RECEIVED
FEB 17 1976
MAT. LAB.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **160**

FLEXIBLE PAVEMENT DESIGN AND MANAGEMENT

SYSTEMS APPROACH IMPLEMENTATION

IDAHO TRANSPORTATION DEPARTMENT
RESEARCH LIBRARY

Cpy	Refer To:	Act	Inf
	Mat'ls. Supv.		1
	Asst. Mat'ls. Engr.		2
	Mat'ls. Engr. II		3
	Off. Mgr.		
	Qual. Cont.		
	Soils & Found.		4
	Chf. Geol.		5
	Research		7
	Testing Chief		6
	Chem - Asph.		8
	Soils - Agg - Mix		9
	Str. - Conc - Insp.		10
	Moscow Lab.		
	File		11

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

TRANSPORTATION RESEARCH BOARD 1975

Officers

MILTON PIKARSKY, *Chairman*
HAROLD L. MICHAEL, *Vice Chairman*
W. N. CAREY, JR., *Executive Director*

Executive Committee

HENRIK E. STAFSETH, *Executive Director, American Assn. of State Highway and Transportation Officials* (ex officio)
NORBERT T. TIEMANN, *Federal Highway Administrator, U.S. Department of Transportation* (ex officio)
ROBERT E. PATRICELLI, *Urban Mass Transit Administrator, U.S. Department of Transportation* (ex officio)
ASAPH H. HALL, *Acting Federal Railroad Administrator, U.S. Department of Transportation* (ex officio)
HARVEY BROOKS, *Chairman, Commission on Sociotechnical Systems, National Research Council*
WILLIAM L. GARRISON, *Director, Inst. of Transp. and Traffic Eng., University of California* (ex officio, Past Chairman 1973)
JAY W. BROWN, *Director of Road Operations, Florida Department of Transportation* (ex officio, Past Chairman 1974)
GEORGE H. ANDREWS, *Vice President (Transportation Marketing) Sverdrup and Parcel*
MANUEL CARBALLO, *Secretary of Health and Social Services, State of Wisconsin*
L. S. CRANE, *Executive Vice President (Operations), Southern Railway System*
JAMES M. DAVEY, *Managing Director, Detroit Metropolitan Wayne County Airport*
LOUIS J. GAMBACCINI, *Vice President and General Manager, Port Authority Trans-Hudson Corporation*
HOWARD L. GAUTHIER, *Professor of Geography, Ohio State University*
ALFRED HEDEFINE, *Senior Vice President, Parsons, Brinckerhoff, Quade and Douglas*
ROBERT N. HUNTER, *Chief Engineer, Missouri State Highway Commission*
A. SCHEFFER LANG, *Assistant to the President, Association of American Railroads*
BENJAMIN LAX, *Director, Francis Bitter National Magnet Laboratory, Massachusetts Institute of Technology*
DANIEL McFADDEN, *Professor of Economics, University of California*
HAROLD L. MICHAEL, *School of Civil Engineering, Purdue University*
D. GRANT MICKLE, *Bethesda, Md.*
JAMES A. MOE, *Executive Engineer, Hydro and Community Facilities Division, Bechtel, Inc.*
MILTON PIKARSKY, *Chairman of the Board, Chicago Regional Transportation Authority*
J. PHILLIP RICHLEY, *Vice President (Transportation), Dalton, Dalton, Little and Newport*
RAYMOND T. SCHULER, *Commissioner, New York State Department of Transportation*
WILLIAM K. SMITH, *Vice President (Transportation), General Mills*
B. R. STOKES, *Executive Director, American Public Transit Association*
PERCY A. WOOD, *Executive Vice President and Chief Operating Officer, United Air Lines*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Advisory Committee

MILTON PIKARSKY, *Chicago Regional Transportation Authority* (Chairman)
HAROLD L. MICHAEL, *Purdue University*
HENRIK E. STAFSETH, *American Association of State Highway and Transportation Officials*
NORBERT T. TIEMANN, *U.S. Department of Transportation*
HARVEY BROOKS, *National Research Council*
WILLIAM L. GARRISON, *University of California*
JAY W. BROWN, *Florida Department of Transportation*
W. N. CAREY, JR., *Transportation Research Board*

General Field of Design
Area of Pavements
Advisory Panel for Project C1-10A

H. T. DAVIDSON, *Retired* (Chairman)
W. B. DRAKE, *Kentucky Department of Transportation*
WILLIAM GARTNER, JR., *Florida Department of Transportation*
J. H. HAVENS, *Kentucky Department of Highways*
FRANK L. HOLMAN, JR., *Alabama Highway Department*
JAMES F. SHOOK, *University of Waterloo (Ontario)*
P. G. VELZ, *Minnesota Department of Highways*
A. S. VESIC, *Duke University*
E. J. YODER, *Purdue University*
RICHARD A. McCOMB, *Federal Highway Administration*
L. F. SPAINE, *Transportation Research Board*
J. W. GUINNEE, *Transportation Research Board*

Program Staff

K. W. HENDERSON, JR., *Program Director*
DAVID K. WITHEFORD, *Assistant Program Director*
LOUIS M. MacGREGOR, *Administrative Engineer*
JOHN E. BURKE, *Projects Engineer*
R. IAN KINGHAM, *Projects Engineer*
ROBERT J. REILLY, *Projects Engineer*
HARRY A. SMITH, *Projects Engineer*
ROBERT E. SPICHER, *Projects Engineer*
HERBERT P. ORLAND, *Editor*
PATRICIA A. PETERS, *Associate Editor*
EDYTHE T. CRUMP, *Assistant Editor*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 160

FLEXIBLE PAVEMENT DESIGN AND MANAGEMENT

SYSTEMS APPROACH IMPLEMENTATION

R. L. LYTTON, W. F. McFARLAND,
AND D. L. SCHAFER
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
PAVEMENT DESIGN
BITUMINOUS MATERIALS AND MIXES
MAINTENANCE, GENERAL
FOUNDATIONS, SOILS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1975

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 and Transportation 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 Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the 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 and transportation departments and by committees of AASHTO. 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 and Transportation 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 Transportation 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.

NCHRP Report 160

Project 1-10A FY '72
ISBN 0-309-02339-4
L. C. Catalog Card No. 75-34977

Price: $4.00

Notice

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the advisory committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the advisory committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

Each report is reviewed and processed according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering, serving government and other organizations. The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities but also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

(See last pages for list of published titles and prices)

Printed in the United States of America.

FOREWORD

By Staff

Transportation Research Board

This report describes an operational computer program (SAMP6) that provides a basis for selecting flexible pavement design and management strategies with the lowest predicted total cost over a prescribed analysis period when considering such cost elements as initial construction, routine maintenance, periodic rehabilitation, interest on investment, salvage value, and roadway user costs. The program uses the AASHTO Interim Guides as its structural subsystem and the predicted decrease in serviceability with time and traffic as developed at the AASHO Road Test. It has been pilot tested in three states and found to be implementable where suitable computer facilities and personnel are available. A certain amount of modification of the current system is likely to be needed to reflect the unique facets of an individual agency's approach to pavement design. The report will be of particular interest to administrators who must make policy decisions concerning use of the systems approach to pavement design and management; to pavement designers who will be involved in its implementation; and to materials, soils, maintenance, and traffic engineers who provide the input information for its operation.

One of the first activities of the Highway Research Board (formed more than 50 years ago, and recently renamed the Transportation Research Board to reflect its actual scope of operation) was to investigate the economics of highway improvements. At its Fourth Annual Meeting, in December 1924, the Committee on Economic Theory of Highway Improvements reported that the superiority of aggregate-surfaced roads over ordinary earth roads was generally conceded, but highway officials were plagued with the question of whether aggregate surfacing was a good investment from a financial standpoint. A study conducted at that time determined that, on the basis of the cost of the road itself, including such items as interest on investment and maintenance, and the cost of operation of the vehicles using the road, a good aggregate-surfaced road was less costly in terms of total annual cost of transportation per mile than either an earth-surfaced or a paved road when traffic averaged 100 vehicles per day. After this early interest in the economics of highway improvements, emphasis shifted to the structural design of pavements to withstand the effects of traffic and environmental conditions.

In recent years there has been renewed interest within the highway field in the concept of total cost analysis. Acceptance of the systems approach to the design and management of pavements is a most timely development because new legislative funding likely will apply to all modes of transportation. Therefore, determination of the total cost of movement of people, goods, and services will be necessary to determine priorities for use of funds and material resources. A Systems Analysis Model for Pavements (SAMP5), as described in *NCHRP Report 139*, "Flexible Pavement Design and Management—Systems Formulation," is one approach to considering initial construction, operational, and user costs in the decision-making process.

The responsibility of the Texas A&M researchers, under Project 1-10A, was to finalize SAMP5 as an operational computer program, including preparation of a users' guide, and to pilot test the program in several states. The project was successful in that the systems model (now designated as SAMP6) has been modified to include full roadbed cross sections, variable unit costs with quantity and time, stochastic variability of some variables, environmental roughness, and a modified structural subsystem. The program has also been modularized into distinct subsystems that can be replaced or reprogrammed with a minimum of effort and placed on magnetic tape. Trial implementation of the SAMP6 program has been undertaken in Florida, Kansas, and Louisiana, with the finding that SAMP6 is a useful tool in the pavement design and management process.

Use of the systems approach to pavement design and management, and more specifically the operational SAMP6 program, provides highway decision-makers with the capability for comprehensively selecting optimum strategies and updating decisions as conditions change. By using computer techniques, a large number of parameters and their interactions (as many as several thousand combinations for one problem) can be evaluated within realistic time and cost limitations. Optimization is normally based on lowest total cost over the analysis period, but other parameters—such as user costs, initial construction costs, use of materials, or rehabilitation programs—can be optimized by proper program control. The strategy selection capability primarily is a quantitative procedure for considering the long-term advantages and disadvantages of staged construction versus strong initial structural designs, thus providing a basis for more objective decision-making. The capability of quantitatively updating decisions is a unique feature of the approach. Existing pavements, as well as those being designed, can be analyzed in terms of optimization and strategy selection, and decisions affecting them can be revised in view of changes in material costs, material availability, funds availability, and traffic conditions.

The researchers have identified several areas for improvement of the program, including (1) development of a rigid pavement system so that both portland cement and asphaltic pavements can be considered simultaneously and (2) development of a new flexible pavement structural subsystem based on mechanistic models. The latter is the objective of NCHRP Project 1-10B, "Development of Pavement Structural Subsystems," scheduled to be completed in 1976.

Appendices B, C, G, and H, containing SAMP6 computer program documentation and a users' guide, are of primary value to persons directly involved in operation of the program. They are not included in this report but are available on a loan basis, as are copies of the SAMP6 program on magnetic tape, from the Program Director, NCHRP, Transportation Research Board, 2101 Constitution Ave., N.W., Washington, D.C. 20418.

CONTENTS

1 SUMMARY

PART I

2 CHAPTER ONE Introduction and Research Approach

Purpose and Scope
Objectives
Background
Research Approach

4 CHAPTER TWO Findings

Systems Approach
The SAMP6 Computer Program Input
SAMP6 Computer Program
Pilot Implementation of SAMP6
SAMP6 Program Changes
SAMP6 Documentation
SAMP6 Users' Guide
Sensitivity Analyses
Pavement Data Feedback Systems

17 CHAPTER THREE Interpretation and Appraisals

SAMP6 Strategy
Strategic Benefits of Using SAMP6
Evaluation of Best Uses for SAMP6
Implementation of SAMP6
SAMP6 Adaptability

20 CHAPTER FOUR Conclusions and Research Recommendations

22 REFERENCES

PART II

24 APPENDIX A Discussion of SAMP6 Computer Program

40 APPENDIX B SAMP6 Computer Program Documentation

40 APPENDIX C SAMP6 Users' Guide

40 APPENDIX D SAMP6 Sensitivity Analysis

48 APPENDIX E States' Evaluations and Expected Use of SAMP6

51 APPENDIX F States' Evaluations of SAMP6 Data Inputs and Pavement Feedback Data Systems

53 APPENDIX G Pavement Feedback Data Systems

53 APPENDIX H Computer Software for Pavement Feedback Data Systems

ACKNOWLEDGMENTS

The research reported herein was conducted by the Texas Transportation Institute of Texas A&M University; Robert L. Lytton served as Principal Investigator, William F. McFarland served as Co-Principal Investigator, and Frank H. Scrivner served as Program Manager. Dale Schafer and Chester Michalak assisted with making computer program changes and preparing program documentation. Other Institute staff members gave suggestions and provided assistance through various phases of the research.

The authors are especially grateful to the numerous individuals in the pilot implementation states who participated in the study through development, implementation, and evaluation of the SAMP6 system. Among the state highway administrators who helped with over-all coordination and provided leadership in implementation were: John D. McNeal, State Highway Engineer and R. R. Biege, Engineer of Location and Design Concepts, State Highway Commission of Kansas; William Gartner, Assistant State Highway Engineer, Koerner Schenk, Assistant State Highway Engineer, and Robert Orth, Engineer of Preliminary Location and Design, Florida Department of Transportation; and Roger Guissinger, Executive Administrator, Louisiana Department of Highways.

To the numerous other individuals in the pilot states who helped with developing SAMP6, collecting data, running programs, and providing evaluations go special thanks. These individuals include: for Florida, Steve Sklute, Engineer of Pavement Design, Jatinder Sharma, Assistant Engineer of Pavement Design, and Steve Fuller, Research Engineer; for Kansas, G. Norman Clark, Soils Engineer, and Herb Worley, Pavement Research Engineer; for Louisiana, Ali S. Kemahli, Soils Design Engineer, J. B. Esnard, Assistant Soils Design Engineer, and Steve Spohrer. Other individuals, too numerous to list, participated in one or more of the pilot study meetings and thanks are extended to them also. Acknowledgment also is given to J. L. Brown of the Texas Highway Department and W. R. Hudson and B. F. McCullough of the Center for Highway Research, University of Texas, for their development of information used in the project.

FLEXIBLE PAVEMENT DESIGN AND MANAGEMENT
SYSTEMS APPROACH IMPLEMENTATION

SUMMARY

The primary objectives of this project were to develop an existing computerized systems analysis model for flexible pavement design (SAMP) to its field application stage, to pilot test it in several state highway departments, and to get an in-depth evaluation by the states of the systems approach. This required that the participating states run the program on their own computers with input variables that were well understood and simple to collect.

The major finding of this project is that the SAMP6 computer program is a working, implementable systems analysis model for pavements. Current weak spots in the computer program are the structural and environmental subsystems. The states in which the computer program was pilot tested expect to use it in their design system: Louisiana, for flexible pavement design; Florida, for design studies and as a building block for a future, more mechanistically oriented design system; Kansas, as a research tool and a supplement to their current design system. States that currently use the AASHO Interim Guide for flexible pavement design can use the SAMP6 computer program directly. Other states that wish to use some other structural subsystem must use one that predicts the decrease of serviceability index with time and traffic. Having met this provision, their structural subsystem can be inserted directly into the SAMP6 computer program as it presently stands.

