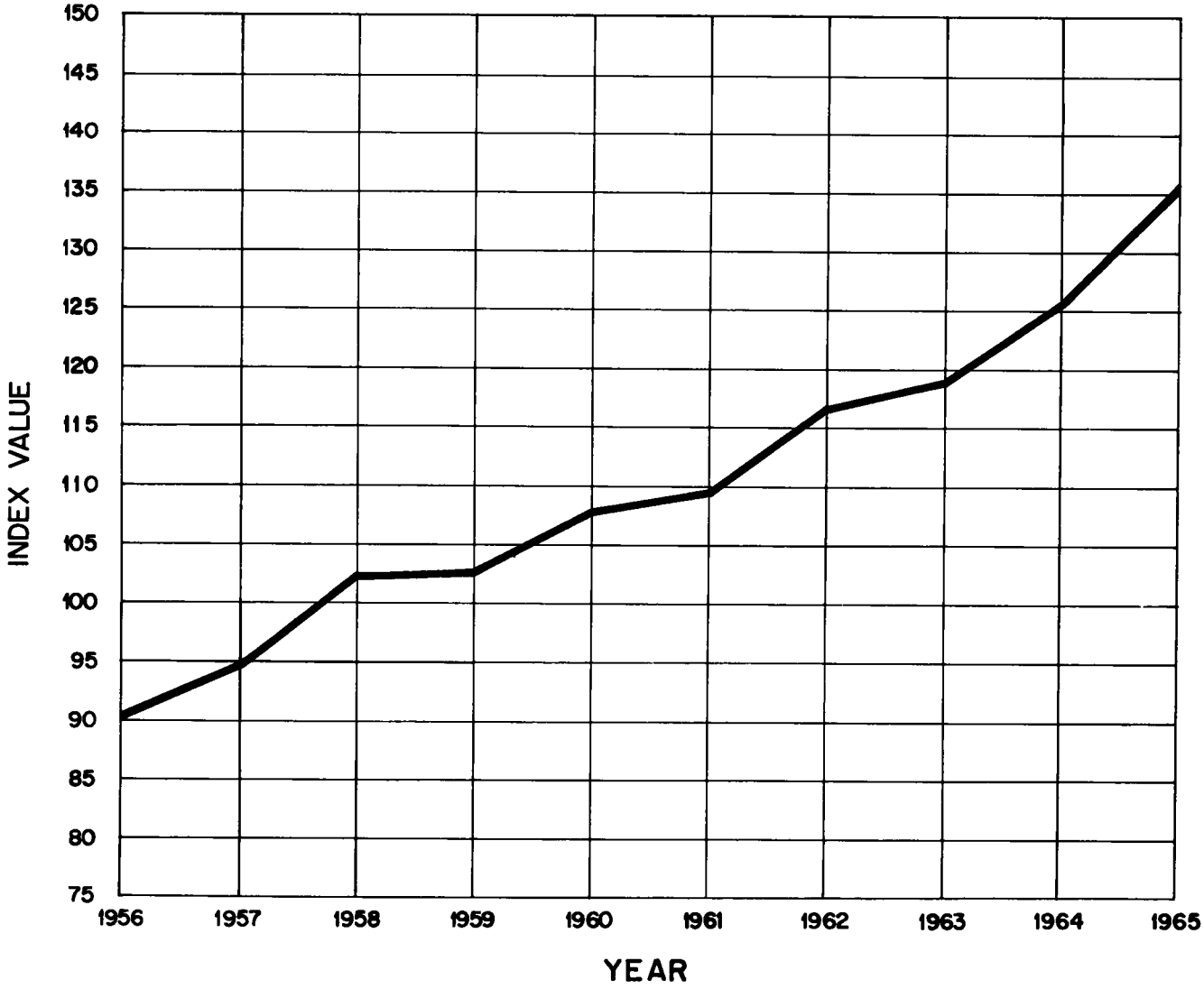


Figure 38. Unit Maintenance Expenditure Index for the rural primary system of State-administered highways in the United States.

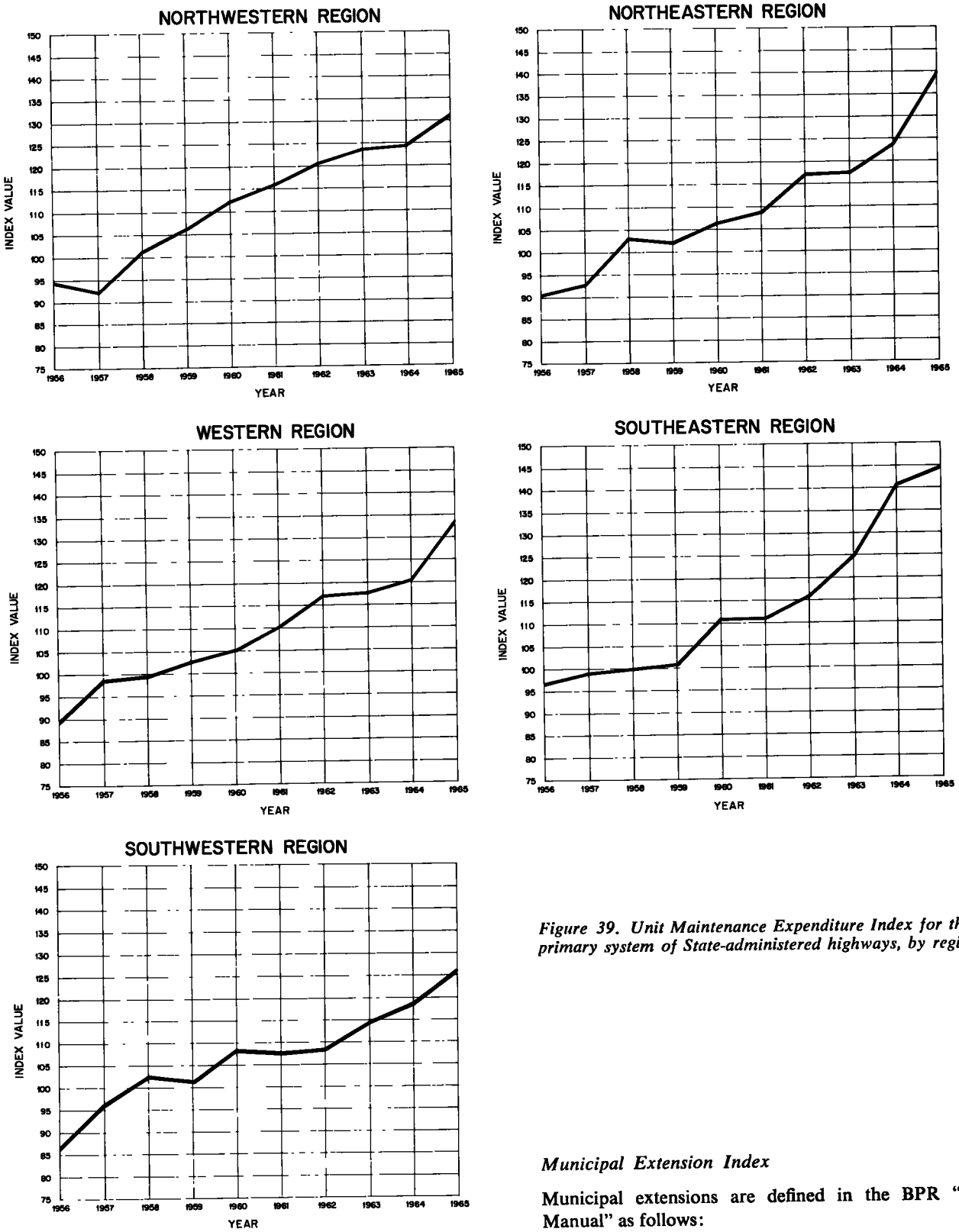


Figure 39. Unit Maintenance Expenditure Index for the rural primary system of State-administered highways, by region.

Municipal Extension Index

Municipal extensions are defined in the BPR "Mileage Manual" as follows:

> The term "municipal extensions" is used to identify the extensions of a State route into or through municipalities. Municipal extensions may be comprised of streets that have been designated as parts of the State highway systems, or may consist of streets not so designated but which provide the necessary municipal connecting links. All municipal extensions necessary to form a continuous route

TABLE 21

UNIT MAINTENANCE EXPENDITURE
MUNICIPAL EXTENSION INDEX

YEAR	INDEX VALUE
1956	95.85
1957	96.27
1958	96.72
1959	106.56
1960	117.14
1961	123.01
1962	129.93
1963	142.37
1964	148.72
1965	172.31

should be included, regardless of administrative control or responsibility.

Although many of the States do not separate their expenditures for these roads and in other States there is no responsibility for their maintenance, a sufficient number did report expenditures to allow for the development of a maintenance index for municipal extensions.

The index was developed in exactly the same manner as previously outlined except that a number of States were not included. Table K-3 gives base year expenditures and mileages for this category. Because of the limited number of States included in this index, only a national index was developed. The index values are given in Table 21 and shown graphically in Figure 40.

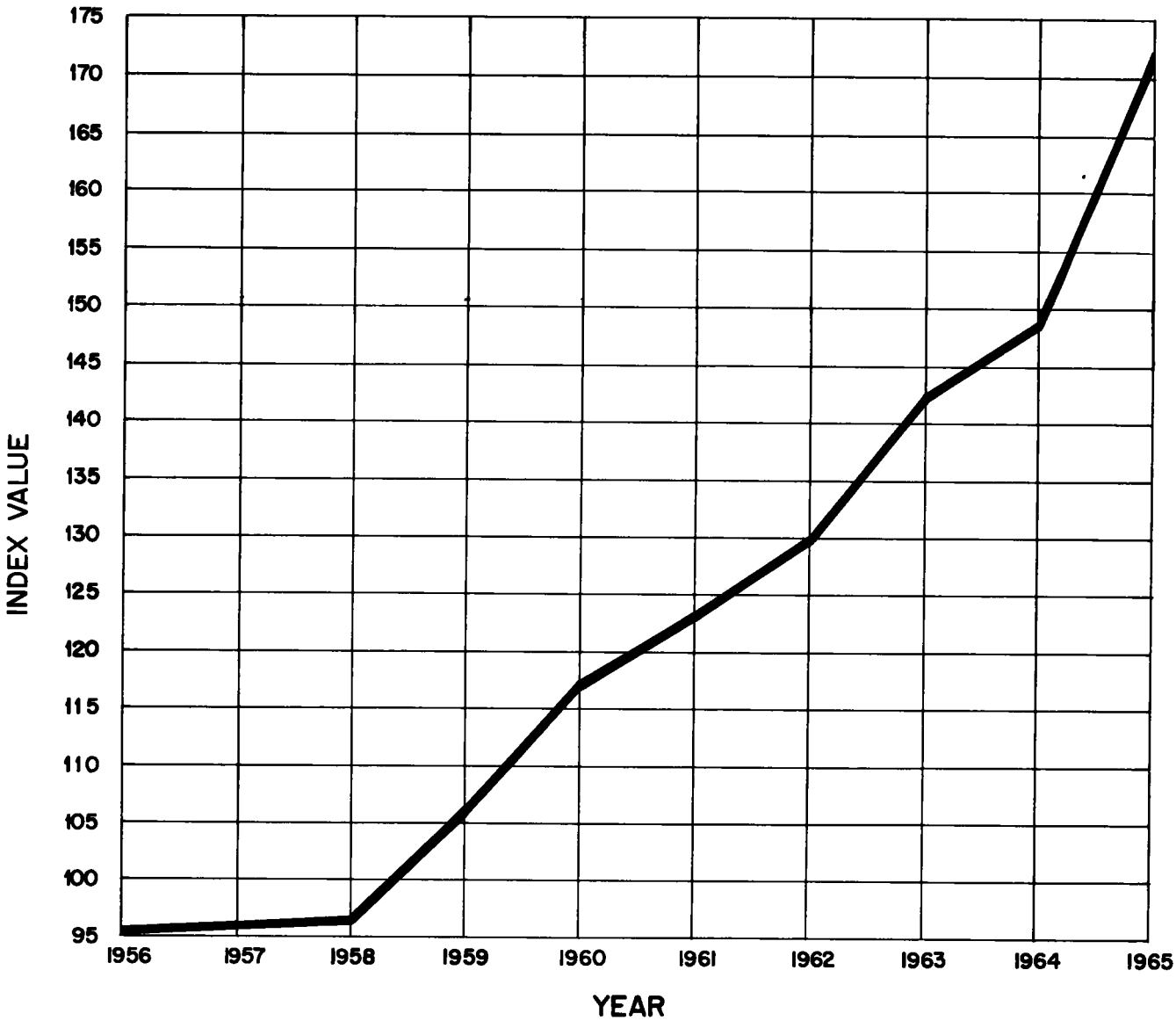


Figure 40. Unit Maintenance Expenditure Index for municipal extensions of State highways in 15 States.

CHAPTER EIGHT

SUPPLEMENTAL INDEXES

In addition to the Unit Maintenance Expenditure Indexes, certain supplemental indexes can prove to be useful management tools in maintenance programs. Several other important indexes, developed from information readily available, also can be updated regularly in the future with minimal special effort.

The fluctuating costs of labor, equipment, and material play an important part in maintenance cost variations. This was acknowledged in the 1947 Maintenance Cost Index, which is based almost entirely on this relationship. The labor, equipment, and material components of that index fairly well reflect changes in these components. However, the indexes are based on relationships which existed in 1947. For that reason, a new base was developed for index values on labor, equipment, and materials.

UNIT LABOR COST INDEX

During the development of the 1947 Unit Maintenance Cost Index, the Bureau of Public Roads initiated a form (Fig. 41) to be used annually by the State highway departments in reporting unit cost data on 36 different items of labor, equipment, and material. The 1947 Unit Labor Cost Index is based on the unit cost data reported for five classes of labor on that form. This information could have been used in developing the new labor index, but it was not. An alternate source which offers advantages is the Progress Report of the Joint Committee on Maintenance Personnel (*47-55*), which has been published annually by the HRB and the American Association of State Highway Officials since 1944. This report outlines the number of State highway employees by job classification and minimum-maximum monthly salaries for each of the State highway departments.

With this information it was possible to develop both unit labor costs and weighting factors for each State highway department. Further, variations in the distribution of labor either by classification within States or by distribution between States are accommodated annually, keeping the index current and eliminating the need for other distribution updating considerations.

The new Unit Labor Cost Index was developed using only those highway job classifications which are readily associated with maintenance work. The classifications used were as follows:

1. Gang foreman.
2. Section man.
3. Common labor.
4. Skilled labor.
5. Equipment operator I.
6. Equipment operator II.
7. Equipment operator III.

First, a composite hourly wage for labor was computed for each State. This was done by averaging the minimum-maximum monthly salary associated with each of the seven labor classifications and multiplying that average by the number of employees in that classification, producing a monthly cost for each labor classification. The monthly costs for each of the seven labor classifications were added together, multiplied by 12, and divided by 2,080 (40 hr × 52 weeks) to produce a total hourly cost. This cost was divided by the total number of employees in all seven classifications to determine the composite unit hourly wage for labor for each State. Regional and national composite unit hourly wages were determined by adding similar sums for the States in each region and for all the States and dividing, respectively, by the total employees in each region and in all the States. The unit wage development can be illustrated by the following hypothetical example:

Labor Class	*No. of Men*	*Monthly wage ($)*	
		Avg.	*Total*
1	100	400	40,000
2	200	380	76,000
3	300	280	84,000
4	400	390	156,000
5	500	360	180,000
6	600	390	234,000
7	700	320	224,000
Total	2,800		994,000

$$\text{Composite unit labor hourly wage} = \frac{994{,}000 \times 12}{2{,}800 \times 2{,}080} = \$2.05/\text{hr}$$

The labor data used in the development of the index base year values are given in Table K-4. In certain years, incomplete information was provided by some State highway departments. In other instances there were unexplained discrepancies in the distribution of personnel in the various maintenance classifications or in the associated wages. Where these caused major discontinuities in the composite labor cost trend for a given State, the information was not used. The average hourly wages for each region and nationally are given in Table 22. The index values are in Table 23. The trend of Unit Cost Indexes for all State highway maintenance is shown in Figure 42 and for each of the five geographical regions of the nation in Figure 43.

BUDGET BUREAU No. 41-R2063 APPROVAL EXPIRES 12-31-67

U. S. DEPARTMENT OF COMMERCE

BUREAU OF PUBLIC ROADS

UNIT MAINTENANCE COST

STATE

LABOR COSTS		
CLASSIFICATION	UNIT	WEIGHTED AVERAGE 1965 RATE
FOREMEN.....	HOUR	
PATROLMEN.....	"	
OPERATORS.....	"	
SKILLED.....	"	
COMMON.....	"	

THE ABOVE RATES ARE BASED ON A WORKWEEK OF _____ HOURS

MATERIAL COSTS *		
TYPE	UNIT	WEIGHTED AVERAGE 1965 UNIT COST
CRACK SEAL.....	GAL.	
BITUMINOUS MIX (ALL GRADES).....	TON	
BITUMINOUS LIQUID (ALL GRADES).....	GAL.	
CEMENT.....	BBL.	
CALCIUM CHLORIDE...	TON	
STONE (ALL GRADES CRUSHED STONE)...	TON	
GRAVEL (ALL GRADES BANK-RUN CRUSHER-RUN AND CRUSHED).....	TON	
SAND (ALL GRADES)..	TON	
PAINT (TRAFFIC & STRUCTURE, INCLUDING BITUMINOUS IF USED)	GAL.	
LUMBER (ALL GRADES, STRUCTURAL & COMMON)	MBF	
PIPE (18-24" & 30" CM OR RC).....	FT.	
TRAFFIC SIGNS, 30x30" (STOP SIGN, METAL, PLAIN).....	EA.	

* DELIVERED

EQUIPMENT RENTAL RATES *			
TYPE	SIZE	UNIT	WEIGHTED AVERAGE 1965 RATE
AUTOMOBILE.....	--	MILE	
PICK-UP.....	½ TON	"	
TRUCK.....	1½ TON	HOUR	
TRUCK.....	5-6 TON	"	
COMPRESSOR.....	105 CU. FT.	"	
KETTLE (BITUMINOUS)	165 GAL.	"	
SHOVEL (POWER).....	½ CU. YD.	"	
GRADER (MOTOR).....	MED.	"	
GRADER (TOWED).....	MED.	"	
MIXER (BITUMINOUS).	10 CU. FT.	"	
MOWER (POWER).....	5-FT. C.B.	"	
MOWER (TOWED).....	5-FT. C.B.	"	
ROLLER (3-WHEEL)...	5-6 TON	"	
SNOWPLOW (BLADE WITHOUT TRUCK).....	10 FT.	"	
SWEEPER (POWER)....	7-FT. BROOM	"	
SPREADER (AGGREGATE CENTRIFUGAL).....	--	"	
TRACTOR (4-WHEEL)..	20-30 H.P.	"	
TRACTOR (CRAWLER)..	40-70 H.P.	"	
LOADER (SELF-PROP.)	BELT	"	

* INCLUDE FUEL AND OIL BUT NOT OPERATOR'S RATE

Figure 41. Form submitted annually to Bureau of Public Roads by States reporting unit maintenance costs.

UNIT EQUIPMENT COST INDEX

Equipment inventory lists from a sample of State highway departments were studied and seven types of equipment, representative of those most frequently used in maintenance, were selected as the basis for an equipment index. These types were as follows:

1. Cars and pickup trucks.
2. Light trucks.
3. Heavy trucks.
4. Graders.
5. Tractors and mowers.
6. Loaders.
7. Rollers.

Unit cost information for the seven equipment types was available from the unit maintenance cost reports (Fig. 41) submitted annually to the Bureau of Public Roads by the States.

To develop the equipment index, it was necessary to establish a composite unit cost for each type of equipment, representative of all of the reporting States. In developing the composite, each State was weighted in the computations. The weighting was done by averaging each State's total maintenance expenditures for the years 1956 and 1964. The individual State averages were then figured as a percentage of the sum of all the State averages. These percentages then were used as weighting factors for the individual States in subsequent computations (Table 24).

For each of the seven equipment types, the unit costs as reported for the years 1955 through 1965 were multiplied by the State weighting factors for each State having substantially complete reports for those years. The results were weighted unit costs.

Again, for each equipment type, the weighted unit costs were totaled for all States used, and the totals were divided by the corresponding sums of the State weighting factors to

Figure 42. Unit Labor Cost Index for maintenance of the total system of State-administered highways in the United States.

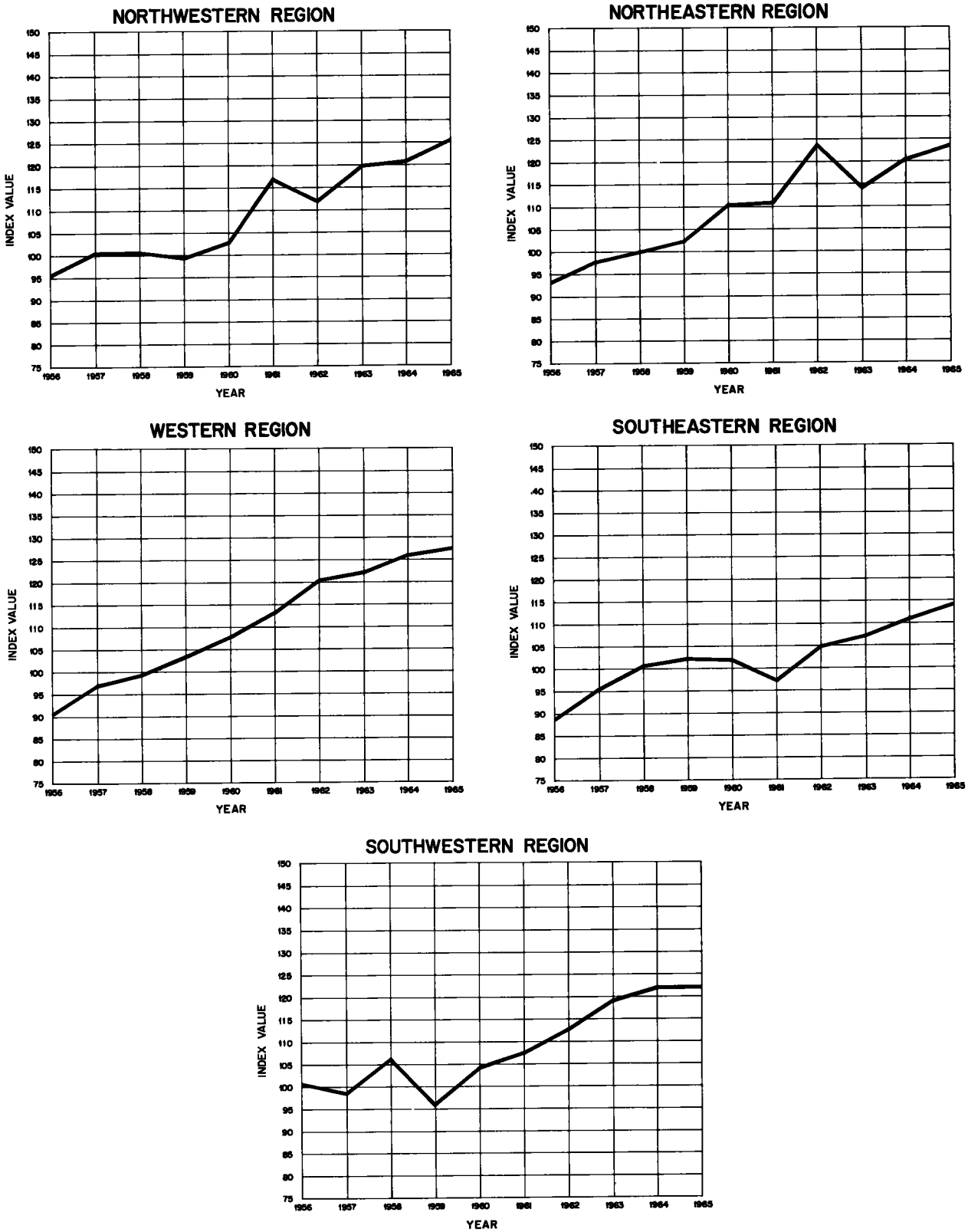


Figure 43. Unit Labor Cost Index for maintenance of the total system of State-administered highways, by region.

TABLE 22

COMPOSITE UNIT LABOR HOURLY WAGES FOR HIGHWAY MAINTENANCE

	UNIT HOURLY WAGE ($)					
YEAR	SOUTHEAST	SOUTHWEST	WEST	NORTHWEST	NORTHEAST	NATIONAL
1956	1.24	1.65	2.95	1.79	1.47	1.49
1957	1.34	1.61	2.20	1.88	1.54	1.56
1958	1.41	1.74	2.25	1.88	1.58	1.62
1959	1.48	1.57	2.35	1.84	1.62	1.63
1960	1.42	1.71	2.45	1.94	1.74	1.71
1961	1.36	1.76	2.57	2.18	1.75	1.75
1962	1.47	1.85	2.73	2.09	1.95	1.88
1963	1.50	1.95	2.77	2.24	1.81	1.83
1964	1.56	2.00	2.86	2.26	1.90	1.91
1965	1.60	2.00	2.89	2.34	1.95	1.95

TABLE 23

HIGHWAY MAINTENANCE UNIT LABOR COST INDEX, 1957-1959 BASE PERIOD

	INDEX VALUE					
YEAR	SOUTHEAST	SOUTHWEST	WEST	NORTHWEST	NORTHEAST	NATIONAL
1956	88.57	100.61	90.31	95.72	93.04	92.55
1957	95.71	98.17	96.92	100.53	97.47	96.89
1958	100.71	106.10	99.12	100.53	100.00	100.62
1959	102.16	95.73	103.52	98.40	102.53	101.24
1960	101.43	104.26	107.93	103.74	110.13	106.21
1961	97.14	107.32	113.22	116.58	110.76	108.70
1962	105.00	112.80	120.26	111.76	123.42	116.77
1963	107.14	118.90	122.03	119.79	114.56	113.66
1964	111.43	121.95	125.99	120.86	120.25	118.63
1965	114.29	121.95	127.31	123.42	123.42	121.12

produce a composite unit equipment cost for each of the years, 1955 through 1965. These are given in Table 25.

The seven types of equipment were then weighted according to the dollar value of their current use, based on data furnished by several States. The weighting factors were arbitrarily converted to increments of $100,000 to provide a convenient base for further computations.

To establish a base year composite cost for each equipment type the composite unit costs for the years 1957 through 1959 were averaged. Then the cost weighting factors were divided by the base year composite unit costs to compute a corresponding weighted use in hours or miles. Table 26 shows the development of the weighting factors.

To compute the cost associated with each type of equipment for a given year, the composite unit cost for that year was multiplied by the use factor.

To compute the Unit Equipment Cost Index value for a given year, the yearly costs for all seven equipment types are totaled and that sum is divided by $100,000 and multiplied by 100. The resulting Unit Equipment Cost Index values for 1956-1965 are plotted in Figure 44.

UNIT MATERIAL COST INDEX

In 1962 the Bureau of Public Roads prepared a report relating to the use of materials for the nation's highways (*56*). In the report, a use distribution for highway maintenance materials was delineated (Table 27). Twelve material items are included in the State's annual unit maintenance cost report to BPR (Fig. 41). The twelve material items were compared with the list in BPR's 1962 material use report, and four materials representing major material use were selected as a basis for a new Unit Material Cost Index. The selected materials are:

1. Cement.
2. Bitumen.
3. Aggregate.
4. Paint.

In developing the Unit Material Cost Index, a composite unit price was established by using the same State weighting factors (Table 24) used in the Unit Equipment Cost Index.

Composite unit costs, computed in the same manner as those for equipment, are given in Table 28. Base year and

TABLE 24

PERCENTAGE OF ANNUAL TOTAL STATE HIGHWAY MAINTENANCE EXPENDITURES IN 48 STATES BY EACH OF THE 48 STATES

STATE	FOR 1956 (%)	FOR 1964 (%)	AVERAGE OF 1956 AND 1964 (%)	STATE	FOR 1956 (%)	FOR 1964 (%)	AVERAGE OF 1956 AND 1964 (%)
Alabama	2.051	1.922	1.986	Nebraska	1.019	0.817	0.918
Arizona	0.645	0.706	0.676	Nevada	0.420	0.390	0.405
Arkansas	1.360	1.425	1.393	New Hampshire	0.880	0.917	0.898
California	3.765	4.688	4.226	New Jersey	2.895	3.406	3.151
Colorado	1.058	0.846	0.952	New Mexico	0.831	1.090	0.961
Connecticut	2.277	1.926	2.102	New York	7.997	7.688	7.842
Delaware	0.476	0.713	0.595	North Carolina	4.852	4.743	4.798
Florida	1.680	2.274	1.977	North Dakota	0.445	0.408	0.426
Georgia	1.400	1.332	1.366	Ohio	4.362	3.410	3.886
Idaho	0.836	0.591	0.714	Oklahoma	1.588	1.375	1.482
Illinois	2.816	4.024	3.420	Oregon	1.752	1.194	1.473
Indiana	1.733	4.123	2.928	Pennsylvania	6.901	7.587	7.244
Iowa	1.326	1.350	1.338	Rhode Island	0.425	0.537	0.481
Kansas	1.759	1.827	1.793	South Carolina	1.739	1.577	1.658
Kentucky	2.498	2.619	2.559	South Dakota	0.665	0.395	0.530
Louisiana	2.136	1.742	1.939	Tennessee	1.247	1.235	1.241
Maine	1.656	1.269	1.463	Texas	5.921	5.984	5.952
Maryland	1.004	1.167	1.086	Utah	0.621	0.690	0.656
Massachusetts	2.636	3.248	2.942	Vermont	0.580	0.577	0.578
Michigan	3.313	2.407	2.860	Virginia	4.894	3.745	4.320
Minnesota	2.236	1.753	1.995	Washington	2.242	1.918	2.080
Mississippi	0.933	0.955	0.944	West Virginia	2.508	1.674	2.091
Missouri	2.815	3.094	2.955	Wisconsin	1.627	1.674	1.600
Montana	0.693	0.660	0.676	Wyoming	0.484	0.405	0.444

TABLE 25

COMPOSITE UNIT EQUIPMENT COST

	COST ($)						
YEAR	PICKUPS [a]	LIGHT TRUCKS [b]	HEAVY TRUCKS [b]	GRADERS [b]	ROLLERS [b]	LOADERS [b]	TRACTORS AND MOWERS [b]
1955	0.058	1.361	2.955	2.870	2.666	3.287	2.161
1956	0.058	1.357	3.070	2.877	2.650	3.631	2.243
1957	0.061	1.426	3.286	2.996	2.831	3.802	2.287
1958	0.061	1.352	3.042	3.168	2.966	3.810	2.290
1959	0.058	1.651	3.504	3.470	3.090	3.930	2.454
1960	0.065	1.506	3.588	3.878	3.259	4.234	2.467
1961	0.060	1.557	3.653	3.821	3.054	4.483	2.456
1962	0.062	1.633	3.842	3.810	2.829	4.568	2.516
1963	0.063	1.677	3.912	4.008	2.987	4.708	2.445
1964	0.059	1.609	3.865	3.690	2.804	4.754	2.524
1965	0.059	1.606	3.844	3.802	2.828	4.854	2.590

[a] Per mile. [b] Per hour.