Implementation of the system will require a policy decision to use the systems approach and a certain amount of modification of the current system to reflect unique facets of the agency's approach to pavement design. Modification efforts will be minimal because:

1. Modularization of SAMP6 into distinct subsystems allows them to be replaced or reprogrammed with a minimum of effort.
2. A Users' Guide, a program documentation deck, and flow charts have been prepared.
3. These programs are available on magnetic tape.
4. The appendices to this report explain modifications.

Several management benefits of using the systems approach were identified as:

1. The ability to quantify decisions. An example of this is the decision of selecting between light pavement with several overlays as opposed to thick, heavy pavements with virtually zero rehabilitation.
2. The capability of updating decisions. Several runs of the program at various stages of design, construction and service will give a good basis for judging the effects of fluctuating prices and interest rates, scarcity of materials, and revised maintenance and rehabilitation policy, among others.
3. The capability of considering large numbers of factors. Several long-range physical and economic factors not normally considered in pavement design are included in the analysis. They include users' costs due to traffic delay around

rehabilitation work, investment costs to the highway agency, and salvage values of materials in place at the end of an analysis period.

The total cost of the system is most sensitive to changes in the following variables:

1. Traffic delay costs when congestion occurs.
2. Serviceability loss because of environmental factors (e.g., swelling clay, frost heave, various forms of cracking).
3. Soil support offered by the subgrade.
4. Material properties and unit costs of the surface and base courses.
5. Degree of reliability the designer requires of the performance of the pavement.

Some of the variables found to be less important were as follows:

1. Serviceability index at the time of overlay.
2. Total 18-kip equivalent single-axle loads applied to the pavement.
3. Interest rates.
4. Length of analysis period.

Further research in areas of the most sensitive variables is strongly indicated, as are further developments of the structural and environmental subsystems of SAMP6. Maintenance management systems and feedback data systems are indicated as valuable collateral developments to provide reliable input data to SAMP6 and to assist in making sound decisions concerning pavement design and management.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PURPOSE AND SCOPE

The performance of pavement systems involves the interaction of numerous variables such as material properties, environment, traffic loading, construction practices, maintenance activities, and management constraints. The pavement design process has as its objective the design and management of a pavement throughout its lifetime in order to minimize the total cost to the general public. In order to select an optimum pavement strategy, methods are needed that consider the interaction of these variables and constraints. One approach to meeting this need was the development of an operational pavement systems model (SAMP5), a computer program produced during work on NCHRP Project 1-10 (*24*). Although the program used up to 100 input variables that were thought to cover the range of variables normally considered in the pavement design process, it still needed to be implemented; that is, to be applied to actual pavement design problems. If discrepancies were noted between the program and practice then the program needed to be changed to reflect as closely as possible the real decision-making process. Full implementation of the computer program required detailed descriptions of how it was to be used, how data was to be input, and how data was to be obtained from the field using data feedback storage systems.

OBJECTIVES

The primary objectives of this project were the further development of the SAMP5 program to the field application stage and its pilot testing in one or more state highway departments. It was anticipated that meeting these objectives would involve:

1. Pilot testing SAMP5, including a sensitivity analysis on one or more state highway departments using the current pavement structural design procedure of the test state as the structural subsystem. It was recognized that considerable development work in pilot testing a pavement de-

sign system similar to SAMP5 was in progress in the Texas Highway Department. However, it was desired that the pilot testing activities of this project would be undertaken in state highway departments other than Texas in order to develop a broader base of experience.

2. Revising the working system as necessary in accordance with the experience gained during pilot testing.
3. Finalizing the SAMP5 working system as a pavement design and management tool, including the preparation of detailed descriptions for the Users' Guide, input forms, and data feedback storage systems.
4. Determining research needs in each of the subsystems of SAMP5, using sensitivity analysis as needed.

The main aim of the project was to pilot test an over-all system with a strategic approach to the pavement design process. The essential element in the pilot test was an in-depth evaluation by the states of the systems approach. The test states ran the SAMP5 program on their own computers using input variables that were well understood and simple to collect.

BACKGROUND

The SAMP5 computer program was developed from Flexible Pavement System (FPS)-4, one of the FPS-series computer programs written for implementation within the Texas Highway Department. Two structural subsystems, the AASHO Interim Guide (*3*) flexible pavement equation and the deflection equation developed by Scrivner and Moore (*1*), were represented in the FPS series. Considerable progress had been made in implementing the latter system within the State of Texas. Successes gave rise to the questions: "Can this system be implemented in other states? Can a pavement design procedure that has been found useful in one state be transported across the boundaries to another state?" These were practical questions and the answers could only be determined by a trial implementation of SAMP5. Major implementation queries posed were:

1. Does the SAMP5 system "fit" design practice in other states?
2. Are the required input data to SAMP5 available in other states?
3. Are the sensitive variables in Texas the same or different in other states?
4. Does the SAMP5 system include most of the important design variables?
5. Is SAMP5 flexible enough to allow major changes of subsystems without a major effort at reprogramming? (Another way of phrasing this question is: Is SAMP5 modularized?)
6. Can SAMP5 be run easily on the states' computers?

A final practical major concern was whether the over-all process of pavement design and management was viewed realistically. The SAMP5 computer program adopts the view that routine maintenance and future rehabilitation (overlays) are part of the total pavement management process. Future costs are discounted to the present and the total cost per square yard is used as the criterion for determining which pavement is the optimum. Included in the total cost are the users' costs, a term for the expense to the traveling public of being delayed while detouring an overlay activity. These costs are weighed equally with actual construction dollars. It is also generally agreed that pavement materials would have a salvage value which depends mainly upon their expected future use. This is an important concern because a major alteration in the salvage value of different paving materials can significantly alter the optimum pavement design and management strategy.

All of these concerns are considered critically in the implementation phase of this project.

RESEARCH APPROACH

The State Highway Departments of Florida, Kansas, and Louisiana cooperated in the implementation phase of this project. Implementing SAMP5 in each of these three states was a heuristic process involving two pilot test cycles separated by a period in which major program revisions were made. In each cycle, the computer program was tried and evaluated to determine the necessary changes to be made. Procedures for each of the three phases in the research approach are outlined.

Pilot Study—Cycle One

The five steps in this first pilot study cycle allowed for:

1. Initial coordination meeting with the states. At this meeting the over-all concept of SAMP5 was explained and detailed input data guides were given to the contact personnel in each state. The states were asked to assemble data on two typical pavement problems.
2. Minor program modifications.
3. Preliminary sensitivity analysis of the SAMP5 program and running all of the states' problems with certain variations they had indicated would be of interest.
4. A second meeting with each state during which they were shown the results of step three.
5. Preliminary evaluation by the states, including an assessment of how SAMP5 designs compare with the states' standard designs under the same circumstances. At this stage, the states were asked to determine whether additional features in SAMP5 would allow more realistic problems to be run. The states were asked what difficulty they had in locating input information and whether they consider their current data collection and feedback system to be adequate.

Major Program Revisions

As a result of the first pilot-study cycle, extensive revisions were recommended by each of the states. While these revisions were being made, the states were being asked to consider the output of the problems that they had in hand and to assemble data for additional runs they might wish to make on the improved computer program. In this phase of research the aim was to:

1. Develop SAMP5 into its final form.
2. Rerun the typical problems and ascertain whether results were as desired.
3. Make selective sensitivity analyses.

4. Develop the Users' Guide as well as a program documentation deck and a dictionary computer card deck.
5. Develop information on data feedback systems.

Pilot Study—Cycle Two

The aim of the second cycle was to have the states run the revised SAMP5 (SAMP6) program on their own computers. The cycle proceeded in four steps:

1. A third meeting was held with each of the participants to familiarize them with the new SAMP6 computer program and to deliver to them the Users' Guide, the program documentation deck, and sensitivity analysis information. During these meetings, the SAMP6 program was run on the states' own computers.
2. Each state tested SAMP6 on selected pavement design problems using data that were either collected or assumed by state personnel.
3. A final meeting was held with each participating state. During this meeting, complete explanations of SAMP6 changes were given. Also discussed thoroughly were the subjects of program documentation, sensitivity analyses, the Users' Guide, and the data feedback system. The participants' experiences in the pilot testing period were discussed and future developments of the computer program were considered.
4. Final evaluation of the SAMP6 computer program from several points of view questioned:
   a. Were the designs produced by the SAMP6 program realistic in terms of thicknesses, projected service lives, costs, and rankings of pavement strategies?
   b. What was the expected future use of the SAMP6 program within the state organization (e.g., design, preliminary design, building block for future)?
   c. What would be desirable future developments of SAMP6?

CHAPTER TWO

FINDINGS

The major finding of this project is that the SAMP6 computer program is a working, implementable systems analysis model for pavements. A number of changes were made in the SAMP5 computer program that SAMP6 replaces and more changes should be made to satisfy the requirements of any state other than those in which the computer program has been implemented. Current weak spots in the computer program are the structural and environmental subsystems. The states in which the computer program was pilot tested expect to use it in their design system: Louisiana, for design; Florida, for design studies and as a building block for a future, more mechanistically oriented design system; Kansas, as a research tool and supplement to their current design system. There were no problems encountered in interfacing computer programs between states. States that currently use the AASHO Interim Guide as a design method can use the SAMP6 computer program directly. Other states desiring to use some other structural subsystem must use one that predicts the decrease of serviceability index with time and traffic. Having met this provision, their structural subsystems can be inserted directly into the SAMP6 computer program as it presently exists. The effort required to implement the SAMP6 system within any state has been reduced to a minimum by modifications made to the SAMP5 program and by providing:

1. Modularization of SAMP6 into distinct subsystems that can be replaced or reprogrammed with a minimum of effort.
2. Preparation of a Users' Guide, a program documentation deck, and flow charts.
3. Availability of aforementioned programs on magnetic tape.
4. Explanations provided in the appendices * to this report.

Each of the states conducting pilot studies developed a major interest in pavement data feedback systems, mainly as part of a larger effort in maintenance management. The main problems encountered in implementation concern:

1. Organization. It is important to consider the agency organization with regard to the pavement design and management process: whether centralized or decentralized or whether a single person, section, or committee has primary responsibility for technical details of pavement design. The more dispersed the responsibility, the more extensive are the required implementation efforts.
2. Establishing confidence in the model. There is a

* Only Appendices A, D, E, and F of the original report are published herein. Appendices B, C, G, and H of the original agency report are published separately as *Supplement to NCHRP Report 160*, which contains the SAMP6 computer program documentation, the SAMP6 Users' Guide, and information on pavement data feedback systems and, thus, will be of interest primarily to those persons desiring to implement the project findings.

greater tendency for pavement designers to use the program when they are familiar with its contents, when they trust and agree with the models used, when they believe that all or most of the pertinent factors are included and, finally, when the predicted results on conventional pavements match what their experience indicates is a suitable design.

3. Collection of reliable data. Sometimes too many data are collected for some subsystems and too few for others. The SAMP6 program provides a framework within which the right amount of data can be collected. With experience, the reliability of the data can be improved.

SYSTEMS APPROACH

Pavement design is normally a heuristic process in which the designer assumes a certain combination of thicknesses of layered materials and subsequently checks the layered system for adequacy from the points of view of traffic and environmental deterioration, construction and rehabilitation costs, as well as costs of future seal coats, overlays, and routine maintenance. If a designer is comparing this layered system with any other, one can attempt to estimate the cost to the traveling public of its use of this system. In the course of this analysis, a designer may see areas in which he could improve the over-all cost by making modifications in his trial designs. The SAMP6 computer program herein follows essentially the same process. A schematic computation diagram of an ideal pavement design system is shown in Figure 1. Actually, SAMP6 considers all of what is shown with the exception of seal coat costs and costs of skidding accidents.

The designer who uses the SAMP6 program will specify ranges of thicknesses for each of the layers and each of the materials he wishes SAMP6 to consider. With the variety of materials and thicknesses available to highway designers, SAMP6 is normally required to consider between one and two thousand different trial designs. The material properties and the traffic and environmental factors are combined to predict a time at which the serviceability index of the pavement would drop below an acceptable level. For each trial design there are a number of different trial overlay strategies that could be used. SAMP6 tries all of those specified by the designer and selects the one least expensive. The total initial cost of the trial design is later added to the cost of the best overlay strategy and the costs of routine maintenance to give a total cost figure to the constructing agency. This cost is paid directly out of taxes.

Pavement costs that are not paid for out of tax money include users' costs and costs of skidding accidents. Both topics are complex and are the subjects of considerable research being done at the present time. Users' costs include the costs of delay time for the traveling public to detour maintenance activities and motorist delay due to general road roughness and reduced skid resistance. The latter delay is due to a reduction in speed to avoid discomfort and the greater likelihood of skidding accidents. Because very few data are available on these important costs to the public, they were not included in the SAMP6 program. As information from current research on these factors becomes available, they should be included as a

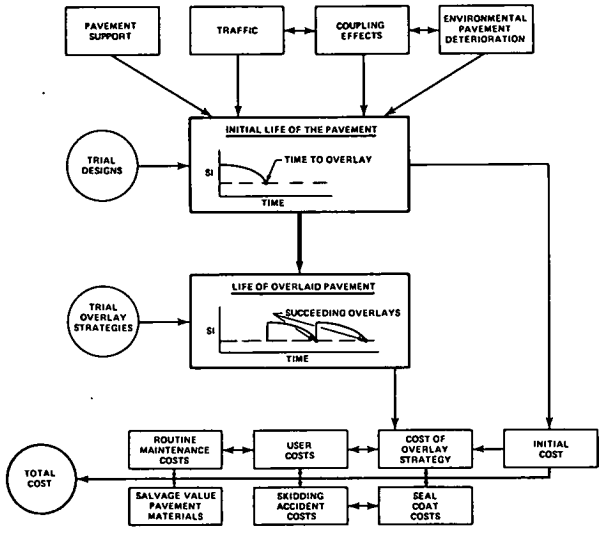


Figure 1. Schematic computation diagram of an ideal pavement design system.

future development of the SAMP6 computer program. At present, the only users' cost included within SAMP6 is that of delay in detouring an overlay operation. This cost is added to the total cost to the construction agency to determine a total cost to the public. It is this total cost per square yard of paved area which is minimized in SAMP6.