TABLE 26

DEVELOPMENT OF WEIGHTING FACTORS FOR EQUIPMENT INDEX

	COMPOSITE UNIT COST ($)					
ITEM	1957	1958	1959	BASE YEAR	TOTAL COST WEIGHTING ($)	USE WEIGHTING
Pickup and cars	0.061	0.061	0.058	0.060	35,000	583,333 mi
Light trucks	1.926	1.352	1.651	1.476	15,000	10,123 hr
Heavy trucks	3.286	3.042	3.504	3.277	21,000	6,408 hr
Graders	2.996	3.168	3.470	3.211	16,000	4,983 hr
Tractors and mowers	2.287	2.290	2.454	2.344	6,000	2,560 hr
Loaders	3.802	3.810	3.930	3.847	5,000	1,300 hr
Rollers	2.831	2.966	3.090	2.962	2,000	675 hr
Total					100,000	

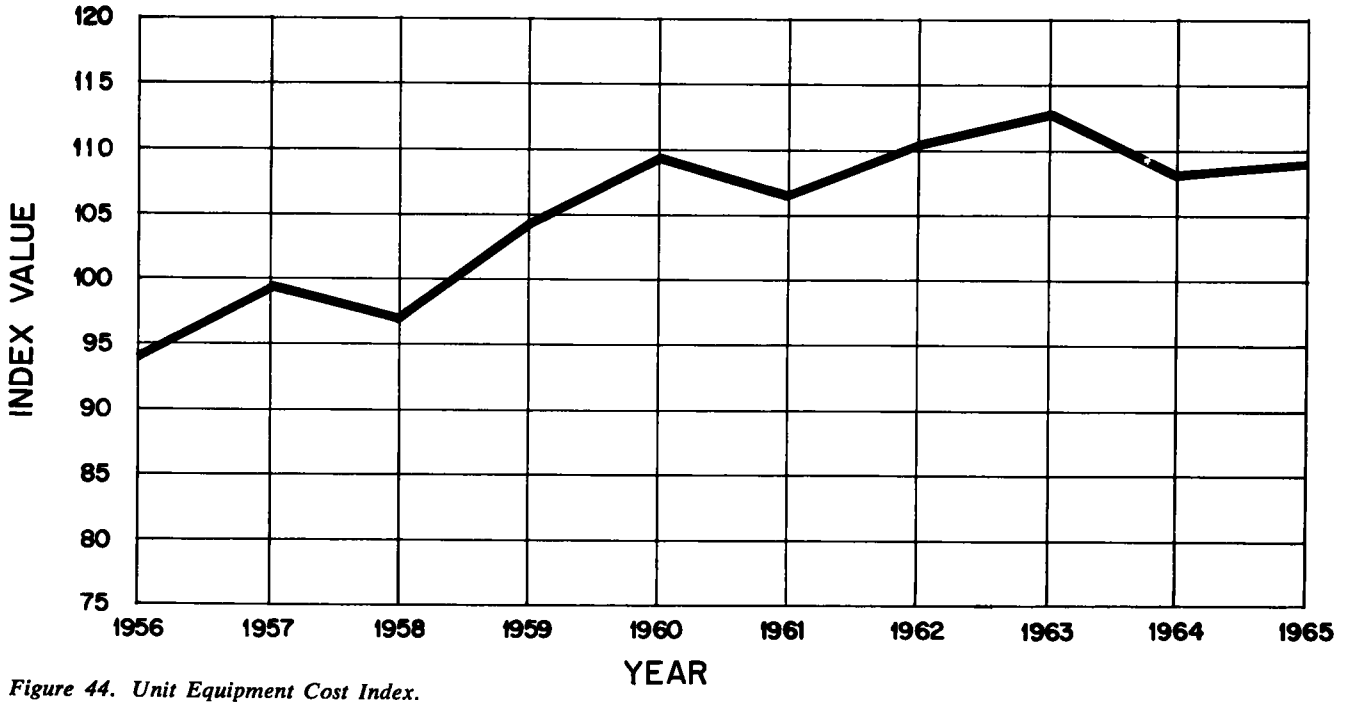


Figure 44. Unit Equipment Cost Index.

weighting factors, computed as for equipment, are given in Table 29.

To compute the cost associated with each type of material for a given year, the composite unit cost for that year was multiplied by the quantity factor. The Unit Material Cost Index value for a given year was computed by dividing the sum of the costs of the four materials for that year by $100,000 and multiplying by 100. The resulting Unit Material Cost Index values for 1956-1965 are plotted in Figure 45.

COMPOSITE UNIT LEM COST INDEX

The distribution of maintenance expenditures for labor, equipment, material, and overhead was obtained from the State highway departments where that information was

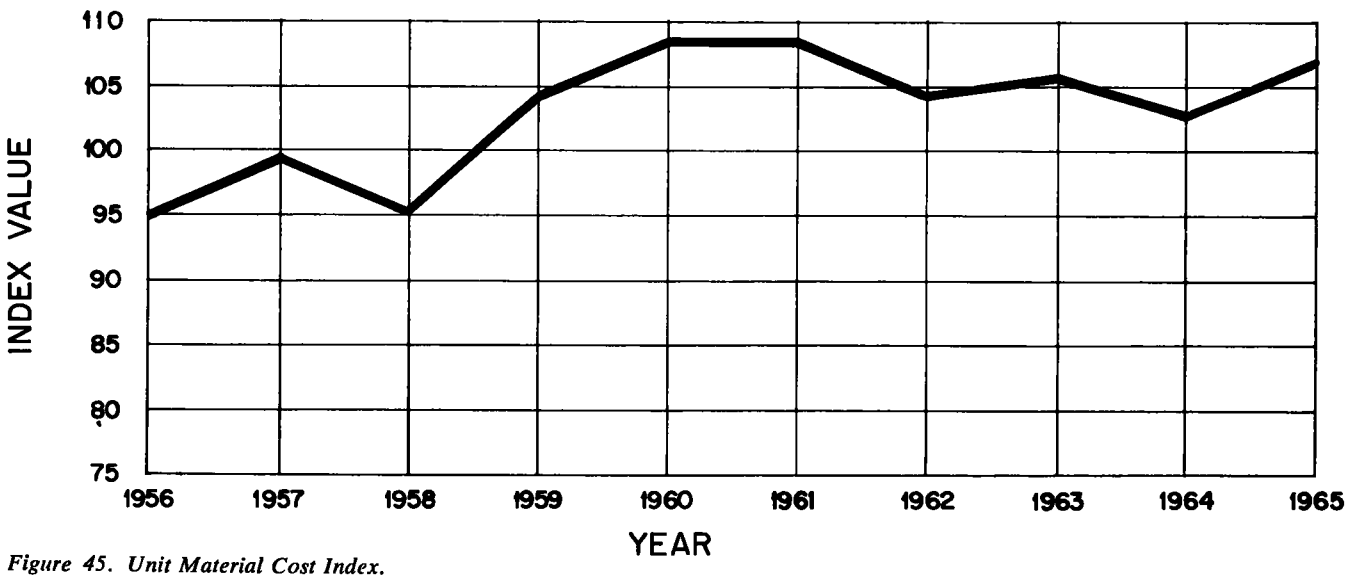


Figure 45. Unit Material Cost Index.

available. A study of the distributions for 1950, 1955, 1960, and 1965 revealed no discernible patterns or trends in either the individual States or for the averages determined for all of the States. The distributions varied widely for each of the items, showing labor from 38 to 60%, equipment from 14 to 38%, material from 22 to 47%, and overhead from 2 to 17% of total maintenance expenditures. The average percentage for each item remained nearly constant over the 15-year study period. Therefore, the following distribution, based on the average values

TABLE 27

ESTIMATE OF ANNUAL USE OF MAJOR MATERIAL FOR HIGHWAY MAINTENANCE

ITEM	UNITS	QUANTITY	ESTIMATED COST ($)	INDEX WEIGHT
Steel	Tons	206,000	108,450,000	—
Aluminum	Tons	3,050	1,830,000	—
Cement	Bbl	2,300	11,500,000	2
Bituminous	Tons	5,700	141,360,000	28
Aggregate	Tons	172,000,000	344,000,000	66
Lumber	FBM	480,000	60,000	—
Paints	Gal	10,635,000	21,270,000	4
Petrol. prod.	Gal	520,000,000	52,000,000	—

TABLE 28

MATERIALS COMPOSITE UNIT COST

	COMPOSITE UNIT COST ($)					
YEAR	GRAVEL (/TON)	STONE (/TON)	SAND (/TON)	CEMENT (/BBL)	BIT. (/GAL)	PAINT (/LB)
1955	1.602	2.172	1.521	4.152	0.121	2.450
1956	1.667	2.293	1.509	4.447	0.127	2.569
1957	1.780	2.335	1.627	4.635	0.136	2.464
1958	1.674	2.330	1.531	4.773	0.129	2.403
1959	1.920	2.517	1.705	5.211	0.133	2.334
1960	2.051	2.541	1.939	5.278	0.130	2.321
1961	1.997	2.467	1.884	4.899	0.131	2.390
1962	1.959	2.427	1.800	4.991	0.130	2.279
1963	2.049	2.527	1.879	4.998	0.126	2.152
1964	2.057	2.451	1.753	4.945	0.124	2.211
1965	2.092	2.536	1.886	4.945	0.127	2.225

TABLE 29

DEVELOPMENT OF WEIGHTING QUANTITIES FOR MATERIAL INDEX

	UNIT COST ($)				WEIGHTED VALUE	
ITEM	1957	1958	1959	BASE YEAR	COST FACTOR ($)	QUANTITY FACTOR
Gravel	*1.780*	*1.674*	*1.920*			
Stone	*2.335*	*2.330*	*2.517*			
Sand	*1.627*	*1.531*	*1.705*			
Aggregates	1.914	1.845	2.047	1.935	66,000	34,108 tons
Paint	2.464	2.403	2.334	2.400	4,000	1,667 gal
Cement	4.635	4.773	5.211	4.873	2,000	410 bbl
Bit. liq.	0.136	0.129	0.133	0.133	28,000	210,526 gal
Total					100,000	

determined from the available information, was selected as the basis for a composite Unit Labor, Equipment and Material (LEM) Cost Index:

Labor	45%
Equipment	24%
Material	31%
	100%

Overhead, where reported, averaged about 12% of total maintenance expenditures.

The composite Unit LEM Cost Index values shown in Figure 46 were developed using the foregoing percentages to weight the index values determined individually for labor, equipment, and material.

TRAFFIC INFLUENCE ON MAINTENANCE COST

The initial approach taken in the development of the new Unit Maintenance Expenditure Index considered the selection of control sections of highways. These control sections were to be classified by traffic volumes for weighting purposes.

Of the several States contacted initially, only Virginia had control section information in a form that was readily obtainable. An analysis of this information was completed before it was decided that the use of control sections to develop a national cost index was impractical. Some meaningful relationships were found during this analysis, however, and are incorporated in this report.

Virginia Maintenance Costs

The maintenance and traffic service expenditures for selected sections in Virginia were obtained from the Department of Highways for a ten-year period. Each control section was classified by its traffic volume for each year, then all sections were grouped in appropriate volume classifications by year. Many sections fell into a number of different classifications in different years. An average unit mile cost was computed for each year to accommodate this

Year	Labor Index	Equipment Index	Material Index	Comp. Index
1956	93	94	95	94
1957	97	99	99	99
1958	101	97	96	98
1959	101	104	104	102
1960	106	104	108	107
1961	109	107	108	108
1962	117	111	104	112
1963	114	113	106	111
1964	119	108	103	112
1965	121	109	107	113

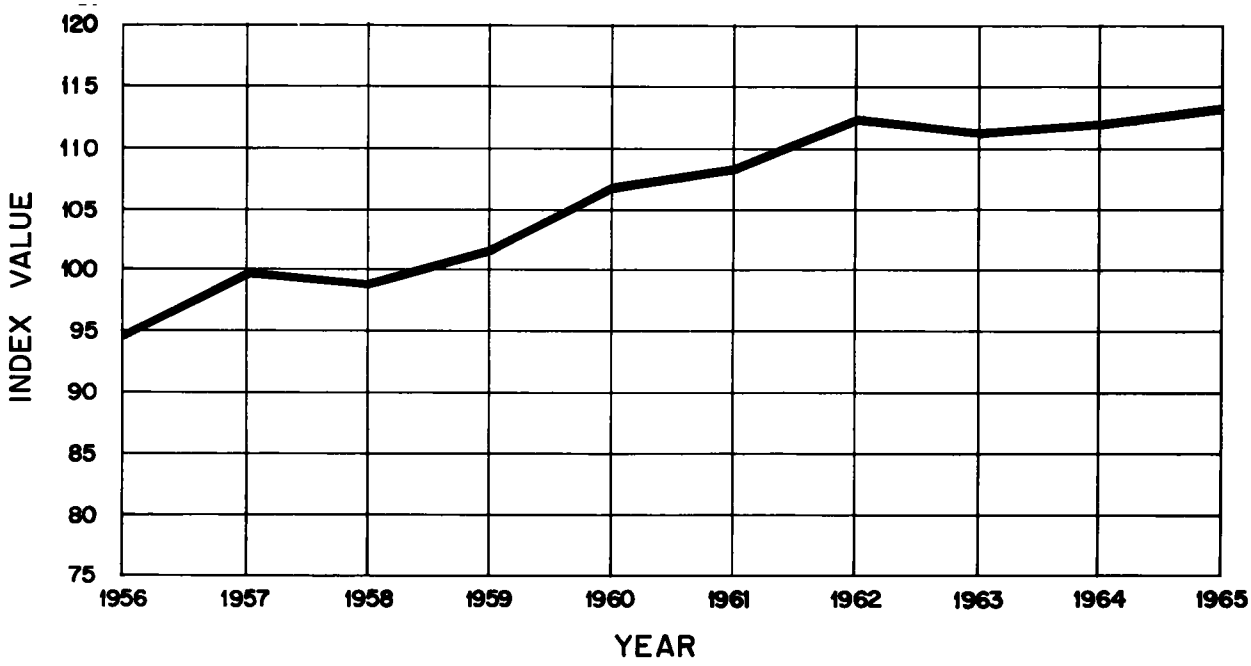


Figure 46. Composite Unit LEM Index.

variation in the number of contributing sections each year. A discussion of this analysis appears in Appendix L.

As expected, for any given traffic volume classification there were wide variations in the annual costs reported during the ten-year period. To eliminate this yearly fluctuation and to establish a trend relationship, a line of regression was computed for each traffic volume classification. A sample regression plot, equation, and slope are shown in Figure 47. Examination of all the regressions for each volume classification indicated that there was a strong relationship between both the per-mile cost and the rate at which the per-mile cost is increasing, with respect to increasing traffic volume. An equation was sought to express this relationship, so the intercept year (1955) was selected as a reference period. The intercept values for each traffic volume classification were plotted against traffic and the regression parameters again computed. The resulting relationships are shown in Figure 48. A similar analysis was made of the slope and traffic volume (Fig. 49). The actual regression analysis which produced Figures 48 and 49 was adjusted to reflect the confidence which could be placed on any of the plotted points (see Appendix L).

National Maintenance Costs

The Virginia traffic equations then were used to examine the effect of traffic volume measures on a national trend of maintenance expenditures. However, before this could be done it was necessary to establish a national composite-mile ADT. This was done using information published annually in Table SM-15 of *Highway Statistics*. The resulting values are shown in Figure 50 together with a computed line of regression to establish the ADT trend.

The expressions developed from the Virginia data included all of the factors affecting the cost of maintenance, such as changes in unit labor, equipment and material costs; traffic volumes; maintenance standards; etc. It was desirable to evaluate separately the effect of some of these components. The influence of increasing unit labor, equipment, and material costs was eliminated by dividing the national unit-mile cost reported each year for the Primary System in *Highway Statistics* by each year's composite labor, equipment, and material index number as developed earlier herein. This produced the unit maintenance costs given in Table 30. The resulting national unit maintenance costs still show an increasing cost trend.

Using the Virginia equations, the relative increase in cost that can be expected each year due to traffic alone was calculated. This was done using the traffic predicted from the regression of national traffic. These cost increases, occasioned by the traffic volume increases, were subtracted from the national LEM adjusted cost per mile for maintenance in Table 30. The resulting costs (Table 31) are much more consistent. This indicates that the major cost increases have been accommodated by eliminating the effect of the rising unit costs of labor, equipment, and material and the increases associated with higher volumes of traffic. Close examination still shows some increase; this increase would have been more pronounced if the noticeable drop in 1959 and 1960 had not occurred. The

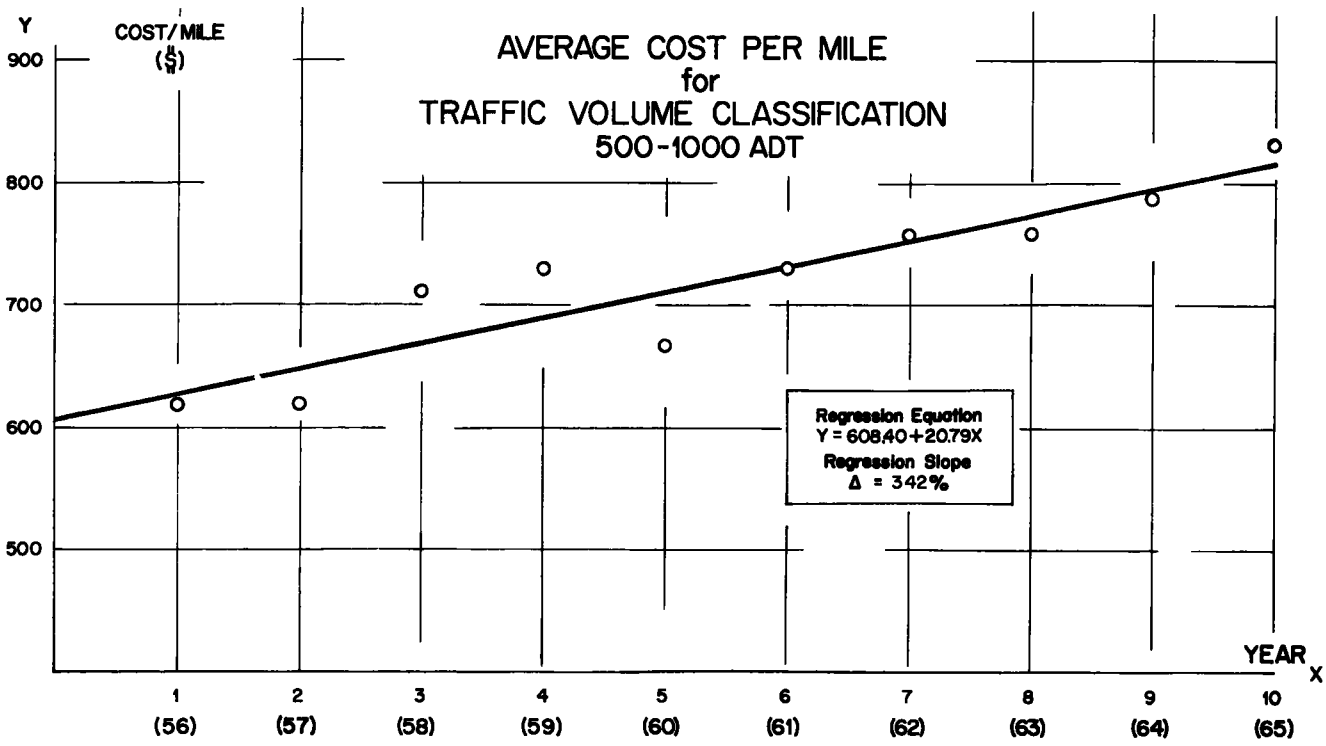


Figure 47. Regression line relating maintenance expenditures to time for the 500-1,000 ADT sections of Virginia highways.

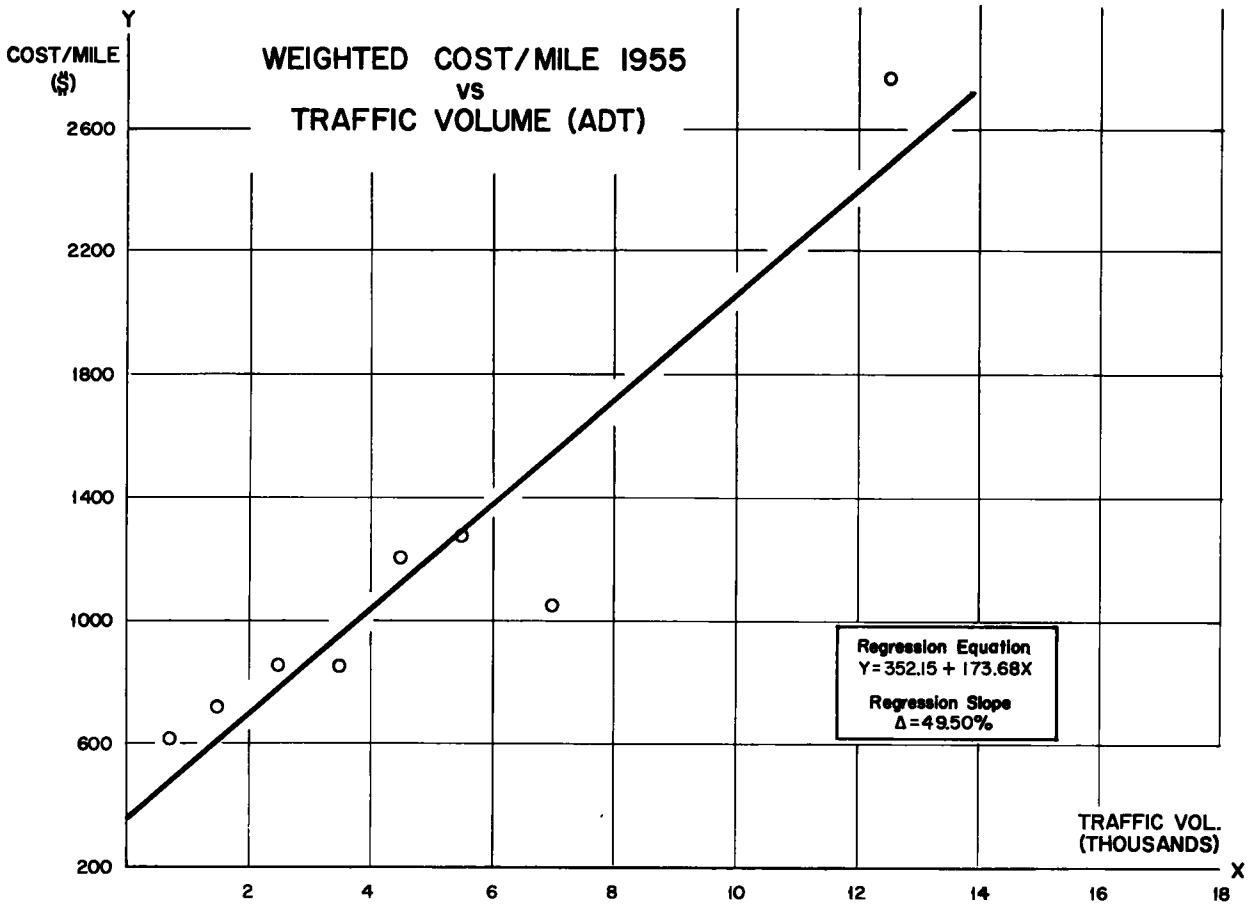


Figure 48. Regression line relating maintenance costs and traffic volumes for the Virginia highway sample.

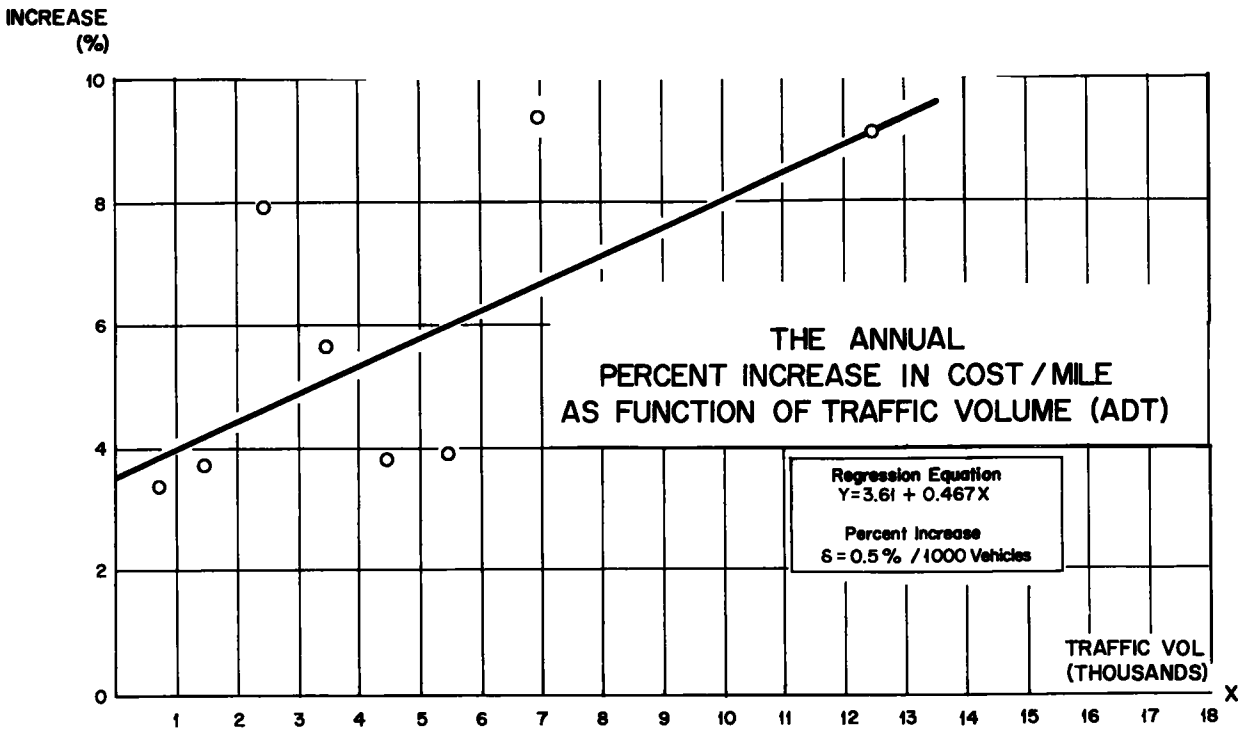


Figure 49. Regression line relating annual rate of cost increases (1955 based) to traffic volumes for the Virginia highway sample.

TABLE 30

ADJUSTMENT TO PRIMARY STATE HIGHWAY SYSTEM UNIT MAINTENANCE COSTS TO ELIMINATE INFLUENCE OF INCREASING LEM COSTS

		COST PER MILE ($)	
YEAR	LEM INDEX	NATIONAL	LEM ADJUSTED
1955	0.89	1280	1438
1956	0.94	1413	1503
1957	0.99	1474	1488
1958	0.98	1562	1594
1959	1.02	1570	1539
1960	1.07	1653	1545
1961	1.08	1711	1584
1962	1.12	1828	1632
1963	1.11	1887	1700
1964	1.12	1991	1778

1959-1960 period coincides with a time of economic recession in the nation, which might be the explanation for the index drop.

A base year (1957-1959) value for unit mile maintenance expenditures on the national primary system (rural and municipal extensions) was established and index values were computed for both adjusted and unadjusted costs. Averaging the difference in index values between 1955 and 1964 produced the following cost trends:

Actual cost increase	5.22%/year
LEM-adjusted cost increase	2.44%/year
LEM and traffic-adjusted cost increase	0.89%/year

This shows that the LEM unit cost adjustment eliminated 2.78% of the total increase and that the traffic adjustment eliminated 1.55%, leaving 0.89% which is caused by unidentified factors. Figure 51 shows this relationship.

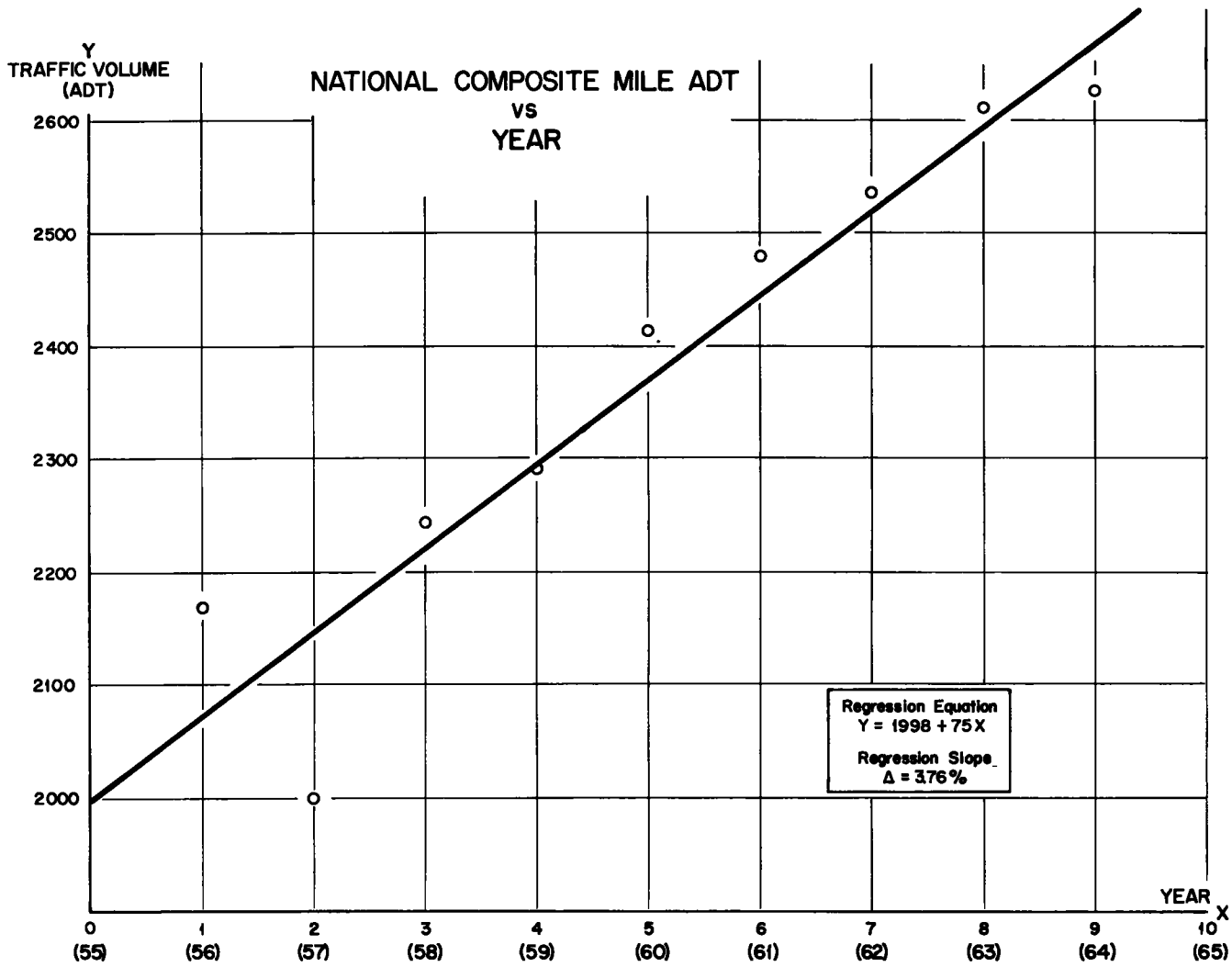


Figure 50. Regression line relating ADT and time for a composite mile of the national primary highway system.

TABLE 31

REDUCTION OF ADJUSTED PRIMARY STATE HIGHWAY SYSTEM UNIT MAINTENANCE COSTS TO ELIMINATE INFLUENCE OF TRAFFIC-RELATED COST INCREASES

	COST PER MILE ($)				
		ACTUAL TRAFFIC		REGRESSION TRAFFIC	
YEAR	LEM ADJUSTED	INCREASE	NATIONAL ADJUSTED	INCREASE	NATIONAL ADJUSTED
1955	1438	0	1438	0	1438
1956	1503	37	1466	18	1485
1957	1488	13	1475	39	1449
1958	1594	65	1529	60	1534
1959	1539	83	1456	83	1456
1960	1545	115	1430	106	1439
1961	1584	138	1446	130	1454
1962	1632	160	1472	155	1477
1963	1700	185	1515	181	1519
1964	1778	197	1581	217	1561

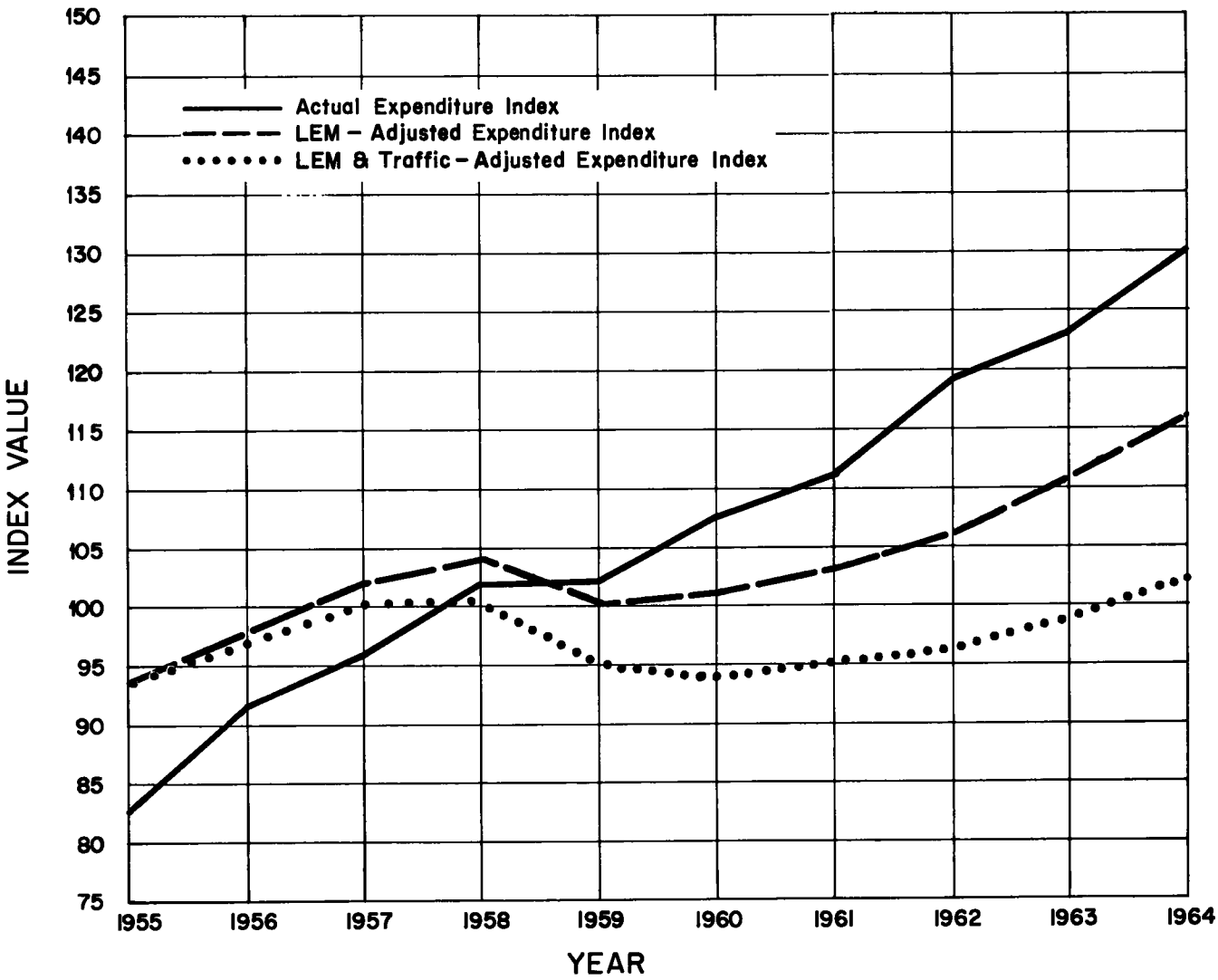


Figure 51. Actual and adjusted index trends for the Primary State Highway System.