All of the component subsystems of the SAMP6 pavement design system are simplified models of what actually happens. Their simplicity is desirable to reduce the computer time required to evaluate many trial layered designs and their associated overlay strategies. In addition to being simple, each of the component subsystems should be as reliable as possible, although simplicity and reliability can very rarely be found to the same degree. The best that can be expected of the output of such a general systems analysis program would be over-all guidelines within which more detailed suboptimization can be done. Once the systems program has determined which combinations of layered materials and thicknesses will produce the lowest total cost within a given analysis period, better designs can be further evaluated on the basis of local experience and more complex models. Such will certainly be the case with the structural subsystem in which stress and distress analysis will be carried out. Also, the traffic delay subsystem, which considers the detours for maintenance activities, should receive further evaluation. Such may be the case in the future when costs associated with pavement safety and salvage value become available through research. While the over-all systems analysis program is concerned with the strategy to minimize total cost, each type of analysis done on a subsystem will be concerned with suboptimization and detailed technical predictions.

A major advantage of using a strategic system of this sort is that all analysis will be coordinated and aimed at producing a minimum total cost. In all of the states where this systematic approach has been tried, the advantages of a coordinated effort at pavement design and management have also pointed toward the advantages of a coordinated effort at data collection. In addition, new combinations of

thicknesses and materials were suggested, as were new cross-section geometries and shoulder treatments. A major organizational benefit is that the use of the systems approach to pavement design requires coordination and engenders cooperation among those who collect and use data for the various subsystems.

THE SAMP6 COMPUTER PROGRAM INPUT

The SAMP6 program requires twelve classes of input variables:

1. Program control and miscellaneous input.
2. Environmental and serviceability variables.
3. Traffic and reliability variables.
4. Constraint variables.
5. Traffic delay variables.
6. Maintenance variables.
7. Cross-section, cost model, and shoulder variables.
8. Tack coat, prime coat, and bituminous materials variables.
9. Wearing surface variables.
10. Overlay variables.
11. Pavement material variables.
12. Shoulder layer material variables.

Although these input variables are discussed in detail in the Users' Guide in Appendix C * herein, a general discussion of each of them follows.

Program Control and Miscellaneous Input

Although listed as miscellaneous inputs, some of these variables are among the most important in the entire program. They include the number of lanes on a highway in both directions, the length of the analysis period in years, the width of each traffic lane, and the interest rate or the time value of money.

Environmental and Serviceability Variables

Two types of environmental variables are considered. One is the regional factor that accounts for general climatic and geologic effects of the region. The numerical value of the regional factor is not well determined anywhere in the United States (*2*). The second environmental variable is that of expansive clay, for which three input variables are required. One gives the frequency of occurrence of expected expansive clay trouble spots, another indicates how active the soil is, and the third gives the rate with which expansive clay roughness develops. Because of the similarity in the roughness patterns and growth characteristics of expansive clay and frost heave, it is expected that this same model could be modified to account for frost effects.

There are three serviceability variables. They are the serviceability index of the pavement immediately after construction, the serviceability index of the pavement immediately after an overlay, and the minimum acceptable value serviceability index at which it is generally believed an overlay must be placed.

Traffic and Reliability Variables

Average daily traffic is assumed to increase uniformly from the beginning to the end of the analysis period. The average daily traffic at the beginning and the end of the analysis period are input variables. Another traffic input is an estimate of the 18-kip equivalent single-axle loads that are expected to be applied to the pavement within the analysis period.

Two reliability variables input are a coefficient of variation and a confidence level indicator. The designer is required to furnish various stiffness coefficients, soil support values, and a regional factor—all of which must be estimated on the basis of field experience and some lab tests. Despite the fact that none of these factors can be determined directly from a lab test, each designer having experience with the design method contained within the AASHO Interim Guide (*3*) has some idea of within what accuracy he knows each of these variables. The coefficient of variation tells within what percentage of the average he is sure that approximately 70 percent of all observed values will fall. The confidence level indicator allows the designer to chose how certain he wants to be that the pavement he is designing will last for at least a minimum period of time before the first overlay and between successive overlays. The confidence levels that can be selected within the program vary between 50 percent and 99.9 percent.

Constraint Variables

The constraint variables usually are specified either by geometry or by fiscal and management policy. These variables include the minimum time allowed between initial construction and the first overlay, as well as the minimum time allowed between successive overlays. Another important constraint specified in this category is the maximum amount of funds available for initial construction. The maximum thickness of initial construction and the maximum allowable thickness for all combined overlays is also specified. This latter value becomes important where drainage inlets might be covered up by successive overlays or where clearance beneath bridges and other overhead structures becomes critical. Although other constraints are specified elsewhere within the program, the constraint variables mentioned here are among the most important in controlling the over-all pavement strategy.

Traffic Delay Variables

These variables affect the cost to the motorist of having to slow down and be diverted around an overlay operation. The traffic delay costs usually are not very large except in cases of high-volume traffic. In such cases, delay costs are sometimes of sufficient size to justify the construction of very strong low-maintenance pavements. Variables include:

1. The distance the traffic is slowed both in the overlay and non-overlay direction.
2. The detour distance around the overlay zone.
3. The number of hours per day of overlay construction.
4. The number of lanes left open in the overlay and non-overlay directions.

* Appendices B, C, G, and H are published as *Supplement to NCHRP Report 160*. See Foreword for additional information.

5. The average approach speed.
6. The average speed of traffic through the overlay zone in both the overlay and non-overlay directions.

Some estimate of the amount of time required for the overlay construction to be completed is computed from an asphaltic concrete production rate, which usually is controlled by the capacity of the batch plant.

Maintenance Variables

Routine maintenance variables are assumed to include all future pavement costs except those associated with overlays and rehabilitation. Two different ways of viewing routine maintenance costs are included within the SAMP6 computer program. One assumes that maintenance costs increase linearly with time after initial construction or overlay. The second routine maintenance costs model is based on *NCHRP Report 42* (*20*); it also assumes that maintenance costs vary with time but includes other variables such as the number of days per year recorded as having below-freezing temperatures, the composite labor rate, the composite equipment rental rate, and a relative material cost for the locality and type of road.

Cross-Section, Cost Model, and Shoulder Variables

The optimum pavement design and management strategy depends on the total cost of all materials used in the entire cross section of a pavement, including those in the shoulders. Studies with the SAMP6 pavement design system have indicated that the cost of these materials in the shoulders can significantly affect the design strategy. The cross-section variables include the width and depth of layers beneath the pavement and in the shoulders and the total area of fill material outside of these layers. There are two cost models that can be selected for use in the SAMP6 program. One assumes that costs decrease linearly with increasing layer thickness and the other assumes a logarithmic decrease. Each of these has been found to accurately represent normal variations of costs with layer thicknesses.

Tack Coat, Prime Coat, Bituminous Material Variables

Pavement designers who are interested in using SAMP6 as a cost estimating tool will find these variables helpful. The costs of tack coat, prime coat, as well as bitumen and layer thicknesses at which tack coats will be applied are specified.

Wearing Surface Variables

In some flexible pavements the wearing surface differs in its gradation, material coefficient, and costs from the asphaltic concrete or black base which lies below it. It may be a very thin layer used to provide a smooth, quiet ride or high skid resistance. Provision has been made in the SAMP6 computer program for considering separately the structural characteristics of this layer, its cost, its salvage value, its density, and its asphalt content. The asphalt content is used by some states in calculating the cost of the wearing surface.

Overlay Variables

When an overlay is applied, the SAMP6 computer program assumes that it covers the full width of the pavement. In addition, if the original pavement shoulders are asphaltic, the overlay material and level-up are assumed to be applied across the shoulder. If the original pavement has shoulders that are not asphaltic, the overlay materials are used only on the traffic lanes and the shoulders are overlaid with the same material used in the top layer in the original shoulder. Provisions are made to specify the minimum and maximum thicknesses of each overlay and the in-place costs of the overlay at those thicknesses. The salvage value of the overlay material at the end of the analysis period as well as other application rate variables, which are used by some states in determining the costs of the overlay, are among these input variables.

Pavement Material Variables

All of the materials considered by the pavement designer to be available for construction are listed here for consideration by the SAMP6 computer program. The designer specifies the maximum and minimum thicknesses and the costs at those thicknesses as well as the material coefficients, the layer and number in which the material is expected to be used, the salvage value of that material at the end of the analysis period, and various bitumen application rates used by some states in determining the costs of these layers.

Shoulder Layer Material Variables

It has been found in various studies using the SAMP6 computer program that the material used in shoulders, as well as the unit costs, the shoulder slopes, and the way the shoulders are built, can affect the choice of an optimum pavement. For this reason the SAMP6 computer program makes provision for including the cost of shoulder material in the complete pavement cross section. These variables include a description of the thickness, the cost and salvage value in the material, tack and prime coat application rates, asphaltic concrete density and asphalt content, and other variables. Provision has been made within the computer program to use the same materials in the shoulder as are used in corresponding layers beneath the pavement.

SAMP6 COMPUTER PROGRAM

The SAMP6 computer program contains the MAIN program, nine subroutine subprograms, and four function subprograms. Table 1 gives a cross-reference listing of the SAMP6 MAIN program and subprograms. Within SAMP6, the MAIN program is followed by the subprograms arranged in alphabetical order. Table 1 shows each subroutine in SAMP6 and which of the other subroutines it calls. A brief description of these subroutines is given below.

MAIN Program

The MAIN program does the following, in sequence, for each problem:

TABLE 1

CROSS-REFERENCE LISTING OF SAMP6 MAIN PROGRAM AND SUBPROGRAMS

	CALLING PROGRAM NAME													
CALLED PROGRAM	MAIN	CALC	DESTYP	HEADNG	INCOST	INPUT	OUTPUT	OVRLAY	PUPY	RMAINT	SOLVE2	SUMARY	TIME	USER
CALC									X					
DESTYP	X													
HEADNG		X				X						X		
INCOST											X			
INPUT	X													
OUTPUT	X													
OVRLAY	X													
PUPY									X					
RMAINT								X						
SOLVE2	X													
SUMARY	X													
TIME								X			X			
USER								X						

1. Calls INPUT to obtain input data for a problem. (Input reads and prints this data for a problem.)

2. Calls DESTYP to obtain a "design type"; that is, a specific set of materials.

3. Calls SOLVE2 to obtain an initial design (i.e., specific depths of layers) with its initial cost, salvage value, and time to first overlay. SOLVE2 calls INCOST to calculate the initial cost and the salvage value of the initial construction and calls TIME to calculate the time to first overlay.

4. Calls OVRLAY to select an optimum overlay policy and its associated cost (including overlay cost, maintenance cost, and user cost) and salvage value. Overlay uses RMAINT, TIME, and USER. OVRLAY determines the optimum overlay policy for each feasible initial design and returns the cost of that policy.

5. Determines if the design being considered should be saved for later printing (i.e., if it is the best design for this design type or if it is one of the better over-all designs considered in this problem).

6. After all initial designs for a design type have been investigated, calls OUTPUT to print optimum design for that design type.

7. After all design types for a problem have been investigated, calls SUMARY to print a summary table of the better over-all designs for a problem; then, goes to the next problem if there is one.

Subprograms

Subroutine CALC is called by subroutine TIME and calculates constants for the performance equation and also returns an estimate of pavement life without environmental losses.

Subroutine DESTYP is called by MAIN and prints the layer materials and number of layers of a design type and returns with the design-type data associated with those materials.

Subroutine HEADING is called by DESTYP, INPUT, and SUMARY and simply prints a page heading with an incremented page number.

Subroutine INCOST is called by SOLVE2 and calculates the volumes, costs, and salvage values for materials in the initial pavement and shoulders.

Subroutine INPUT is called by MAIN and reads and prints the input data. It also calculates the wearing surface cost and the overlay cost equation constants.

Subroutine OUTPUT is called by MAIN and prints the optimum design for each design type.

Subroutine OVRLAY is called by MAIN. OVRLAY calls the following subprograms: TIME, which calculates the times at which overlays occur; USER, which calculates motorists' costs associated with overlay operations; and RMAINT, which calculates the routine maintenance cost.

Function PUPY is called by TIME and determines a stochastic multiplier for traffic based on the stochastic inputs.

Function RMAINT is called by OVRLAY and calculates the discounted routine maintenance cost for a performance period using one of two maintenance models.

Subroutine SOLVE2 is called by MAIN. It selects an initial design and returns with the time to first overlay, which is obtained by calling TIME, and the initial cost and salvage value of the initial construction, which are obtained by calling INCOST.

Subroutine SUMARY prints a summary table of the better (lowest cost) designs for each problem.

Function TIME is called by SOLVE2 to calculate the length of time to first overlay for the initial pavement and is called by OVRLAY to calculate the length of time between successive overlays.

Function USER is called by OVRLAY and calculates motorists' vehicle operating and time costs associated with overlays. It contains POLATE, a statement function for linear interpolation and extrapolation of unit user costs.

Program Output

The output of the SAMP6 computer program is provided in three parts, as follows:

1. A summary of the input data, shown in Figure 2.
2. An output summary of the best design strategy for each material and layer combination, shown in Figure 3.
3. An output summary of the better over-all design strategies in order of increasing total cost per square yard of traffic lane, shown in Figure 4.

The input summary is an echo printing of all of the input data. Designers find this tabulation useful in checking the accuracy of the data input. The second part of the output presents a summary of the better design strategies for each set of materials and layers, including the optimum thickness, overlay policy, costs, and other characteristics. Many of these designs may not appear in the over-all summary table, the third item of output. By comparing these designs with the over-all optimum designs, the program user can determine why some sets of materials do not appear in the over-all optimum ranking. The third part of the output is presented in tabular form showing the thirty better over-all designs in order of increasing total costs. Based on judgment and experience, the pavement designer can then select which of these designs he will use for the pavement under consideration.

PILOT IMPLEMENTATION OF SAMP6

Implementation of a systems analysis model program such as SAMP6 requires attention to details. The research team had to become familiar with the organization of each of the states as well as with their current method of structural design, traffic projection, and cost estimation. The team had to be familiar with the states' performance criteria, the expected lives of pavements, and the dominant modes of distress that caused the pavements to lose riding quality. The team determined what data were being collected within each state, how they were being collected, whether more were needed for SAMP6 input, and what kind of assistance each state needed in assuming those variables for which data were not currently available. Each state had different design requirements and although many of these were common with the other states there were still unique features which each state regarded as essential to its design effort. The research team had the task of modifying SAMP5 so that it would meet the major requirements of each of the states. It soon became apparent that SAMP5 needed to be reorganized completely in order to minimize the reprogramming effort that major changes might cause. Thus, although it had not been envisioned as a project objective, the modularization of the systems analysis program into distinct subsystems became a major consideration in this project. In the following subsections the general design requirements of each of the states, and particularly those that required revisions of SAMP5, are described.

Design Requirements of Florida

The Florida Department of Transportation currently uses a number of methods for design and compares the results of one with another. The department is currently in the process of establishing a single design method for Florida and in the past few years has been committed to extensive field and laboratory tests of base courses. One of the design methods used in Florida has been the AASHO Interim Guide, but the general consensus among the pavement designers is that a more mechanistic structural subsystem, one which predicts stresses and strains, is going to be required. Florida had to assume a number of the material coefficients for the paving materials used in their example problems and the relation between material coefficient and soil support value, which is explained in Appendix A, was valuable to them in using the SAMP6 program. The Florida DOT considers cost important in the selection of a final design. It wanted to consider the costs of all materials used in the full cross-sectional width of the pavement. In normal construction practice in Florida, the same materials are used in the shoulder layers as in the corresponding layers beneath the pavement. In addition, the cost of asphaltic concrete is separated into the costs of the aggregate and the bitumen. These requirements were the occasion of a major revision of the SAMP6 computer program. An unusual problem in Florida that causes a decrease of riding quality is pavement cracking, the source of which has not been determined. The implementation effort in Florida was greatly aided by the fact that all pavement design is conducted in a central office in Tallahassee. Florida's interest in pavement data feedback stems from the maintenance management system presently in operation in the state.

Design Requirements of Kansas

The State Highway Commission of Kansas has had in operation for over two decades a flexible pavement design method that is based on elastic theory and triaxial testing of the subgrade soil. The method considers different load levels and moisture corrections and estimates thicknesses of base course and surface course using the cube root of the ratio of elastic moduli. The final design is decided upon by a committee which had considered a number of different designs once detailed cost estimates were worked out. These cost estimates include assumptions about the contractors' operations, plant and pit locations, haul distances, and prevailing wages. Cost records kept by Kansas showed that the unit prices of the same material may vary quite widely depending upon the previously mentioned factors. Kansas wanted to consider the costs of all materials used in the full cross-sectional width of the pavement, including the shoulders and select fill. In planning a highway, future land developments were projected and, especially in proposed industrial areas, this resulted in a nonlinear growth of average daily traffic with time and in a change of 18-kip equivalents per vehicle with age. Kansas uses the AASHO Interim Guide on occasion to evaluate

```
SAMP6 RUN='SAMP6 EXAMPLE PROBLEM  4 LANE INTERSTATE HIGHWAY (NO SWELLING CLAY)                PAGE  1
PROB=    ='1  MINIMUM TIME TO OVERLAY OF TWO YEARS.

INPUT DATA

     PROGRAM CONTROL AND MISCELLANEOUS VARIABLES
          NPG-THE NUMBER OF OUTPUT PAGES FOR THE SUMMARY TABLE(10 DESIGNS/PAGE).          3
          NL-THE NUMBER OF LANES ON THE HIGHWAY (BOTH DIRECTIONS).                        4
          CL-THE LENGTH OF THE ANALYSIS PERIOD(YEARS).                                20.
          XLWFT-THE WIDTH OF EACH LANE (FEET).                                        12.
          PCTRAT-THE INTEREST RATE OR TIME VALUE OF MONEY(PERCENT).                  5.00
          UPLVL-THE LEVEL-UP THICKNESS REQUIRED PER OVERLAY(INCHES).                  0.5
          WSPR-WEARING SURFACE PRODUCTION RATE(TONS/HOUR).                           75.0

     ENVIRONMENTAL AND SERVICEABILITY VARIABLES
          R-REGIONAL FACTOR.                                                          1.5
          PSI-THE SERVICEABILITY INDEX OF THE INITIAL STRUCTURE.                      4.2
          P1-THE SERVICEABILITY INDEX OF AN OVERLAY.                                  4.5
          P2-THE MINIMUM ALLOWED VALUE OF THE SERVICEABILITY INDEX,                   2.0
               AT WHICH AN OVERLAY WILL BE APPLIED.
          SACT-PROPORTION OF THE PROJECT'S LENGTH LIKELY  TO SWELL                    0.0
          SRISE-VERTICAL DISTANCE THE SURFACE OF A CLAY LAYER CAN RISE(INCHES)        0.0
          SRATE-CALCULATES HOW FAST SWELLING OCCURS                                   0.0

     LOAD AND TRAFFIC VARIABLES
          RO-THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE START OF THE ANALYSIS PERIOD.   5635.
          RC-THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE END OF ANALYSIS PERIOD.        8635.
          XNC-THE ONE-DIRECTION ACCUMULATED NUMBER OF EQUIVALENT 18-KIP AXLES DURING    6700000.
               THE ANALYSIS PERIOD.
          PROPCT-THE PERCENT OF ADT WHICH WILL PASS THROUGH THE OVERLAY ZONE DURING         5.5
               EACH HOUR WHILE OVERLAYING IS TAKING PLACE.
          ITYPE-THE TYPE OF ROAD UNDER CONSTRUCTION(1-RURAL,2-URBAN)..                     2
          COEFVR-COEFFICIENT OF VARIATION.                                               0.0
          MCONF-CONFIDENCE LEVEL INDICATOR.                                                3

     CONSTRAINT VARIABLES
          XTTO-THE MINIMUM ALLOWED TIME TO THE FIRST OVERLAY.                          2.0
          XTBO-THE MINIMUM ALLOWED TIME BETWEEN OVERLAYS.                              2.0
          CMAX-THE MAXIMUM FUNDS AVAILABLE FOR INITIAL CONSTRUCTION.                 10.00
          TMAXIN-THE MAXIMUM ALLOWABLE TOTAL THICKNESS OF INITIAL CONSTRUCTION(INCHES).  32.00
          TMOVIN-THE ACCUMULATED THICKNESS MAXIMUM OF ALL OVERLAYS  (INCHES),        10.00
               (EXCLUDING WEAR-COAT AND LEVEL-UP).
          UPGCST-COST/CU. YD. TO UPGRADE AFTER AN OVERLAY.                            0.0
          WIDUPG-WIDTH OF PAVEMENT & SHOULDERS TO BE UPGRADED(FEET).                  0.0

     TRAFFIC DELAY VARIABLES ASSOCIATED WITH OVERLAY AND ROAD GEOMETRICS
          ACPR-ASPHALTIC CONCRETE PRODUCTION RATE(TONS/HOUR).                        75.0
          ACCD-ASPHALTIC CONCRETE COMPACTED DENSITY(TONS/COMPACTED CY)               1.80
          XLSO-THE DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE OVERLAY DIRECTION.   0.50
          XLSN-THE DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE NON-OVERLAY DIRECTION.  0.50
          XLSD-THE DISTANCE AROUND THE OVERLAY ZONE(MILES).                          0.0
          HPD-THE NUMBER OF HOURS/DAY OVERLAY CONSTRUCTION TAKES PLACE.              8.0
          NLRO-THE NUMBER OF LANES IN THE RESTRICTED ZONE IN THE OVERLAY DIRECTION.    1
          NLRN-THE NUMBER OF LANES IN THE RESTRICTED ZONE IN THE NON-OVERLAY DIRECTION.  2


SAMP6 RUN='SAMP6 EXAMPLE PROBLEM  4 LANE INTERSTATE HIGHWAY (NO SWELLING CLAY)                PAGE  2
PROB=    ='1  MINIMUM TIME TO OVERLAY OF TWO YEARS.

     TRAFFIC DELAY VARIABLES ASSOCIATED WITH TRAFFIC SPEEDS AND DELAYS
               THE PERCENT OF VEHICLES STOPPED DUE TO MOVEMENT OF PERSONNEL OR EQUIPMENT.
          PPO2-IN THE OVERLAY DIRECTION.                                             5.00
          PPN2-IN THE NON-OVERLAY DIRECTION.                                         0.0
               THE AVERAGE DELAY PER VEHICLE STOPPED DUE TO MOVEMENT OF PERSONNEL & EQUIP.
          DO2 -IN THE OVERLAY DIRECTION(HOURS).                                    0.150
          DN2 -IN THE NON-OVERLAY DIRECTION(HOURS).                                  0.0
          AAS-THE AVERAGE APPROACH SPEED TO THE OVERLAY AREA.                        60.
               THE AVERAGE SPEED THROUGH THE OVERLAY AREA
          ASO-IN THE OVERLAY DIRECTION(MPH).                                         45.
          ASN-IN THE NON-OVERLAY DIRECTION(MPH).                                     60.
          MODEL-THE TRAFFIC HANDLING MODEL USED.                                       3

     MAINTENANCE VARIABLES
          MNTMOD-THE MAINTENANCE MODEL(EXPLICIT=1,NCHRP=2).                            2
          CM1-INITIAL ANNUAL ROUTINE COST($/LANE MILE, MNTMOD=1).                    0.0
          CM2-ANNUAL INCREMENTAL INCREASE IN COSTS($/LANE MILE/YR, MNTMOD=1).        0.0
          X2-DAYS THE TEMPERATURE REMAINS BELOW 32F.(DAYS/YEAR, MNTMOD=2).           10.
          CLW-THE COMPOSITE LABOR WAGE($/HR).                                       2.05
          CERR-THE COMPOSITE EQUIPMENT RENTAL RATE.                                 2.50
          CMAT-THE RELATIVE MATERIAL COST(1.00 IS AVERAGE).                         1.00
```

Figure 2. An example summary of the input data.

```
CROSS SECTION MODEL, COST AND SHOULDER VARIABLES
     MDXSEC-THE CROSS SECTION MODEL USED.                                    1
     MDCOST-THE COST MODEL USED.                                             1
     MASPHS-ASPHALTIC SHOULDER MODEL (0 IF NOT ASPHALTIC SHOULDERS).         1
     SOWID-WIDTH OF OUTSIDE SHOULDER, IN FEET                            10.00
     SIWID-WIDTH OF  INSIDE SHOULDER, IN FEET                             4.00
     XOWID-CROSS SECTION WIDTH OUTSIDE OF OUTSIDE SHOULDER(FEET)          0.0
     XIWID-CROSS SECTION WIDTH OUTSIDE OF  INSIDE SHOULDER(FEET)          0.0

ADDITIONAL WIDTH(FEET) OF LAYERS RELATIVE TO LAYER ONE.

     LAYER   PAVEMENT-LAYERS    SHOULDER-LAYERS
       NO.    OUTSIDE INSIDE    OUTSIDE INSIDE
         1      0.0     0.0       0.0     0.0
         2      2.00    2.00      0.25    0.25
         3     10.25    4.25
         4     10.25    4.25

TACK, PRIME, AND BITUMINOUS VARIABLES
     ACTL-TACK  COAT COST($/GAL).                                            0.0
     ALPC-PRIME COAT COST($/GAL).                                            0.0
     ACG-BITUMINOUS MATERIAL COST($/GAL).                                    0.0
     TLMAX-MAXIMUM LAYER DEPTH FOR NO TACK COATS, INCHES                    4.00
     TLINC-MAXIMUM DEPTH OF EACH LIFT ABOVE TLMAX, INCHES                   3.00


SAMP6 RUN='SAMP6 EXAMPLE PROBLEM  4 LANE INTERSTATE HIGHWAY (NO SWELLING CLAY)          PAGE  3
PROB=    ='1  MINIMUM TIME TO OVERLAY OF TWO YEARS.

                    THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE

LAYER  -PAVEMENT MATERIALS-  STRENGTH  SOIL    ----MINIMUM----  ----MAXIMUM----  SALVAGE
NO.    CODE  DESCRIPTION       COEFF.  SUPPORT DEPTH  $/CU.YD. DEPTH  $/CU.YD.  VALUE  INCREMENT
 -      -   NO SEP. W.S.        0.0    ------  0.0    0.0      ------  ------    0.0    ------
 -      -   AC,TYPE3           0.44    ------  1.00   18.00    5.00    18.00     30.00  1.00
 1      A   ASPH.CONC.TYPE 3    0.44    0.0     1.50   18.00    1.50    18.00     30.00  0.50
 2      3   ASPH.CONC.TYPE3     0.40    10.00   2.00   18.00    12.00   18.00     30.00  2.00
 3      L   LIME STAB.S-C-G     0.11    7.80    4.00   7.00     20.00   5.00      50.00  4.00
 4      M   SELECT MATERIAL     0.04    3.50    4.00   2.00     10.00   2.00      50.00  2.00
 -      -   SUBGRADE           ------   3.10   ------ ------   ------  ------    ------

                          ---APPLICATION RATES----  ASPHALT
LAYER  -PAVEMENT MATERIALS-  TACK    PRIME  ASPHALT  CONTENT
NO.    CODE  DESCRIPTION     COAT    COAT   (LB/IN)  (PCT)
 -        NO SEP. W.S.       0.0     0.0    0.0      0.0
 -        AC,TYPE3           0.0     0.0    0.0      0.0
 1      A   ASPH.CONC.TYPE 3  0.0     0.0    0.0      0.0
 2      3   ASPH.CONC.TYPE3   0.0     0.0    0.0      0.0
 3      L   LIME STAB.S-C-G   0.0     0.0    0.0      0.0
 4      M   SELECT MATERIAL   0.0     0.0    0.0      0.0

                                                  ---APPLICATION RATES----  ASPHALT
LAYER  -SHOULDER MATERIALS-  ----------------  SALVAGE   TACK    PRIME  ASPHALT  CONTENT  ADJUST.
NO.     DESCRIPTION          DEPTH  $/CU.YD.  VALUE     COAT    COAT   (LB/IN)  (PCT)    VOLUME
 1      -  AC-WC-SH-MIX       1.50   18.00     30.00     0.0     0.0    0.0      0.0      0.0
 2      -   SELECT MAT'L      8.00   2.00      50.00     0.0     0.0    0.0      0.0      0.0
 -      -  NO FILL MAT.      ------   0.0       0.0     ------  ------ ------   ------   0.0
```

Figure 2. (Continued)

specific variables referenced in questionnaires and research papers. On the basis of their triaxial tests on the variety of materials available within the state, the committee was able to estimate material coefficients fairly readily and they found the relation between materials coefficients and soil support value explained in Appendix A to be helpful. There are a number of sections of highway in Kansas on which performance and sufficiency rating data are being collected. Kansas pavements have a variety of problems caused by the environment. There is a mild expansive clay area in the Kansas River Valley, extensive transverse cracking of pavement is found in southern and western Kansas, and frost heave occurs in a number of areas of the state. Implementation of the SAMP6 computer program was greatly aided by the fact that Kansas has a centralized pavement design operation.