CHAPTER NINE

CONCLUSIONS, APPLICATIONS, AND RECOMMENDATIONS

The 1957-1959 based Unit Maintenance Expenditure Index, as computed for this report, ranges from 91 in 1956 to 140 in 1965. This represents an increasing maintenance expenditure trend of 5.4% per year. Regional trends have been much more erratic on a year-to-year basis. The Southwest, Northwest, and Southeast Regions, respectively, are the lowest, each showing an increase since 1956 of less than the national. The West and Northeast showed increases since 1956 greater than the national, with the West being the highest.

The Primary Rural System Index has shown a slightly lesser increase than the national, being 5.14% per year, whereas the Municipal Extension Index is considerably greater, being 8.61% per year, or about 1.7 times the primary rural value.

The formal establishment and continuation of the proposed UME Index is warranted for the important contributions it can make to budgeting and management problems and to a number of related areas.

The UME Index can provide a uniform accurate record of the changes in maintenance expenditures on a national and regional basis. The computation procedure will permit the development of a separate local index by an individual State, where desired. Meaningful comparisons by regions or States can be made of trends in unit maintenance expenditures and management attention can be directed to those areas of need.

As historical records of UME Indexes are accumulated, a sound basis for estimating and projecting future requirements will be available. By inspection of supplemental indexes such as the LEM Index or the Traffic Index, evaluation of various influences on maintenance expenditures is possible.

Therefore, it is recommended that the proposed UME Index be established and continued on an annual basis. It is also recommended that a Primary Rural and a Municipal Extension Index and five Regional UME Indexes be established and computed annually. As further supplements, it is recommended that a new Unit Labor Cost Index, Unit Equipment Cost Index, Unit Materials Cost Index, and a composite Unit LEM Cost Index be established and computed annually as outlined in this report.

It is suggested that the foregoing indexes can be processed most efficiently by the Bureau of Public Roads, using the present data collection system of the Bureau, supplemented by the labor cost data annually collected and published by the Joint Committee on Maintenance Personnel of the American Association of State Highway Officials. The indexes should be published regularly in *Highway Statistics,* but separate publication of the indexes at an earlier date also would be useful to the highway industry.

The excellent correlation between increases in traffic and increases in maintenance expenditures on Virginia highways indicate the authenticity and value of a Unit Traffic-Related Maintenance Expenditure Index. It is recommended that further studies be undertaken to develop acceptable traffic and mileage data on a national basis and to establish a procedure for the regular annual computation of a Unit Traffic-Related Maintenance Expenditure Index.

PART III

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APPENDIX A

TEST SECTION DESCRIPTIONS

CALIFORNIA

All 131.89 centerline miles in the six test sections in California are under the jurisdiction of the State highway department.

Sections 4 and 5 are in the highly urbanized areas of San Francisco Bay and Los Angeles County. Section 6 is in the desert and mountainous area of southeastern California. Sections 2 and 3 are in the Sierras east and west of the divide with heavy annual snowfall. Section 1, in the north, is on the western slope of the Sacramento River canyon in an area of high rain and snowfall.

Test Section 1

This section is located on the western slope of the Sacramento River Canyon in a spur of the Coast Range, part of a complex of ranges which meet near Mt. Shasta and lie across the northern part of the State, the Siskiyou and Cascade Ranges. The Southern Pacific Railroad parallels the highway on the same side of the river, but on a much lower elevation.

The terrain along the test section is wooded hills and canyon sides; many small and medium sized creeks cross the route to enter the river.

Annual precipitation averages 49 in., most of which falls as rain. Total snowfall averages 48 in. at lower elevations and 108 in. at the higher elevations; elevations range from 1,780 to 2,254 ft. Temperatures range from a low of 15 F to a high of 100 F, the average low is 30 F and the average high 95 F. During construction stabilization trenches were built, blankets of permeable gravel 2-3 ft in thickness were placed on several areas where high fills were to be constructed and where the underlying ground showed the presence of water-bearing clays. Horizontal drains were

Test Section	Interstate Route	County	Length (mi)	Limits
1	5	Shasta	10.93	0.6 mi N of Shotgun Creek to Siskiyou County line
2	80	Placer and Nevada	18.75	Gold Run to junction of Calif. 20 and I80
3	80	Nevada and Sierra	20.16	Donner Park to Nevada line
4	80	Alameda and Contra Costa	18.90	Distrib. struct. E end of Bay Bridge to Carquinez Bridge
5	405	Los Angeles	15.64	Los Angeles coastal plain to San Fernando Valley
6	15	San Bernardino	47.51	2 mi E of Baker to Nevada line

installed, perforated pipe drains and intercepting ditches were installed or constructed, and cuts were benched to catch loose rocks and to intercept drainage from the cut slopes. Still settlement occurred at many locations along the section and is continuing, but at a much slower rate. There is evidence of some lateral displacement of the pavement slab on one high fill, indicating movement of the fill laterally as well as vertically. Slopes are becoming stable, as a great deal of slide and slough material has been removed, and cut slopes have been flattened and benched. There is considerable ravel of small rocks during and after rains, wind storms, or freeze-thaw cycles.

Cut slopes are generally 1:1 to 1½:1, with some flatter slopes where slides or heavy erosion has occurred. Embankment slopes are variable—2:1 where possible and 1½:1 where there are lateral restrictions. The embankment slopes are generally stable. Structures are stable due to good foundation practices.

Maintenance problems arise from erosion caused by heavy rains, settlement caused by saturated and unstable basement materials, and snow and sleet storms in winter with the attendant hazard to traffic. Ice forms on the pavement because the mist rising from the Sacramento River often freezes on the traveled way.

Average daily traffic volume is 5,660 vehicles, of which 10% are commercial.

The pavement, of portland cement concrete with asphaltic concrete shoulder, is separated by a paved 16-ft median which carries drainage. It is about five years old.

There are seven interchanges, diamond or modified in type, all connecting with frontage or other country roads and one State Park road.

The entire section is in cut or fill or sidehill cut and fill. Fills are as high as 140 ft at some locations and cuts reach 190 ft in height.

There are seven regular crew members responsible for maintenance on the test section as well as on an additional 16 miles of I-5 below the test section. In winter additional men are hired locally. Special service crews assist when needed. The regular crew personnel live with their families in State-owned houses adjacent to the maintenance yard.

Major items of work include patching settled areas, ditch and culvert cleaning, minor slide and slough removal, snow removal (generally in the months of December through March), maintaining delineators, removing dangerous debris such as falling rocks and dead animals. Signs, signals and lights are maintained by special crews from Redding; litter pickup is done by the regular crew with a packer truck from Redding cleaning the vista areas.

Test Section 2

normal years this is a region of moderate to heavy snow-This section, in the eastern portion of north central California, traverses the western slope of the Sierra Nevada Mountains. Elevations range from 3,100 to 5,800 ft. In fall and rainfall.

The section begins in an ancient river channel, which was mined extensively by hydraulic methods in the 1850-60 era. The highway crosses the channel, which is about a mile wide, and enters hillside and canyon areas. The alignment traverses a country of moderate relief. Most of the area is covered with brush and second growth pine, fir, and cedar.

Precipitation data are as follows:

	Gold Run	Blue Canyon	Emigrant Gap
Rain	44 in.	60 in.	52 in.
Snow	28 in.	240 in.	271 in.

The heaviest snowfall on record at Blue Canyon occurred in 1952 when 526 in. of snow fell and the pack reached a depth of 152 in. with 26-ft drifts on the old highway.

Physical information:

(a) Four lanes.

(b) No turf, some summer weed mowing.

(c) The traveled way is four lanes of portland cement concrete with asphaltic concrete shoulders. From mile 41.4 to mile 49 the traveled ways are separated by a cobbled median. On the remainder of the section, except for short distances, the roadways are completely separated laterally and vertically.

(d) The entire section is in cut or fill or sidehill cut and fill. Cuts range up to 200 ft and fills up to 175 ft.

Cuts are benched above 20 ft to catch eroding material and to serve as drainage intercepts.

The maintenance crew of 8 employees is also responsible for 13.9 miles of two-lane Highway 20.

The crew live with their families within a radius of 20 miles in owned or rented dwellings. For winter work there is a hotel-type dormitory at the maintenance station with modern kitchen and dining rooms.

Major items of work include: Snow removal for five months every year, patching, leveling subsided areas, removing bank slough, cleaning culverts, keeping drainage facilities in good condition, removing fallen rocks.

The nearest source of supply for asphaltic patching material is 40 miles distant. Crushed rock is available within 25 miles. Sand for icy pavements is available at the latter source. Salt is obtained from the San Francisco Bay area, is purchased delivered to the bunkers, from salt refineries and in bulk, blown by air pressure to the storage bunkers.

Test Section 3

This section is located on the eastern slope of the Sierra Nevada Range beyond the limits of the heavy snowfall of the western slope. Elevations range from 5,970 to 5,100 ft.

The section begins at the east end of Donner Lake in a glacial valley of the Pleistocene Age, parallels Donner Creek for about 2 miles, passes the town of Truckee on the North and traverses a glacial moraine above the Truckee River. The highway crosses the river and the Southern Pacific Railroad at mile 20.2 and enters the canyon of the Truckee River. From this point to the Nevada state line portions of the highway are on flat stream terraces and portions are on steep canyon slopes.

Average precipitation varies from 28 in. at Truckee to 21 in. at Boca (eight miles easterly), most of which falls as snow, and 27 in. at Farad (13 miles east of Truckee), mostly rainfall. Average snowfall at Truckee is 190 in., and at Boca 150 in.; no records are available for average snowfall at Farad.

Cut slopes are benched to contain falling rocks and to provide drainage along the slopes; 1½:1 cut slopes are widened at the toe for drainage. Considerable rock fall is encountered at three locations and chain-link "rock" fence has been erected to reduce the hazard to traffic and contain the major portion of the fall at the toe. This reduces maintenance problems, although a patrol is necessary to remove the occasonal rock that bounds over the fence to the traveled way.

Problems due to environment are those of keeping the road open during heavy snowstorms, and of erosion caused by heavy rains in a short period of time. Flooding occurs in cyclic intervals when warm Pacific rains melt the snowpack. Road surfaces deteriorate from the effects of freezing and thawing and chemical ice control, wearing by tire chains, and the use of snowplows and graders in contact with the pavement.

Average daily traffic volume is 6,600 vehicles, of which 9% are commercial.

The pavement consists of four lanes of portland cement concrete. There are numerous random cracks in the slabs except for the 5-mile section west of the Nevada line, which is undivided except by a 4-ft painted strip and delineators.

Shoulders are of asphaltic concrete, 10 ft wide on the outer lane and 5 ft wide at the median, except for the undivided section, which has shoulders only on the outside.

The maintenance crew of nine men assigned to the section also maintain an additional 3½ miles on I-80 adjoining the test section.

During five months of the year snow removal and related services are the major items of work. Pavement patching, removal of bank slough, maintainence of safety devices, and patrolling for fallen rocks are the other main items of work.

Test Section 4

This section is on the East Shore Freeway in Alameda and Contra Costa Counties. It begins about 0.7 mile east of the toll plaza on the eastern approach to the Bay Bridge, skirts the shore of the bay for about 4 miles, and then winds through low-lying hills to the Carquinez Straits, through which flow the waters of the Sacramento and San Joaquin Rivers.

The section traverses a low tidal area, much of it landfill or alluvial and river deposits, until it enters the previously mentioned low hilly sections interspersed with little valleys. A higher range of hills (part of the Coast Range) lies to the east. The highway follows ravines and low hillsides until it reaches the Straits.

Normal yearly rainfall is 22 in. Snow falls about once in 5 years, but is not measurable and is the result of freak storms.

Slopes are becoming stable, although during rainstorms there may be considerable slough in the lower cuts. The high cuts were benched and laid back during construction to conform to the natural slopes. Landscaping and functional planting has been a big factor in slope stabilization.

The test section passes through a portion of each of eight cities (Oakland, Emeryville, Berkeley, Albany, Richmond, El Cerrito, San Pablo, Pinole). With the exception of Pinole, these cities form one continuous urban complex.

The local and artificial environment of population centers creates the problem of ever increasing traffic with demands for more or improved connections to the freeway. The structural weakness of the underlying soil has caused and is still causing settlement of the roadbed and subsequent distortion of the pavement. Rainfall is frequently intense and even lanscaped slopes will slough.

The average daily traffic volume ranges from 139,000 vehicles in Oakland to 39,900 at the Carquinez end of the test section.

The pavement is portland cement concrete with asphaltic concrete shoulders. There are eight lanes from mile 2.6 to mile 7.2, then six lanes for the remainder of the distance. An additional lane is being added inbound from about mile 4 to provide added safety to that traffic wishing to cross the Bay. The mowing area of about 20 acres is covered with weeds rather than turf. Weeds are controlled by machine mowing and chemical sprays, preferably preemergent in the fall.

There are 22 interchanges, all but three of the major urban variety.

The road maintenance is in two superintendents' territories; traffic line and pavement marking is the responsibility of a third superintendent, who also has other highways and maintains minor signs; a fourth superintendent, in San Francisco, is responsible for the maintenance of traffic signals (ramp-street connections), highway lighting, and major signs. This last crew is a special service crew and handles radio maintenance as well.

Landscape maintenance is the responsibility of the superintendent in the Oakland metropolitan area. This crew consists of 41 men.

Litter cleaning and pickup is a never-ending chore. Much of this work is done by the landscape crews and trash is gathered at regular intervals in a special "packer" truck and hauled to a disposal site owned by the county and/or city. Highway maintenance crews also pick up litter along the roadside.

Median fence repair is a major work item in point of time, inasmuch as there are usually 2 to 6 holes in the fence, especially after weekends. Safety devices such as delineators are very vulnerable. Restoring traffic line and barrier lines is done at regular intervals, on Saturday or Sunday mornings when interference with traffic is less than on other days.

A patrol is on regular schedule at night once or twice a month to check highway lighting and the illuminated signs.

Test Section 5

This section is on the San Diego Freeway, in Los Angeles County and City, in Southern California. The section begins on the Los Angeles coastal plain and terminates in the San Fernando Valley. Grade elevations are from 40 ft to 1,118 ft.

The section traverses the coastal plain and through some small rolling hills, and then through a spur of the Santa Monica Mountains. Although it is now almost covered with city, the plain is composed of alluvial deposits washed down from the mountains, which form a basin rim.

Rainfall averages 12 in. annually, with extremes of dry and wet years. Most of the rain occurs in November, December, and January (in 1965 most rainfall occurred in two weeks in November). Rains are usually of short duration but intense in volume and cause considerable wash and flooding from "instant" runoff.

The test section is in a heavily populated urban area except for about 3½ miles through the Santa Monica spur. However, houses and other structures are rapidly occupying the hills.

The highly populated area is responsible for the problem of moving traffic safely and expeditiously. The generally dry and hot summer climate creates an expensive landscape operation in that watering becomes a major item. There is little settlement of the roadway except for bridge ends, where differential compaction poses a problem.

The average daily traffic volume is about 140,000 vehicles.

Only weed mowing is done along roadsides outside the landscaped areas, and for fire control as well as for appearance. Chemical weed control is used along landscaped sections around sign posts and railings.

There are six and eight lanes of portland cement concrete pavement and asphaltic concrete paved shoulders. Near bridges and interchanges there is usually a very shallow paved (rolled) gutter between the traveled way and the shoulder.

There are 22 interchanges, of which only 3 can be classed as minor. There is one complex interchange at the intersection of route 405 and route 10. Collector roads are used to carry traffic to the more involved interchanges and where streets are cut off from freeway entrance.

On the section there are four crews for maintenance generally, and one traveling crew repairing fences territory-wide. One crew is for road maintenance and three crews are for landscaping. There are 13 men, including the foreman and leading man, on the road crew. The landscape crews have 14 men including 1 foreman and 2 leading men. The territory fence crew has 1 foreman, 1 leading man, and 12 maintenance men. The regular crews are responsible for 10 miles of highway.

The major work load includes landscape maintenance, fence repair (median), keeping the drainageways open, patching, crack sealing, and general housekeeping. Sign, signal and highway lighting maintenance is handled by a central special crew responsible for other highways and from a separate superintendent's headquarters.

Test Section 6

This section is located in the southern region of California in San Bernandino County, lying south of the Sierra Nevada and the Tehachapi Ranges. The section begins 2 miles east of Baker and ends at the Nevada state line.

The highway crosses a region of dry lakes, volcanic ridges, alluvial fans, finally traversing the Clark Mountains at Mountain Pass, and ends in a dry lake country typical of Nevada physiography. The test section begins in Soda Dry Lake, gradually rises along an alluvial fan to the top of a ridge at Halloran Summit, then runs down grade, levels off to Cima, rises to Mountain Pass, then runs down grade almost to the Nevada line.

Annual precipitation amounts to about 6 or 7 in. of rainfall.

The area is rural, desert, mountainous, barren lands, with large sand dunes creeping up mountain sides. Desert growth is scattered in density, depending on available water. Drifting sands, windstorms that can blast a windshield in minutes, and flash floods that fill a drainageway, blocking culverts and sometimes overtopping the highway, occur from time to time.

Average daily traffic volume is 6,600 vehicles of which 10% is commercial.

There are four lanes of asphaltic concrete pavement and shoulders with wide unpaved medians. There are six interchanges, all serving local county roads and all of "diamond" type. There are cuts and fills to 60 ft in the mountain area.

The crew of five is responsible for the maintenance of the section only. Additional help is available from the

Order	Acct.	Description
1	467	Mowing and weed control.
2	461	Roadside, cuts, fills, washouts.
3	441	Shoulder patching.
4	533	Signs and delineators.
5	531	Centerline and pavement markings.
6	445	Shoulder reshaping.
7	468	Reseeding, mulching, fertilizing, spreading dirt on roadside.
8	573	Litter cleanup.
9		All other.

From this tabulation it is obvious that in Florida mowing and weed control is always one of the most costly items. In this case mowing runs over 50% of the total cost, with erosion and shoulder patching running second and third high at approximately 6% each of the total cost.

The high cost of shoulder patching is due to the design features. These shoulders are surface-treated on a 6½-in. stabilized limerock base. On other jobs, where the shoulders are constructed of asphaltic concrete on a true limerock base, less maintenance costs occur. The surface-treated shoulders tend to ravel too quickly.

Test Section 24

This section, with a combined length of 10.1 centerline miles of urban Interstate highways located in the City of Jacksonville, consists of a 4.6-mile portion of I-10 and a 5.5-mile length of I-95. At the time of this study the section was six years old.

This urban section in the northwest area of Jacksonville is in flat terrain. The average annual temperature is 69 F, ranging from an average low of 59 F to an average high of 80 F. The annual average rainfall is 53 in. Here there is no snowfall or hard freezes to cause damage to the roads. The soil at this location is sandy loam, which is very conducive to erosion.

The traffic volume on this project varies from 32,000 to 70,000 vehicles, with the higher density on that part of I-10 nearest the "hub" and three miles of I-95 nearest the same point, with the lower volumes toward the extremities of the section on each route.

This test section is constructed of 9 in. of portland cement concrete, with four lanes over 65% of the test section covering the extremities, while the other 35% nearest the hub on both routes has six lanes. The shoulders vary from 8 ft to 10 ft wide outside and inside. The outside shoulders are constructed of double surface treatment of 6 in. of limerock base, whereas the inside shoulders are primarily of turf only over stabilized material.

Mowing on this project is a very expensive item of maintenance. The turf area represents approximately 370 acres, with 30% on steep slopes and 70% flat. As is typical in Florida, the steep slopes have to be mowed by a combination of hand mowers, hand labor, and the use of tractor-type slope mowers; the flatter slopes are mowed with the jeep and tractor mowers, with minor cleanup being done by hand crews.

The following tabulation shows the major items relating to the cost of maintenance on this test section in order of magnitude:

Order	Acct.	Description
1	573	Litter cleanup.
2	467	Mowing and weed control.
3	534	Guardrails.
4	531	Pavement marking.
5	441	Shoulder patching.
6	466	Trees, shrubs, and plantings.
7	449	Shoulders, other costs.
8	533	Traffic signs and delineators.
9		All other costs.

Test Section 25

This urban test section, 2.97 centerline miles in length, is located in Orlando on I-4. It is a portland cement concrete pavement five to six years old.

This section begins ¼ mile south of US 17 and 441 and runs northward. The average rainfall is 51 in. per year. The average temperature is 71.5 F, with a range from an average low of 62.0 F to an average high of 80.9 F.

The soil in this section is very sandy with a little loam. A good turf cover is necessary to prevent erosion from the frequent rains.

The traffic volume on the first two miles of this section was approximately 16,000 increasing to 33,000 in the last mile, which is closer to the downtown area. Numerous interchanges provide passage to and from town to the Interstate highway.

This portion of I-4 is six lanes wide, constructed of 9 in. of portland cement concrete with surface-treated outside shoulders over a limerock base. The inside shoulders are primarily of turf, all 8 ft in width. This section is covered with a Bahaia grass turf, which provides excellent protection to the slopes against erosion, even during the heaviest of rains. The total turf area is estimated at 65 acres, 25% of which (16 acres) is steep slopes, and the balance is of flatter slopes. The entire area is mowed by the use of small hand-type mowers (36 in. width) and hand labor, except for the tractor-type slope mowers used on the steep slopes. No large jeep or tractor mowers were used on the flatter slopes, as is the case in most of the other test sections. This partially accounts for the very high cost of mowing on this section.

This section includes a large amount of beautification work, which must necessarily be maintained by hand labor and small mowers. The five major and two minor interchanges do not present a major problem.

The following tabulation indicates the order of maintenance costs on this section:

Order	Acct.	Description
1	467	Mowing and weed control.
2	463	Cleaning for drainage.
3	461	Roadside, cuts, fills, and washouts.
4	573	Litter cleanup.
5	468	Reseeding, resodding, fertilizing, mulching.
6	466	Trees, shrubs, plantings.
7		All other costs.

Test Section 26

This 6.3-mile section is on I-95 in the northwestern part of Miami. It begins just north of the Municipal Airport interchange and runs north to the Golden Glades interchange on the main arterial route leading through and north from Miami. The southern 2.7-mile portion was opened to traffic in 1961 and the northern portion during 1962.

The test section is in the southernmost part of the State where the terrain is very flat. The runoff is very poor except through underground porous channels. Rainfall averages 46 in. per year. The temperature averages 75 F, ranging from an average low of 67 F to an average high of 83 F.

This entire section is flat, with high man-made fills at the interchanges and overheads. These slopes, however, are quite stable, as most of the fills are composed of a sandy marl or limerock substance that compacts well and does not erode easily. It is usually necessary to bring in a topsoil cover to obtain a good turf growth.

Traffic volumes on this test section range from 83,000 to 93,000 per day, with the highest figures being on the southern half of the project. Eight lanes of travel are provided where traffic is heaviest, dropping off to six lanes elsewhere. The mainline pavement is constructed of 9 in. of concrete flanked by an 8-ft double surface-treated shoulder on the outside and 5¼ ft to 8 ft on the inside. The mainline pavement has a 12-in. limerock stabilized base and the shoulders are constructed with a 6½-in. stabilized base. This section has six minor and six major interchanges, all of simple construction, spaced approximately ½ mile apart.

The roadside turf area along this 6.3-mile stretch involves 96 acres. This requires a constant mowing and litter cleanup program.

In order of magnitude the maintenance work load is distributed as follows:

Order	Description
1	Machine mowing, small machines and hand labor.
2	Signs.
3	Cleaning drainage ditches.
4	Guard rail.
5	Litter.
6	All other.

NEW YORK

With the exception of Long Island, New York State may be considered to have two types of terrain—rolling and mountainous. The Interstate highways in the mountainous (Adirondack) sections either were still under construction or were too recently completed to be considered proper for inclusion in this study. All of the test sections are in rolling terrain.

Test Section 41

This section, on I-81 in Oswego County, consists of 20.07 miles of portland cement concrete and 10.84 miles of bituminous concrete, and was completed in 1961. The southerly 4½ miles are six-lane portland cement concrete, reduced to four lanes for the rest of the concrete section and continuing the same pavement width for the balance of the test section.

The traffic on the southerly 4 miles is suburban in character, feeding communities and business establishments located short distances on either side of I-81. The balance of the section is rural. The entire section carries a heavy summer tourist traffic load to the Thousand Islands area, the St. Lawrence River, and Canada.

The north half of this section is a short distance east of Lake Ontario and is subject to frequent heavy rain and snowstorms. Many of these are sudden and unpredictable, making extreme measures necessary for proper traffic protection.

Test Section 42

This 27.49-mile section of bituminous concrete on I-81 was completed in 1961. This section is the northward extension of Test Section 41, all in Jefferson County, beginning at the Oswego County line and ending a short distance north of Watertown. I-81 continues north, approximately 20 miles to the Thousand Islands Bridge and resort area, the St. Lawrence River, and Canada. It runs through rolling verdant country of meadows and woods, with little evidence of land cultivation for particular crops.

The southern half of this section is in the same weather belt as the north portion of Section 41, subject to the same unexpected and severe turns of weather.

Although I-81 passes close to Watertown, the entire section must be classed as rural. Traffic is light except for the summer vacation period, when tourists and vacationers, bound for Adirondack Mountain resorts, the St. Lawrence vacation area, or Canadian summer retreats increase the traffic to an extent that it can be classed as "heavy" on certain days. The summer of 1967 is expected to see a tremendous increase in this traffic, due to the added attraction of Canada's "Expo 67."

Test Section 43

This 10.29-mile section of portland cement concrete on I-87 was completed in 1960. The test section is located in southern Westchester County adjacent and roughly parallel to the north city line of New York and

connects the New York State Thruway at Tarrytown with the Merritt Parkway at the Connecticut state line, passing through White Plains. It is distinctly urban, serving many large shopping complexes, industrial developments, and builtup residential areas, as well as New York City commuter traffic to and from Connecticut and the Boston area of New England.

There is a minimum of six lanes of concrete divided by a mall varying in width from a few feet with median barrier to 100 ft. The shoulders are bituminous-stabilized gravel or stone, 8 ft wide outside, and of variable width on the mall side. The cut and fill sections are about normal in depth for this type of highway (max. about 30 ft), mostly in rock, and there is no problem of stability of slopes.

Most maintenance operations can be carried on only from about 9:30 AM to 3 PM because of the extremely heavy commuter traffic volume. A 50,000-vehicle traffic count in not uncommon for this road.

Test Section 44

This 21.30-mile section of portland cement concrete on I-87 was completed in 1959 and 1961. The section starts at Exit 24 of the New York State Thruway and is the southern end of the "Northway," that portion of I-87 extending from Albany to the Canadian border near Rouses Point. For ½ mile it is within the city of Albany; the balance is in Albany and Saragota Counties.

Traffic on the south 6 or 7 miles must be classed as urban, serving the State University, the State's many departments located on the Campus, several large shopping centers, and many smaller businesses. These traffic generators have combined accommodations for more than 35,000 cars. The balance of the section should be classed as a busy rural section, except in the summer season, when the attractions at Saratoga, Lake George, and many other summer resort areas draw a traffic that approaches an urban classification. For short periods the three lanes, north or south, carry capacity traffic.

The Northway is carried over the Mohawk River on two-hinged riveted cellular arches more than 700 ft in length.

OHIO

The Ohio highways included in this study totaled some 135.52 centerline miles in six separate test sections. Four sections, totaling 77.32 miles, were selected on Interstate routes under the jurisdiction and control of the Ohio Department of Highways; two sections, totaling 58.20 miles, were selected on the Ohio Turnpike under the jurisdiction and control of the Ohio Turnpike Commission. The sections on the Turnpike were included primarily for the advantage offered to study roadways of comparable Interstate design and traffic having greater age than could be found on any other Interstate routes in Ohio. There was the added advantage of excellent maintenance records for the additional years during which the highway had been under maintenance.

Sections in Ohio were available in rural areas on both hilly and flat terrain in the northern and central portions of the State. The section selections were made with regard to traffic volumes, heavy and light snow areas, and hilly and flat terrain.

At the time of this study, State (including Interstate) highways in large cities were under the maintenance jurisdiction of the city through which such highways passed. Records of the kind needed in this study were apparently not readily obtainable from cities; therefore, none of the selected Ohio sections are located in urban areas. The sections selected and included in the study were as follows:

Test Section	*Interstate Route*	*County*	*Length (mi)*	*Description*
51	I-75	Hancock	25.23	Allen Co. line to Wood Co. line
53	I-71	Ashland	16.14	Richland Co. line to Wayne Co. line
55	I-70	Licking	21.88	Ohio 158 to 1 mi. E. of Muskingum Co. line
56	I-71	Franklin	14.07	S. city line Columbus to Pickaway Co. line
58	I-80 *	Portage	29.70	Milepost 183.2 to milepost 212.9
59	I-80 and I-90 *	Ottawa and Sandusky	28.50	Milepost 64.5 to milepost 93.0

* Ohio Turnpike.

All test sections are of the rigid pavement type.

The Ohio maintenance organization is set up on an area basis. The personnel and equipment used on the State-maintained test sections also have assignments on other sections of highways within their counties.

Test Section 51

This 25.23-mile four-lane divided test section on I-75, which by-passes Findlay, is the longest test section in Ohio. The pavement is in very good condition and has been in

service for 5½ years. The section presently carries an average daily traffic volume of 8,032 vehicles, of which 28% is of heavy commercial type.

The rural section is located in relatively flat terrain in northwest Ohio and receives an annual average of 36.3 in. of snow and 35.0 in. of rain. Temperatures range between − 10 and 100 F, averaging 52 F. The section experiences ice and snow problems and summer vegetation control problems. The amount of rainfall and the type of soil also create erosion problems where earth slopes were disturbed during construction.

The section contains four minor and one major interchange, and one rest area on each side. The rest areas contain a total of approximately 6 acres.

Maintenance of the section is performed under the daily supervision of a foreman with three equipment operators. Additional equipment operators and laborers are employed on the section from the remainder of the area employees as work load requires. In addition, a custodian is employed on a 40-hr week basis to take care of a pair of rest areas. The maintenance area is served by a yard and appropriate storage buildings and work space for minor equipment adjustments immediately adjacent to an interchange in Findlay.

Principal equipment units used on the section include three heavy trucks, two pickups, straight reversible-blade snowplows, hydromatic salt spreaders, an air compressor with pneumatic tools, and a small asphalt distributor.

This section is a four-lane divided portland concrete pavement with the usual acceleration and deceleration lanes at interchanges and at rest areas.

The total mowing required on this section is 645 acres, including 271 acres of median and shoulder mowing.

Test Section 53

This 16.14-mile section on I-71 is located in north central Ohio approximately 50 miles south of Lake Erie. It is a four-lane divided portland cement concrete highway opened to traffic in December 1959 and traversing rather rolling terrain in a rural area.

This section has a lush growth, receiving an average of 35.7 in. of rainfall per year. It also experiences an average annual snowfall of 41.3 in. These data indicate a need for an annual vegetation control program and a well-organized snow removal and ice control program.

The traffic volume on this section is 11,400 vehicles per day, of which 68% are passenger cars and light trucks and the remainder heavy trucks and buses.

The right-of-way required for this section of highway averages 300 ft and has only one interchange of minor classification. There are two rest areas at the south end of the section, one on each side of the highway. Six acres were required for these areas. The section has a 75-ft depressed turf median.

This section is quite rolling in most of its length, and therefore has some deep cuts and fills ranging from 20 to 40 ft. Several of the cuts are through solid rock. The portland cement concrete pavement is in very good condition, although some indication of pumping is evident and corrective treatment is needed.

Personnel and equipment used in the maintenance of this section are housed in a maintenance storage area at the Division Headquarters in Ashland. A foreman and a crew of three equipment operators are assigned.

Test Section 55

This 21.88-mile section of I-70 in a rural area of east central Ohio has served traffic since 1959. This pavement through the rolling hills of Licking County is in the snowbelt and experiences an average snowfall of 34.3 in., with a total average annual precipitation of 36 in.

Several deep rock cuts in the hilly sections show deterioration of the shale-like formations of the exposed slopes, causing slow and continuous fall of rock to the small and shallow roadside ditches. This results in frequent and costly ditch cleaning. A rather high water table and flat terrain on the western portion of the section causes drainage problems, as evidenced by the need to clear cattails repeatedly from the drainage channels.

This highway is a divided four-lane concrete pavement with the normal acceleration and deceleration lanes. There are two major and four minor interchanges and one pair of roadside rest areas. The right-of-way width of this section is generally 300 ft, with added width for heavy cuts and fills.

Of the average daily traffic volume of approximately 10,500 vehicles on this section approximately 3% is commercial.

Personnel and equipment used in the maintenance of this section are housed in a maintenance storage area at the Division Headquarters in Ashland. Although a foreman and a crew of 10 equipment operators are assigned primarily to this section, they also perform maintenance on other sections of highway in their county area.

Test Section 56

This 14.07-mile section is in the center of the State just south of the city limits of Columbus and extends southerly toward Cincinnati on I-75. The section is a four-lane divided portland cement concrete pavement in flat terrain.

The pavement was opened to traffic in 1960. The average daily traffic volume is 8,000 at the southerly end, increasing to an average daily total of 31,120 at the south limits of Columbus. The heavy-vehicle count increases from 2.4% at the south end to 5.6% of the total at the southern limits of Columbus.

The section experiences an average total annual precipitation of 36.3 in. Snowfall amounts to an average of 32.5 in.

Inasmuch as the section is in relatively flat terrain, there is little or no erosion problem except on several cut slopes in the very southern end. Here some sheet erosion of the cut slopes will require attention for a few years until ground cover is established.

The right-of-way width is generally 300 ft, with additional land for interchanges and one pair of rest areas. Mowing of the entire right-of-way requires the cutting of 375 acres.

At present the pavement is in excellent condition. The

shoulders, originally constructed of bituminous concrete, are in good condition but have settled and require a wedge of bituminous material at the pavement edge to restore the original shoulder elevation.

Access to the test section is provided by five major interchanges within the section limits.

A maintenance storage and headquarters area is conveniently located on a service road approximately midway in the section at the US 665 interchange.

In addition to a superintendent, personnel assigned to this section include five equipment operators, three laborers in rest areas, and one mechanic, one mechanic's helper and one clerk in the headquarters building.

Test Section 58

This 29.70-mile section on the Ohio Turnpike is located in the northeastern part of Ohio approximately 50 miles from Lake Erie. It is a four-lane portland cement concrete highway opened to traffic in October 1955. It is in rolling terrain, with cuts and fills of varying depths.

This section has good ground cover on all medians and outside shoulders, and on the right-of-way. There are some cuts through shale, which cause an erosion problem. It has an average of 37.2 in. of precipitation and 66.7 in. of snow per season. This necessitates a good vegetation control program, as well as snow and ice removal program for Ohio Turnpike patrons.

The average daily traffic volume on this section was 14,645 vehicles, with 20% heavy trucks and buses.

The right-of-way averages 200 ft wide. It has two major interchanges. The 40-ft depressed median is turf covered throughout its entire length.

Total area to mow is 254 acres. Unmowed areas are chemically treated two or three times per year.

Maintenance housing and shops are adjacent to the eastbound roadway approximately midway in the length of the test section. Facilities are provided for equipment repairs, personal services and conveniences, storage of materials and supplies, and an office for report preparation. Field operations on this section are controlled by radio communication equipment.

Twenty-four persons are assigned to the maintenance of this section.

Test Section 59

This 28.50-mile section on the Ohio Turnpike is located in the northwest part of Ohio approximately 20 miles from Lake Erie. It is a four-lane portland cement concrete highway opened to traffic in October 1955. It is on level terrain throughout its length.

This section has exceptionally good ground cover. It receives an average of 34.3 in. of precipitation each year and 41.3 in. of snowfall, requiring a good system of vegetation control and a snow and ice removal program.

The section has an average daily traffic count of 15,445, of which 22.2% are heavy trucks and buses.

The right-of-way for this section averages some 200 ft. It has two major interchanges and a 40-ft depressed median.

Complete mowing involves 245 acres; the remainder are treated with weed control chemicals two or three times each year.

Maintenance housing and shops are provided adjacent to the west-bound roadway approximately midway in the length of the section. Facilities are provided for equipment repairs, personal services and conveniences, storage of materials and supplies, and an office for report preparation. Field operations are controlled by radio communication.

Twenty-four persons are assigned to the maintenance of this section.

TEXAS

Texas highways included in this study total 120.50 centerline miles in six separate test sections. All six sections were selected on Interstate routes under the jurisdiction and control of the Texas State Highway Department.

Sections were available in both rural and urban areas on both flat and rolling terrain and located in various areas of the State. Two sections are in urban areas and four sections in rural areas. The section selections were made with regard to traffic volumes, heavy and light rainfall areas, and flat and rolling to hilly terrain. These sections are typical urban and rural types present in Texas. Sections having heavy, moderate, and light traffic have been selected. The sections selected and included in the study are as follows:

Test Section	*Interstate Route*	*County*	*Length (mi)*	*Limits*
65	I-40	Oldham	15.04	Vega to Potter Co. line
68	I-20	Howard	33.60	Martin Co. line to Mitchell Co. line
74	I-35	Hays	24.30	Travis Co. line to Comal Co. line
75	I-10	Bexar	11.06	Martin St. in San Antonio, northwest 11.06 mi
78	I-45	Ellis	23.40	Dallas Co. line to Navarro Co. line
79	I-35-E	Dallas	13.10	Trinity R. Bridge in Dallas, northwest 13.10 mi

The two urban sections, one in Dallas and the other in San Antonio, and the rural section in Ellis County are portland cement concrete pavements with bituminous surface on the service roads. The other three rural sections are entirely bituminous surface.

Inasmuch as the Texas maintenance organization is set up on an area basis, the personnel and equipment used on the test sections have assignments on other highway sections within their counties or areas.

Test Section 64

This 15.04-mile four-lane diveded section on I-40 has service roads throughout its length. The pavement is in good condition and has been in service approximately three years. The section carries an average daily traffic volume of 4,660 vehicles, of which 7% is of heavy commercial type.

This rural section, located in flat terrain in the panhandle of northwest Texas, receives an average rainfall of 19.67 in. each year and an average snowfall of 13.8 in. Temperatures range from an average annual low of 44.8 F to an average annual high of 72.5 F, averaging 58.7 F. Due to the flat terrain and low rainfall, there are no erosion problems on this section.

Maintenance of the section is performed under the daily supervision of a maintenance foreman. The maintenance area is served by a yard and appropriate warehouse, and work space for minor equipment repair and adjustments.

Principal units of equipment for this maintenance area which are available for use on the test section are dump trucks, pickups, large (Sno-go) snowplow, small push snowplows, air compressor with pneumatic tools, mowers, small asphalt distributor, and front-end loader.

This section is a four-lane divided bituminous pavement with several crossovers. This section does not have fully controlled access. There are no rest areas.

Total mowing requirements are 310 acres.

Test Section 68

This 33.60-mile four-lane divided section on I-20 has service roads throughout its entire length. The pavement is in good condition and 26.3 miles have been in service approximately eight years and the other 7.3 miles in service approximately three years. The section carries an average daily traffic volume of 5,640 vehicles, of which 8% is of heavy commercial type.

This rural section, located in flat to rolling terrain in the west part of Texas, receives an average annual rainfall of 15.5 in. and an average annual snowfall of 2.5 in. Temperatures range from an average annual low of 51.4 F to an average annual high of 76.9 F, averaging 64.2 F. On short sections the terrain is hilly and the soil is sandy clay, causing some minor erosion.

Maintenance of the section is performed under the daily supervision of a maintenance foreman. The maintenance area is served by a yard, warehouse, appropriate storage buildings, and work space for making minor repairs and adjustments to equipment.

Principal units of equipment for this maintenance area, which are available for use on the test section, are dump trucks, pickups, maintainers, rollers, front-end loader, mowers, air compressor with pneumatic tools, and an asphalt distributor.

This section is a four-lane divided bituminous pavement and has fully controlled access. It includes several minor interchanges with the usual acceleration and deceleration lanes. There are no rest areas; however, four such areas are under construction and will contain picnic tables with arbors, fireplaces, and incinerators. No water or comfort facilities are planned at this time.

Total mowing requirements are 635 acres.

Test Section 74

This 24.3-mile section is a four-lane divided highway on I-35 and has service roads throughout the entire length. The pavement is in good condition; 18.5 miles have been in service approximately seven years and the other 5.8 miles in service approximately ten years. The entire 24.3 miles received an asphaltic concrete level-up course recently. A bituminous seal coat was placed on the newer 18.5 miles and a hot-mix asphaltic concrete course was placed on the older 5.8 miles. This hot-mix asphaltic course is approximately 1.1 in. thick. The section carries an average daily traffic volume of 9,650 vehicles, of which 7.3% is of heavy commercial type.

This rural section, located in rolling terrain in the central part of Texas, receives an average annual rainfall of 32.8 in. and practically no snowfall. Temperatures range from an average annual low of 57.7 F to an average annual high of 78.7 F, averaging 68.3 F.

Maintenance of the section is under the daily supervision of a maintenance foreman. The maintenance area is served by a yard, warehouse, appropriate storage buildings, and work space for making minor repairs and adjustments to equipment.

Principal units of equipment for this maintenance area, which are available for usè on the test section, are dump trucks, pickups, maintainers, front-end loader, rollers, mowers, air compressor with pneumatic tools, and an asphalt distributor.

This section is a four-lane divided bituminous pavement and has fully controlled access, with several minor interchanges with the usual acceleration and deceleration lanes. There are two rest areas served by the usual acceleration and deceleration lanes and containing picnic tables, fireplaces, and incinerators.

Total mowing requirements are 490 acres.

Test Section 75

This 11.06-mile four-lane divided section on I-10 has service roads throughout its entire length. The pavement is in good condition; 8.9 miles has been in service approximately 5 years and the other 2.2 miles approximately 16 years. The average daily traffic volume is 28,120 vehicles, of which 12% is of heavy commercial type.

This urban section, located in rolling terrain in the south part of Texas, receives an average annual rainfall of 27.84 in. with practically no snowfall. Temperatures range from

an average annual low of 58.1 F to an average annual high of 79.2 F, averaging 68.7 F.

Maintenance of the section is performed under the daily supervision of a maintenance foreman. The maintenance area is served by a yard, warehouse, appropriate storage buildings, and work space for making minor repairs and adjustments to equipment.

Principal units of equipment for this maintenance area, which are available for use on the test section, are dump trucks, pickups, maintainers, rollers, front-end loader, mowers, air compressor with pneumatic tools, and an asphalt distributor.

This is a fully controlled access section with several minor and one major interchange. It has a four-lane divided portland cement concrete pavement with the usual acceleration and deceleration lanes at the interchanges.

Total mowing requirements are 220 acres.

Test Section 78

This 23.4-mile four-lane divided section on I-45 has service roads throughout its entire length. The pavement is in fair condition and has been in service approximately seven years. The section carries an average daily traffic volume of 7,370 vehicles, of which 18.4% is of heavy commercial type.

This rural section, located in rolling terrain in the north part of Texas, receives an average annual rainfall of 33.9 in. and very little snowfall, averaging only 0.8 in. per year. Temperatures range from an average annual low of 54.4 F to an average annual high of 77.0 F, averaging 65.6 F. The soil is heavy and black and the amount of rainfall creates vegetation control problems. Ditch and culvert cleaning is a continuing problem.

Maintenance of this section is performed under the daily supervision of a maintenance foreman. The maintenance area is served by a yard, warehouse, appropriate storage buildings, and work space for making minor repairs and adjustments to equipment.

Principal units of equipment for this maintenance area, which are available for use on the test section, are dump trucks, pickups, maintainers, rollers, front-end loader, air compressor with pneumatic tools, and an asphalt distributor.

This section is a four-lane divided portland cement concrete pavement and has fully controlled access with several minor interchanges with the usual acceleration and deceleration lanes. The service roads are bituminous surfaced. There are no rest areas.

Total mowing requirements are 505 acres.

Test Section 79

This 13.1-mile section on I-35E has service roads on a portion of the length. The pavement is in good condition. It was constructed in several sections and has been in service from approximately three to approximately nine years. This is a divided section with the number of lanes varying from six to ten. The average daily traffic volume is 22,150 vehicles, of which 8% is of heavy commercial type.

This urban section, located in rolling terrain in the north part of Texas, receives an average annual rainfall of 34.6 in. and an average annual snowfall of 2.3 in. Temperatures range from an average annual low of 55.6 F to an average annual high of 76.0 F, averaging 65.8 F.

Maintenance of the section is performed under the daily supervision of a maintenance foreman. The maintenance area is served by a yard, warehouse, appropriate storage buildings, and work space for making minor repairs and adjustments to equipment.

Principal units of equipment for this maintenance area, which are available for use on the test section, are dump trucks, pickups, maintainers, rollers, front-end loaders, air compressors with pneumatic tools, and an asphalt distributor.

This divided portland cement concrete pavement has fully controlled access with several minor interchanges with the usual acceleration and deceleration lanes.

Total mowing requirements are 305 acres.

APPENDIX B

CHART OF ACCOUNTS

INTERSTATE PHYSICAL OR GENERAL MAINTENANCE AND TRAFFIC SERVICES

Code	*Function*
410	Routine roadway surface operations:
411	Patching
413	Joint and crack filling
419	Other costs
420	Special roadway surface operations:
421	Mudjacking and undersealing
425	Bituminous treatment
426	Resurfacing (bituminous less than ¾ in. thick)
429	Other costs
440	Shoulders:
441	Patching

443 Bituminous resealing
444 Replacing in kind
445 Reshaping
446 Edge joint sealing
449 Other costs

460 Roadside and drainage:
461 Cuts, fills, and washouts
462 Drainage channels and structures
463 Cleaning for drainage
464 Cleaning and repairing catchment basins
465 Walls, cribbing, and riprap
466 Trees, shrubs, and planting
467 Mowing and weed control
468 Reseeding and resodding
479 Other costs

480 Structures:
482 Repairing and maintaining walls
483 Repairing and maintaining structures serving drainage systems
494 Repairing and maintaining bridges
499 Other costs

510 Snow, ice, and drift sand:
511 Snow and ice removal
512 Erection, removal, and maintenance of snow fences
513 Application of abrasives and chemicals
516 Opening of inlets and drainage channels
517 Removal of sand drifts
529 Other costs

530 Traffic control and service facilities:
531 Pavement marking
532 Repairing, maintaining, and operating electrical signal equipment
533 Repairing, maintaining, and operating traffic signs and delineators
534 Repairing and maintaining guardrail
535 Repairing and maintaining right-of-way fences
538 Repairing and maintaining highway lighting system
539 Operating highway lighting systems
548 Repairing and maintaining weighing and inspection facilities
550 Repairing and maintaining roadside rest areas and picnic grounds
553 Detours not chargeable to construction
559 Other costs

570 Other services:
573 Litter cleaning
574 Pavement sweeping
579 Other costs

600 Unusual or disaster maintenance

DEFINITIONS

410 Routine roadway surface operations:

The physical or general maintenance charges to accounts under this hearing include (a) all replacements in kind not exceeding 500 continuous feet, all (b) all repairs.

411 Patching—All permanent and temporary patching on both concrete and bituminous pavements.

413 Joint and crack filling—All work associated with joint and crack filling of a pavement, including cleaning and cutting wells, but not including any work associated with the edge crack between the pavement and shoulder, which should be charged to account 449.

419 Other costs—All routine work done on the pavement surface which is not included under accounts 411 and 413.

420 Special roadway surface operations:

The physical or general maintenance charges to accounts under this heading include (a) all replacements in kind not exceeding 500 continuous feet, and (b) all repairs.

421 Mudjacking and undersealing—All work associated with raising concrete slabs by pumping material under the slab or any work associated with filling voids under either rigid or flexible-type pavements regardless of the type of material used.

425 Bituminous treatment—All work where bituminous liquids are placed on a pavement surface, not including joint or crack filling, and regardless of whether aggregates are used to cover the bituminous liquid. Covering excess bituminous material with sand or aggregate also is included under this item.

426 Resurfacing (bituminous less than ¾ in. thick)—All work where a bituminous mix is used on pavement surface, not including items normally included under patching, and where final thickness of the bituminous material does not exceed ¾ in.

429 Other costs—All special work done on the pavement surface which is not included under accounts 421, 425, or 426.

440 Shoulders:

The stabilized or specially treated area which parallels and adjoins the roadway pavement surface.

Berm—The sodded area which parallels and adjoins the shoulder surface.

The physical or general maintenance charges to accounts under this heading include (a) all replacements in kind not exceeding 500 continuous feet, and (b) all repairs.

441 Patching—All permanent and temporary patching done on shoulders.

443 Bituminous resealing—All work associated with shoulder surfaces where bituminous liquid or mixes are used and not included under account 441.

444 Replacing in kind—All work associated with rebuilding a shoulder to its original design. This item specifically excludes any items which would fall under accounts 441 or 443, which should be used if in doubt.

445 Reshaping—All work connected with reshaping, cutting, or rolling the berm or shoulder area.

446 Edge joint sealing—All work associated with the sealing of the edge joint between the pavement surface and the shoulder and the placement of a bituminous wedge course at the same location.

449 Other costs—All work done on the shoulder which is not covered by accounts 441, 443, 444, 445, or 446.

460 Roadside and drainage:

The physical or general maintenance charges to accounts under this heading include all repairs, cleaning, rebuilding, care, and replacements meeting essentially the original design.

461 Cuts, fills, and washouts—All work associated with repair or replacement to original design standards of any cuts, fills, or slopes.

462 Drainage channels and structures—All repair and reshaping of drainage ditches, diversion ditches, and channels, and repair of culverts, underdrains, outfall, and paved ditches.

463 Cleaning for drainage—All cleaning associated with drainage ditches, diversion ditches, channels, culverts, underdrains, outfall, and paved ditches.

464 Cleaning and repairing catchment basins—Any work directly associated with catchment basins.

465 Walls, cribbing, and riprap—All work done on riprap and cribbing plus all small walls serving primarily in conjunction with drainage and not included under account 482, which is reserved for major classes of retaining walls.

466 Trees, shrubs, and planting—All work associated with the maintenance of existing trees, shrubs, and planting. This item includes new materials to replace old materials, but not additional new material.

467 Mowing and weed control—All work associated with mechanical and chemical mowing or weed control.

468 Reseeding and resodding—All work associated with seeding or sodding when existing turf is involved. Does not include the seeding or sodding of previously unturfed areas. Includes any reseeding or resodding of areas occasioned by reshaping operations.

479 Other costs—All work associated with the maintenance of the roadside and drainage facilities which is not included in accounts 461-468.

480 Structures:

The physical or general maintenance charged to accounts under structures includes all cleaning, painting, repairs and minor replacements meeting essentially the original design.

482 Repairing and maintaining walls—All work associated with major retaining walls and cribbing.

483 Repairing and maintaining structures serving drainage systems—All work associated with pumphouses, lift stations, and other such structures serving highway drainage facilities.

494 Repairing and maintaining bridges—All work associated with bridges, grade separations, underpasses, overpasses, or pedestrian bridge structures.

499 Other costs—All work associated with any structure not covered in accounts 462, 482, 483, or 494.

510 Snow, ice, and drift sand:

All items related to the prevention or the removal of ice, snow, and sand on the travel way and any measures taken to reduce the hazards associated with the presence of either ice, snow, or drift sand.

511 Snow and ice removal—All work associated with the removal of ice or snow from the travel way such as sweeping, plowing, scraping, hauling, loading to haul, blowing, or by use of heating devices either within pavement or by direct application to the pavement surface from some external source.

512 Erection, removal, and maintenance of snow fences—All work associated with the repair, painting, installation, and removal of temporary snow fences and the care and maintenance of permanent snow fences.

513 Application of abrasives and chemicals—All work associated with the handling, applying, or eventual cleaning and removal of deicing chemicals and abrasives such as sand, cinders, slag, or stone from the travel way.

516 Opening of inlets and drainage channels—All work associated with the removal of ice and snow from inlets and drainage channels or the removal of materials used to combat the effects of ice and snow.

517 Removal of sand drifts—All work associated with the removal of drift sand from the travel way such as blowing, sweeping, plowing, scraping, hauling, or loading to haul.

529 Other costs—Traffic control during storms and all work associated with the prevention, removal or elimination of hazards occasioned by the presence of ice, snow, or drift sand not covered in accounts 511-517.

530 Traffic control and service facilities:

The maintenance and operation of traffic control and service facilities.

531 Pavement markings—All work associated with the placement, painting, or removal of any lines, marks, or signing set into or applied upon the pavement or curbing for regulating, warning, and guiding traffic on the travel way.

532 Repairing, maintaining, and operating electrical signal equipment—All work associated with powered devices used for the purpose of alerting traffic to take some specific action.

533 Repairing, maintaining, and operating traffic signs and delineators—All work associated with repairing, operating, painting, and replacing in kind devices mounted on fixed or portable supports which regulate, warn, guide, or direct traffic on a travel way.

534 Repairing and maintaining guardrail—All work associated with painting, repairing, and replacing in kind any guardrail or median barrier fences.

535 Repairing and maintaining right-of-way fences—All work associated with painting, repairing, and replacing in kind any right-of-way fences.

538 Repairing and maintaining highway lighting system—All work associated with painting, repairing, and replacing in kind poles, luminaires, conduits, power lines, or other lighting components and all bulb replacement cost.

539 Operating highway lighting systems—Cost of electric power for highway lighting.

548 Repairing and maintaining weighing and inspection facilities—All work associated with the facilities that is not accommodated under a more specific account; e.g., patching of any pavement belongs in account 411, while any mowing or weed control belongs in account 467.

550 Repairing and maintaining roadside rest areas and picnic grounds—All work done in the rest or picnic ground area that cannot be accommodated under a more specific account; e.g., 511 (snow and ice removal) or 466 (trees, shrubs, and planting).

553 Detours not chargeable to construction—All work associated with the installation, maintenance, and removal of detours not chargeable to construction.

559 Other costs—All work items related to directing, aiding, or assisting the highway user which are not covered by any other account.

570 Other services:

The charges under this account cover other miscellaneous services provided directly for the comfort and convenience of the highway user.

573 Litter cleaning—All work associated with the routine or scheduled removal of litter from any area within the right-of-way (other than mechanical sweeping).

574 Pavement sweeping—The mechanical sweeping or cleaning of the pavement surface.

579 Other costs—Towing and ambulance service, fire fighting service, special removal of hazardous debris (such as dead animals, lumber, tires) from the pavement, and other work not included in items 573 or 574.

600 Unusual or disaster maintenance:

Any repair or replacement occasioned by storms, floods, military operation, etc., which results in extensive or extraordinary maintenance.

APPENDIX C

INSTRUCTIONS FOR TEST SECTION DAILY REPORT

1. Interstate route number refers to the Federal designation given to the National Interstate and Defense Highway System.
2. Control section number is the section number used by the agency maintaining the section and will be different from our designation.
3. Each data page shall be numbered using the "Sheet _____ of _____" designation, including single data sheets where the indication will be "Sheet 1 of 1."
4. Date should be given as month, day and year (Date 8/20/65).
5. Our identification number for the Study Section is Test Section No. _____.
6. Each operation performed on the test section for a particular day should be noted with our chart of account code number. A comprehensive description of the operation should be provided. When our account classification is very broad; e.g., repairing and maintaining bridges, additional information relating to the specific nature of the operation should be provided (i.e., painting, spot painting, bridge deck sealing, etc.)
7. The location of the operation should be identified by one of the following categories:
    1. Main roadway.
    2. Interchange.
    3. Roadside rest.
    4. Truck weighing stations.
    5. Service roads.
    6. Other.

8. Milepost refers to the mileage stationing limits encompassing the location where the operation was performed. Frequently a single spot location will suffice and in these cases a single entry for milepost can be recorded. For structures, an identifying number may be adequate and should be recorded under location. Where this is done, no milepost designation will be necessary.
9. The number of work units should be noted for the following accounts:

   411 Pavement, patches.
   421 Mudjacking and undersealing, sites.
   441 Shoulder, patches.
   461 Cut, fill, and washout, locations.
   462 Drainage channels and structures, locations.
   463 Cleaning for drainage, sites.
   464 Catchment, basins.
   516 Inlets and drainage channel, sites.
   538 Lights.

10. Under the heading "Labor," list the total number of hours, hourly wage rate, general labor classifications, and account number that can be associated with a particular operation. The general labor classifications are: (1) supervisors, (2) heavy equipment operators, (3) light equipment operators, (4) skilled labor, and (5) common labor.
11. Under the heading "Equipment," list each unit of equipment by the agency's equipment number, our classification type, the total time operated or miles used for each operation and account number. List the rental rate used by the agency for their equipment.
12. Under "Material," record our general classification of material plus a brief description. The total material quantity plus unit cost should be shown for each operation and the account number for the operation should be shown.
13. For later identification, the agency representative filling out the Test Section Daily Report should note his last name and initials, title, and office location.
14. The purpose of the column heading "Work Units," is to show how many work sites or places were involved in a particular activity. For instance, if a pavement patching crew set up three different work zones and performed patching work at three different sites or places during the day, the report would show the figure "3" in the Work Units column (regardless of the number of patches made at each site). If washouts were repaired by maintenance crews at four different locations on embankment slopes, "4" should be reported in the Work Units column.

    Another type of work, for example, would be fence or guardrail repairs. If fence repairs were made by crews at two different work sites, the figure "2" would be shown in the "Work Unit" column. The same system would be followed for delineator repairs, catch basin or culvert cleaning, ditch or drainage work, etc.

    Where an operation is continuous throughout a section of highway, the whole section of highway is considered as one work site and the figure "1" is shown in the "Work Unit" column. Examples of this type of activity might include most mowing work, cleaning of delineators, guardrail painting, paint striping, litter removal, etc.

    All operations should show an entry in the "Work Unit" column. The examples shown in item 9 are those most frequently involved, but all operations (whether listed in item 9 or not) should be reported by work units.

TEST SECTION CREW, EQUIPMENT, AND JURISDICTION RECORD

1. Obtain the name, job classification, and hourly pay rate (or other wage rate) for all personnel who participate in maintenance work on the Test Section or anyone charging his time to the Test Section.
2. Obtain a complete list or record of all equipment used on the Test Section or charged to the Test Section. Make sure that there is an identifying number, rental rate or cost, and a complete description for each piece of equipment.
3. There will frequently be a division of responsibility for maintaining service roads, structures, bridges, etc. For that reason, it will be necessary to determine the exact responsibility of the State where such divisions of responsibility exist. Obtain a detailed list of all components of the Test Section not maintained completely by the State agency. Identify each component by number or milepost location and outline the exact maintenance responsibility of the State in each case.

FIELD REPRESENTATIVE PROCEDURES

1. As soon as practical after the selection of the Test Sections, a maintenance condition survey should be conducted. Subsequent maintenance condition surveys should be made in the spring, midsummer, and late fall of 1966.
2. Periodic visits should be made to each Test Section. The recommended interval is 4 weeks. Field representatives should complete each of the following tasks during each Test Section visit:

   (a) Collect and review all Test Section Daily Reports accumulated between visits.
   (b) Assign Tallamy Associates classification and chart of account numbers to any items not presently having these designations on the Test Section daily reports.
   (c) Make a cursory examination of any major maintenance work performed during the reported interval and evaluate the adequacy of the work. The criteria outlined in the condition survey definitions can be used as a guide. The actual

THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by President Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as an official—yet independent—adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE HIGHWAY RESEARCH BOARD, organized November 11, 1920, as an agency of the Division of Engineering, is a cooperative organization of the highway technologists of America operating under the auspices of the National Research Council and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the Board are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.

evaluation should be noted under remarks on the back of the Test Section daily report form. Make sure that the operation being evaluated is also noted.

(d) Through discussion with local personnel, identify any work performed on the section which is not accounted for on the Test Section daily reports. Make arrangements to insure that any such work is reported on a Test Section daily report form by the unit doing the work.

3. After field visits to Test Sections are completed and Test Section daily reports have been collected, checked, and corrected or supplemented as required, reports should be mailed to the Washington office for processing.

APPENDIX D

INSTRUCTIONS FOR TEST SECTION MAINTENANCE CONDITION SURVEY

The purpose of making the Test Section condition survey is to provide information on (1) how much maintenance work is needed; (2) how much maintenance work was accomplished; and (3) how well the maintenance work was done on the Test Section.

The following definitions should be used in rating each of the items listed on the Test Section maintenance condition survey record form.

Pavement Maintenance

Patching:

Number of sites requiring patching:

Slight (rigid): A site which is lightly scaled. A site where joint or crack has spalled to between 2 and 3 in. in width. The riding surface is neither hazardous or rough.

Slight (flexible): A site where fine cracks or light raveling exists. A light skin patch, paint patching, or light spot seal is indicated. Areas showing initial evidence of settlement, distortion, rutting, corrugating, or shoving. The riding surface is neither hazardous nor rough.

Moderate (rigid): A site where progressive scaling has occurred. A site where cracking has resulted in pavement movement or the creation of a rough spot. Joint or crack spalling where width of spall exceeds 3 in. or has created a pronounced bump in pavement.

Moderate (flexible): Small chuck or pot holes (up to 6 in. in diameter). Site where riding surface is rough due to settlement, distortion, rutting, corrugating or shoving. Site where limited disintegration has occurred due to abrasion, raveling, rutting, or oxidation.

Severe (rigid): Site where a section of pavement has failed. Extensive scaling and surface deterioration creating a substantial hazard to highway user. Sites where chunks of pavement are missing, creating holes hazardous to highway user. Progressive disintegration of pavement at joints due to major spalling and subsequent traffic action.

Severe (flexible): Large chuck or pot holes (over 6 in. in diameter). Sites where extensive disintegration of pavement has created a rough and hazardous riding surface. Raveling, rutting, shoving, or settlement which creates hazardous conditions.

Number of sites having temporary patches in place:

Good: Patching is completely adequate, with possibly a few minor deficiencies.

Fair: Patching looks sloppy but is sufficient.

Poor: Patching is inadequate and should be replaced. Loose patching creates a traffic hazard.

Number of sites having permanent patches in place:

Good: Patching is completely adequate, with possibly a few minor deficiencies.

Fair: Patching looks sloppy but is sufficient.

Poor: Patching is inadequate and should be replaced. Loose patching creates a traffic hazard.

Joint and crack filling:

Percentage of joints and cracks which are adequate and the percentage which require sealing in the following conditions:

Slight: Cracks between ¼ and ⅜ in. wide which have not been sealed. Existing sealant becoming surface dry. Initial contamination of joint evidenced by dirt and possibly small stones.

Moderate: Cracks between ⅜ and ⅝ in. wide which have not been sealed. Existing sealant becoming brittle or "dead," as evidenced by lack of adherence or bonding to pavement. Appreciable contamination by dirt and stones in the disintegrated sealant present in joint or crack.

Severe: Cracks over ⅝ in. wide which have not been sealed. Complete disintegration of existing sealants. Joints completely open or filled with dirt or stones.

Mudjacking:

Number of sites which require mudjacking:

Slight: Any evidence of a void under pavement, such as pumping or deflection cracking.

Moderate: Evidence of void under pavement, plus a slab vertical displacement not exceeding ½ in. at joints and cracks.

Severe: Slabs with vertical displacement beyond ½ in. at joints and cracks.

Number of sites which have been mudjacked:

Good: No vertical displacement of slab or evidence of pumping.

Fair: No breaking or cracking of slab. Mudjack holes well filled. Slight vertical displacement not exceeding ½ in. and no evidence of pumping. Some slab cracks evident. Unsealed mudjack holes.

Poor: Vertical displacement of slab exceeding ½ in. or evidence of pumping. Slab broken and cracked, unsealed and spalled mudjack holes.

Bituminous surface treatment:

Percentage of surface area which is adequate and the percentage which requires surface treatment in the following conditions:

Slight: Initial evidence of extensive fine cracking or drying of the pavement surface.

Moderate: Evidence of surface disintegration due to abrasion, raveling, rutting, or oxidation. Extensive fine cracking.

Severe: Significant surface disintegration. Excessive cracking and raveling.

Shoulders

Patching:

Number of sites which require patching:

Slight: A site where fine cracks or light raveling exists. A light skin patch, paint patching, or light spot seal is indicated. Areas showing initial evidence of settlement, distortion, rutting, corrugating, or shoving.

Moderate: Small chuck or pot holes (over 6 in. in diameter). Site where limited disintegration has occurred due to abrasion, raveling, rutting, or oxidation.

Severe: Large chuck or pot holes (over 6 in. in diameter). Site where extensive disintegration of shoulder exists. Extremes of raveling or settlement, which create hazardous conditions.

Bituminous surface treatment:

Percentage of area which is adequate and the percentage which requires surface treatment in the following conditions:

Slight: Initial evidence of extensive fine cracking or drying of the pavement surface.

Moderate: Evidence of surface disintegration due to abrasion, raveling, rutting, or oxidation. Extensive fine cracking.

Severe: Significant surface disintegration. Excessive cracking and raveling.

Edge joint sealing:

Percentage of edge joint which is adequate and the percentage which requires treatment in the following conditions:

Slight: Cracks between ¼ and ⅜ in. wide which have not been sealed. Existing sealant has become surface dry. Initial contamination of joint evidenced by dirt and possibly small stones.