Design Requirements of Louisiana

The Louisiana Department of Highways uses the AASHO Interim Guide for designing pavements. In the number of years that the department has been using this method, it has arrived at a set of material coefficients for most of the materials available within the state (*4*). Traffic projections for

```
SAMP6 RUN='SAMP6 EXAMPLE PROBLEM  4 LANE INTERSTATE HIGHWAY (NO SWELLING CLAY)          PAGE  7
PROB=    ='1  MINIMUM TIME TO OVERLAY OF TWO YEARS.

DESIGN TYPE   4, A 4 LAYER DESIGN
MATERIAL ARRANGEMENT A3LM

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER -----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750
 2      3  ASPH.CONC.TYPE3      1.000   6.000
 3      L  LIME STAB.S-C-G      0.778   2.778
 4      M  SELECT MATERIAL      0.222   0.556

  4   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
      FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
            A    ASPH.CONC.TYPE 3    1.50 INCHES
            3  * ASPH.CONC.TYPE3     8.00 INCHES
            L    LIME STAB.S-C-G     4.00 INCHES
            M    SELECT MATERIAL     4.00 INCHES
      THE LIFE OF THE INITIAL STRUCTURE =   8.6 YEARS     STRUCTURAL NUMBER  4.46
      THE OVERLAY SCHEDULE IS
          1.00INCHIES) (EXCLUSIVE OF LEVEL-UP AND WEAR-COURSE) AFTER   8.6 YEARS.
      THE TOTAL LIFE =   22.6 YEARS.

      THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
            INITIAL CONSTRUCTION COST          7.653
            TOTAL ROUTINE MAINTENANCE COST     0.453
            TOTAL OVERLAY CONSTRUCTION COST    0.781
            TOTAL USER COST DURING
                  OVERLAY CONSTRUCTION         0.028
            SALVAGE VALUE                     -1.135
            TOTAL OVERALL COST                 7.780

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A3LM
 INITIAL DESIGNS
      72 WITHIN COST AND THICKNESS CONSTRAINTS
      45 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
     163 CONSIDERED
      98 FEASIBLE
      72 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
      43 FEASIBLE
```

Figure 3. Example output summary of an optimum design strategy for a four-layer system.

an analysis period of 20 years are usually made by load categories and converted into 18-kip single-axle equivalents. Because Louisiana had already implemented a maintenance management system within the Department of Highways, there was already an interest in salvage value of paving materials and the problems involved in data collection and feedback. Louisiana has a number of sections of roadway around the state where measurements of skid, deflection, and roughness are being made periodically and these data are filed in the central office in Baton Rouge. Special problem areas causing deterioration of pavement riding quality are settlement of soft clays, expansive clay heaving, differential movement of bridge approach slabs, pavement cracking, reflection cracking, and a tendency for the asphaltic wearing surface to be softer than the underlying asphalt layers. Because Louisiana had a centralized pavement design operation and because they were experienced in the use of the AASHO Interim Guide, the implementation effort in that state was minimal. In fact, Louisiana had a version of SAMP5 running on its own computer within 6 months of the beginning of this project.

Modularization Needed

At the end of the first cycle of pilot study meetings it was the general impression in each state that SAMP5 had a number of desirable features but more were needed. Considering the many different requirements on costs, cross sections, structural subsystems, environmental roughness subsystems, and the like, as well as the needs other states might have in the future, it was decided that the first and most important job in this project—one not envisioned in the project objectives—was to modularize SAMP5. Other major changes and additions had to be made as well and these are discussed in the next subsection of this report. The reworking of the SAMP5 computer program was so extensive and the additions and revisions were so numerous that the new program was named SAMP6.

SAMP6 PROGRAM CHANGES

The changes that were made included modularization of the program, as discussed previously, and some other changes further discussed. For more detail on any of these changes, see Appendix A.

SAMP6 RUN='SAMP6 EXAMPLE PROBLEM 4 LANE INTERSTATE HIGHWAY (NO SWELLING CLAY) PAGE 8
PROB= ='1 MINIMUM TIME TO OVERLAY OF TWO YEARS.

PROBLEM SUMMARY OF THE BETTER FEASIBLE DESIGNS
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8	9	10
MATERIAL ARRANGEMENT	A3	A3	A3LM	A3LM	A3L	A3L	A3LM	A3L	A3LM	A3LM
INIT. CONST. COST	6.049	7.215	7.653	7.349	7.296	7.808	7.831	8.074	7.527	8.009
OVERLAY CONST. COST	2.302	0.680	0.781	1.533	1.338	0.818	0.742	0.781	1.457	0.701
USER COST	0.082	0.026	0.028	0.055	0.050	0.029	0.027	0.028	0.053	0.026
ROUTINE MAINT. COST	0.115	0.515	0.453	0.231	0.400	0.480	0.452	0.453	0.276	0.484
SALVAGE VALUE	-1.101	-0.965	-1.135	-1.300	-1.202	-1.252	-1.169	-1.390	-1.334	-1.202
TOTAL COST	7.446	7.471	7.780	7.867	7.882	7.883	7.883	7.946	7.979	8.019
NUMBER OF LAYERS	2	2	4	4	3	3	4	3	4	4
LAYER DEPTH (INCHES)										
D(1)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(2)	8.00*	10.00*	8.00*	6.00*	8.00*	6.00*	8.00*	4.00*	6.00*	8.00*
D(3)			4.00	8.00	4.00	12.00	4.00	20.00	8.00	4.00
D(4)			4.00	4.00			6.00		6.00	8.00
STRUCTURAL NUMBER	3.86	4.66	4.46	4.10	4.30	4.38	4.54	4.46	4.18	4.62
NO.OF PERF.PERIODS	4	2	2	3	3	2	2	2	3	2
PERF. TIME (YEARS)										
T(1)	3.3	11.4	8.6	4.9	6.8	7.6	9.6	8.6	5.6	10.8
T(2)	9.8	28.6	22.6	14.0	18.4	20.4	25.0	22.6	15.6	27.5
T(3)	15.5			21.7	21.6				24.1	
T(4)	20.7									
OVERLAY POLICY(INCH) EXCLUSIVE OF LEVEL-UP & WEAR-COURSE)										
O(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
O(2)	1.00			1.00	1.00				1.00	
O(3)	1.00									

Figure 4. Example output summary of the better over-all designs.

Soil Support Options

The original SAMP5 computer program required use of soil support values for the subgrade and all pavement layers except the top layer. These soil support values were used together with material coefficients to calculate critical interface lives. The soil support option is retained in SAMP6 but two additional options were added. Each of the two new options uses only the soil support value of the subgrade in estimating pavement life, but one of the options also calculates and identifies critical interfaces when soil support values are provided for layers other than the subgrade.

Wearing Surface and Overlay

The SAMP5 program was changed to allow for separate strength and cost estimates for wearing surface and overlay materials. Also, the program was changed to allow the program user to stipulate the increments used within the program for changing overlay and layer thicknesses.

Cross-Section Volumes

The SAMP5 program did not consider the entire pavement cross section in estimating pavement costs, but considered the cross section of a square yard of pavement in the traffic lanes. The SAMP6 program includes a method of calculating full cross-section volumes, including shoulders.

Variable Unit Costs

The SAMP5 program used fixed unit costs for pavement layers and overlays. The SAMP6 program allows the user to input unit costs at the minimum and maximum depths of each layer and fits either a logarithmic or linear equation to these costs, whichever is designated in the program inputs. This new method of calculating costs allows unit costs to decrease with increased quantities.

Environmental Roughness

An improved method of estimating the reduction in pavement serviceability due to swelling clay was developed and incorporated in SAMP6. This new method uses input variables that are easy to obtain and are reliable characteristics of a moisture-reactive subgrade as well.

Stochastics

A method of including stochastic considerations in pavement life predictions was developed for the SAMP6 program. This method allows the program user to determine

one of several possible confidence levels together with an estimated coefficient of variation. The program uses these two inputs to reject pavement designs that will not last the minimum times to first overlay and between overlays, with the stipulated level of confidence.

Maintenance Costs

The SAMP5 computer program had one maintenance cost equation, which was based on regression analysis performed with maintenance cost data from Interstate highways. An additional, linear maintenance cost equation was incorporated in SAMP6, and both methods were modified to use continuous cost discounting to increase program accuracy and to reduce running time.

Other Cost Calculations

The SAMP6 program now has provisions for calculating the costs of bitumen, prime coats, tack coats, and upgrading of earth shoulders. Also, the users' costs and capacity tables for estimating motorists' costs were updated and an interpolation and extrapolation scheme was added to increase the accuracy of users' costs calculations.

Other Changes

A change was made in the TIME subroutine of SAMP5 to decrease program running time. Numerous other changes were made in the program output and input subroutines.

SAMP6 DOCUMENTATION

The mathematical formulas used in SAMP6 are documented in Appendix A, and documentation of the computer program is given in Appendix B.* The mathematical formulas used in SAMP6 include the traffic equation and the performance equations, in addition to the different cost calculation procedures and formulas. Documentation of the SAMP6 program includes program external cross-reference tables, a name dictionary, a SAMP6 flow-chart listing, and other information. The cooperating states had little difficulty using the SAMP6 program and rated the program documentation favorably in their evaluations (See Appendix E).

SAMP6 USERS' GUIDE

The SAMP6 Users' Guide is included as Appendix C.* It contains explanations of the SAMP6 program input and output, in addition to providing input format guides. The states had little difficulty understanding the SAMP6 inputs and output, even though they did have some difficulty in estimating some of the inputs.

Cooperating States' Evaluations

The results of the states' evaluations of SAMP6 subsystems are summarized in Table 2. These evaluations were made with point ratings from 1 to 5 and the states also gave reasons for most of their ratings. The lowest average evaluations were given to the structural and the environmental subsystems, and some of the other subsystems received fairly low ratings from one or two states. Each of the major subsystems is discussed below giving the states' reasons for their ratings. States' evaluations of the inputs, computer operation, documentation, and data feedback capabilities are given in Appendices E and F.

Structural Subsystem

Since Louisiana personnel have extensive experience with the AASHTO structural subsystem used in SAMP6 and plan to use it in the future, they gave it a high rating. Neither Kansas nor Florida is satisfied with the AASHTO structural subsystem, however. Kansas personnel believe that they need better correlation for AASHTO design parameters and would like to develop a new structural subsystem that utilizes their current design procedure. One of the principal difficulties encountered in using the Kansas design method directly is that designs giving estimated initial lives other than ten years cannot be considered at present. Kansas has extensive data and experience with triaxial testing procedures and it would be desirable to make better use of this information than can be done with the current SAMP6 structural subsystem. Although Florida plans to make interim use of SAMP6 with the AASHTO structural subsystem, it is not satisfied with the program and wants to change the entire structural subsystem to a mechanistic approach. It is especially interested in predicting pavement cracking and rut depth. In the over-all scheme, the structural subsystem received one of the lowest subsystem ratings; only one of the three participating states was satisfied with it.

Environmental Subsystem

The SAMP6 environmental subsystem was ranked low by all states and had the lowest average of any subsystem. None of the states has a significant problem with expansive clay and only Kansas has frost-heave deterioration. Florida's main environmental problem is with pavement cracking allowing water to penetrate to their limerock base materials. Therefore, they believe environmental effects should consider cracking and might best be considered in material characterization. Kansas needs better values for the regional factor and would like a provision in SAMP6 for applying swelling soil parameters to only the portion of the project that is affected. Although this can be accomplished in SAMP6 by dividing the project into several sections, it cannot be done within a specific SAMP6 problem.

Users'-Cost Traffic Delay Subsystem

Kansas would like a provision within SAMP6 that would allow the introduction of a variable to reduce the effect of users'-costs data. Florida noted that the users'-costs subsystem needs verification in Florida and users'-costs information needs to be developed specifically for Florida.

* Appendices B, C, G, and H are published as *Supplement to NCHRP Report 160*. See Foreword for additional information.

Maintenance Cost Subsystem

Kansas and Louisiana believed that better information concerning maintenance costs should be developed, although the emphasis was placed more on the data inputs than on the structure of the subsystem.

Unit Cost Subsystem

Kansas gave a low rating to the unit cost calculation methods in SAMP6. Kansas noted that the program, as written, does not allow for variation of soil support or traffic within a project. Therefore, each time the soil support or traffic values change, each project must be divided into sections and each section must be run as a separate problem. The variation of unit cost with thickness then becomes meaningless because each section would have a different thickness and, therefore, would use a different unit cost. The shoulder quantity would also increase the volume sufficiently to reduce the unit cost, but this is not considered.

Cross-Section Geometry

Kansas cross sections are not accurately represented by the current SAMP6 cross-section model. Kansas would like to use different cross-section models that include the pavement width and sideslope and shoulder width and sideslope. Such models also would be useful for some of Louisiana's cross sections.

Traffic Prediction Subsystem

Both Kansas and Florida would like to have modifications in the traffic prediction subsystem of SAMP6. Kansas would like to be able to change the rate of traffic growth at given times within the analysis period, instead of assuming that traffic growth is linear. Florida would like to have restraints in the program based on roadway geometry such that the traffic growth rate would decrease when level of service E is reached. This is the congestion level as defined in the *Highway Capacity Manual* (*23*). Congestion level varies with the type of roadway and vehicle characteristics.

Salvage Value

Louisiana would like to have a different method of considering salvage value or better guidelines for determining the salvage value percentages in different situations.

Over-All Rating of Subsystems

The average rating of all subsystems was 3.5. The fact that the structural and environmental subsystems were consistently rated lower than any others is a reflection of the fact that, of all of the technical problems involved in engineering an economical pavement, these two have not yet been solved adequately. The more severe ratings of these two subsystems may indicate an engineering design bias because a number of problems remain to be resolved in the representation of such important factors as user costs, maintenance costs, and traffic prediction.

TABLE 2

STATES' EVALUATIONS OF ADEQUACY OF SAMP6 SUBSYSTEMS IN PILOT TEST

TYPE OF SUBSYSTEM	RATING OF SUFFICIENCY FOR DESIGN FROM LOW(1) TO HIGH(5)			
	FLORIDA	KANSAS	LOUISIANA	AVERAGE
Structural	2	2	4	2.7
Environmental	2	2	1	1.7
Users'-costs traffic delay	5	4	3	4
Maintenance costs	5	4	3	4
Initial unit costs	5	1	5	3.7
Cross-section geometry	5	2	5	4
Traffic prediction	3	4	5	4
Salvage value	5	5	2	4
Average:	4.0	3.0	3.5	3.5

SENSITIVITY ANALYSES

A sensitivity analysis of a computer system is a study of the way output values change as the input variables are adjusted one at a time between their high and low values. Sensitivity analyses are undertaken for two reasons. The first is to determine from output sensitivities whether or not the system is working properly. The second is to determine those input variables that produce the most important effects on the output. Once a reliable system has been developed, sensitivity analyses to determine important input variables can be expected to give reliable results. In this respect, some of the sensitivity analyses conducted on SAMP6 are premature. However, because some of the models within SAMP6 are fairly reliable, the results of the sensitivity analyses made on SAMP6 are reported in Appendix D and they record the current state of sensitivity of the SAMP6 computer program.

Pavement Strategy Sensitivity

The sensitivity analysis brought to light several results that may be important for pavement design strategy. Use of variable unit cost and consideration of all of the materials in the full cross section tended to lead the computer program to select fewer and thicker layers as the optimum design. Variations in unit costs can greatly affect the total cost of the pavement, and this is particularly true of the surface course materials. This would indicate the wisdom of the procedure now in practice in Kansas of making very careful cost estimates based upon detailed consideration of the contractor's most likely construction operations. The area of construction simulation is a fruitful field for study and optimization, and can bring about significant reductions in total costs. Computer programs written to simulate paving operations have been verified with actual construction data and are available (*5*).