Moderate: Cracks between ⅜ and ⅝ in. wide which have not been sealed. Existing sealant becoming brittle or "dead," as evidenced by lack of adherence or bonding to pavement. Appreciable contamination by dirt and stones in disintegrated sealant present in joint or crack.

Severe: Cracks over ⅝ in. wide which have not been sealed. Complete disintegration of existing sealants. Joint completely open or filled with dirt or stones.

Drainage System

Ditch cleaning:

Percentage of total ditch length which is adequate and the percentage which requires cleaning or reshaping in the following conditions:

Slight: Initial evidence of erosion or silting of ditch bottom.

Moderate: Erosion or scour of ditch bottom. Silting or filling of invert with some ponding of water. Undesirable vegetative growth present.

Severe: Flooding during rain, standing water in ditches, extensive erosion or silting. Extensive growth obstructing water flow.

Culverts, drainage walls, cribbing, and riprap:

Number of culverts which need cleaning:

Slight: Some deposit or trash and debris in culvert invert without any loss of capacity.

Moderate: Extensive deposits, trash, or debris present in culvert invert, causing up to a one-third loss of capacity.

Severe: Very extensive deposits, trash, or debris present in culvert, causing over a one-third loss of capacity.

Number of structures which require repair:

Major: Any repair required to correct structural integrity or performance inadequacies.

Minor: Repairs not related to the structural integrity or performance capabilities of culverts, drainage walls, cribbing, or riprap.

Slopes:

Percentage of total slope area which is adequate and the percentage which requires erosion repair in the following conditions:

Slight: Initial evidence of erosion ruts and channels.

Moderate: Extensive rutting and channeling on slopes.

Severe: Major erosion and subsequent instability or collapse of segments of the slope.

Turf and Plant Maintenance

(No instructions are needed for this self-explanatory section of the condition survey.)

Traffic Control

Guardrail and barrier fencing:

Percentage of total guardrail and barrier fence which is adequate and percentage which needs repair in the following conditions:

Slight: Minor dents and some need for painting. Wire tightening. Minor fence and rail straightening.
Moderate: Painting needed. Extensive wire tightening required. Major denting. Spot destruction of rail (must be replaced). Major fence and rail straightening.
Severe: Complete destruction of rail. Broken supports. Fence hazardous to motorist. Lack of effective guardrail protection.

Right-of-way fence:

Percentage of r/w fence which is adequate and percentage which requires repair in the following conditions:

Slight: Isolated spots requiring straightening or wire tightening.
Moderate: Areas where straightening, wire tightening, and minor restoration is needed.
Severe: Broken, flattened, or damaged fence requiring extensive repair or replacement.

Major traffic sign structures (more than single-pole support):

(Section self-explanatory.)

Minor traffic signs (single-pole support):

Percentage of total minor signs which are adequate and percentage which require cleaning, straightening or repair:

Slight: Becoming dirty. Minor straightening.
Moderate: Dirty, need painting, extensive straightening, minor repairs.
Severe: Signs ineffective due to lack of legibility. Destroyed beyond recognition. Missing.

Delineators:

Percentage of total delineators which are adequate and percentage which require cleaning, straightening, or repair:

Slight: Becoming dirty. Minor straightening.
Moderate: Dirty, need painting, extensive straightening, and minor repairs.
Severe: Signs ineffective due to lack of legibility. Destroyed beyond recognition. Missing.

Structures

Retaining walls:

Number of retaining walls which require repair:

Major: Any repair needed to correct structural integrity or performance inadequacies.
Minor: Repairs not related to the structural integrity or performance capabilities.

Structure painting:

Major: Extensive evidence of rusting and need for a substantially complete repainting of the structure.
Minor: Little or no rusting apparent. Some spot painting required.

Structure repairing:

Major: Repairs needed to insure structural integrity or performance capabilities, deck resurfacing or replacement, structural steel replacement, or concrete replacement.
Minor: Repairs or items not related to structural integrity, such as deck spot patching, rail replacement, or cleaning.

Cleaning and sweeping

Appearance of pavement areas:

Good: No papers, dirt, or debris in evidence.
Fair: Miscellaneous debris noticeable, but does not create a cluttered appearance.
Poor: Obvious need for cleaning and sweeping.

Appearance of unpaved right-of-way area:

Good: No papers, dirt, or debris in evidence.
Fair: Miscellaneous debris noticeable, but does not create a cluttered appearance.
Poor: Obvious need for cleaning.

APPENDIX E

PROCEDURE STUDIES

During this study 150 "observations of work procedures" were made and reported. These observations covered approximately 20 different kinds of work procedures in the five States. Included were snow removal operations, pavement patching, mudjacking, bituminous surface sealing, pavement edge joint sealing, ditch and culvert cleaning, mowing, bridge deck repair, pavement marking, guardrail repainting, litter removal, shoulder patching, sign repair, median fence repair, and roadway lighting repairs. Most of these procedures were well planned and carried out under existing conditions and policies.

Utilizing the information obtained and recorded on the observation of work procedure form, the Field Representative studied the possibility of improving the maintenance procedures within the limits of equipment and personnel available and the conditions existing on the test section. As expected, many of the procedures were well planned and no particular improvements could be suggested. In several instances, however, improvements were devised and proposed for testing in the field. Several revisions proved to offer distinct advantages.

Edge Seal, Test Section 3

Sealing the crack between portland cement concrete and a bituminous shoulder was studied on the test section and a revised procedure was suggested and tested in the field. The original procedure was performed using a lead worker with three men. Here, the several hours required to heat the solid asphalt to proper flow temperature caused some lost time. Also, the practice of cleaning too far ahead of the pouring operation created double effort because debris refilled the crack.

In the revised procedure, a yard man was instructed to start the asphalt heating operation several hours before normal shift time. This eliminated waiting time for the crew while the asphalt was heated to proper temperature. Also, cleaning the joint with a jet of compressed air just ahead of the pouring operation eliminated some loss of time. Finally, the efficiency of the workmen pouring the heated asphalt was improved by welding a bracket fitted with a caster wheel on the pouring can so that it could ride on the pavement edge and take the weight of the loaded pouring can off the arms of the workmen.

A study of the resultant changes revealed that production was doubled per day, while the labor cost per day was reduced 9.4%. This resulted in a reduction in costs for the completed edge seal operation from $162.10 per mile to $61.39 per mile.

Shoulder Buildup, Test Section 50

The operation to correct the depressed shoulder at the pavement edge required a buildup of 1 to 3 in. adjacent to the pavement of 1 to 2 or more feet in width.

The observed procedure was as follows: Under the direction of a foreman, the shoulder at the pavement edge, over a 14-in. width, was given a shot of liquid asphalt. From a 2-ton truck loaded with a bituminous mix, a man hand shoveled mix onto the shoulder adjacent to the pavement in the quantity required to bring the shoulder elevation up to the pavement elevation. A roller compacted this material with two passes. A shot of liquid asphalt (0.15 gal/sq yd) was applied to the newly compacted material, followed by a light cover of stone chips. The labor force was composed of the working crew chief, two equipment operators, and two laborers. The equipment consisted of one pickup truck, two light (2 ton, 4 cu yd) trucks, one roller, and one asphalt distributor. The work completed by this method averaged 2 miles per 8-hr day.

Upon analyzing the procedure, the Field Representative determined that this procedure could be improved by placing the bituminous mix mechanically. Accordingly, a spreader box and hitch for a two-ton truck was made in the shop for the purpose. Using the same labor force and equipment complement with the towed spreader box for the bituminous mix, a trial run was made on the job. It required two days to train the crew in the new procedure, during which they averaged 1.6 miles per day. However, after the third day the crew accomplished an average of 4.1 miles per day and the cost of the operation was reduced from $161.37 per mile to $92.41 per mile.

Shoulder Sealing, Test Section 58

The original procedure for the surface sealing of asphaltic shoulders used a work zone of 2 miles protected by the usual placement of cones and signs. Much time was lost after work in the 2-mile zone had been completed until the new work zone was protected and marked.

A plan was developed to institute a "moving zone" type of protection. A large sign (approx. 8 ft × 10 ft) bearing the legend "Lane Closed" with a large left arrow was affixed to the rear of a large truck. The truck was also equipped with a flashing beacon light and large iridescent red flags at a high elevation above car height fixed to the rear sign on the truck. In lieu of the fixed zone markers, this truck followed the sealing operation at a distance of 2,500 ft. The change increased the personnel complement by two equipment operators, one to drive the truck for hauling increased material requirements and one to drive the sign truck. The equipment requirements increased by the two trucks mentioned. Production by this change in procedure increased from an average of 8 miles per shift to 14 miles per shift and significantly reduced the unit cost for sealing of shoulders.

Sealing Edge Joint, Test Section 55

The hand work being done to open or clean out the joint between the concrete pavement and the bituminous shoulder for sealing resulted in a low daily progress rate. Observation indicated that better progress and better sealing could be obtained within the capacity of equipment now used if a method could be devised to eliminate the present hand cleaning of the joint to receive the sealing material. To accomplish this, a heavy disc wheel, about 14″ in diameter and beveled on one side, was mounted on the hydraulically-controlled undercarriage of a motor grader. Traveling along the edge of the pavement, the disc wheel with beveled edge to the outside pushed the bituminous shoulder material out about ½ in. from the pavement for a depth of about 1½ in., creating a well to receive the bituminous sealing compound. The remainder of the procedure was as previously performed. The addition of the motor grader more than doubled the rate of production and effectively reduced the unit cost of the work.

Litter Pickup, Test Section 21

For litter removal, with foreman, truck operator, and four laborers, a truck was driven down the right shoulder. Three laborers picked up litter and placed it in the sacks each man was carrying. One man collected litter in the same manner on the near half of the median. When the sacks were filled, they were taken to the truck and emptied. When one side of the highway was completed, the other side was similarly treated on the return trip.

A revised procedure used the foreman-truck operator with six laborers. In this operation, two laborers were assigned with sacks to each side of the 4-lane divided

highway and two were assigned to the center median. In this manner, the litter was collected from the entire roadside with one trip over the route. The time was reduced from 4 hr 45 min to 2 hr. Although the number of laborers was increased, labor and equipment time was reduced with the net average savings in two separate trials on two separate test sections showing an average reduction of 37% in cost per mile for litter pickup.

Guardrail Painting, Test Section 22

Hand cleaning and brush painting was the standard procedure. By using an air brush painting system, cleaning in the same manner as previously, cost per unit of fence painted both sides was reduced by 31%.

Mowing, Test Section 23

The practice had been to use two 80-in. rotary mowers for the operation, together with one garden-type rotary for trim work. One mower was pulled by a jeep, which also provided transportation for personnel to and from the work area, and one was pulled by a 40-hp tractor. In a revised operation, the tractor pulled a 15-ft rotary mower unit in place of the 80-in. unit. As a result, production was increased with a saving of 40.6% in cost per acre mowed.

APPENDIX F

EQUIPMENT RENTAL RATE FACTOR

In the development of the daily report format, ten general categories of equipment were designated for classification purposes (Chapter Two). This made it possible to determine the total dollars spent in each classification in each of the five States. Further, because the raw data also contained the hours or miles used, along with an associated rental rate, it was possible to get a composite unit cost of equipment for each of the ten classifications. The total dollars spent in each classification also were determined and a percentage distribution for the reported cost of equipment by classification was calculated. A measure of rental rate and use by classification was the sum of the products: composite unit cost multiplied by percentage distribution based on costs, for each classification. The resulting values reflect in magnitude a use weighting by classification and composite rental rate. Before these values could be used to weight the reported equipment costs in the States, they had to be converted to an index. This was done by averaging the numbers from the five States and equating the average to 1. The ratio of each State's number to the average then produced a weighting factor proportional to the average value, which was 1.

Before developing the foregoing factors, it was necessary to convert the mileage rate, which was reported in three of the five States for the 1 and 2 classifications, to a comparable hourly rate. As a first step, the other eight hourly classifications were examined to identify those where there was considerable use reflected for all test sections. Only class 3 appeared to fit, so the class 3 composite rate was used to effect the conversion of the mileage rate to an hourly rate. This was accomplished by first calculating a composite rate for a combined class 1 and 2 for all five States. This resulted in the following values:

California	\$0.151/mile
Florida	\$0.104/mile
New York	\$3.240/hour
Ohio	\$2.160/hour
Texas	\$0.080/mile

The mileage values were compared with the class 3 hourly rates and a factor determined for each:

	3	*Factor 1 & 2*
California	5.24 /	34.6 = \$0.151
Florida	3.28 /	31.6 = \$0.104
Texas	3.02 /	37.7 = \$0.080
	Average	103.9/3 = 34.6
New York	5.54 /	1.71 = \$3.240
Ohio	4.76/	2.21 = \$2.160
	Average	3.92/2 = 1.96

The mileage factor was determined by dividing the two factors (34.6/1.96 = 17.6), or 17.6 miles use was equal to one hour at 17.6 times the mileage rental rate.

After making the mileage-hourly conversion where needed, the following combined classification distribution-composite rental rates were developed for each of the States:

	Sum	*Index*
California	4.92/3.17	= 1.55
Florida	1.77/3.17	= 0.56
New York	3.71/3.17	= 1.17
Ohio	3.11/3.17	= 0.98
Texas	2.34/3.17	= 0.74
	15.85/5	= 3.17

Although these index values reflected the actual distribution of use, in many cases they were influenced by rental rates which included both equipment and an operator. If a factor had been developed for each activity, this would be appropriate; however, the same factor was applied to all activities. It was felt that the index factors should be modified so they more closely reflected variations in the rental rates. To do this, a second index factor based on a combined 1 and 2 classification was developed. These classes were selected because a comparable type of equipment was always used by all of the States for these two classes. The index factors developed from this approach were as follows:

			Index
California	0.151 × 17.6 =	2.66/2.26	= 1.18
Florida	0.104 × 17.6 =	1.83/2.26	= 0.81
New York	3.240 =	3.24/2.26	= 1.43
Ohio	2.160 =	2.16/2.26	= 0.96
Texas	0.080 × 17.6 =	1.41/2.26	= 0.62
	Average	11.30/5	= 2.26

The actual equipment factor used in the compilation of adjusted equipment cost was the average of the foregoing two index factors, which resulted in the following values:

	Ave. Index	*1 Index*
California	(1.55 + 1.23)/2 = 1.39	0.72
Florida	(0.56 + 0.81)/2 = 0.68	1.47
New York	(1.14 + 1.43)/2 = 1.28	0.78
Ohio	(0.98 + 0.96)/2 = 0.97	1.03
Texas	(0.74 + 0.63)/2 = 0.69	1.45

The inverse of these values was multiplied by the total equipment use.

APPENDIX G

TEST SECTION INVENTORY DATA

Test Sect No	Mainline Pavement Type	Mainline Pavement Width	Mainline Pavement Age	Shoulder Width Outside	Shoulder Width Inside	Ditching Miles	Catchbasin & Drop Inlets	Pipe Culverts ≤ 36" dia No	Pipe Culverts ≤ 36" dia Lin Ft	Pipe Culverts Over 36" dia No	Pipe Culverts Over 36" dia Lin Ft	Box Culverts No	Box Culverts Lin Ft	Guardrail Lin Ft	Lighting Units	Signs Major	Signs Minor	Signs Delineators
1	C	48 Ft.	4 5	10 Ft	4 Ft	35	140	295	28,546	22	3,640	2	560	30,624	43	103	225	2,775
2	C	48 Ft	4 4	10 Ft	5 Ft			613	90,920	12	5,462	1	10	8,698	0	91	959	4,318
3	C	48 Ft	6 5	10 Ft	5 Ft			452	54,182	17	3,126	12	1,020	32,366	40	89	541	4,091
4	B & C	78 Ft	7 0	10 Ft	8 Ft			1709	243,883	58	17,562	33	11,606	103,370	458	278	1,156	3,115
5	C	96 Ft	5 2	10 Ft	8 Ft			613	56,121	78	17,655	17	2,825	45,566	352	106	608	2,800
6	B	48 Ft	3 0	10 Ft	5 Ft			433	33,338	23	2,348	17	1,652	7,630	0	94	206	3,840
21	B	48 Ft	3 0	8 Ft.	4 Ft	49	--	44	8,484	6	1,930	15	3,443	7,445	27	43	140	1,920
22	C	48 Ft	5 0	8 Ft	8 Ft	55	60	25	3,632	4	534	6	1,161	10,390	None	54	177	2,150
23	B	60 Ft	5 0	8 Ft	8 Ft	15	56	31	4,034	4	737	7	1,653	7,400	None	54	180	1,840
24	C	60 Ft	6 5	10-8 Ft	10-8 Ft	45	369	377	37,856	51	9,635	1	44	27,835	603	81	334	2,283
25	C	72 Ft	5 2	8 Ft	8 Ft	6	80	10	1,198	None	None	1	302	6,200	None	25	116	680
26	C	84 Ft	4 7	8 Ft.	5-8 Ft	8	351	392	25,462	103	21,946	--	--	7,654	896	32	227	520
41	B & C	48 Ft	5 0	8 Ft	4 Ft	95	30	230	22,860	30	5,667	14	833	63,116	None	446	0	3,046
42	B & C	48 Ft	6 1	8 Ft	4 Ft	100	43	315	26,114	52	8,756	10	1,591	107,458	None	93	385	2,600
43	C	72 Ft	6 0	8 Ft	4 Ft	18	554	205	54,362	15	7,395	12	2,663	67,842	None	498	50	3,720
44	C	72 Ft	4 8	8 Ft	4 Ft	85	141	400	43,836	60	10,449	None	None	200,884	None	240	321	5,669
51	C	48 Ft	5 8	10 Ft.	4 Ft	86		175	36,002	28	5,122	15	9,388	2,600	18	75	440	1,147
53	C	48 Ft	6 0	10 Ft	4 Ft	48		92	87,992	39	9,229	--	--	124,743	None	233	195	883
55	C	48 Ft.	7 0	10 Ft	4 Ft	41		54	9,550	32	5,102	None		122,915	None	140	121	1,324
56	C	48 Ft	4 8	10 Ft	4 Ft	43		183	17,352	21	6,470	None		2,250	None	33	25	303
58	C	48 Ft	10 0	10 Ft	8 Ft	86		246	66,409	50	9,711	--	--	183,552	52	50	170	1,040
59	C	48 Ft	10 0	10 Ft	8 Ft	54		124	11,378	23	3,962			158,836	52	50	170	960
64	B	48 Ft	2 2	11 Ft	6 Ft	75	15	28	1,502	None	None	18	1,434	3,850	None	10	132	396
68	B	48 Ft	6 2	10 Ft	4 Ft	156	71	34	3,467	None	None	146	12,539	72,948	None	190	605	3,182
74	B	48 Ft	7 0	10 Ft	6 Ft	115	347	81	18,109	12	5,526	15	5,068	20,960	317	147	361	2,013
75	C	49 Ft	6 9	10 Ft	4 Ft	19	865	42	5,631	4	568	13	1,550	122,027	2,413	72	358	814
78	C	48 Ft	6 7	10 Ft	4 Ft	120	121	229	27,271	22	9,506	12	1,450	12,340	None	130	410	2,141
79	C	79 Ft	5 7	10 Ft	10 Ft	25	447	13	960	2	910	12	1,853	156,456	1,348	81	328	1,287

Test Sect No	Structures No	Structures Area(1000 sq ft)	Interchanges No	Interchanges Lane Mile	Traffic Volume ADT/100	Mowing Acre/Mile	Mowing Season Months	Mowing Season Precip	Mowing Season Temp Ave	Snowfall (Nov -Apr) Precip	Snowfall Days	Snowfall Cover	Temperature (Nov -Apr) Ave	Temp Max 32	Temp Min 32	Temp Min 0
1	3	30 5	7	1 25	56 6		1	4 1	49 3	33 39	50 0	82 0	37.6	3 0	120 0	0.0
2	13	103.5	12	0 68	70 0		1	5 0	50 1	41 43	43.0	146 0	39 6	21 0	93 0	0 0
3	15	150 9	6	0 67	66 0		1	2.2	50 1	12 13	30 0	118.0	29 6	21 0	173 0	47 0
4	31	612 9	22	1 24	658 7	15 6	10	18 6	58 0	18 87	0 0	0 0	52 0	0 0	1 0	0 0
5	3	122 5	22	1 23	1302 0	17 0	12	12 63	60 9	12 37	0.0	0 0	57 0	0 0	0 0	0 0
6	19	76 2	6	1 15	66.0		--	--		4 06	0 0	0 0	56 2	0 0	29 0	0 0
21	18	165 4	5	1 54	92 7	28 0	11	54 62	70 4	26 75	0 0	0 0	58 0	0 0	27 0	0 0
22	22	160 1	10	1 22	149 1	20 5	11	52 94	73 6	16 48	0 0	0 0	55 7	0.0	6 0	0 0
23	26	132 5	7	1 00	99 1	29 9	12	52 80	72 5	18 16	0.0	0 0	62.3	0.0	6 0	0 0
24	54	585 8	16	1 13	515 0	36 5	9	45 15	81 9	19 16	0 0	0 0	58 8	0 0	14 0	0 0
25	18	236 8	7	1 07	195.0	21 8	12	51 37	72 5	18 54	0 0	0 0	64 8	0 0	2 0	0 0
26	14	464 8	12	0 85	897 4	15 1	10	41 88	78 0	12.19	0.0	0 0	70 6	0.0	0 0	0.0
41	8	75.9	8	1 04	45 3	11 7	6	18 59	64 8	17 15	103 0	108 0	31 6	50 0	127 0	15 0
42	12	429.8	11	1 20	42 0	15 0	6	16 70	64 8	12 52	89 0	78.0	29 6	57 0	146 0	20 0
43	22	440 5	19	0 77	416 5	7 5	8	20 97	63 0	16 73	30 0	28 0	38 6	16 0	92 0	0 0
44	15	205 6	10	1.48	150 1	15 2	5	12 7	67 3	13 05	72.0	82.0	32 0	38 0	142 0	12 0
51	25	280 4	5	0 84	74 4	25.6	7	28 91	62 3	10.38	66.0	36.0	35 9	41.0	113.0	4.0
53	16	112 4	1	1 44	114 0	25 9	6	21 14	62 3	12 24	81 0	71 0	34.6	45 0	126 0	5 0
55	27	416 2	5	1 22	103 8	29.6	6	22 12	66 5	13 82	62.0	36.0	37.0	35.0	112 0	4 0
56	18	207 2	5	1.61	140 2	26 7	6	14 74	66.5	12 66	51.0	39 0	39 0	32.0	89 0	2 0
58	21	121 0	2	0 51	146 5	15 0	5	16 99	64 8	16 95	38.0	51.0	36 4	39.0	120 0	3.0
59	26	1331 7	2	0 51	154 5	15 0	5	14 88	67.2	11 91	78 0	62 0	33 6	48.0	103 0	5 0
64	2	10 6	1	0 10	46 6	20 6	6	17 22	69 9	2 45	23.0	20 0	43 5	16 0	99.0	5 0
68	65	699 0	22	0 10	56 4	18 9	7	11.77	75 0	8 08	0 0	0 0	53 5	4.0	52 0	0 0
74	52	757.8	15	0 10	96 5	21.0	9	15.27	72.5	20.09	0 0	0.0	56.2	0.0	34.0	0 0
75	55	1569 2	16	0 19	281 2	19 9	12	27.84	68 8	13.51	3.0	2 0	57 3	0.0	32.0	0 0
78	67	630 8	15	0 10	74 0	21 6	11	31 14	69 8	22 85	0 0	0 0	55 0	2.0	24 0	0.0
79	58	1536.0	24	0 10	221 5	22.3	9	27.05	62.9	26 47	12 0	8 0	53 8	4.0	31.0	0 0

APPENDIX H

REGRESSION ANALYSES

The regression program permitted up to 40 variables and 99,999 observations, and was therefore adequate to handle any multiple regression analysis needed for the study. Any combination of dependent and independent variables could be called from data read into core storage using a single selection card for each combination desired. The program computed means, standard deviations, correlation criteria, regression coefficients, and various confidence measures. The first confidence measure examined was the coefficient of correlation between each independent variable and the dependent variable. Perfect correlation is 1.00 and a maximum value was sought for this measure. With those independent variables which seemed to have a significant effect on the dependent variables multiple regression analyses were made. The results were then tested using various significance tests.

SIGNIFICANCE TEST

When statistical methods are applied to experimental data it is necessary to determine which observed effects can be included in the interpretation of any results. Because experiments are subject to errors, there is a need to distinguish between variations caused by chance and those which can be attributed to real differences in the data. An objective basis is needed for making these decisions and this is provided by significance tests. Essentially these are tests based on some hypothesis or theory and an associated set of values which have a low probability of occurring. If an actual observation gives a result included in the set of values, the hypothesis may be rejected. This is know as the null hypothesis. A null hpyothesis assumes that there is no difference between the value calculated from a sample and the corresponding value from the population. If there is a difference which is significant, the null hypothesis is rejected—in other words, there may be some functional relationship between a calculated value and the corresponding value from the population.

The probability level for the rejection of the null hypothesis is called the significance level of the test—for the analysis of the test section data using multiple regression techniques, a 0.05 significance level was used. This means that a 5 percent risk of error was accepted.

Although significance tests were used in the interpretation of the analysis of the maintenance requirements data, they were not rigorously applied to every situation, particularly where judgment and previous experience dictated a conclusion which was at variance with the dictates of the significance test. For example, traffic is known to have an effect on certain maintenance costs, so its exclusion from a model which predicted cost associated with traffic is not warranted even if significance test indicated no evidence of its effect. Generally, evidence which a significance test admits is less conclusive than that which has been demonstrated by previous experience.

THE *t* TEST

The *t* test was used to determine whether the regression coefficient obtained for each variable was significantly different from zero. In this case, the null hypothesis was based on the assumption that the coefficient might be zero.

The computed *t* value, which is the ratio of the calculated regression coefficient to the standard error of that coefficient, was compared to a table of *t* values having a 0.05 significance level for the appropriate degrees of freedom. If the computed value was larger than the table value, the hypothesis was rejected and the regression coefficient accepted as being significantly different from zero.

F TEST

Like the *t* test, the *F* test also includes setting up a hypothesis and then calculating *F* on the basis that the hypothesis is true. However, where the *t* test is a measure of the probability that the regression coefficient is significantly different from zero, the *F* test provides a method for determining whether the ratio of the variances is larger than might be expected by chance if they had been drawn from the same population. Actually, the *F* values are to test specifically whether one variance estimate is larger than another, not just whether the variances are significantly different. The indicated probability levels must be doubled in the *F* test to see if there is a significant difference between two variance estimated. For the multiple regressions used in the study, the *F* value to be exceeded ranged between 4 and 6 for 95% confidence. In other words, if the *F* value did not exceed these values there was insufficient evidence that the second variance included factors not included in the first, and therefore the hypothesis that the variances estimated are equal is accepted meaning that the multiple regression model was not acceptable.

The *F* values calculated for multiple regression model for the seven general maintenance activity areas all exceeded the before-mentioned 4-6 range, so there is no basis for rejecting the results of any of the regressions.

The multiple correlation coefficient, normally expressed as *R*, is a measure of the correlation between the independent and dependent variables. *R* can have any value from 0 to 1, but none greater than any single *X* versus *Y* correlation. Where there is a strong correlation (i.e., a value close to 1) between variables, the multiple correlation, *R*, is not much better than the single values alone. However, where the correlation coefficient for two inde-

pendent variables is fairly small, the multiple correlation is generally larger than the simple correlation coefficients taken separately. Therefore, for good correlation between independent variables little is gained by having multiple correlation in terms of both, whereas when there is little correlation between two independent variables the use of a multiple correlation containing both will improve the overall correlation.

MULTIPLE REGRESSIONS

Pavement and Shoulders, Selection 1

VARIABLE NO.	MEAN	STANDARD DEVIATION	CORRELATION X VS Y	REGRESSION COEFFICIENT	STD. ERROR OF REG.COEF.	COMPUTED T VALUE
1	33.27962	23.05664	0.83900	19.72308	2.41203	8.17696
2	15.73333	19.46336	0.66701	13.72267	2.85733	4.80261
DEPENDENT 3	689.43311	666.03442				

INTERCEPT	-182.84644
MULTIPLE CORRELATION	0.91669
STD. ERROR OF ESTIMATE	275.82520

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F VALUE
ATTRIBUTABLE TO REGRESSION	2	10810302.00000	5405151.00000	71.04602
DEVIATION FROM REGRESSION	27	2054149.00000	76079.56250	
TOTAL	29	12864451.00000		

TABLE OF RESIDUALS

CASE NO.	Y VALUE	Y ESTIMATE	RESIDUAL	X_1	X_2	Y
1	545.00000	257.71387	287.28613	20.25	3.00	545.00
2	614.00000	487.16772	126.83228	19.36	21.00	614.00
3	359.00000	938.62939	-579.62939	42.25	21.00	359.00
4	775.00000	783.58447	-8.58447	49.00	0.0	775.00
5	552.00000	350.46558	201.53442	27.04	0.0	552.00
6	324.00000	-5.33868	329.33862	9.00	0.0	324.00
7	91.00000	-5.33868	96.33868	9.00	0.0	91.00
8	646.00000	310.23047	335.76953	25.00	0.0	646.00
9	254.00000	310.23047	-56.23047	25.00	0.0	254.00
10	623.00000	652.42578	-29.42578	42.35	0.0	623.00
11	238.00000	350.46558	-112.46558	27.04	0.0	238.00
12	3.00000	252.83618	-249.83618	22.09	0.0	3.00
13	1093.00000	996.36377	96.63623	25.00	50.00	1093.00
14	988.00000	1333.24121	-345.24121	37.21	57.00	988.00
15	1059.00000	746.74707	312.25293	36.00	16.00	1059.00
16	847.00000	793.03442	53.96558	23.04	38.00	847.00
17	892.00000	1043.26709	-151.26709	33.64	41.00	892.00
18	1123.00000	1144.70459	-21.70459	36.00	45.00	1123.00
19	1237.00000	1263.87769	-26.87769	49.00	35.00	1237.00
20	421.00000	709.90967	-288.90967	23.00	32.00	421.00
21	2579.00000	2324.64575	254.35425	100.00	39.00	2579.00
22	2937.00000	2448.14990	488.85010	100.00	48.00	2937.00
23	334.00000	132.17595	201.82405	4.84	16.00	334.00
24	155.00000	629.41040	-474.41040	38.40	4.00	155.00
25	514.00000	783.58447	-269.58447	49.00	0.0	514.00
26	409.00000	773.72290	-364.72290	48.50	0.0	409.00
27	839.00000	729.96802	109.03198	44.89	2.00	839.00
28	232.00000	512.84692	-280.84692	32.49	4.00	232.00
29	0.0	-182.84644	182.84644	0.0	0.0	0.0
30	0.0	-182.84644	182.84644	0.0	0.0	0.0

Drainage and Erosion, Selection 1

VARIABLE NO.	MEAN	STANDARD DEVIATION	CORRELATION X VS Y	REGRESSION COEFFICIENT	STD. ERROR OF REG.COEF.	COMPUTED T VALUE
1	2.41607	3.17877	0.77905	41.32495	7.25993	5.69220
2	32.21492	15.64585	0.45017	2.67855	1.47500	1.81596
DEPENDENT 3	258.80762	185.68790				

INTERCEPT 72.67455

MULTIPLE CORRELATION 0.80792

STD. ERROR OF ESTIMATE 113.71817

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F VALUE
ATTRIBUTABLE TO REGRESSION	2	607664.37500	303832.18750	23.49492
DEVIATION FROM REGRESSION	25	323295.62500	12931.82422	
TOTAL	27	930960.00000		

TABLE OF RESIDUALS

CASE NO.	Y VALUE	Y ESTIMATE	RESIDUAL	X_1	X_2	Y
1	700.00000	608.66626	91.33374	9.80	48.91	700.00
2	514.88589	639.36230	-124.47241	9.80	60.37	514.89
3	491.34985	547.72559	-56.37573	9.75	26.93	491.35
4	395.79980	140.88535	254.91446	0.20	22.38	395.80
5	577.00000	313.12891	263.87109	5.00	12.63	577.00
6	65.79999	89.57616	-23.77617	0.0	6.31	65.80
7	312.09985	264.82837	47.27148	1.00	56.31	312.10
8	277.59985	255.42668	22.17317	1.00	52.80	277.60
9	330.79980	339.57642	-8.77661	3.00	53.36	330.80
10	321.89990	266.83643	55.06348	1.70	46.26	321.90
11	36.20000	214.76637	-178.56638	1.00	37.62	36.20
12	199.70000	229.02713	-29.32713	1.50	35.23	199.70
13	249.50000	305.86450	-56.36450	3.50	33.06	249.50
14	399.69995	464.33374	-64.63379	7.50	30.51	399.70
15	314.69995	189.59639	125.10356	0.40	37.48	314.70
16	246.09999	191.41779	54.68221	0.40	38.16	246.10
17	282.00000	220.48674	61.51326	1.20	36.67	282.00
18	139.29999	171.20651	-31.90652	0.20	33.70	139.30
19	112.59999	188.22281	-75.62282	0.30	38.51	112.60
20	293.50000	154.37019	139.12981	0.0	30.50	293.50
21	54.59999	125.36153	-70.76154	0.0	19.67	54.60
22	106.39999	159.64941	-53.24942	1.10	15.50	106.40
23	46.00000	206.01503	-160.01503	1.10	32.81	46.00
24	76.39999	188.57021	-112.17021	1.00	27.84	76.40
25	212.09999	233.72963	-21.62964	1.70	33.90	212.10
26	490.59985	392.63916	97.96069	5.50	34.60	490.60
27	0.0	72.67455	-72.67455	0.0	0.0	0.0
28	0.0	72.67455	-72.67455	0.0	0.0	0.0

Vegetation Control, Selection 3

VARIABLE NO.	MEAN	STANDARD DEVIATION	CORRELATION X VS Y	REGRESSION COEFFICIENT	STD. ERROR OF REG.COEF.	COMPUTED T VALUE
1	7.95238	2.43877	0.77382	97.52240	49.73303	1.96092
2	26.92467	14.16341	0.83424	35.11951	8.58532	4.09065
3	297.51807	436.52124	0.66921	0.97516	0.18193	5.36006
DEPENDENT 4	1266.99072	981.14648				

INTERCEPT -744.25244

MULTIPLE CORRELATION 0.94913

STD. ERROR OF ESTIMATE 335.09521

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F VALUE
ATTRIBUTABLE TO REGRESSION	3	17344080.00000	5781360.00000	51.48645
DEVIATION FROM REGRESSION	17	1908912.00000	112288.93750	
TOTAL	20	19252992.00000		

TABLE OF RESIDUALS

CASE NO.	Y VALUE	Y ESTIMATE	RESIDUAL	X_1	X_2	X_3	Y
1	3227.05981	2337.02051	890.03931	11.00	54.62	92.60	3227.06
2	2147.95996	2333.11597	-185.15601	11.00	52.94	149.10	2147.96
3	2197.73999	2376.96387	-179.22388	12.00	52.80	99.10	2197.74
4	2338.82983	2723.31250	-384.48267	9.00	45.15	1029.80	2338.83
5	3507.82983	3451.99023	55.83960	10.00	41.88	1794.80	3507.83
6	452.56982	537.92773	-85.35791	6.00	18.59	45.30	452.57
7	732.06982	468.33398	263.73584	6.00	16.70	42.00	732.07
8	1742.75000	1584.88403	157.86597	8.00	20.97	833.20	1742.75
9	483.32983	335.74805	147.58179	5.00	12.70	150.10	483.33
10	778.64990	1026.26050	-247.61060	7.00	28.91	74.40	778.65
11	705.59985	694.37866	11.22119	6.00	21.14	113.90	705.60
12	505.52979	718.94653	-213.41675	6.00	22.12	103.80	505.53
13	577.40991	495.26025	82.14966	6.00	14.74	140.20	577.41
14	483.15991	482.89990	0.26001	5.00	16.99	146.50	483.16
15	334.78979	416.59937	-81.80957	5.00	14.88	154.50	334.79
16	309.33984	491.08154	-181.74170	6.00	17.22	46.60	309.34
17	496.08984	406.75952	89.33032	7.00	11.77	56.40	496.09
18	938.50000	763.82642	174.67358	9.00	15.27	96.50	938.50
19	2016.92993	1952.17212	64.75781	12.00	27.84	562.40	2016.93
20	800.60986	1493.98437	-693.37451	11.00	31.14	73.70	800.61
21	1830.08984	1515.42627	314.66357	9.00	27.05	443.00	1830.09

Structures, Selection 1

VARIABLE NO.	MEAN	STANDARD DEVIATION	CORRELATION X VS Y	REGRESSION COEFFICIENT	STD. ERROR OF REG.COEF.	COMPUTED T VALUE
1	33.92592	43.68149	0.67350	1.62543	0.35680	4.55564
DEPENDENT 2	82.77777	105.42195				

INTERCEPT 27.63347

MULTIPLE CORRELATION 0.67350

STD. ERROR OF ESTIMATE 79.47011

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F VALUE
ATTRIBUTABLE TO REGRESSION	1	131071.18750	131071.18750	20.75388
DEVIATION FROM REGRESSION	25	157887.50000	6315.50000	
TOTAL	26	288958.68750		

TABLE OF RESIDUALS

CASE NO.	Y VALUE	Y ESTIMATE	RESIDUAL	X_1	Y_2
1	100.00000	160.91896	-60.91896	82.00	100.00
2	183.00000	264.94653	-81.94653	146.00	183.00
3	119.00000	219.43456	-100.43456	118.00	119.00
4	36.00000	27.63347	8.36653	0.0	36.00
5	146.00000	27.63347	118.36653	0.0	146.00
6	14.00000	27.63347	-13.63347	0.0	14.00
7	0.0	27.63347	-27.63347	0.0	0.0
8	7.00000	27.63347	-20.63347	0.0	7.00
9	2.00000	27.63347	-25.63347	0.0	2.00
10	2.00000	27.63347	-25.63347	0.0	2.00
11	9.00000	27.63347	-18.63347	0.0	9.00
12	33.00000	27.63347	5.36653	0.0	33.00
13	205.00000	203.18022	1.81978	108.00	205.00
14	282.00000	154.41724	127.58276	78.00	282.00
15	194.00000	73.14558	120.85442	28.00	194.00
16	415.00000	160.91896	254.08104	82.00	415.00
17	41.00000	86.14905	-45.14905	36.00	41.00
18	118.00000	143.03920	-25.03920	71.00	118.00
19	30.00000	86.14905	-56.14905	36.00	30.00
20	0.0	91.02534	-91.02534	39.00	0.0
21	203.00000	128.41031	74.58969	62.00	203.00
22	0.0	60.14212	-60.14212	20.00	0.0
23	7.00000	27.63347	-20.63347	0.0	7.00
24	10.00000	27.63347	-17.63347	0.0	10.00
25	4.00000	30.88432	-26.88432	2.00	4.00
26	28.00000	27.63347	0.36653	0.0	28.00
27	47.00000	40.63693	6.36307	8.00	47.00

Ice and Snow Control, Selection 2

VARIABLE NO.	MEAN	STANDARD DEVIATION	CORRELATION X VS Y	REGRESSION COEFFICIENT	STD. ERROR OF REG.COEF.	COMPUTED T VALUE
1	30.54637	48.29124	0.93779	14.84776	5.60385	2.64956
2	29.67856	33.75952	0.56149	-37.48770	7.59604	-4.93517
3	34.53571	42.98618	0.92333	24.28178	7.97117	3.04620
4	16.85713	19.67836	0.54532	50.97586	11.23478	4.53733
DEPENDENT 5	1065.02734	1548.96924				

INTERCEPT 26.16797

MULTIPLE CORRELATION 0.97503

STD. ERROR OF ESTIMATE 372.69678

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F VALUE
ATTRIBUTABLE TO REGRESSION	4	61586480.00000	15396620.00000	110.84445
DEVIATION FROM REGRESSION	23	3194768.00000	138902.93750	
TOTAL	27	64781248.00000		

TABLE OF RESIDUALS

CASE NO.	Y VALUE	Y ESTIMATE	RESIDUAL	X_1	X_2	X_3	X_4	Y
1	1834.71997	1572.72388	261.99609	86.00	50.00	82.00	3.00	1834.72
2	5506.51953	5602.94531	-96.42578	173.30	43.00	146.00	21.00	5506.52
3	4566.83984	4915.96484	-349.12500	140.00	30.00	118.00	21.00	4566.84
4	2.24000	26.16797	-23.92796	0.0	0.0	0.0	0.0	2.24
5	4.52000	26.16797	-21.64796	0.0	0.0	0.0	0.0	4.52
6	133.59999	41.01572	92.58427	1.00	0.0	0.0	0.0	133.60
7	0.0	26.16797	-26.16797	0.0	0.0	0.0	0.0	0.0
8	0.0	26.16797	-26.16797	0.0	0.0	0.0	0.0	0.0
9	0.0	26.16797	-26.16797	0.0	0.0	0.0	0.0	0.0
10	0.0	26.16797	-26.16797	0.0	0.0	0.0	0.0	0.0
11	0.0	26.16797	-26.16797	0.0	0.0	0.0	0.0	0.0
12	0.0	26.16797	-26.16797	0.0	0.0	0.0	0.0	0.0
13	3834.00000	3088.19580	745.80420	118.00	103.00	108.00	50.00	3834.00
14	2360.47998	2974.14160	-613.66162	100.00	89.00	78.00	57.00	2360.48
15	1149.83984	855.83643	294.00342	30.90	30.00	28.00	16.00	1149.84
16	1932.19995	2230.73975	-298.53979	65.70	72.00	82.00	38.00	1932.20
17	681.11987	618.58374	62.53613	6.90	66.00	36.00	41.00	681.12
18	1084.43994	1322.35669	-237.91675	21.20	81.00	71.00	45.00	1084.44
19	378.27979	620.06543	-241.78564	17.50	62.00	36.00	35.00	378.28
20	732.19995	891.47241	-159.27246	13.40	51.00	39.00	32.00	732.20
21	3537.55981	2372.97729	1164.58252	36.70	38.00	51.00	39.00	3537.56
22	1291.63989	1348.42656	-56.78467	19.80	78.00	62.00	48.00	1291.64
23	51.20000	600.31494	-549.11475	9.10	23.00	20.00	16.00	51.20
24	202.71999	240.46483	-37.74484	0.70	0.0	0.0	4.00	202.72
25	57.48000	85.55901	-28.07901	4.00	0.0	0.0	0.0	57.48
26	77.51999	14.23558	63.28441	3.50	3.00	2.00	0.0	77.52
27	108.71999	162.26952	-53.54953	2.30	0.0	0.0	2.00	108.72
28	292.95996	53.16650	239.79346	5.30	12.00	8.00	4.00	292.96

Traffic Control Facilities, Selection 1

VARIABLE NO.	MEAN	STANDARD DEVIATION	CORRELATION X VS Y	REGRESSION COEFFICIENT	STD. ERROR OF REG.COEF.	COMPUTED T VALUE
1	201.19949	265.92407	0.95756	3.21300	0.19343	16.61067
DEPENDENT						
2	811.18237	892.28320				

INTERCEPT 164.72852

MULTIPLE CORRELATION 0.95756

STD. ERROR OF ESTIMATE 262.28149

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F VALUE
ATTRIBUTABLE TO REGRESSION	1	18980624.00000	18980624.00000	275.91455
DEVIATION FROM REGRESSION	25	1719792.00000	68791.62500	
TOTAL	26	20700416.00000		

TABLE OF RESIDUALS

CASE NO.	Y VALUE	Y ESTIMATE	RESIDUAL	X_1	Y_2
1	632.04980	346.58423	285.46558	56.60	632.05
2	284.50000	389.63843	-105.13843	70.00	284.50
3	541.12988	376.78638	164.34351	66.00	541.13
4	2332.28979	2281.13159	51.15820	658.70	2332.29
5	4214.90625	4348.05078	-133.14453	1302.00	4214.91
6	84.31999	376.78638	-292.46631	66.00	84.32
7	217.84999	462.25220	-244.40221	92.60	217.85
8	608.41992	643.78662	-35.36670	149.10	608.42
9	244.56000	483.13672	-238.57672	99.10	244.56
10	1715.14990	1818.45947	-103.30957	514.70	1715.15
11	730.10986	790.94214	-60.83228	194.90	730.11
12	476.60986	310.27734	166.33252	45.30	476.61
13	530.78979	299.67432	231.11548	42.00	530.79
14	1729.17993	1503.26392	225.91602	416.60	1729.18
15	1316.33984	646.99976	669.34009	150.10	1316.34
16	308.10986	403.77563	-95.66577	74.40	308.11
17	460.51978	530.68921	-70.16943	113.90	460.52
18	105.64000	498.23779	-392.59766	103.80	105.64
19	86.65999	615.19092	-528.53076	140.20	86.66
20	802.65991	635.43286	167.22705	146.50	802.66
21	778.63989	661.13696	117.50293	154.50	778.64
22	104.45999	314.45410	-209.99411	46.60	104.46
23	325.25000	345.94165	-20.69165	56.40	325.25
24	432.96997	474.78296	-41.81299	96.50	432.97
25	1559.17993	1068.22388	490.95605	281.20	1559.18
26	350.36987	401.52661	-51.15674	73.70	350.37
27	929.29980	874.80151	54.49829	221.00	929.30

Litter and Sweeping, Selection 1

VARIABLE NO.	MEAN	STANDARD DEVIATION	CORRELATION X VS Y	REGRESSION COEFFICIENT	STD. ERROR OF REG.COEF	COMPUTED T VALUE
1	226.08844	292.25171	0.68267	0.50683	0.29015	1.74677
2	1.28571	0.46004	0.83016	780.88647	182.17143	4.28655
4	2.45357	3.13326	0.25569	50.88721	18.27283	2.78486
DEPENDENT						
3	575.97485	569.18213				

INTERCEPT -667.46582

MULTIPLE CORRELATION 0.87934

STD. ERROR OF ESTIMATE 287.47949

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F VALUE
ATTRIBUTABLE TO REGRESSION	3	6763678.00000	2254559.00000	27.28018
DEVIATION FROM REGRESSION	24	1983470.00000	82644.56250	
TOTAL	27	8747148.00000		

TABLE OF RESIDUALS

CASE NO.	Y VALUE	Y ESTIMATE	RESIDUAL	X_1	X_2	X_3	Y
1	607.14990	640.80225	-33.65234	56.60	1.00	607.15	9.80
2	477.82983	647.59375	-169.76392	70.00	1.00	477.83	9.80
3	666.09985	645.56641	20.53345	66.00	1.00	666.10	9.80
4	1401.20996	1238.33594	162.87402	658.70	2.00	1401.21	0.20
5	1969.62988	1564.38232	405.24756	1302.00	2.00	1969.63	0.20
6	55.57999	146.87183	-91.29184	66.00	1.00	55.58	0.0
7	99.96999	175.61967	-75.64969	92.60	1.00	99.97	0.30
8	179.12000	239.87695	-60.75696	149.10	1.00	179.12	1.00
9	62.78999	214.53516	-151.74516	99.10	1.00	62.79	1.00
10	1566.23999	1307.93750	258.30249	514.90	2.00	1566.24	3.00
11	596.11987	1120.30713	-524.18726	194.90	2.00	596.12	2.50
12	575.46997	1435.64795	-860.17798	897.40	2.00	575.47	1.70
13	418.46997	187.26758	231.20239	45.30	1.00	418.47	1.00
14	386.30981	211.03857	175.27124	42.00	1.00	386.31	1.50
15	1044.83984	1283.55957	-238.71973	416.60	2.00	1044.84	3.50
16	677.94995	571.15063	106.79932	150.10	1.00	677.95	7.50
17	262.32983	171.48402	90.84581	74.40	1.00	262.33	0.40
18	219.56999	191.50404	28.06595	113.90	1.00	219.57	0.40
19	98.09999	227.09467	-128.99467	103.80	1.00	98.10	1.20
20	320.08984	194.65643	125.43341	140.20	1.00	320.09	0.20
21	135.46999	202.93803	-67.46805	146.50	1.00	135.47	0.30
22	192.93999	191.72656	1.21342	154.50	1.00	192.94	0.0
23	53.98000	137.03931	-83.05931	46.60	1.00	53.98	0.0
24	206.95999	197.98199	8.97800	56.40	1.00	206.96	1.10
25	232.07999	218.30621	13.77377	96.50	1.00	232.08	1.10
26	1876.91992	1240.37769	636.54224	281.20	2.00	1876.92	4.00
27	297.53979	237.28265	60.25714	73.70	1.00	297.54	1.70
28	1446.57983	1286.45068	160.12915	221.50	2.00	1446.58	5.50

APPENDIX I

DEVELOPMENT OF COMPOSITE LABOR AND EQUIPMENT RATES

LABOR

In the development of maintenance requirement units a value which reflected a composite hourly wage of $2.20 for labor was used. This represented an average for the five States providing test section data. Recognizing that each State would have its own composite wage, Table I-1 provides an illustration of how the composite can be computed. The steps involved are as follows:

1. The average monthly wage associated with each labor classification is multiplied by the number of men in that classification to provide a total monthly wage.
2. The total monthly wages for all classifications are totaled and multiplied by 12 to produce an annual labor expenditure.
3. The annual labor expenditure is divided by the total men in all classifications and then by the total working hours in a year (52 40-hr weeks) to produce an average composite hourly wage.

EQUIPMENT

In the development of the requirements equations the value of the equipment component reflects a composite use-rental rate value of $2.72. Recognizing that each State has its own schedule of equipment rental rates, Table I-2 provides an example to illustrate how the equipment computed from the model can be adjusted for any State's rates. The interpretation of the table is as follows:

1. The equipment classifications are identified in Chapter Two.
2. The rate associated with each classification reflects an average rate representative of all equipment falling in that classification and is weighted to reflect the contribution of each type of equipment in the classification.
3. The hours are representative of the use made of each classification using the noted rates and reflect the actual dollar use in each classification as reported for the 28 test sections used in this study.
4. The rates and hours were multiplied to produce cost in dollars for each classification. These dollars were totaled and divided by total hours to produce a single composite use-rental rate value.
5. The equipment cost associated with the example equipment rental schedule would be determined by:

(a) Dividing the equipment value produced by the requirements equation by $2.72 to produce composite equipment hours.
(b) Multiplying composite equipment hours by the sample composite ($2.50) to produce equipment cost.

TABLE I-1

SAMPLE COMPUTATION OF COMPOSITE LABOR CHARGE

LABOR CLASS	NO. OF MEN	MONTHLY WAGE ($) AVG.	MONTHLY WAGE ($) TOTAL
1	100	400	40,000
2	200	380	76,000
3	300	280	84,000
4	400	390	156,000
5	500	360	180,000
6	600	390	234,000
7	700	320	224,000
Total	2,800		994,000

$$\text{Avg. composite hourly wage} = \frac{994{,}000 \times 12}{2{,}800 \times 2{,}080} = \$2.05/\text{hr}$$

TABLE I-2

SAMPLE COMPUTATION OF COMPOSITE EQUIPMENT RENTAL RATE

EQUIP. CLASS	HOURLY RATE ($)	USE (HR)	TOTAL COST
1	1.20	60	72.00
2	2.65	150	397.50
3	4.75	25	118.75
4	4.95	24	118.80
5	3.80	3	11.40
6	2.90	53	153.70
7	2.55	15	38.25
8	2.00	7	14.00
9	2.40	9	21.60
10	1.00	54	54.00
Total		400	$1,000.00

Avg. composite hourly rate = 1,000/400 = $2.50/hr

APPENDIX J

INTERSTATE VARIABLES

The seven models developed in this study to predict Interstate maintenance requirements were used to predict total requirements in 1975 on a completed Interstate System of highways. The environmental variables needed in the models were estimated for each State. A rural and urban equivalent four-lane mile factor to accommodate interchanges and multilane facilities was based on the study sample. This sample represented 1.4% of the 41,200-mile Interstate System and had a rural-to-urban percentage of 86% to 14% compared with the national System's 83% to 17%.

Age was based on the assumption that the present 23,500 miles would average 15 years in 1975 and that the unbuilt 17,700 miles would average 5 years in 1975. This resulted in a 10.7-year-old system in 1975. 1964 composite traffic volumes for both the rural and urban portions of the Interstate System in each State was based on Table INT-15 of *Highway Statistics* (*45*). These volumes were projected to 1975 using the composite ADT trend of the primary highway system between 1955 and 1965, which was determined using Table FM-15 of *Highway Statistics* (*45*).

The variables for each State were applied to the seven regression models and urban and rural centerline-mile requirement units were determined. These were multiplied by the rural and urban Interstate mileage in each State to get the total State requirement units. These units were then totaled for all States for each of the seven activity groups.

The labor, equipment, and material requirements were determined for each activity and then added to produce the total requirements for labor, equipment, and materials nationally. The national requirement units were then converted to dollars using 1975 composite unit costs for the labor, equipment, and a direct proportion of 1975 material cost.

APPENDIX K

CALCULATION OF BASE YEAR VALUES

TABLE K-1

BASE YEARS DISBURSEMENTS AND MILEAGE, TOTAL STATE-ADMINISTERED HIGHWAY SYSTEM

STATE	DISBURSEMENTS FOR MAINTENANCE AND TRAFFIC SERVICES [a] ($1,000)				LENGTH [b] (MILES)			
	1957	1958	1959	AVG.	1957	1958	1959	AVG.
Alabama	9,492	8,694	13,253	10,480	17,121	17,486	17,768	17,458
Alaska	—	—	—	—	—	—	—	—
Arizona	5,717	5,236	6,305	5,753	4,231	4,301	4,438	4,323
Arkansas	11,226	12,228	12,492	11,982	10,094	11,023	11,022	10,713
California	32,089	34,965	37,406	34,820	14,663	14,814	15,148	14,875
Colorado	7,493	8,035	8,145	7,891	8,176	8,211	8,232	8,206
Connecticut	14,178	20,155	17,843	17,392	3,292	3,444	3,585	3,440
Delaware	4,408	4,630	4,679	4,572	4,046	4,122	4,152	4,107
Florida	14,665	17,591	17,246	16,501	13,739	14,385	14,744	14,289
Georgia	11,559	11,736	9,969	11,088	15,267	15,716	15,924	15,636
Hawaii	—	—	—	—	—	—	—	—
Idaho	6,368	5,656	6,748	6,257	4,735	4,761	4,777	4,758
Illinois	22,486	25,081	28,703	25,423	12,533	12,833	12,931	12,766
Indiana	16,391	20,719	23,082	20,064	10,909	10,901	10,885	10,898
Iowa	10,221	10,627	12,827	11,225	9,770	9,839	10,061	9,890
Kansas	14,743	16,381	16,901	16,008	10,378	10,403	10,439	10,407
Kentucky	20,841	25,677	29,429	25,316	19,463	19,599	20,002	19,688
Louisiana	16,746	19,923	19,082	18,584	15,119	15,129	15,206	15,151
Maine	12,419	13,090	14,219	13,243	11,328	11,351	11,392	11,357
Maryland	8,846	10,641	10,277	9,921	4,701	4,703	4,750	4,718
Massachusetts	22,340	25,853	21,556	23,250	2,519	2,579	2,612	2,570
Michigan	27,858	24,368	27,870	26,699	9,367	9,478	9,354	9,400
Minnesota	17,760	17,916	17,389	17,688	13,119	13,045	12,921	13,028
Mississippi	6,703	6,799	8,029	7,177	10,281	10,552	10,552	10,462
Missouri	23,052	23,309	26,012	24,124	26,860	27,887	28,729	27,825
Montana	5,237	5,129	5,491	5,286	10,829	10,943	11,086	10,953
Nebraska	8,036	8,688	8,122	8,282	9,307	9,293	9,291	9,297
Nevada	2,922	3,430	4,116	3,489	6,079	6,151	6,206	6,145
New Hampshire	8,102	9,222	8,800	8,708	4,023	4,056	4,085	4,055
New Jersey	22,843	26,475	28,433	25,917	2,652	2,648	2,671	2,657
New Mexico	6,551	8,980	9,236	8,256	11,722	11,753	11,806	11,760
New York	65,432	64,064	67,576	65,691	14,368	14,502	14,455	14,442
North Carolina	39,718	37,585	49,673	42,325	70,647	71,042	71,519	71,069
North Dakota	3,184	3,684	4,971	3,946	6,468	6,458	6,274	6,400
Ohio	34,569	32,399	32,062	33,010	18,535	18,532	18,653	18,573
Oklahoma	13,532	11,292	11,112	11,979	11,320	11,743	11,811	11,625
Oregon	14,370	14,079	13,253	13,901	8,442	8,482	8,545	8,490
Pennsylvania	52,336	60,990	62,682	58,669	46,071	46,344	46,390	46,268
Rhode Island	4,397	4,974	5,087	4,819	973	983	988	981
South Carolina	13,984	14,070	15,181	14,412	26,676	27,099	27,719	27,165
South Dakota	4,613	5,372	5,546	5,177	6,929	6,923	7,316	7,056
Tennessee	10,034	11,142	9,738	10,305	8,722	8,773	8,840	8,778
Texas	51,044	56,448	58,262	55,251	53,506	54,940	56,410	54,952
Utah	4,939	5,525	5,311	5,258	5,560	5,578	5,603	5,580
Vermont	5,236	5,237	4,961	5,145	2,163	2,184	2,188	2,178
Virginia	41,371	41,759	35,464	39,531	50,048	50,286	50,368	50,234
Washington	17,993	17,720	18,429	18,047	6,582	6,585	6,597	6,588
West Virginia	19,101	31,236	20,636	23,658	31,494	31,508	31,516	31,506
Wisconsin	13,637	14,284	17,266	15,062	11,550	11,517	11,603	11,557
Wyoming	3,564	3,896	4,518	3,993	5,122	5,127	5,164	5,138

[a] From Table SF-4, *Highway Statistics*, U. S. Dept. of Commerce, Bureau of Public Roads.
[b] From Table SM-1, *Highway Statistics*, U. S. Dept. of Commerce, Bureau of Public Roads.

TABLE K-2

BASE YEARS DISBURSEMENTS AND MILEAGE, STATE-ADMINISTERED PRIMARY STATE HIGHWAYS (RURAL)

STATE	DISBURSEMENTS FOR MAINTENANCE AND TRAFFIC SERVICES [a] ($1,000)				LENGTH [b] (MILES)			
	1957	1958	1959	AVG.	1957	1958	1959	AVG.
Alabama	6,064	4,234	6,861	5,720	7,077	7,188	7,333	7,199
Alaska	—	—	—	—	—	—	—	—
Arizona	5,515	5,076	6,049	5,546	4,106	4,151	4,248	4,168
Arkansas	11,226	12,228	12,492	11,982	9,982	10,279	10,256	9,975
California	25,482	27,138	28,668	27,096	12,331	12,337	12,419	12,362
Colorado	7,190	7,739	7,745	7,558	7,793	7,807	7,822	7,807
Connecticut	—	—	—	—	—	—	—	—
Delaware	—	—	—	—	—	—	—	—
Florida	12,034	14,561	13,496	13,363	8,856	9,023	9,018	8,966
Georgia	11,559	10,769	9,155	10,494	13,477	13,863	14,013	13,784
Hawaii	—	—	—	—	—	—	—	—
Idaho	6,368	5,656	6,748	6,257	4,484	4,505	4,513	4,501
Illinois	19,127	21,546	24,968	21,880	10,581	10,632	10,657	10,623
Indiana	11,827	15,513	17,576	14,972	9,845	9,834	9,816	9,832
Iowa	9,051	9,580	11,524	10,051	8,591	8,653	8,706	8,650
Kansas	13,000	14,682	15,257	14,313	9,615	9,627	9,658	9,633
Kentucky	20,184	24,839	28,260	24,427	18,599	18,716	19,094	18,803
Louisiana	8,605	10,113	9,684	9,467	3,700	3,677	3,664	3,680
Maine	6,670	7,500	8,027	7,399	3,211	3,206	3,199	3,205
Maryland	—	—	—	—	—	—	—	—
Massachusetts	—	—	—	—	—	—	—	—
Michigan	24,240	20,980	23,742	22,987	8,288	8,360	8,228	8,292
Minnesota	13,938	14,067	13,661	13,888	10,153	10,144	10,175	10,157
Mississippi	6,039	6,346	7,560	6,648	9,613	9,874	9,853	9,780
Missouri	9,033	8,647	9,210	8,963	7,745	7,744	7,823	7,771
Montana	5,183	5,099	5,409	5,230	5,765	5,759	5,746	5,757
Nebraska	8,036	8,688	8,122	8,282	8,885	8,864	8,859	8,869
Nevada	1,804	2,066	2,374	2,081	2,137	2,125	2,128	2,130
New Hampshire	3,760	4,155	4,053	3,989	1,482	1,484	1,508	1,491
New Jersey	—	—	—	—	—	—	—	—
New Mexico	6,551	8,980	9,236	8,255	11,206	11,219	11,252	11,226
New York	32,935	33,286	32,958	33,059	12,140	12,233	12,153	12,175
North Carolina	14,073	13,429	14,515	14,005	11,160	11,252	11,290	11,234
North Dakota	3,184	3,684	4,971	3,946	6,216	6,203	6,016	6,145
Ohio	30,631	28,612	28,355	29,199	15,781	15,746	15,827	15,763
Oklahoma	13,532	11,292	11,112	11,978	10,549	10,957	11,014	10,840
Oregon	10,082	9,909	9,286	9,759	4,497	4,476	4,474	4,482
Pennsylvania	—	—	—	—	—	—	—	—
Rhode Island	—	—	—	—	—	—	—	—
South Carolina	—	—	—	—	—	—	—	—
South Dakota	4,613	5,372	5,546	5,177	6,649	6,642	7,032	6,774
Tennessee	—	—	—	—	—	—	—	—
Texas	45,632	52,022	51,277	49,644	49,932	51,122	52,379	51,144
Utah	4,939	5,529	5,311	5,258	4,959	4,969	4,988	4,972
Vermont	5,236	5,237	4,961	5,144	1,919	1,934	1,938	1,930
Virginia	17,501	17,856	16,749	17,369	7,635	7,621	7,613	7,623
Washington	14,401	14,182	14,273	14,285	3,831	3,819	3,794	3,815
West Virginia	7,188	14,203	7,449	9,613	4,581	4,582	4,585	4,583
Wisconsin	13,008	13,743	16,791	14,514	10,075	10,017	10,048	10,047
Wyoming	3,531	3,896	4,518	3,982	4,995	4,999	5,032	5,009

[a] From Table SF-4, *Highway Statistics*, U. S. Dept. of Commerce, Bureau of Public Roads.
[b] From Table SM-1, *Highway Statistics*, U. S. Dept. of Commerce, Bureau of Public Roads.

TABLE K-3

BASE YEARS DISBURSEMENTS AND MILEAGE, MUNICIPAL EXTENSIONS OF STATE-ADMINISTERED HIGHWAY SYSTEM

	DISBURSEMENTS FOR MAINTENANCE AND TRAFFIC SERVICES [a] ($1,000)				LENGTH [b] (MILES)			
STATE	1957	1958	1959	AVG.	1957	1958	1959	AVG.
Alabama	1,176	1,928	2,556	1,887	1,068	1,233	1,256	1,186
California	6,607	7,827	8,738	7,724	1,440	1,546	1,610	1,532
Florida	178	324	390	297	1,465	1,516	1,634	1,538
Iowa	1,170	1,047	1,303	1,173	1,059	1,064	1,081	1,068
Kentucky	657	838	1,169	888	780	800	823	801
Michigan	3,618	3,388	4,128	3,711	1,079	1,118	1,126	1,108
Minnesota	3,822	3,849	3,728	3,800	1,646	1,650	1,659	1,652
Missouri	681	687	948	772	1,208	1,286	1,287	1,260
Montana	51	30	71	51	223	224	228	225
New York	19,729	19,697	20,410	19,945	1,077	1,079	1,092	1,083
Oregon	621	746	810	726	425	428	432	428
Texas	5,412	4,426	6,985	5,609	3,544	3,788	4,001	3,778
Washington	799	880	1,049	909	472	474	507	484
West Virginia	654	1,171	644	823	586	599	604	596
Wisconsin	527	449	370	449	1,387	1,422	1,479	1,429

[a] From Table SF-4, *Highway Statistics*, U. S. Dept. of Commerce, Bureau of Public Roads.
[b] From Table SM-1, *Highway Statistics*, U. S. Dept. of Commerce, Bureau of Public Roads.