Important Variables

Traffic delay costs incurred by having to redirect motorists around overlay operations are insignificant until congestion occurs, at which time these costs become enormous, sometimes doubling the total cost of the pavement. Those factors that directly affect the riding quality of the pavement greatly affect the total cost. Serviceability loss due to expansive clay activity does not have much effect on the total cost under light traffic situations, but as the traffic begins to build, so does an increase in total cost. Overlays are required in less than half the normal expected time in order to restore riding quality. The soil support value of the subgrade is one of the most important structural properties of the pavement so far as total costs are concerned. A 100-percent variation in the soil support values can cause the total cost to vary by as much as 40 to 60 percent. The structural number is important in determining what the total cost of the pavement will be. It is made up of the sum of the products of the thickness and material coefficient of each of the layers. The sensitivity analyses indicated that under moderate to heavy traffic conditions the base and subbase course material coefficients are the most important in changing total cost. Under light traffic conditions the surface course material coefficient is most effective in changing total cost. The cost of uncertainty of these material properties runs high. If the designer wishes to be 90 percent certain that his pavement will not be overlaid before some minimum specified time, the total cost of that pavement may run 15 to 20 percent higher than if he were willing to have a 50-percent certainty. To obtain 95-percent certainty, total costs increase approximately 25 to 31 percent, and to obtain a 99.5-percent certainty, total costs are increased approximately 80 percent.

Less Important Variables

There were several factors which, although causing variations, did not prove to be very important. The serviceability index level at overlay raises the total cost by around 7 percent in going up from 2.0 to 3.0 under moderate to heavy traffic. Being off by 100 percent on the estimate of the total 18-kip equivalent single-axle loads that will be applied to the pavement over the analysis period will only change the total cost by 5 to 10 percent. Interest rates or the time value of money can be doubled (changed from 5 to 10 percent) and only decrease the present value of the total cost by 9 percent. The analysis period can change from 20 to 40 years and raise the total cost of the pavement about 6 to 7 percent.

Obviously, there will be cases that can be found to differ significantly from what has been reported above. Such will always be the case with any sensitivity analysis because the sensitivity of the system to a single variable often depends on the values of a number of other variables. Consequently, the results previously given and reported in Appendix D must be regarded only as general indications of the trends of the SAMP6 computer program. If the designer wishes to know more precise sensitivity results on a given problem, it would be best for him to make his own sensitivity analysis upon that specific problem.

The major research needs pointed up by the sensitivity analyses made upon SAMP6 were requirements to be more certain of the variables in the structural subsystem and in the environmental serviceability loss subsystem. Also indicated was that accurate choice of unit costs of materials, particularly those of the surface course, could profitably be studied in some detail, even to the extent of estimating the cost by using computer simulation of the envisioned construction operation. Another critical need is to determine the point at which congestion begins to occur and users' costs begin to mount up. Finally, the cost of uncertainty about material properties in the structural subsystem seems high. Better characterization of the materials and perhaps a more mechanistic approach to predicting loss of riding quality will pay dividends in reduced pavement costs.

PAVEMENT DATA FEEDBACK SYSTEMS

All states expressed an interest in developing pavement data feedback systems. Florida has an excellent maintenance management system that includes much information on pavement condition. They also have developed a comprehensive system for estimating unit material costs. Their primary difficulty with developing a pavement data feedback system is in developing computerized records of pavement structure.

Louisiana has a comprehensive maintenance management system for determining maintenance costs. They also are planning to purchase generalized data management software in the near future and are considering using their pavement test sections as a data system for deriving design inputs and testing the SAMP6 computer program.

Kansas had excellent pavement structure records, which are almost completely computerized. Since their planned use of the SAMP6 computer program in the immediate future is as a research tool, it is not expected that they will develop a SAMP6 pavement data feedback system, even though they may further develop their pavement data system for research and design purposes.

CHAPTER THREE

INTERPRETATION AND APPRAISALS

The SAMP6 computer program developed in this project has been found to be implementable in several states. Because of unique facets of the organization and design philosophy within other states, implementation will always require some revision of the program. All future revisions will be accomplished much easier by the fact that the SAMP6 is now modularized; that is, the subsystems have been broken into distinct subroutines or subprograms, making their replacement much easier and reducing the necessity for any extensive reprogramming. Although none of the states that pilot tested SAMP6 believed that they would use it in its present form for establishing final flexible pavement designs, they indicated the probability was fairly high that the program would be used for design strategy studies, preliminary design, sensitivity analysis, or as a building block for a future design system.

SAMP6 STRATEGY

One of the major questions to be answered by this implementation phase of the SAMP6 program was whether the over-all systems approach to pavement design and management is realistic. The management of pavements in the public interest is usually concerned with carrying the traveling public in comfort and safety at a minimum total cost to the public. The total cost of a pavement system is the sum of the following costs: the cost of initial construction, the cost of maintenance and rehabilitation strategy, and the costs to the traveling public. At present, the sum of these costs is not easily minimized for major highway systems because Federal-aid financing provides a large portion of the initial construction cost but leaves all maintenance and rehabilitation work to be financed by the states. The scarcity of state tax revenues and the fluctuating priorities on rehabilitation efforts make it difficult to carry out such work at the optimum time. Nevertheless, studies of pavement management strategy made by SAMP6 can show what combinations of initial construction, maintenance, and rehabilitation can reasonably be expected to minimize the costs to the public. Findings from such studies as these may indicate the need for a change in policy on cooperative financing of rehabilitation activities.

Costs to the Traveling Public

Not all costs to the traveling public are included within the present version of SAMP6. The costs to the users of being delayed by an overlay operation are included within this program and have proven to be important under heavy traffic conditions. Another important delay cost not presently included in SAMP6 is attributed to roughness because motorists slow down when the pavement is rough. As the serviceability index drops, time delay costs gradually overcome the benefits due to more efficient gasoline use. Another cost that is not presently considered in the SAMP6 program, but should be, is the cost of accidents directly attributable to pavement properties. The causes of skidding accidents are very complex and the skid resistance and hydroplaning characteristics of a pavement are only part of the factors involved. Before accident costs can be considered in a strategic pavement design, some means of relating them to pavement properties must first be found.

Construction Costs

Many of the unit costs of initial construction used in the SAMP6 example problems of this project were either assumed or taken from historical data of contractor bid items. These latter unit costs rarely reflect the true unit costs of the material in place. Both highway contractors and highway departments have become aware of this in the past decade and, with a view toward optimizing operations, have begun to make more careful estimates of the unit costs. Deterministic estimates of the unit costs include such factors as the prevailing local wage rates, projected plant and pit locations, haul distances, and contractors' capitalization and set-up costs. Non-deterministic cost estimation methods are more complex and involve the computer simulation of expected construction operations. Such simulation programs are available (*5*) and have the advantage of including the stochastic nature of the delays in construction operations and variable haul, laydown, and compaction rates.

The purpose of making more accurate cost estimates or of using computer simulation of construction operations to get more accurate unit costs is not to arrive at a truer engineers' estimate of the construction cost. Rather, it is to give a reliable means of comparing one pavement design alternative with another. Such comparisons are best made in a strategic program such as SAMP6.

Structural Subsystem

A strategic pavement design program must be capable of comparing a wide variety of possible pavement types. A characteristic SAMP6 run will consider 1,000 to 2,000 different combinations of materials, layers, and layer thicknesses. From these, it selects and retains in its memory the 30 better designs from the point of view of total cost. The initial service life and service life of the overlaid pavements of each of these 1,000 or 2,000 possible combinations must be predicted and costs must be calculated from them. In order to make such calculations on the computer in a reasonable period of time (2 to 15 min), it is desirable to have simplified models that relate the performance of the pavement to its material and geometric properties. SAMP6 has such a simplified model and others have been proposed

(1, 6). These models can be supplemented by checking rules which have been developed either analytically or from experience. Any such checking rule will exclude from consideration those combinations of materials and thicknesses known to be unsuitable and will reduce the running time of the strategic pavement design program.

STRATEGIC BENEFITS OF USING SAMP6

One illustration of the kinds of studies that can be made with SAMP6 is a comparison of the economics of staged construction and rehabilitation versus the "zero maintenance" approach. The top ten designs shown in Figure 4 were of the staged-rehabilitation type because the minimum time to the first overlay was set at a very unrestrictive 2-year period and the minimum time period between overlays was 5 years. By way of contrast, the top ten designs in Figure 5 use the same input data as the other example problem but the minimum time period to first overlay has been set at 20 years. The initially constructed pavement is required to last for that period of time with only routine maintenance being done.

Table 3 compares average results of the top ten designs for each of the two strategies.

In all cases, the zero maintenance strategy is more expensive by approximately 25 percent. This is true regardless of whether the initial cost or the present value of the total cost is considered. The reason for this difference becomes obvious only on closer investigation of the optimum designs. These are compared in detail in Table 4. In each case, the optimum design had a 1½-in. surface course underlain by a black base. Other designs in the top ten used a lime-stabilized sand-clay-gravel subbase below which was a select compacted material.

The major difference between the two kinds of pavement strategy is in the cost of routine maintenance, which is needed far less frequently on the pavement built and rehabilitated by stages. This fact raises several important questions:

1. Is the routine maintenance cost subroutine accurate? The answer is that it is based on the best maintenance cost information available—which is not adequate but is improving.
2. Would it actually cost that much to perform routine maintenance on a "zero maintenance" pavement? This answer cannot be given except by means of experience throughout which careful records have been kept.
3. What is the payoff for keeping detailed records of routine maintenance costs? The answer is that it appears to be the swing element between two attractive pavement management strategies. Detailed cost records can improve the prediction of these costs within SAMP6 and possibly indicate where more economy and efficiency can be introduced into routine maintenance activities.

SAMP6 RUN='SAMP6 EXAMPLE PROBLEM 4 LANE INTERSTATE HIGHWAY (NO SWELLING CLAY) PAGE 20
PROB= 2=' MINIMUM TIME TO OVERLAY OF 20 YEARS
PROBLEM SUMMARY OF THE BETTER FEASIBLE DESIGNS
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8	9	10
MATERIAL ARRANGEMENT	A3	A3L	A3LM	A3LM	A3LM	A3LM	A3LM	A3LM	A3L	A3LM
INIT. CONST. COST	8.382	9.150	9.176	9.176	9.184	9.354	9.354	9.363	9.374	9.646
OVERLAY CONST. COST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
USER COST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROUTINE MAINT. COST	1.684	1.684	1.684	1.684	1.684	1.684	1.684	1.684	1.684	1.684
SALVAGE VALUE	-0.962	-1.195	-1.200	-1.200	-1.202	-1.234	-1.234	-1.235	-1.237	-1.464
TOTAL COST	9.103	9.638	9.660	9.660	9.666	9.804	9.804	9.811	9.820	9.865
NUMBER OF LAYERS	2	3	4	4	4	4	4	4	3	4
LAYER DEPTH (INCHES)										
D(1)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(2)	12.00*	10.00*	10.00*	10.00*	10.00*	10.00*	10.00*	10.00*	10.00*	6.00*
D(3)		8.00	4.00	4.00	6.00	4.00	4.00	6.00	8.00	20.00
D(4)			8.00	8.00	4.00	10.00	10.00	6.00		4.00
STRUCTURAL NUMBER	5.46	5.54	5.42	5.42	5.48	5.50	5.50	5.56	5.54	5.42
NO.OF PERF.PERIODS	1	1	1	1	1	1	1	1	1	1
PERF. TIME (YEARS)										
T(1)	30.5	33.3	29.2	29.2	31.2	31.9	31.9	34.0	33.3	29.2
OVERLAY POLICY(INCH)										
EXCLUSIVE OF LEVEL-UP & WEAR-COURSE)										

Figure 5. Example summary of ten best over-all designs with a 20-year minimum time to overlay.

Note: A = surface course, asphaltic concrete, type 3.
3 = base course, asphaltic concrete, type 3.
L = subbase course, lime-stabilized sand-clay-gravel.
M = subbase course, select material.

TABLE 3

AVERAGED COSTS OF STAGED CONSTRUCTION COMPARED WITH THOSE OF ZERO MAINTENANCE FOR TOP TEN DESIGNS

CATEGORY	STAGED CONSTRUCTION AND REHABILITATION	ZERO MAINTENANCE	PERCENT DIFFERENCE
Number of overlays (20-yr period)	2.5	0	—
Thickness, inches	17.85	22.7	+27
Costs, dollars per square yard			
Total	7.82	9.71	+24
Initial	7.48	9.26	+24
Difference	0.34	0.45	+34

TABLE 4

STAGED CONSTRUCTION VERSUS ZERO MAINTENANCE, COMPARISON OF THE OPTIMUM DESIGNS

CATEGORY	STAGED CONSTRUCTION AND REHABILITATION	ZERO MAINTENANCE	PERCENT DIFFERENCE
Thickness, inches			
Surface course [a]	1½	1½	—
Base course [b]	8	12	+50
Number of overlays (20-yr period)	4	0	—
Costs, dollars per square yard			
Initial	6.05	8.38	+39
Overlay construction	2.30	0.00	—
Users' costs	0.08	0.00	—
Routine maintenance	0.12	1.68	+1360
Total:	8.55	10.06	+18
Less salvage value	−1.10	−0.96	−13
Present value of total cost:	7.45	9.10	+22

[a] Asphaltic concrete. [b] Asphaltic concrete black base.

The previous discussion illustrated the use of SAMP6 in studying various pavement strategies. It is also possible to study the effect of fluctuating costs on the optimum design within a given pavement strategy.

An example of this latter use is a typical problem run for Florida in 1973 when the cost of asphalt was estimated at $0.18 per gallon. SAMP6 was run again in 1974 with the same data assuming that the asphalt cost had doubled to $0.36 per gallon. The results are shown in Table 5.

Pavement designs using thick asphalt surface courses or sand-asphalt hot-mix base courses generally remained in the top thirty designs, but lost an average of 3.3 positions in the rankings. On the other hand, designs using water-bound limerock base moved up in the rankings by an average of 2.4 positions. The general trend is obviously to use less asphalt.

The ability to make routine studies of this sort can result in a fine-tuning of pavement design practice to the current market situation. The management and financial benefits to the highway department and the public are readily apparent.

These two examples illustrate the use of SAMP6 in making strategic pavement management decisions. When using the systems approach, it is possible to quantify decisions concerning light pavements with many overlays versus heavy pavements with little or no required major rehabilitation. In addition, the decision process can be updated as market prices of materials, available finances, or the time-value of money changes. The systems approach makes it possible to consider a large number of factors, including investment and users' costs, in minimizing the total cost to the public.