TABLE K-4

DEVELOPMENT OF BASE YEAR VALUES FOR MAINTENANCE UNIT LABOR COST INDEX

STATE	COMPUTED TOTAL HOURLY LABOR COSTS ($)				TOTAL NUMBER OF EMPLOYEES			
	1957	1958	1959	AVG.	1957	1958	1959	AVG.
Alabama	1,683.72	1,661.82	2,166.42	1,837	1,285	1,148	1,440	1,291
Alaska	—	—	—	—	—	—	—	—
Arizona	532.75	548.27	209.77	4,303	239	229	94	187
Arkansas	2,413.75	1,915.96	1,133.30	1,821	1,718	1,415	824	1,319
California	5,225.10	5,374.13	5,888.64	5,596	2,192	2,251	2,300	2,248
Colorado	1,380.68	978.94	1,460.15	1,273	636	496	655	596
Connecticut	2,408.94	1,618.12	3,003.91	2,344	1,420	927	1,744	1,364
Delaware	864.66	959.87	863.37	896	635	652	644	644
Florida	1,820.35	2,545.10	2,395.42	2,254	1,204	1,600	1,504	1,436
Georgia	2,367.85	2,506.85	2,453.89	2,443	2,155	2,246	1,896	2,099
Hawaii	—	—	—	—	—	—	—	—
Idaho	864.77	947.47	729.12	847	400	456	343	400
Illinois	3,650.24	3,482.10	3,864.89	3,666	1,855	1,636	1,896	1,796
Indiana	2,809.15	2,360.89	852.22	2,007	2,085	1,640	598	1,441
Iowa	1,922.58	1,984.30	1,819.12	1,909	1,212	1,227	1,110	1,183
Kansas	2,295.80	1,008.68	2,485.64	1,930	1,371	668	1,782	1,274
Kentucky	4,887.80	—	6,811.68	5,850	3,764	—	4,479	4,122
Louisiana	2,942.27	8,107.99	4,246.95	5,099	2,227	5,948	3,140	3,772
Maine	1,758.84	1,221.89	885.17	1,289	1,192	745	576	838
Maryland	2,374.92	2,636.84	1,741.88	2,251	1,592	1,769	1,160	1,507
Massachusetts	2,624.39	2,824.28	2,052.06	2,500	1,549	1,636	1,177	1,454
Michigan	976.22	1,158.72	1,585.34	1,240	471	553	731	585
Minnesota	2,607.22	2,791.63	3,241.94	2,880	1,596	1,698	1,816	1,703
Mississippi	685.31	—	875.89	781	529	—	602	566
Missouri	3,785.97	4,985.44	3,699.44	4,157	2,843	3,319	2,338	2,833
Montana	1,433.00	1,592.93	1,385.08	1,470	628	616	554	599
Nebraska	1,678.50	1,575.09	1,703.72	1,652	1,006	957	994	986
Nevada	539.60	674.90	679.23	631	273	332	312	306
New Hampshire	676.36	1,203.11	844.48	908	448	818	576	614
New Jersey	3,059.00	3,113.53	3,427.64	3,200	1,669	1,702	1,744	1,705
New Mexico	526.28	807.57	1,240.99	858	331	453	789	524
New York	9,303.00	9,320.28	8,608.60	9,077	5,302	5,308	4,802	5,137
North Carolina	7,656.20	7,253.94	6,287.80	7,066	4,912	4,513	3,887	4,437
North Dakota	779.72	793.02	752.77	775	392	397	353	381
Ohio	6,855.92	6,176.85	7,287.00	6,773	4,427	3,585	4,228	4,080
Oklahoma	1,423.71	1,411.21	1,605.58	1,480	957	962	1,034	984
Oregon	3,018.14	2,922.82	2,839.02	2,927	1,475	1,434	1,391	1,433
Pennsylvania	15,370.00	14,469.83	7,416.50	12,419	9,396	9,592	4,794	7,927
Rhode Island	470.43	821.47	772.01	688	376	504	507	462
South Carolina	2,987.06	4,872.05	3,363.53	3,741	2,635	3,179	2,621	2,812
South Dakota	1,040.09	5,500.23	1,084.03	2,541	572	3,536	597	1,568
Tennessee	3,268.54	2,305.42	2,365.57	2,647	2,577	1,724	1,804	2,035
Texas	9,802.00	14,301.27	9,568.80	11,224	6,085	7,989	5,935	6,670
Utah	1,118.17	1,004.86	522.86	882	610	562	455	542
Vermont	647.65	779.33	784.94	737	379	472	461	437
Virginia	6,640.90	7,571.88	7,903.50	7,372	5,400	5,820	5,834	5,685
Washington	2,460.98	2,228.23	1,270.40	1,987	1,185	947	522	885
West Virginia	4,254.53	4,463.62	4,200.73	4,306	2,997	3,124	3,153	3,091
Wisconsin	—	—	—	—	—	—	—	—
Wyoming	562.48	648.85	610.33	607	286	321	274	294

APPENDIX L

INFLUENCE OF TRAFFIC ON MAINTENANCE COST

Before selecting control sections to determine the influence of traffic on maintenance cost, it was necessary to establish the number of sections required for each volume classification. These numbers were established by examining sample sections from Virginia. To eliminate yearly fluctuations in maintenance expenditures, a straight line (line of regression) was computed for each section. This is illustrated for a typical section in Figure L-1, where the regression equation is

$$Y = 10{,}164 + 416\,X \qquad \text{(L-1)}$$

in which Y is the cost, 10,164 is the Y intercept, and 416 is the annual increase factor. In this report, Δ, the ratio of the X coefficient to the Y intercept (416/10,164), is referred to as the slope.

Average daily traffic volumes for 1964 were known for each control section, so it was possible to group sections in various volume classifications. The slopes of the lines of regression for each control section within a given classification were compared. This permitted an evaluation of the dispersion between sections. Table L-1 gives the results of this analysis. Next, a line of regression was computed for all sections within a given classification. A summary of the resulting regression relations is given in Table L-2.

From these results it was estimated that about 400 miles would be required in each volume classification to establish a good sample. It was believed that this mileage requirement might be reduced by reclassifying the sections to reflect the traffic volumes occurring during each of the ten years. For example, one section might have constant traffic for the entire study period, whereas another passed through two or three classifications. This would materially affect the annual cost if traffic volume influenced cost. Therefore, another analysis was made. Additional control sections were selected to permit a more comprehensive analysis. The sections were grouped into their appropriate volume classifications (Table L-3). This time each control section was classified by traffic volume for each year.

To eliminate the yearly fluctuations and to establish a trend relationship, a line of regression was computed for each traffic volume classification. The resulting regression plots, equations, and slopes are shown in Figures 47 and L-2 through L-8.

The confidence limits for each of the regression equations and slopes shown in Figures 47 and L-2 through L-8 are shown in Figures L-9 and L-10. These limits are shown by bands and reveal that all of the points on the curve are not equally good. That is, more data were available to calculate some of the regression lines than others, which resulted in better confidence limits.

To compute an equation to express the relationship between cost and traffic, the intercept value for each traffic volume classification was plotted against traffic. A line of regression was computed to fit these points after being weighted to reflect the confidence limits associated with each point. This was done by linearly relating the ratios determined by dividing the confidence limits by the cost per mile. To illustrate, the weighting factors for the 1955 cost/mile vs traffic volume values were determined as follows:

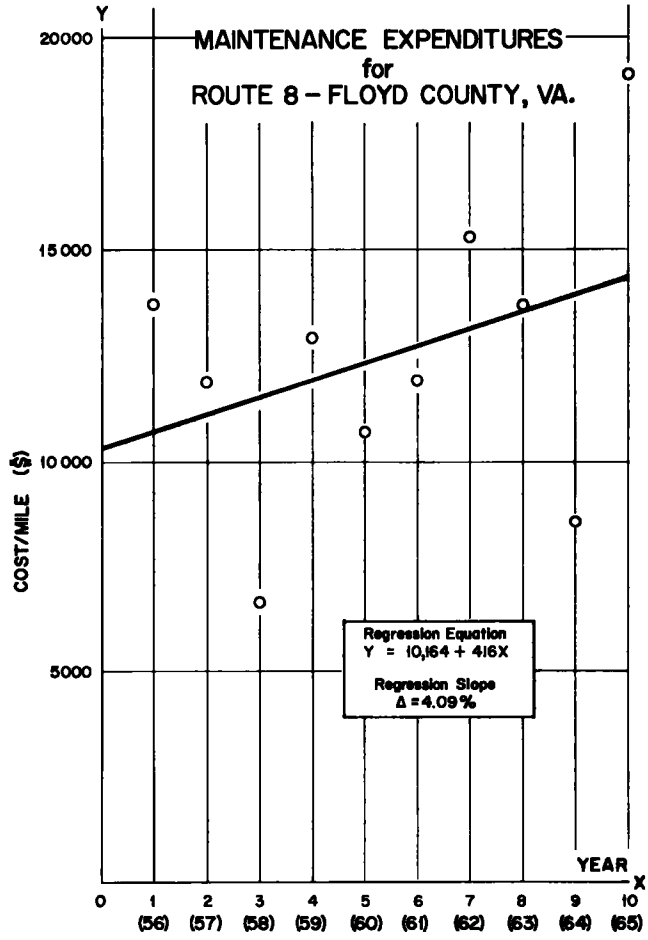

Figure L-1. Straight-line regression of maintenance costs for a highway section in Virginia.

TABLE L-1

SUMMARY OF REGRESSIONS FROM A SAMPLING OF HIGHWAY SECTION MAINTENANCE EXPENDITURES, VIRGINIA DEPARTMENT OF HIGHWAYS

TRAFFIC VOLUME (VPD)	COUNTY	ROUTE	LENGTH (MI)	*Y* INTERCEPT	SLOPE
0-500	Orange	522	15.73	10,318	0.98
500-1,000	Louisa	522	28.50	13,392	7.63
500-1,000	Smyth	16	30.02	23,392	3.53
500-1,000	Dinwiddie	40	27.81	15,762	6.87
500-1,000	Brunswick	46	36.18	14,507	7.2
500-1,000	Pittsylvania	40	29.77	16,367	2.77
500-1,000	Rockbridge	39	23.00	13,427	6.31
500-1,000	Patrick	8	25.51	16,247	8.92
500-1,000	Sussex	40	29.69	20,203	1.40
500-1,000	Surrey	40	9.06	3,548	9.67
500-1,000	Bath	39	37.28	31,504	0.41
500-1,000	Sussex	35	17.75	11,109	3.42
500-1,000	Scott	65	28.40	3,636	60.73
1,000-2,000	Bath	220	26.90	14,363	4.47
1,000-2,000	Lunenburg	40	27.57	12,593	3.42
1,000-2,000	Patrick	57	11.25	6,503	4.15
1,000-2,000	Nottoway	40	11.38	6,423	4.76
1,000-2,000	Floyd	221	36.80	32,705	0.76
1,000-2,000	Floyd	8	17.33	10,164	4.09
1,000-2,000	Fluvanna	15	12.06	15,144	15.01
1,000-2,000	Surry	10	24.27	15,206	2.68
1,000-2,000	Southampton	35	24.00	10,220	7.14
1,000-2,000	Grayson	21	17.39	10,909	9.15
1,000-2,000	Grayson	58	50.02	33,309	2.16
1,000-2,000	Albemarle	20	31.62	20,133	7.22
1,000-2,000	Bath	42	11.57	7,577	7.80
1,000-2,000	Wythe	21	27.80	15,015	11.98
1,000-2,000	Culpeper	522	18.73	14,889	2.61
1,000-2,000	Rockingham	340	20.63	10,125	4.08
1,000-2,000	Louisa	15	11.46	11,798	4.33
2,000-3,000	Loudoun	15	25.85	46,779	−1.60
2,000-3,000	Culpeper	229	14.72	11,161	3.75
2,000-3,000	Carroll	100	8.12	6,485	5.17
2,000-3,000	Botetourt	220	31.95	24,042	8.00
2,000-3,000	Northumberland	360	23.87	22,956	2.18
2,000-3,000	King & Queen	360	9.20	6,960	10.55
2,000-3,000	Page	211	15.79	19,448	10.41
2,000-3,000	Orange	20	35.70	29,318	3.07
2,000-3,000	Rappahannock	522	19.66	8,309	16.16
2,000-3,000	Rappahannock	211	25.16	16,175	7.92
2,000-3,000	Page	340	32.71	26,058	3.86
2,000-3,000	Richmond	3	17.86	11,533	14.22
2,000-3,000	Northumberland	200	10.18	15,811	7.39
3,000-4,000	Fauquier	17	35.69	41,049	3.11
3,000-4,000	Hanover	360	12.89	6,613	24.69
3,000-4,000	Southampton	58	30.65	17,917	8.82
3,000-4,000	Powhatan	60	21.66	16,002	8.58
3,000-4,000	Buchanan	460	35.51	32,246	3.96
3,000-4,000	Tazewell	19	32.69	26,643	4.86
3,000-4,000	Cumberland	60	14.82	10,937	5.90
4,000-5,000	Madison	29	16.67	12,888	13.20
4,000-5,000	Henry	58	20.43	14,189	12.09
4,000-5,000	Nelson	29	21.68	14,556	16.91
4,000-5,000	Pittsylvania	58	24.26	23,026	8.96
4,000-5,000	Isle of Wight	460	9.95	9,334	15.40
4,000-5,000	Washington	19	10.76	10,578	10.19
4,000-5,000	Chesterfield	60	14.47	17,545	1.85
4,000-5,000	Chesterfield	360	24.63	28,430	4.43
5,000-10,000	Bedford	460	14.62	19,267	14.61
5,000-10,000	Dinwiddie	1	25.43	29,696	5.48
5,000-10,000	Brunswick	1	20.84	26,987	7.35
5,000-10,000	King George	301	17.05	22,037	8.25
5,000-10,000	Sussex	301	17.83	14,339	20.11
5,000-10,000	Albemarle	29	28.20	17,027	26.85
5,000-10,000	Shenandoah	11	35.08	51,573	1.23

TABLE L-2

SUMMARY OF REGRESSIONS FOR TRAFFIC VOLUME GROUPINGS OF HIGHWAY SECTION MAINTENANCE EXPENDITURES, VIRGINIA DEPARTMENT OF HIGHWAYS

TRAFFIC VOLUME (VPD)	NO. OF SEC-TIONS	TOTAL LENGTH (MI)	1955 MAINT. COST ($)		SLOPE
			TOTAL [a]	PER MILE	
0-500	1	15.73	10,319.00	656.01	0.98
500-1,000	10	269.07	167,054.00	620.86	2.75
1,000-2,000	15	375.85	233,879.00	653.57	5.59
2,000-3,000	13	273.77	235,047.00	858.56	6.06
3,000-4,000	7	183.91	150,896.00	820.49	6.05
4,000-5,000	7	132.09	118,835.00	899.65	9.41
5,000-10,000	7	159.05	182,260.00	1,145.93	8.93
0-10,000	60	1,391.47	1,079,954.00	776.13	6.57

[a] *Y* intercept.

TABLE L-3

MAINTENANCE AND TRAFFIC SERVICE COSTS FOR SELECTED SECTIONS OF VIRGINIA HIGHWAYS

COUNTY AND ROUTE	LENGTH (MI)	REPORTED EXPENDITURE ($)									
		1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
(*a*) 500-1,000 AVERAGE DAILY TRAFFIC VOLUME											
Louisa 522	28.50	12,200	13,700	22,800	18,400	18,400	15,800	19,700	24,300	19,400	25,600
Smyth 16	30.02	24,700	24,300	28,200	27,300	23,800	27,400	29,600	30,200	32,100	31,600
Sussex 35	17.75	12,300	12,600	10,400	9,500	8,100	5,200	4,100	8,100	6,500	13,400
Dinwiddie 40	27.81	18,000	16,000	15,200	24,200	19,400	25,400	23,100	27,500	23,200	25,200
Pittsylvania 40	29.77	13,000	19,600	19,400	20,200	16,300	20,100	20,400	17,600	22,600	19,500
Rockbridge 39	23.00	15,700	14,200	15,600	16,000	15,000	20,800	23,600	16,500	23,600	20,200
Brunswick 46	36.18	17,300	15,700	16,400	21,800	17,700	18,500	22,400	20,900	27,000	24,900
Sussex 40	29.69	20,800	17,100	23,100	26,500	17,900	22,500	21,300	21,900	23,300	23,100
Bath 39	37.28	27,900	28,600	34,200	30,200	38,400	34,900	37,400	33,800	27,600	29,300
Scott 65	28.40	—	—	—	16,100	17,800	20,300	17,800	18,800	22,900	25,900
(*b*) 1,000-2,000 AVERAGE DAILY TRAFFIC VOLUME											
Grayson 21	17.39	13,500	12,800	11,300	14,400	15,200	13,400	22,900	23,400	20,800	16,300
Albemarle 20	31.62	20,200	23,700	27,500	29,500	24,700	25,400	41,800	32,500	25,500	30,400
Wythe 21	27.80	17,900	16,700	20,800	20,100	27,600	25,600	29,700	32,200	32,100	31,400
Orange 20	35.70	29,000	26,400	47,400	30,200	26,600	33,600	35,400	33,700	41,600	38,800
Rappahannock 522	19.66	7,700	10,000	12,900	14,300	18,000	14,700	21,200	17,000	—	—
Culpeper 522	18.73	13,700	17,300	18,700	11,000	17,200	16,600	23,800	16,900	17,800	17,200
Rockingham 340	20.63	8,300	10,600	10,900	12,600	13,800	15,700	12,100	16,800	11,000	12,200
Page 340	32.71	30,000	31,000	32,800	23,700	24,600	33,500	28,600	36,200	33,200	42,200
Prince William 55	6.09	6,400	6,800	8,700	7,700	7,200	9,500	10,400	7,300	—	—
Patrick 57	11.25	—	—	—	7,900	5,200	8,400	10,500	11,600	4,200	10,600
Grayson 58	50.02	36,600	34,900	36,600	40,300	30,500	40,200	35,800	23,500	43,800	50,500
Louisa 15	11.46	11,200	12,900	15,600	9,400	17,700	17,000	14,600	15,400	14,300	18,000
Fluvanna 15	12.06	15,300	24,900	19,400	20,500	29,600	25,500	34,000	34,300	35,000	37,900
Richmond 3	17.86	13,100	17,800	17,900	—	—	—	—	—	—	—
Surry 40	9.06	4,100	3,300	5,100	6,100	5,900	4,500	3,600	6,400	7,000	8,400
Lunenburg 40	27.57	15,200	15,300	17,700	20,200	18,100	19,500	14,800	22,900	26,100	30,100
Nottoway 40	11.38	7,400	7,400	9,100	7,700	9,300	7,200	10,000	10,000	9,700	—
Southampton 35	24.00	11,900	12,800	12,000	10,600	11,600	13,100	15,800	16,100	18,200	18,100
Bath 42	11.57	6,000	9,800	8,800	11,400	11,600	11,600	12,000	12,000	11,100	13,900
Patrick 8	25.51	—	18,400	19,100	18,200	27,200	19,500	27,000	27,800	38,300	24,100
Floyd 8	17.33	13,700	11,900	6,700	12,900	10,700	12,000	15,300	13,700	8,600	19,100
Surry 10	24.27	16,400	14,400	16,200	16,900	23,100	13,500	17,600	17,600	16,800	22,000
Culpeper 229	14.72	11,900	17,900	10,700	10,200	9,700	14,400	12,400	12,700	—	—
Botetourt 220	31.95	23,500	34,600	31,400	—	—	—	—	—	—	—
Bath 220	26.90	15,400	15,100	20,100	14,400	19,200	16,500	15,900	17,400	21,700	23,400
Floyd 221	36.80	31,900	27,700	38,900	40,000	26,100	40,800	39,700	22,100	34,900	38,600
Northumberland 200	10.18	14,900	20,200	18,900	—	—	—	—	—	—	—

TABLE L-3—*Continued*

COUNTY AND ROUTE	LENGTH (MI)	REPORTED EXPENDITURE ($) 1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
(*c*) 2,000-3,000 AVERAGE DAILY TRAFFIC VOLUME											
Nelson 29	21.68	18,300	18,300	18,000	—	—	—	—	—	—	—
Rappahannock 522	19.66	—	—	—	—	—	—	—	—	22,700	18,300
Augusta 340	25.76	—	—	—	—	—	—	46,700	40,900	—	—
Northumberland 360	23.87	8,400	18,400	23,600	25,700	24,100	21,100	23,100	33,500	40,200	29,200
King & Queen 360	9.20	7,300	9,000	10,300	—	—	—	—	—	—	—
Amelia 360	17.82	18,000	24,500	—	—	—	—	—	—	—	—
Fauquier 55	19.25	18,000	23,900	19,700	28,500	29,100	35,100	37,800	27,600	—	—
Henry 58	20.43	12,400	29,900	18,900	—	—	—	—	—	—	—
Loudoun 15	25.85	30,200	49,700	59,800	32,400	42,700	54,100	51,200	42,500	30,400	33,500
Richmond 3	17.86	—	—	—	16,400	18,300	18,100	19,800	19,200	—	—
Frederick 11	22.38	—	—	—	—	—	—	—	—	—	26,400
Madison 29	16.67	14,500	—	—	—	—	—	—	—	—	—
Albemarle 29	28.21	18,900	27,600	—	—	—	—	—	—	—	—
Culpeper 229	14.12	—	—	—	—	—	—	—	—	16,300	18,500
Northumberland 200	10.18	—	—	—	20,200	22,100	22,900	29,500	22,600	20,200	31,000
Botetourt 220	31.95	—	—	—	26,800	33,000	34,100	35,300	39,800	43,700	44,000
Page 211	15.79	—	—	—	20,800	31,400	29,600	31,500	41,900	40,300	40,000
Rappahannock 211	25.16	14,000	13,800	17,600	21,800	26,800	24,200	28,100	29,200	29,700	26,900
Powhatan 60	21.66	17,300	22,500	23,800	19,100	19,900	21,200	24,900	20,700	—	—
Cumberland 60	14.82	11,400	9,800	15,200	16,300	14,700	14,400	13,900	12,100	—	—
Giles 100	16.29	12,500	8,900	14,600	—	18,800	18,200	21,300	—	—	—
Carroll 100	8.12	5,700	6,200	14,500	6,900	6,200	5,600	7,500	—	—	—
(*d*) 3,000-4,000 AVERAGE DAILY TRAFFIC VOLUME											
Nelson 29	21.68	—	—	—	19,100	32,300	29,700	34,100	34,200	—	—
Bedford 460	31.13	20,000	27,500	32,000	25,700	34,600	35,200	39,600	—	—	—
Buchanan 460	35.51	41,100	35,800	33,000	36,600	34,800	32,300	39,600	39,000	—	—
Augusta 340	25.76	—	—	—	—	—	—	—	—	49,900	45,300
King & Queen 360	9.20	—	—	—	8,200	11,100	12,300	14,000	9,200	11,600	17,500
Chesterfield 360	24.63	29,700	29,100	30,600	—	—	—	—	—	—	—
Amelia 360	17.82	—	—	29,800	—	—	—	—	—	—	—
Hanover 301	12.00	—	—	—	—	—	—	—	24,600	19,600	23,051
Clarke 50	9.86	12,300	9,000	14,200	10,500	18,800	18,200	21,900	23,000	—	—
Prince William 55	6.09	—	—	—	—	—	—	—	—	10,100	10,300
Henry 58	20.43	—	—	—	22,200	24,000	21,600	29,000	24,500	—	—
Southampton 58	30.65	22,300	23,300	27,400	23,400	19,900	21,800	23,000	29,300	33,600	42,100
Halifax 58	30.65	29,100	40,500	39,300	—	—	—	—	—	—	—
Gloucester 17	27.84	17,700	18,300	9,700	21,000	23,600	25,500	31,500	22,700	—	—
Fauquier 17	35.69	35,100	34,000	58,900	49,600	47,800	49,800	55,000	52,400	48,200	49,800
Tazewell 19	32.69	33,100	26,500	35,300	29,600	30,900	31,700	36,200	21,300	45,500	47,500
Richmond 3	17.86	—	—	—	—	—	—	—	—	23,189	36,718
Brunswick 1	20.84	32,200	29,900	37,300	25,600	34,100	38,400	—	—	—	—
Loudoun 7	29.19	35,500	42,600	—	—	—	—	—	—	—	—
Greene 29	6.87	5,800	5,700	—	—	—	—	—	—	—	—
Madison 29	16.67	—	19,200	20,400	12,500	17,600	22,100	29,400	—	—	—
Amherst 29	22.10	23,500	30,800	30,300	—	—	—	—	—	—	—
Goochland 250	44.71	16,000	18,800	20,300	15,600	22,500	21,600	19,000	25,400	19,600	30,200
Caroline 207	11.72	—	—	—	—	—	—	—	13,100	12,700	12,200
Roanoke 221	14.97	11,500	10,200	—	—	—	—	—	—	—	—
Page 211	15.79	22,400	18,100	34,800	—	—	—	—	—	—	—
Powhatan 60	21.66	—	—	—	—	—	—	—	—	28,400	37,600
Cumberland 60	14.82	—	—	—	—	—	—	—	—	15,600	21,300
Chesterfield 60	14.47	13,600	18,400	—	—	—	—	—	—	—	—
Giles 100	16.29	—	—	—	—	—	—	—	25,600	20,200	28,500
Carroll 100	8.12	—	—	—	—	—	—	—	9,200	9,000	12,400

TABLE L-3—*Continued*

COUNTY AND ROUTE	LENGTH (MI)	REPORTED EXPENDITURE ($) 1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
(*e*) 4,000-5,000 AVERAGE DAILY TRAFFIC VOLUME											
Nelson 29	21.68	—	—	—	—	—	—	—	—	41,100	36,000
Bedford 460	31.13	—	—	—	—	—	—	—	38,900	43,100	51,000
Buchanan 460	35.51	—	—	—	—	—	—	—	—	42,800	55,100
Isle of Wight 460	9.95	11,000	11,600	13,900	16,100	14,600	19,300	21,300	18,700	18,700	27,000
Chesterfield 360	24.63	—	—	—	30,100	35,500	46,400	33,500	47,200	34,600	36,900
Amelia 360	17.82	—	—	—	34,500	27,300	25,400	—	36,620	27,600	37,252
Loudoun 50	28.37	27,200	33,700	34,300	—	—	—	—	—	43,800	34,700
Clarke 50	9.86	—	—	—	—	—	—	—	—	19,300	20,400
Fauquier 55	19.25	—	—	—	—	—	—	—	—	27,300	26,000
Pittsylvania 58	24.26	36,800	17,900	31,500	—	—	—	—	—	—	—
Henry 58	20.43	—	—	—	—	—	—	—	—	27,700	30,600
Halifax 58	30.65	—	—	—	38,400	39,600	37,300	44,100	39,400	49,100	46,114
Gloucester 17	27.84	—	—	—	—	—	—	—	—	36,500	39,600
Spotsylvania 1	14.14	38,500	38,100	38,100	—	—	—	—	48,300	50,000	48,300
Dinwiddie 1	25.43	38,300	32,900	36,400	31,600	36,700	29,700	38,600	41,800	—	—
Brunswick 1	20.84	—	—	—	—	—	—	45,500	44,200	48,100	43,500
Loudoun 7	29.19	—	—	58,700	24,700	37,200	34,900	—	—	—	—
Washington 19	10.76	10,900	11,800	15,100	—	—	—	17,200	24,200	17,700	20,200
Greene 29	6.87	—	—	8,300	8,100	8,400	11,200	10,500	14,700	8,900	10,500
Culpeper 29	8.05	4,300	6,200	6,900	—	—	—	—	—	—	—
Amherst 29	22.10	—	—	—	20,100	28,300	29,000	30,900	30,000	34,000	38,600
Albemarle 29	28.21	—	—	38,300	34,000	32,900	46,200	44,800	—	—	—
Roanoke 221	14.97	—	—	17,300	12,000	19,400	14,600	19,400	19,500	22,400	21,800
Chesterfield 60	14.47	—	—	21,800	16,300	19,200	26,900	17,200	23,900	20,200	15,800
(*f*) 5,000-6,000 AVERAGE DAILY TRAFFIC VOLUME											
King George 301	17.05	22,100	27,600	28,800	—	—	—	—	—	37,600	39,000
Sussex 301	17.83	18,600	17,800	—	—	—	—	—	—	—	—
Loudoun 50	28.37	—	—	—	37,500	34,000	38,000	38,000	42,300	—	—
Pittsylvania 58	24.26	—	—	—	26,800	34,400	32,300	36,000	34,700	—	—
Frederick 11	22.38	28,600	40,100	28,000	32,500	22,700	29,600	26,300	43,900	41,700	—
Rockingham 11	23.32	30,400	31,800	45,900	27,000	39,300	31,300	36,900	39,100	—	—
Spotsylvania 1	14.14	—	—	—	—	—	—	68,600	—	—	—
Dinwiddie 1	25.43	—	—	—	—	—	—	—	—	51,500	49,200
Loudoun 7	29.19	—	—	—	—	—	—	45,800	46,200	44,800	42,300
Shenandoah 11	35.08	59,600	52,400	50,100	42,700	59,300	64,100	58,700	63,400	59,300	51,400
Madison 29	16.67	—	—	—	—	—	—	—	32,400	34,300	24,100
Campbell 29	21.13	—	—	—	—	—	—	—	38,500	35,400	32,600
Albemarle 29	28.21	—	—	—	—	—	—	—	58,600	57,700	62,900
Albemarle 250	27.13	38,100	43,400	38,100	32,200	39,800	47,900	—	—	—	—
(*g*) 10,000-15,000 AVERAGE DAILY TRAFFIC VOLUME											
Prince William 1	12.17	42,800	53,200	67,500	49,600	71,000	62,900	94,100	59,500	86,300	70,400
Stafford 1	15.91	37,400	36,500	42,300	38,500	50,300	57,400	61,400	63,200	67,000	60,700

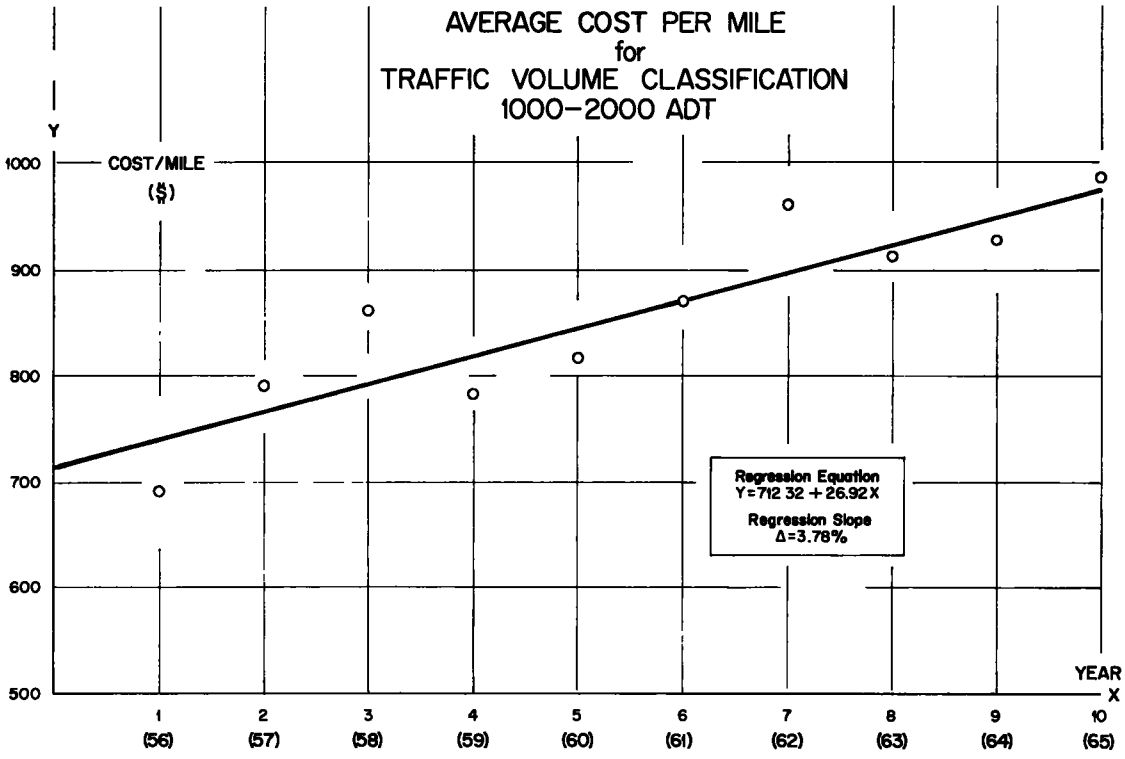

Figure L-2. Maintenance cost regression line for the 1,000-2,000 ADT sections of Virginia highways.

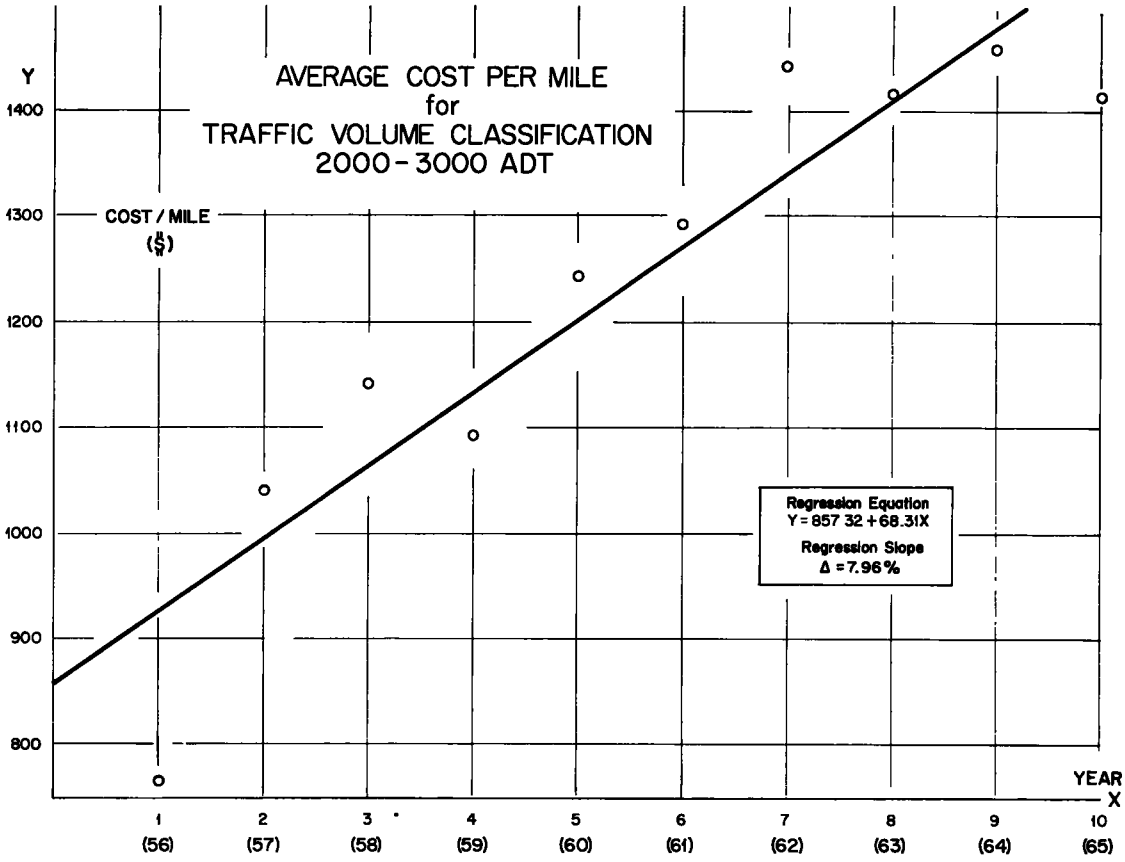

Figure L-3. Maintenance cost regression line for the 2,000-3,000 ADT sections of Virginia highways.

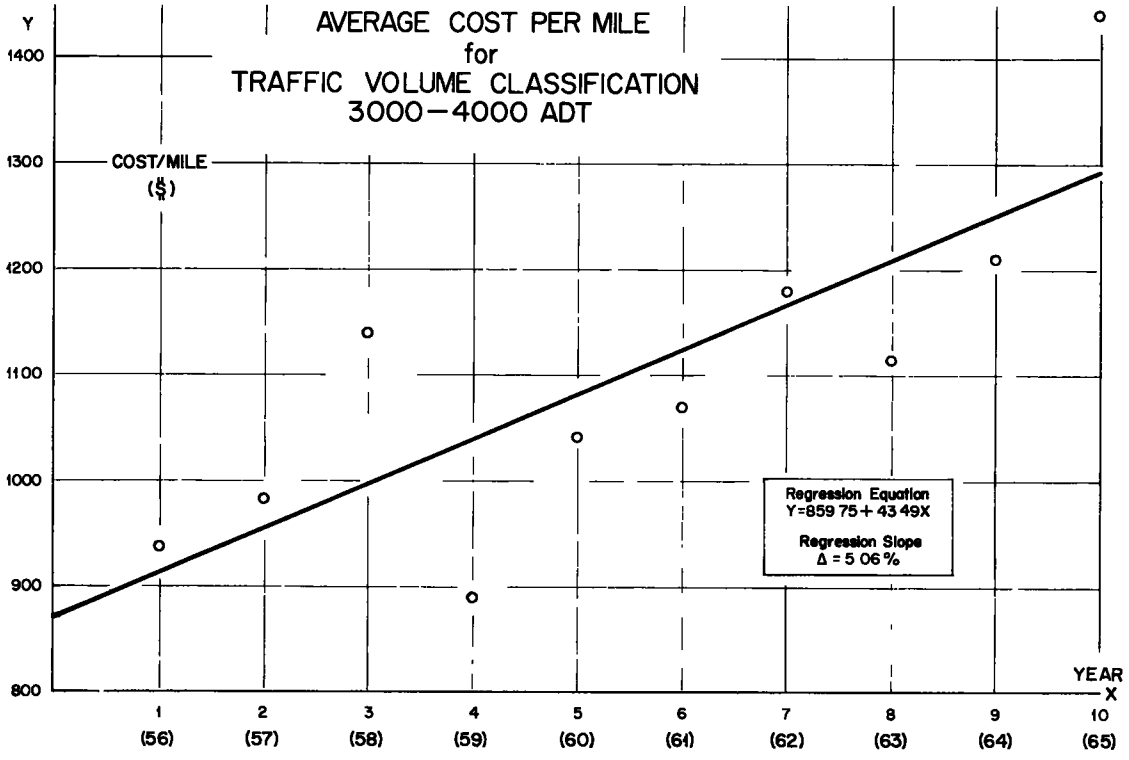

Figure L-4. Maintenance cost regression line for the 3,000-4,000 ADT sections of Virginia highways.

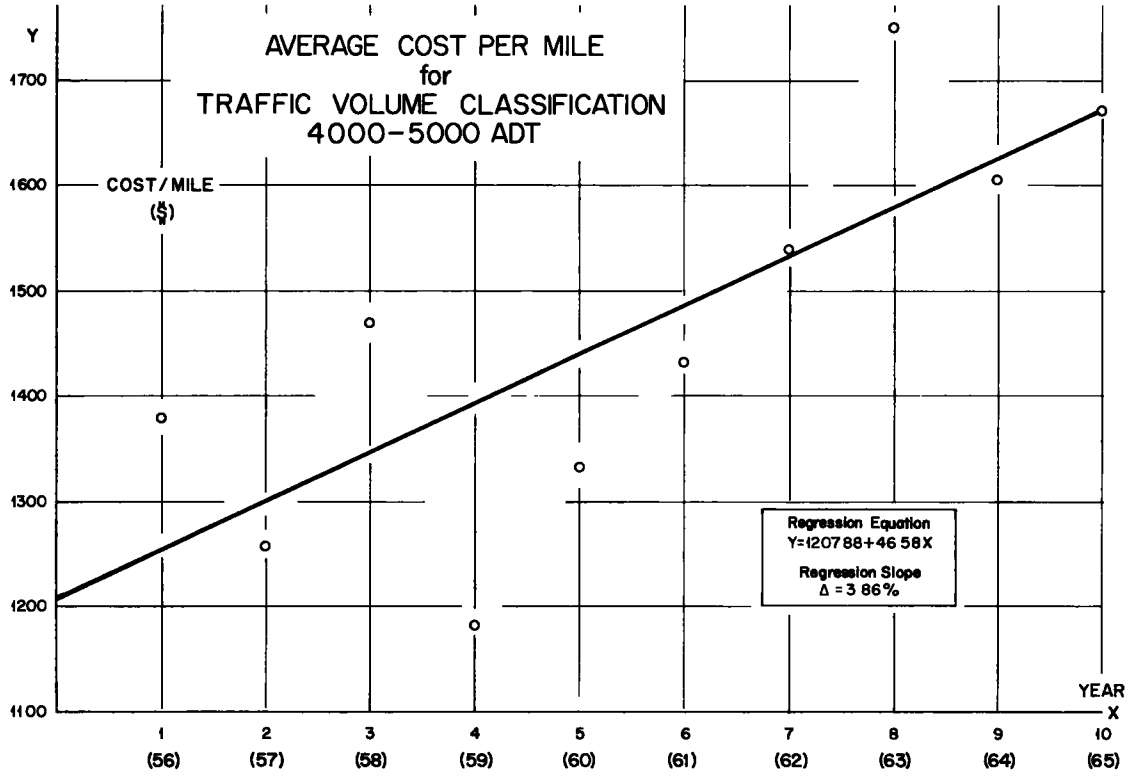

Figure L-5. Maintenance cost regression line for the 4,000-5,000 ADT sections of Virginia highways.

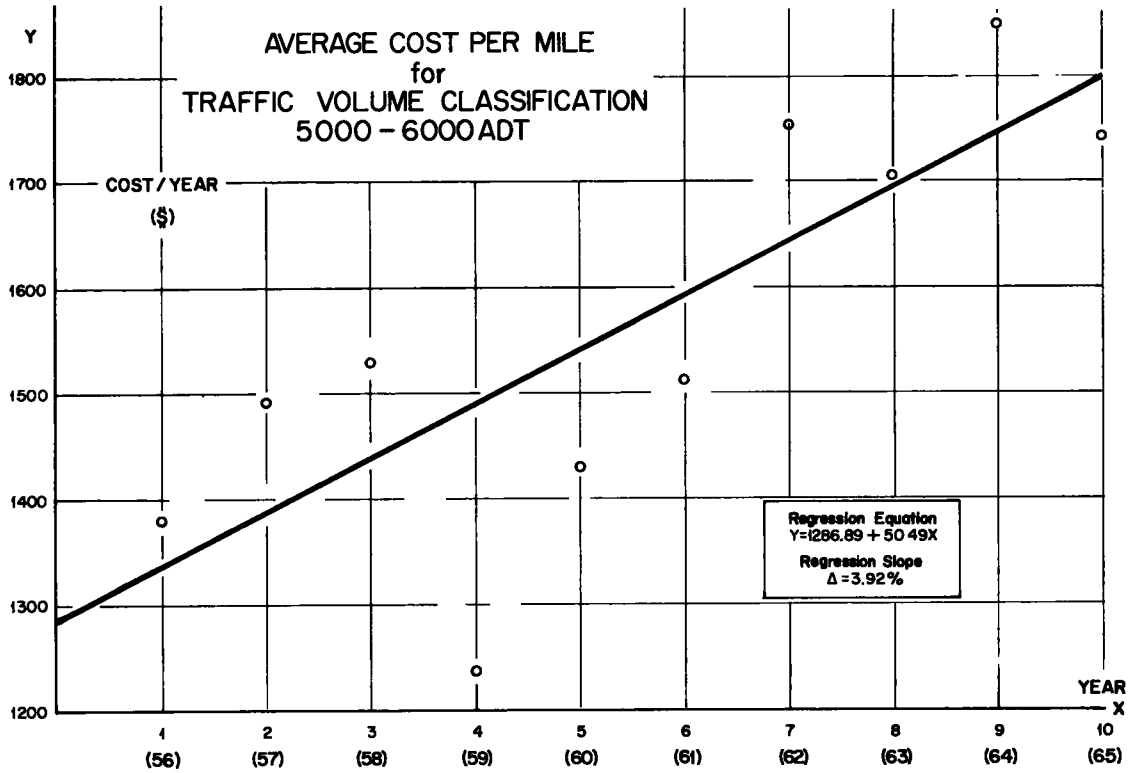

Figure L-6. Maintenance cost regression line for the 5,000-6,000 ADT sections of Virginia highways.

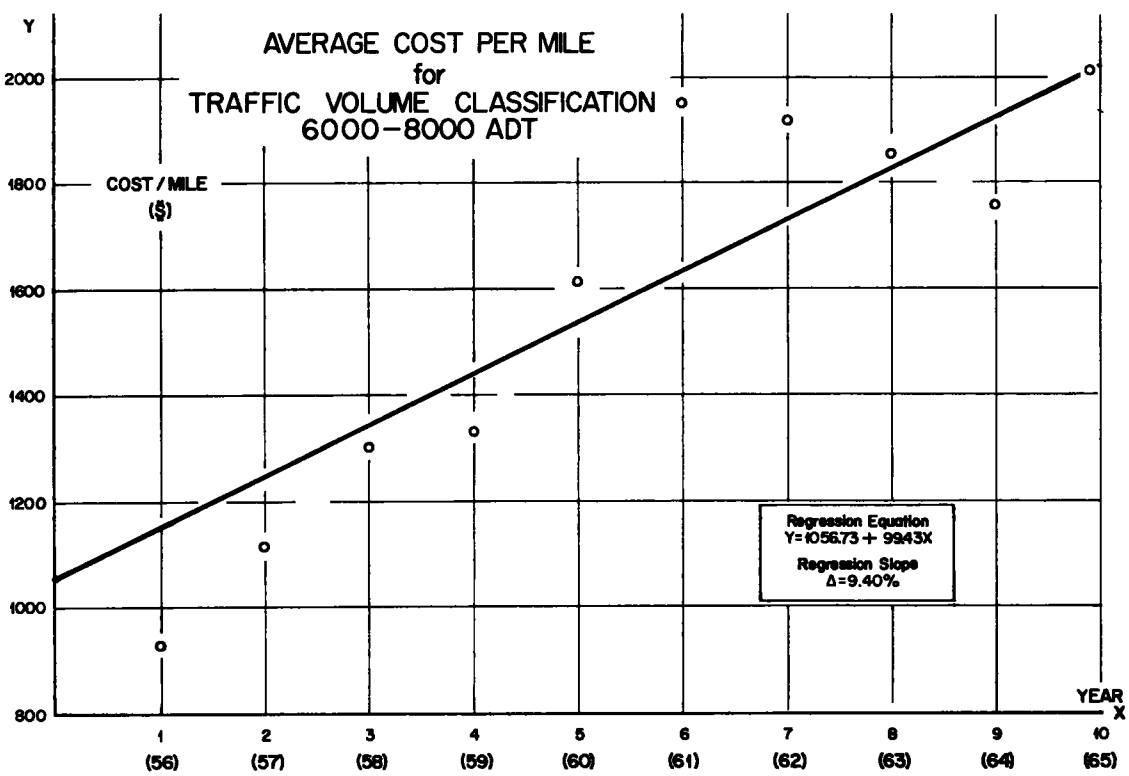

Figure L-7. Maintenance cost regression line for the 6,000-8,000 ADT sections of Virginia highways.

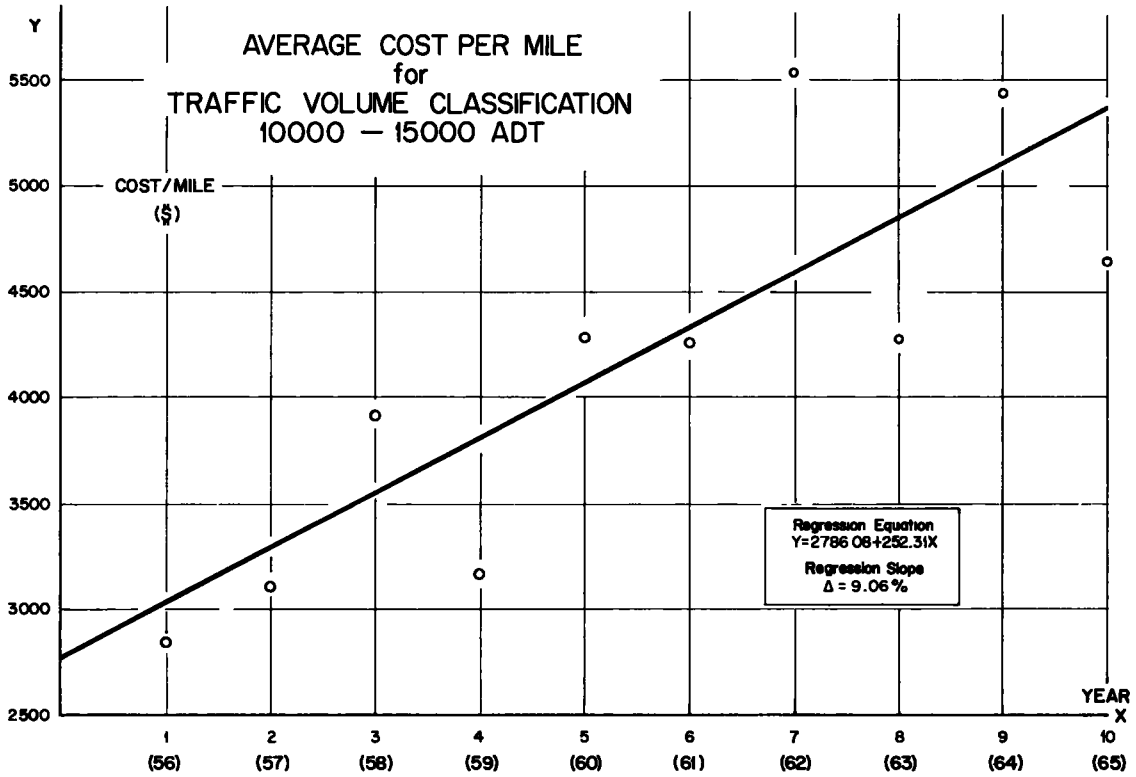

Figure L-8. Maintenance cost regression line for the 8,000-10,000 ADT sections of Virginia highways.

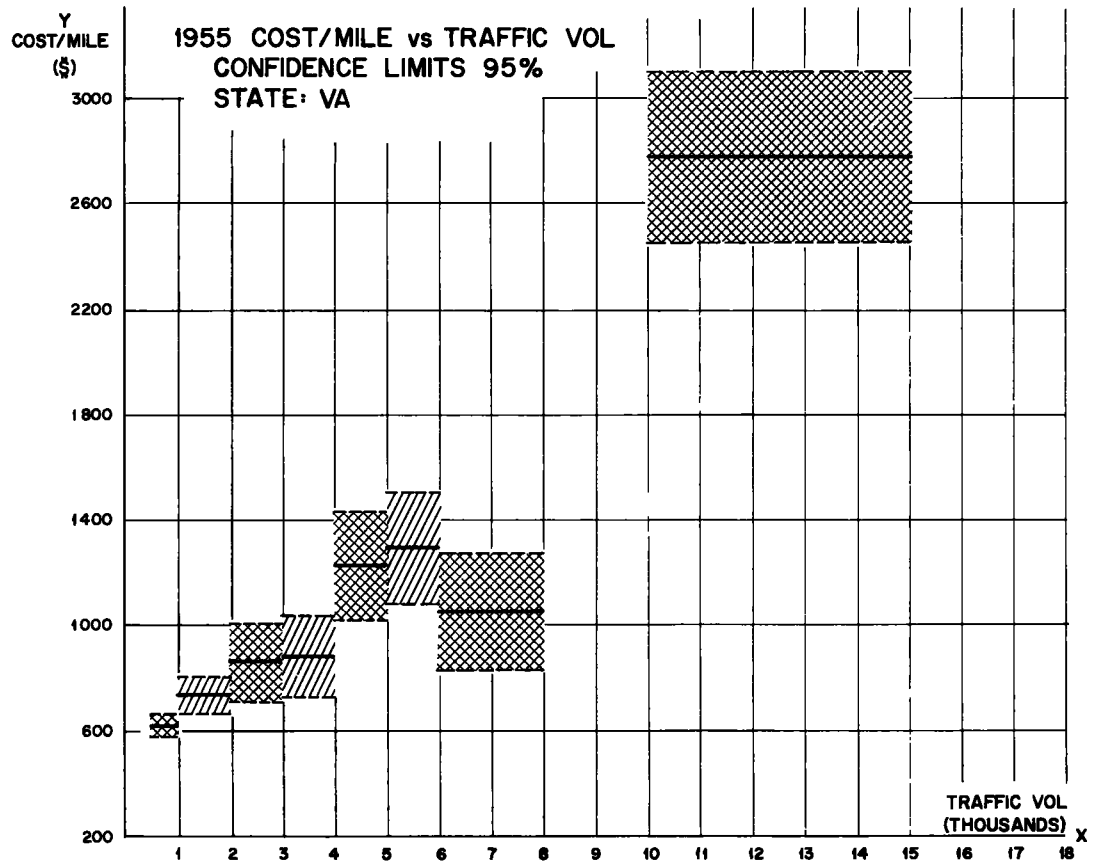

Figure L-9. Confidence limits for intercepts (1955) of regression lines relating maintenance expenditures and time.

A = 1955 cost/mile value;
B = 95% confidence limit;
$C = B/A$;
D = Ratio of C to the maximum C value;
$E = 1/D$; and
F = Rounded weighting factor.

Vol. Class [a]	A	B	C	D	E	F
0.5-1	665	27	4.07	0.23	4.35	4
1-2	788	42	5.39	0.31	3.23	3
2-3	1160	87	7.50	0.43	2.33	2
3-4	990	90	9.17	0.52	1.92	2
4-5	1465	119	8.14	0.46	2.16	2
5-6	1438	123	8.61	0.49	2.04	2
6-10	1400	247	17.65	1.00	1.00	1
10-15	3540	532	15.03	0.85	1.18	1

[a] In 1,000 vpd.

In determining the line of regression through the points on Figure 48, the weighting factors were used to establish the number of times each of the points occurred; i.e., the point representing $665 and 750 vpd had a factor of 4, so it was treated as though it had occurred 4 times. The same type of weighting approach was used in determining the regression for the rate of cost increase in Figure 49.

Before it was possible to check the traffic volume-maintenance cost relationships developed from the Virginia sample, it was necessary to determine actual traffic volumes and trends. The Virginia sample was taken from the State's primary system, so it was possible to use the mileage-traffic volume relationships published annually in Table SM-15 of *Highway Statistics*.

This table gives the primary mileage in each State associated with twelve different traffic volume classifications. Using this table, yearly composite ADT volumes for Virginia and for the nation were calculated. The computation was done by multiplying an average ADT volume classification by the associated mileage to produce vehicle-miles per day. The total of the vehicle-miles generated by classifications was divided by the total mileage to produce a composite ADT for each year. To illustrate, the following sample is expanded to a composite ADT:

ADT Class (vpd)	Mileage in Class	Avg. ADT (vpd)	Total Veh-Miles
2-3,000	1,000	2,500	2,500,000
3-4,000	2,000	3,500	7,000,000
4-5,000	3,000	4,500	13,500,000
Total	6,000		23,000,000

Thus, composite ADT = 23,000,000/6,000 = 3,833 vpd.

The composite ADT values were determined for the years 1956 through 1964. The resulting regression lines and slopes, computed to fit the yearly ADT composite values, are shown in Figures L-11 and 50.

Using the equations developed in Figures 48, 49, and L-11, the traffic volumes and maintenance costs in Virginia for the years 1955 through 1965 were calculated. These costs are compared in Table L-4 with the actual cost as obtained from the Virginia Department of Highways. The comparison was not good, but principally because the reported costs included replacements, which were not in the section costs used for the analysis. The Virginia Department of Highways estimated that replacement represented roughly one third of their reported actual cost. Applying this rough correction improved the correlation, but not enough to substantiate the validity of the equations developed from the sample data. However, considering that accurate costs were not available for comparison and that the confidence limits for the computed

TABLE L-4

COMPARISON OF VIRGINIA MAINTENANCE COSTS AS CALCULATED WITH ACTUAL COSTS AS REPORTED

YEAR	t	REGRESSION ADT	$COST_{55}$	$1 + 0.47tV$ [a]	PREDICTED COST ($)	CORRECTED ACTUAL COST ($)	DIFFERENCE ($)
1955	0	2241	741.37	1.00	741.37	937	196
1956	1	2346	759.60	1.0471	795.38	916	121
1957	2	2451	777.84	1.1026	857.65	1017	159
1958	3	2556	796.08	1.1443	910.95	1148	237
1959	4	2661	814.31	1.1944	972.61	1071	98
1960	5	2766	836.55	1.2455	1041.92	1049	7
1961	6	2871	850.79	1.2976	1103.99	1202	98
1962	7	2976	869.02	1.3507	1173.79	1225	51
1963	8	3081	887.26	1.4048	1246.42	1271	25
1964	9	3186	905.49	1.4599	1321.92	1247	−75
1965	10	3291	923.73	1.5160	1400.37	1267	−133

[a] V = ADT/1,000.

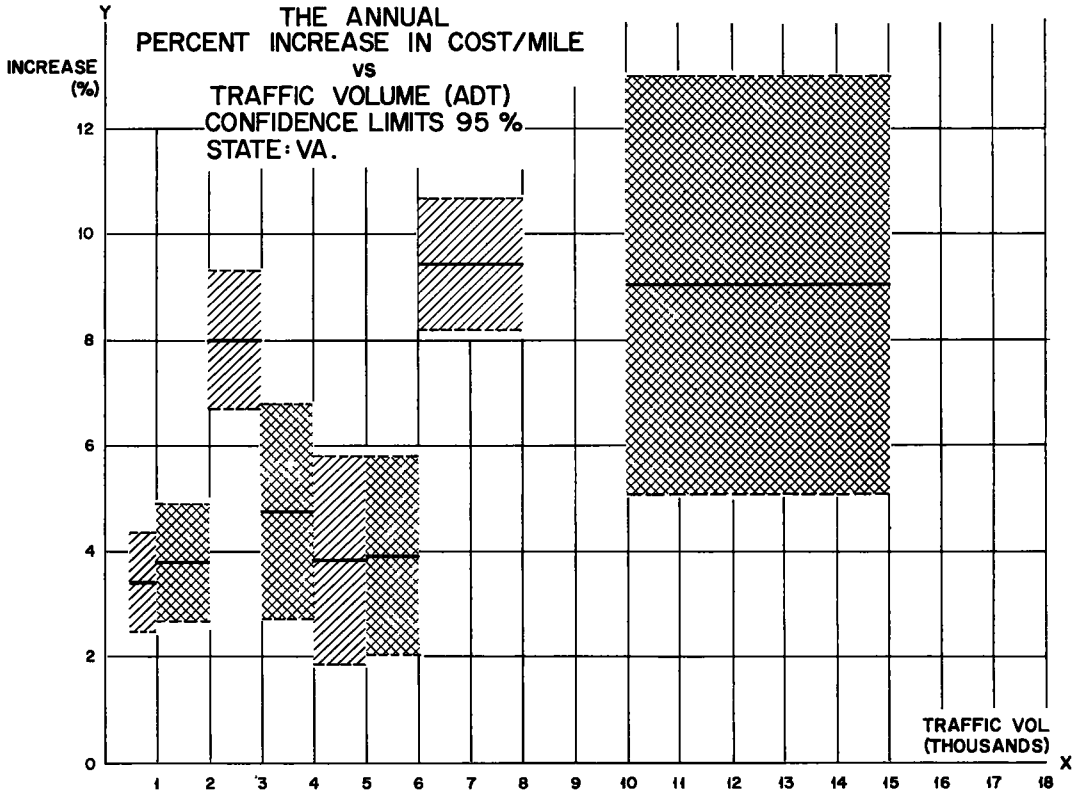

Figure L-10. Confidence limits for slopes of regression lines relating maintenance expenditures and time.

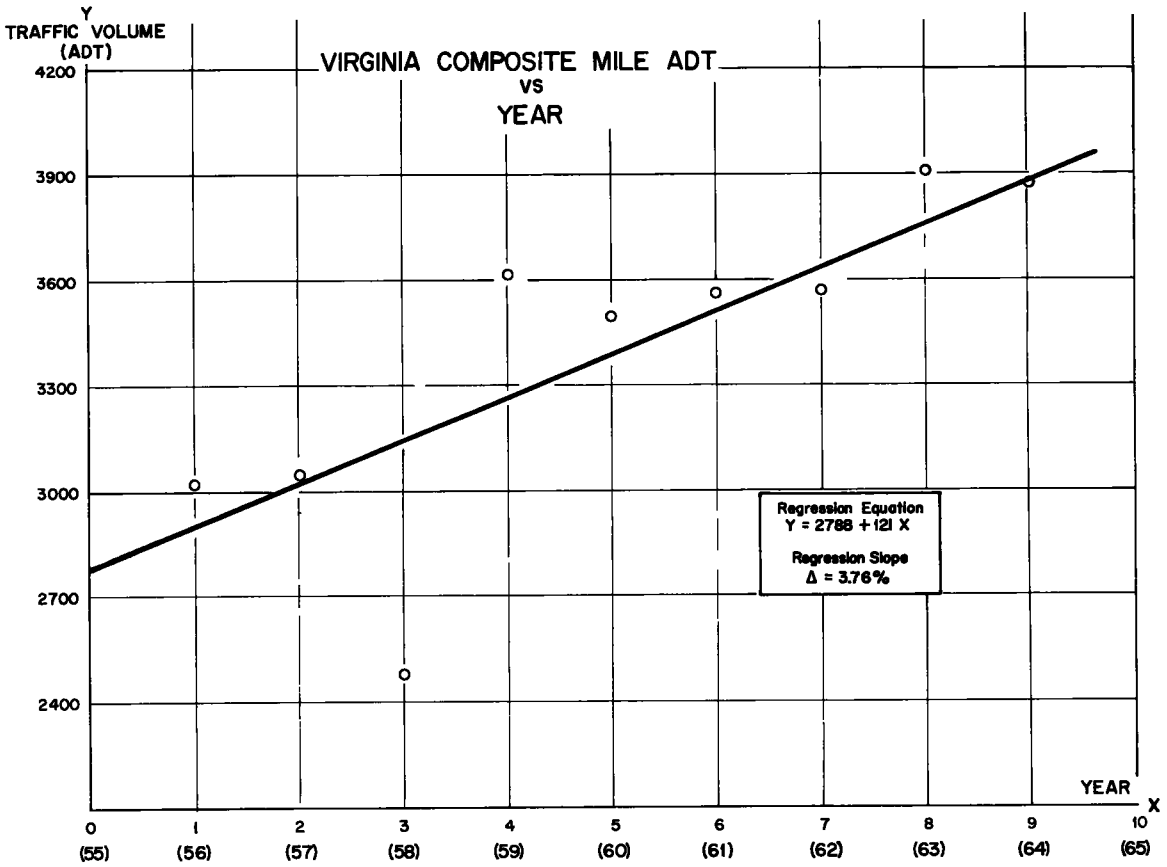

Figure L-11. Regression line relating ADT and time for a composite mile of the Virginia primary highway system.

TABLE L-5

NATIONAL COMPOSITE ADT AND COMPUTED 1955 MAINTENANCE COST[a] BASED ON VIRGINIA EQUATION

YEAR	ACTUAL COMPOSITE ADT		REGRESSION COMPOSITE ADT	
	ADT/1,000	COST ($)	ADT/1,000	COST ($)
1955	2.00	699.56	2.00	699.16
1956	2.17	729.03	2.06	710.45
1957	2.00	699.51	2.14	723.48
1958	2.24	741.19	2.21	736.50
1959	2.29	750.08	2.29	749.53
1960	2.41	770.72	2.36	762.56
1961	2.48	782.88	2.44	775.58
1962	2.54	743.30	2.51	788.61
1963	2.61	805.95	2.59	801.63
1964	2.62	807.19	2.66	814.66

[a] $Cost_{55} = 352.15 + 173.68$ (ADT/1,000).

equations were quite good, particularly in Figure 48, it was felt that there was still merit to examining national cost trends in terms of the traffic equations developed from the Virginia data.

Using the Virginia equations, the relative increase in cost that can be expected each year due to traffic alone can be calculated. This was done for both actual composite average daily traffic and for the traffic predicted from the national regression of traffic in Figure 50. The 1955 cost for this traffic is given in Table L-5.

The Virginia slope equation contains a constant intercept factor of 3.61 which does not relate to traffic. Rather, it includes those cost increases associated with labor, equipment, and material unit cost charges and, possibly, some other factors such as higher standards or variations in productivity. The slope calculated in Table L-6 does not include the 3.61. Only the 0.47(ADT/1000) was applied to the 1955 cost, as determined in Table L-5, to produce the final predicted cost.

TABLE L-6

INCREASE IN MAINTENANCE COST RELATIVE TO 1955 BASED ON VIRGINIA TRAFFIC EQUATIONS AND COMPOSITE TRAFFIC VOLUMES FOR THE NATIONAL PRIMARY SYSTEM OF HIGHWAYS

YEAR	$COST_{55}$	SLOPE	YEARS, n	$1 + \frac{(SLOPE)^a(n)}{100}$	PREDICTED COST ($)	INCREASE FROM 1955 ($)
		(*a*) ACTUAL NATIONAL COMPOSITE ADT				
1955	699.51	0.94	0	1.0000	699.51	0
1956	729.03	1.02	1	1.0102	736.47	36.96
1957	699.51	0.94	2	1.0188	712.66	13.16
1958	741.19	1.05	3	1.0315	764.54	65.03
1959	750.08	1.08	4	1.0438	782.93	93.42
1960	770.72	1.13	5	1.0565	814.27	114.76
1961	782.88	1.17	6	1.0702	837.94	138.33
1962	793.30	1.19	7	1.0839	854.86	160.35
1963	805.95	1.23	8	1.0989	884.71	185.20
1964	807.17	1.23	9	1.1107	896.55	197.09
		(*b*) REGRESSION COMPOSITE ADT				
1955	699.16	0.94	0	1.0000	699.16	0
1956	712.18	0.97	1	1.0097	719.00	19.93
1957	723.48	1.00	2	1.0200	737.95	40.56
1958	736.50	1.04	3	1.0312	759.48	60.32
1959	749.53	1.08	4	1.0432	781.91	82.75
1960	762.56	1.11	5	1.0555	804.88	105.72
1961	775.58	1.15	6	1.0640	829.10	129.94
1962	788.61	1.18	7	1.0826	853.75	154.59
1963	801.63	1.22	8	1.0980	880.19	181.03
1964	814.66	1.25	9	1.1250	916.49	217.33

[a] Slope = 0.47 (ADT/1,000).

APPENDIX M

MAINTENANCE AND OPERATIONS COST TRENDS ON FEDERAL-AID HIGHWAYS, 1950-1965

TABLE M-1

FEDERAL AID COST TRENDS, HIGHWAY MAINTENANCE AND OPERATIONS,[a] 1957-59 = BASE PERIOD

YEAR	LABOR	MATERIAL	EQUIPMENT	OVERHEAD	TOTAL
1950	66.44	81.15	72.77	70.95	70.49
1951	72.82	88.27	81.20	77.36	77.50
1952	77.99	89.27	84.38	80.87	81.44
1953	79.28	89.87	86.78	81.72	82.89
1954	83.69	90.90	88.85	82.57	85.94
1955	85.30	90.15	93.69	84.18	88.05
1956	89.50	94.63	93.47	87.71	91.10
1957	96.36	98.93	95.48	97.25	96.56
1958	100.24	100.46	99.58	100.96	100.16
1959	103.40	100.61	104.94	101.79	103.28
1960	108.28	103.09	109.77	104.66	107.65
1961	111.68	103.63	110.03	105.77	109.66
1962	115.97	105.24	112.02	107.50	112.79
1963	121.15	105.47	112.63	109.46	115.85
1964	124.70	106.14	115.16	111.86	118.64
1965	130.66	108.04	118.92	114.39	123.19

[a] From Table PT-5 *Highway Statistics 1964*, U. S. Department of Commerce, Bureau of Public Roads.

APPENDIX N

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