EVALUATION OF BEST USES FOR SAMP6

As part of the pilot studies, each state was asked to evaluate possible uses for SAMP6. Details of the evaluation are given in Appendix E. The most probable immediate use of the program is for preliminary pavement design and sensitivity analysis. Florida indicated that they would begin using the SAMP6 program for preliminary design and Louisiana indicated that this would be their probable use of the program. Florida also plans to use the SAMP6 program as a building block for a future design system by replacing the SAMP6 structural subsystem. Kansas indicated that they might use the SAMP6 program for preliminary and final design if the program could consider rigid as well as flexible pavements. Kansas also noted that because present policy does not favorably consider frequent overlays and no means exist for programming them, probable use of SAMP6 for the immediate future will be as a research tool.

IMPLEMENTATION OF SAMP6

The implementation effort in the pilot states was discussed in Chapter Two. The major factors found to aid the implementation effort were centralized organization of the states' pavement design operations, modularization of SAMP6, adaptability of the structural subsystem to predict pavement performance, credibility of the models, and adequate data collection capability. Other states desiring to implement SAMP6 will be aided by this information. At the beginning of their implementation efforts their first decision will be to determine how SAMP6 will be used, given what is known of its capabilities. If it is to be used for preliminary design or final design, attention should be paid to the structural subsystem. The determination should be made whether to keep the present structural subsystem, which is compatible with the AASHO Interim Guide, or to switch to the Texas Deflection Equation (*1*) or to linear

TABLE 5

EFFECT OF ENERGY CRISIS ON OPTIMUM PAVEMENT STRATEGY

CATEGORIES	BEFORE ENERGY CRISIS	AFTER ENERGY CRISIS
Optimum pavement thickness, inches:		
Surface course [a]	4	1
Base course [b]	—	4
Subbase course [c]	—	8
Number of overlays (40-yr period)	9	4
Average thickness of best 30 designs, inches	10.5	11.6
Minimum total cost, dollars per square yard	7.18	7.94
Increase of cost, percent	—	+10.6

[a] Asphaltic concrete. [b] Limerock base. [c] Type B stabilized.

elasticity (*6*), both of which are compatible with SAMP6 as it is presently written. The advantage of the latter two is that deflection field data can be used to obtain the required material properties. If the anticipated use of SAMP6 is as a cost-estimating tool, more attention should be paid to the cost models within the program. If it is determined that SAMP6 will be used as a building block for some future design system, a list should be made at the outset of all of those SAMP6 subsystem models that need to be improved. If the experience with this project holds true, the structural and the environmental subsystems are two that will need further attention.

Those implementing SAMP6 will need to determine the level of data collection. Consideration of material in Appendix C (Users' Guide) and Appendices G and H * having to do with pavement data feedback systems will be of assistance.

* Appendices B, C, G, and H are published as *Supplement to NCHRP Report 160*. See Foreword for additional information.

SAMP6 ADAPTABILITY

Chapter One posed eight practical questions concerning the ability of SAMP5 to be implemented in states other than Texas. The same questions could be asked of SAMP6 and now, as a result of this implementation project, can be answered. SAMP6, as it presently stands, does fit design practice in other states reasonably well. Input data required for SAMP6 are available in other states and the sensitive variables (structural, environmental, congestion, and cost factors being the dominant ones) in other states are generally the same as in Texas. As it presently stands, SAMP6 does include most of the variables ordinarily used in flexible pavement design and management. In addition, SAMP6 is flexible enough to allow changes of subsystems without a major effort at reprogramming. This is because SAMP6 is modularized. There was no difficulty in running SAMP6 on the states' own computers. This is partly due to the fact that the research team and the states all had access to IBM equipment. Because very few extensions of standard FORTRAN were used in programming SAMP6 and the program can be read onto magnetic tape at a number of different densities, the transfer of SAMP6 to other equipment is expected to be a fairly simple matter. Almost all of the input data are simple to understand and fairly easy to collect. It was the states' opinions that the over-all view of the pavement design and management process, as incorporated in SAMP6, is realistic. It considers the cost of initial construction, pavement maintenance, rehabilitation, and the costs to the users of their delay during these operations as part of the total cost of the pavement. SAMP6 then seeks out those strategies with the lowest total cost during a prescribed analysis period. Whether users' costs dollars should be rated equally with actual construction dollars is a problem not resolved. By considering users' costs as part of the total cost to be minimized, the computer program generally arrives at optimum pavements which decrease inconvenience to the public and reduce complaints to the maintaining agency. A final appraisal of SAMP6 is that it is a working program capable of being readily implemented.

CHAPTER FOUR

CONCLUSIONS AND RESEARCH RECOMMENDATIONS

SAMP6 is a working computer program for the design and management of flexible pavements. It has been developed to a point that it can be implemented within any state that chooses to have it. It incorporates most of the major variables involved in the pavement design process in a realistic way. Certain desirable improvements should be made to the system and to specific subsystems, such as the structural and environmental subsystems.

The states in which the computer program was pilot tested expect to use it in their design system: Louisiana, for flexible pavement design; Florida, for design studies and as a building block for a future, more mechanistically

oriented design system; Kansas, as a research tool and a supplement to the current design system. States which currently use the AASHO Interim Guide for pavement design can use the SAMP6 computer program directly. Other states that desire to use some other structural subsystem must use one that predicts the decrease of serviceability index with time and traffic. Having met this provision, their structural subsystem programs can be inserted directly into the SAMP6 computer program as it presently exists. The effort required to implement the SAMP6 system within any state has been reduced to a minimum by providing:

1. Modularization of SAMP6 into distinct subsystems, which can be replaced or reprogrammed with a minimum of effort.
2. Preparation of a Users' Guide, a program documentation deck, and flow charts.
3. Availability of these programs on magnetic tape.
4. Explanations provided in the appendices to this report.

The management benefits of using a systems approach include:

1. Strategy. It is possible to determine the effect on total costs of fluctuations in unit prices and interest rate, variations of construction techniques, and maintenance and rehabilitation policies and thus provide a more comprehensive and objective basis for decisions.
2. Optimization. It is possible to select optimum pavements that minimize total cost to the public or that maintain total cost at a reasonable level and minimize users' costs, initial construction cost, or rehabilitation costs.
3. Updating decisions. It is possible to make new studies of pavements that have already been built to update the management decisions that have been made in the light of changing service and financial conditions.
4. Comprehensiveness. It is possible to consider explicitly a large number of factors, including users' costs, highway agency investment costs, and salvage value of materials in place at the end of the analysis period.
5. Organization. Assembling data for the systems approach both requires and builds teamwork among people of several sections within the highway agency.

RECOMMENDED RESEARCH

Research is recommended in the three major areas of improvements to the system itself, improvements to the subsystems, and collateral improvements that, although they are not contained within the SAMP6 program, can contribute greatly to the reliability of input data and output results.

These recommendations are based on evaluations by the participating pilot-test states and the research team of the current capabilities and limitations of the SAMP6 computer program. Recommended system and subsystem improvements can be incorporated within the SAMP6 program. The collateral improvements to be suggested are entirely separate computer programs or data systems.

System Improvements

An improvement that would expand the usefulness of the SAMP6 program is an ability to consider different designs along a single stretch of road. A designer is normally faced with variations in subgrade type as well as transitions from cut to fill along the length of a project. Although one could consider each of these sections separately using the current version of SAMP6, the separate design of pavement sections which are, in reality, constructed in series may not be the optimum design. For example, the designer may wish to match depths and material of each of the pavement sections. The use of nearly standard details may result in an over-all savings in construction cost. In addition to its present inability to consider pavement sections in series, SAMP6 also lacks the capability of considering pavement sections in parallel, such as is the case when the pavement width must be expanded to carry more traffic. It may be that the optimum material and layer combinations for a widened pavement to be built 10 or 15 years in the future will be different from those combinations which will prove to be optimum if built now. A longer-range improvement of SAMP6 would be the development of a rigid pavement system similar to the flexible one so that both concrete and asphalt pavements can be considered side by side in the same program. In addition, a need exists to develop criteria for determining the weighting of various costs. The decision to be made will indicate whether the following costs should be considered equally in arriving at the total cost of the system: initial construction, routine maintenance, and rehabilitation; users' costs, such as traffic delay due to rehabilitation, roughness, and accidents; salvage value; and inflation and time value of money. Finally, a need appears to exist for an additional measure of system performance. A serviceability index measures riding quality; perhaps a safety index might also be added to SAMP6.

Collateral Improvements

Three major developments aid the operation and reliability of a pavement design and management system such as SAMP6. These are (1) data feedback systems, whether or not computerized, (2) construction cost estimation by computer simulation, and (3) maintenance rating systems. The pavement data feedback system is used most efficiently when part of an over-all maintenance management system as is the case in Louisiana and Florida. Construction cost estimation by computer simulation can be done with existing programs and can show areas where improved operations can save substantial costs. A maintenance rating system should be composed carefully so as to provide numerical values for various forms of pavement distress.

Subsystem Improvements

A number of improvements should be made in the subsystems currently in SAMP6. Generally they fall into the areas of the structural subsystem, environmental serviceability loss subsystem, users' costs and maintenance costs subsystems, and safety. In the case of the structural subsystem, the models to be developed should be based on mechanistic techniques but should not be so complicated as to require extensive computer running time. Any new structural subsystem for SAMP6 should be capable of predicting a pavement's riding quality and safety deteriora-

tion due to traffic and environmental conditions. Each of these is affected differently by distress mechanisms such as cracking, roughness, rutting, and polishing. Cracking can be caused by thermal cooling, thermal fatigue, and shrinkage. Roughness can be caused by cracking, frost heave, and expansive clay. An adequate structural subsystem should include the interaction between traffic and environmentally induced distress and should consider the amplification of traffic loads as the roughness increases. The development of such a structural subsystem will probably require the characterization of the different kinds of roughness using stochastic measures of pavement profiles, such as power spectral density and coherence. Experimental and analytical studies should be made to determine the response of typical vehicles to each kind of roughness.

The users' costs subsystem should be improved and updated. A currently funded FHWA project is expected to produce results that will be applicable in the users' costs subsystem. There is a continuing need to keep the unit costs within that subsystem up to date. The maintenance cost models within SAMP6 should be improved to include important variables such as traffic and temperature, which are not presently included in a satisfactory way.

There is a need for the SAMP6 program to consider the effect of seal coats. The opinion of many experienced engineers is that seal coating extends the service life of a pavement and upgrades the skid resistance of the surface as well. Studies of the effect of seal coating on service life are needed.

All of these research recommendations are summarized in Table 6 and assigned priorities, in order of decreasing importance, that the research team believes are warranted by the results of this study.

Although it is a high-priority item, the data feedback system is listed in second priority under collateral improvements because a long period of time will be required to develop the system and because its development will be guided and assisted best when added as an integral part of a maintenance management system.

TABLE 6

TABLE OF PRIORITIES FOR RESEARCH RECOMMENDATIONS

SYSTEM IMPROVEMENTS	SUBSYSTEM IMPROVEMENTS	COLLATERAL IMPROVEMENTS
1. Rigid pavement design system	1. Structural	1. Maintenance rating system
2. System performance criteria on safety	2. Environmental	2. Data feedback system
3. Decision criteria: weights on costs	3. Users' costs	3. Construction cost estimation by simulation
4. Pavement sections in series	4. Maintenance costs	
5. Pavement sections in parallel	5. Seal coating effects on safety, service life.	

REFERENCES

1. SCRIVNER, F. H., and MOORE, W. M., "An Empirical Equation for Predicting Pavement Deflections." *Res. Rept. 32-12,* Texas Transportation Inst. (1968).
2. VAN TIL, C. J., MCCULLOUGH, B. F., VALLERGA, B. A., and HICKS, R. G., "Evaluation of AASHO Interim Guides for Design of Pavement Structures." *NCHRP Report 128* (1972) 111 pp.
3. AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS, *AASHO Interim Guide for Design of Pavement Structures* (1972).
4. "Flexible Section Design Procedure." Report (Rev.) of R&D Section of Louisiana Dept. of Hwys. (Sept. 1970).
5. "Systems Analysis of Storage, Hauling and Discharge of Hot Asphalt Paving Mixtures." *NAPA Pub. QIP-94,* Prepared by Civil Eng. Systems Lab., Texas A&M Univ., for National Asphalt Pavement Assoc. (1972).
6. LU, DANNY Y, CHIA SHUN SHIH, and SCRIVNER, FRANK H., "The Optimization of a Flexible Pavement System Using Linear Elasticity." *Res. Rep. 123-17,* Published

jointly by Texas Highway Dept., Texas Transportation Inst., Texas A&M Univ., and Center for Highway Research, The University of Texas at Austin (March 1973).

7. "The AASHO Road Test, Report 5, Pavement Research." *HRB Spec. Rept. 61E* (1962) 352 pp.
8. *Manual of Instructions,* "Part 8, Materials." Utah Dept. of Highways (1966).
9. LYTTON, R. L., "Expansive Clay Roughness in the Highway Design System." *Proc.,* FHWA Workshop on Expansive Clays and Shales, Denver (1972).
10. MCDOWELL, C., "Interrelationship of Load, Volume Change, and Layer Thickness of Soils to the Behavior of Engineering Structures." *Proc. HRB,* Vol. 35 (1956) pp. 754-770.
11. SCRIVNER, F. H., MCFARLAND, W. F., and CAREY, G. R., "A Systems Approach to the Flexible Pavement Design Problem." *Res. Rept. 32-11,* Texas Transportation Inst. (1968).
12. HUDSON, W. RONALD, MCCULLOUGH, B. FRANK, SCRIVNER, F. H., and BROWN, JAMES L., "A Systems Approach Applied to Pavement Design and Research." *Res. Rept. 123-1,* Published jointly by Texas Highway Dept., Texas Transportation Inst., Texas A&M Univ., and Center for Highway Research, The University of Texas at Austin (Apr. 1970).
13. SCHAFER, DALE L., "Flexible Pavement System Computer Program Documentation." *Res. Rept. 123-11,* Published jointly by Texas Highway Dept., Texas Transportation Inst., Texas A&M Univ., and Center for Highway Research, The University of Texas at Austin (April 1972).
14. WINFREY, ROBLEY, *Motor Vehicle Running Costs for Highway Economy Studies.* Arlington, Va. (Nov. 1963).
15. HANEY, DAN G., and THOMAS, THOMAS C., "The Value of Time for Passenger Cars." Stanford Research Inst., Menlo Park, Calif. (May 1967).
16. LISCO, THOMAS E., "Value of Commuters' Travel Time: A Study in Urban Transportation." *Hwy. Res. Record No. 245* (1968) p. 36.
17. ADKINS, W. G., WARD, A. W., and MCFARLAND, W. F., "Values of Time Savings of Commercial Vehicles." *NCHRP Report 33* (1967) 74 pp.
18. TANNER, J. C., "A Problem of Interference Between Two Queues." *Biometrica,* Vol. 40, Parts 1 and 2 (June 1953) pp. 58-69.
19. SMITH, WALTER P., JR., "Delay to Traffic Due to Future Resurfacing Operations." *Traffic Bull. No. 7,* Dept. of Public Works, Div. of Highways, Sacramento, Calif. (Nov. 1963).
20. TALLAMY, BERTRAM D., AND ASSOCIATES, "Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index." *NCHRP Report 42* (1967) 144 pp.
21. HAAS, R. C. G., "Developing a Pavement Feedback Data System." *Res. Rept. 123-4,* Published jointly by Texas Highway Dept., Texas Transportation Inst., Texas A&M Univ., and Center for Highway Research, The University of Texas at Austin (1970).
22. STROM, O. G., HUDSON, W. R., and BROWN, J. L., "A Pavement Feedback Data System." *Res. Rept. 123-12,* Published jointly by Texas Highway Dept., Texas Transportation Inst., Texas A&M Univ., and Center for Highway Research, The University of Texas at Austin (1972).
23. "Highway Capacity Manual." *HRB Spec. Rept. 87* (1965) 149 pp.
24. HUDSON, W. R., and MCCULLOUGH, B. R., "Flexible Pavement Design and Management—Systems Formulation." *NCHRP Report 139* (1973) 64 pp.

APPENDIX A
DISCUSSION OF SAMP6 COMPUTER PROGRAM

To expedite publication the appendices included herein are reproduced as submitted by the research agency.

INTRODUCTION

The purpose of this appendix is to give a general description of the SAMP6 computer program and to provide additional documentation of the formulas used in the program. Appendix B provides overall documentation of the SAMP6 program and contains a flowchart listing of the program. Appendix C is the SAMP6 Users' Guide and provides descriptions of SAMP6 inputs and output.

SAMP6 COMPUTER PROGRAM

The SAMP6 computer program contains the MAIN program, nine (9) subroutine subprograms, and four (4) function subprograms. Table A-1 gives a cross-reference listing of the SAMP6 MAIN program and subprograms. Within SAMP6, the MAIN program is followed by the subprograms which are arranged in alphabetical order, and are as follows: SUBROUTINE CALC, SUBROUTINE DESTYP, SUBROUTINE HEADNG, SUBROUTINE INCOST, SUBROUTINE INPUT, SUBROUTINE OUTPUT, SUBROUTINE OVRLAY, FUNCTION PUPY, FUNCTION RMAINT, SUBROUTINE SOLVE2, SUBROUTINE SUMARY, FUNCTION TIME, FUNCTION USER.

TABLE A-1

SUBPROGRAM AND MAIN CROSS-REFERENCE

CALLED \ CALLING PROGRAM NAME	MAIN
CALC	X
DESTYP	X
HEADNG	X X X
INCOST	X
INPUT	X
OUTPUT	X
OVRLAY	X
PUPY	X
RMAINT	X
SOLVE2	X
SUMARY	X
TIME	X X
USER	X

Main Program

The MAIN program does the following, in sequence, for each problem:

(1) Calls INPUT to obtain input data for a problem. (Input reads and prints this data for a problem.)

(2) Calls DESTYPE to obtain a "design type," i.e., a specific set of materials.

(3) Calls SOLVE2 to obtain an initial design (i.e., specific depths) with its initial cost, salvage value, and time to first overlay. SOLVE2 calls INCOST which calculates the initial cost and the salvage value of the initial construction and calls TIME which calculates the time to first overlay .

(4) Calls OVRLAY to select an optimum overlay policy and its associated cost (including overlay cost, maintenance cost, and user cost) and salvage value. OVRLAY calls the following subprograms: TIME, which calculates the times at which overlays occur; USER, which calculates motorists' costs associated with overlay operations; and RMAINT, which calculates the routine maintenance cost .

(5) Determines if the design being considered should be saved for later printing (i.e., if it is the best design for this design type or if it is one of the better overall designs considered in this problem).

(6) After all initial designs for a design type have been investigated, calls OUTPUT to print optimum design for that design type.

(7) After all design types for a problem have been investigated, calls SUMARY which prints a summary table of the better overall designs for a problem; then, goes to next problem if there is one.

Subprograms

Subroutine CALC is called by Subroutine TIME and calculates constants for the performance equation and also returns an estimate of pavement life without environmental losses.

Subroutine DESTYP is called by MAIN and prints the layer materials and number of layers of a design type and returns with the design type data associated with those materials.

Subroutine HEADNG is called by DESTYP, INPUT, and SUMARY and simply prints a page heading with an incremented page number.

Subroutine INCOST is called by SOLVE2 and calculates the volumes, costs, and salvage values for materials in the initial pavement and shoulders.

Subroutine INPUT is called by MAIN and reads and prints the input data. It also calculates the wearing surface cost and the overlay cost equation constants. It contains a statement that sets the soil support option (SSOPT) equal to 3. (Values of 1., 2., or 3. are valid for SSOPT.)

Subroutine OUTPUT is called by MAIN and prints the optimum design for each design type.

Subroutine OVRLAY is called by MAIN. It uses RMAINT, TIME, and USER. OVRLAY determines the optimum overlay policy for each feasible initial design and returns the cost of that policy.

Function PUPY is called by TIME and determines a stochastic multiplier for traffic based on the stochastic inputs.

Function RMAINT is called by OVRLAY and calculates the discounted routine maintenance cost for a performance period using one of two maintenance models.

Subroutine SOLVE2 is called by MAIN. It selects an initial design and returns with the time to first overlay which is obtained by calling TIME,

and the initial cost and salvage value of the initial construction, which are obtained by calling INCOST.

Subroutine SUMARY prints a summary table of the better (lowest cost) designs for each problem.

Function TIME is called by SOLVE2 to calculate the length of time to first overlay for the initial pavement and is called by OVRLAY to calculate the length of time between successive overlays. Each of these times is the length of time before the pavement serviceability index deteriorates to is minimum acceptable level (P2), with the constraint that neither the initial pavement nor an overlay will be predicted to last to a time beyond twice the analysis period (2 CL).

Function USER is called by OVRLAY and calculates motorists' vehicle operating and time costs associated with overlays. It contains POLATE, a statement function for linear interpolation and extrapolation of unit user costs.

TRAFFIC EQUATION

This equation appears in subroutine INPUT and is used in calculating cumulative 18-kip equivalents at some specified time t. The equation was proposed by the Texas Highway Department (11) and is as follows:

$$N = \frac{N_C}{C(r_o + r_c)} \left[2r_o t + \left(\frac{r_c - r_o}{C}\right)t^2\right] \qquad (A.1)$$

where

t = the time in years since initial construction.

N = the total number of 18-kip equivalent axle loads that will be applied in one direction during the time, t.

C = length of the analysis period in years.

N_C = total number of 18-kip equivalents that will be applied in the entire analysis period.

r_o = average daily traffic (ADT) in one direction when t = o

r_c = ADT in one direction when t = C

The average daily traffic at the beginning (r_o) and at the end (r_c) of the analysis period should be the total number of vehicles per day expected in one direction regardless of whether the highway is single lane or multi-lane in that direction. The variable Nc is the total number of 18 kip equivalent loads that will travel in the design lane within the analysis period. On rural multi-lane highways, the entire amount of 18 kip equivalent loads can be assumed to be applied to the outside lane because of the amount of truck traffic that normally travels there. On urban multi-lane highways, trucks are more evenly distributed among the lanes. In this case, a special determination must be made of the total number of 18-kip equivalents that will be expected in the design lane. The accuracy of the estimate is not critical however, since the optimum design of the pavement will not be greatly effected by large variations in the total 18 kip equivalent applied.

LOAD-ASSOCIATED PERFORMANCE EQUATION

The load-associated performance equation expresses the present serviceability index in terms of traffic, structural number, soil support value and other variables. It is the AASHO Road Test equation (7) which is further developed in the AASHO Interim Guide (3) and has been modified for use in the CALC subroutine of SAMP6. The equation is as follows:

$$P = P_1 - (P_1 - 1.5)\left[R(N - N_k)\left(\frac{1.051}{(SN + 1)X_j}\right)^{9.3633}\right]^{\beta} \qquad (A.2)$$

where

P = the present serviceability index at time, t.

P_1 = the initial serviceability index either after construction or after an overlay, as appropriate.

N_k = the total 18-kip equivalent axles that had been applied up to the end of the kth performance period. The first performance period is ended when the first overlay is placed.

SN = the structural number which is to be discussed separately below.

R = the regional factor which is a multiplier on the 18-kip equivalent loading.

$$X_j = 10^{0.03973\ (SS\ -\ 3)} \qquad (A.3)$$

SS = the soil support value of subgrade material.

$$\beta = 0.4 + \frac{0.081\ (19)^{3.23}}{(SN + 1)^{5.19}} \qquad (A.4)$$

STRUCTURAL NUMBER EQUATION

The structural number was taken from the results of the AASHO Road Test (7). It represents the "strength of the pavement layers and is given below.

$$SN = a_1 D_1 + a_2 D_2 + \cdots + a_n D_n \qquad (A.5)$$

where

SN = the structural number of the pavement.

a_i = material coefficient of the ith pavement layer.

D_i = the thickness of the ith layer in inches.

n = the total number of pavement layers above the subgrade.

INTERFACE LIFE EQUATION

An alternative procedure for selecting pavement thickness which is given in Appendix C of the AASHO Interim Guide enforces the condition that the first place where "failure" will occur is at the interface between the bottom layer and the subgrade. This alternate procedure and one other to be discussed below are provided as options in subroutine CALC. The two design constraint conditions are illustrated in Figure A.1 for a four layer pavement. Each layer below the surface course is considered in turn to be a subgrade with an appropriate soil support value. (An assumed equivalence between each layer material coefficient and its soil support value is discussed below). The total 18-kip equivalent axle loads which will cause each "pavement" to reach a minimum serviceability index (P_2) is calculated using Equation A.2 in the following form.

$$N_j = \frac{9.62766}{R}\, g^{1/\beta}\left[(SN_j + 1)X_j\right]^{9.3633} + N_k \qquad (A.6)$$

where

$g = \frac{P_1 - P_2}{P_1 - 1.5}$ is the damage function.

P_2 = the minimum allowable serviceability index.

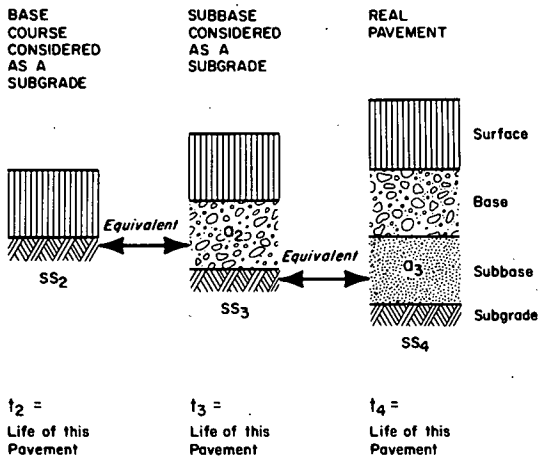
$SN_j = a_1 D_1 + \cdots + a_{j-1} D_{j-1}$

N_j = the total 18-kip equivalent loading that will cause a j-layered pavement to "fail".

$X_j = 10^{0.03973\ (SS_j\ -\ 3)}$ repeated here for ready reference.

SS_j = the soil support value for the material in the jth layer.

The time t_j at which the j-layered pavement will "fail" is calculated using Equation A.1 in the following form.



DESIGN CONSTRAINTS

OPTION 1: DESIGN LIFE = Minimum of t_i
OPTION 2: $t_2 \geq t_3 \geq t_4$ = DESIGN LIFE

FIGURE A.1.
SAMP6 ALTERNATE SCHEMES FOR SELECTING PAVEMENT THICKNESSES

Figure C. 3-1 is the correlation between soil support value and CBR assumed by the Utah Department of Highways (8). Figure C. 4-3 shows a measured correlation between CBR and the second layer material coefficient a_2 and Figure C. 4-7 shows the same kind of correlation for a_3. These correlations were established by the Illinois Division of Highways.

Second Layer Coefficient

The object of the following derivations is to find a change of soil support value $\overline{\Delta SS}$ in terms of a_2 that will make the following expressions equal.

$$(SN + 1)\ 10^{0.03973\ (SS\ -\ 3)} = (SN^* + 1)\ 10^{0.03973\ (SS\ +\ \overline{\Delta SS}\ -\ 3)}$$

where

$SN^* = a_1 D_1$

$SN = a_1 D_1 + a_2 D_2$

The change of soil support value in terms of a_2 is thus

$$\left[1 + \left(\frac{D_2}{1 + a_1 D_1}\right) a_2\right] = 10^{0.03973\ \overline{\Delta SS}}$$

The problem is to find values of the function f that satisfies the following equation

$$1 + f\ a_2 = 10^{0.03973\ \overline{\Delta SS}}$$

Using the data from figures C. 3-1 and C. 4-3 (AASHO Interim Guide), Table A.2 can be composed.

$$t_j = (-b + \sqrt{b^2 - 4ac})\ /2a \qquad (A.7)$$

where

t_j = the time to failure of the j-layered pavement

$$a = \frac{N_c\ (r_c - r_o)}{c^2\ (r_c + r_o)}$$

$$b = \frac{2\ r_o\ N_c}{c\ (r_o + r_c)}$$

$c = -N_j$ in the first performance period.

$= -(N_j - N_k) - bt_k - at_k^2$ in the kth performance period.

t_k = the time at the end of the kth performance period.

Two soil support options are provided within SAMP6 to deal with these constraints. The first option (called SSOPT = 1 in subroutine INPUT) uses the shortest calculated time to failure as the design life of the pavement. The second option (SSOPT = 2) automatically increases the layer thickness above a weak interface so that no calculated interface life is shorter than that of the subgrade. This second option is the one specified in Appendix C of the AASHO Interim Guide. After running SAMP6, it is found that both options produce the same optimum pavement designs although Option 1 permits a few more designs to be considered.

EQUIVALENCE: MATERIAL COEFFICIENT AND SOIL SUPPORT VALUE

The following is a description of a method used to obtain equivalent values of soil support and AASHO layer material coefficients. Data used to develop these equivalencies are shown in Figures C. 3-1, C. 4-3 and C. 4-7 of the AASHO Interim Guide.

TABLE A.2

CORRESPONDING VALUES OF a_2 AND SOIL SUPPORT VALUE

a_2	Soil Support Value	$\overline{\Delta SS}$
0.00	5.65	0.00 (Assumed)
0.07	6.88	1.23
0.11	7.72	2.07
0.14	9.16	3.51

Fitting a curve through these points results in the following equation.

$$S.S.V._2 = 5.65 + 25.17\ \log_{10}\ (1 + 3.73\ a_2 - 50.71\ a_2^2 + 309.52\ a_2^3) \qquad (A.8)$$

Third Layer Coefficient

In a similar manner as for the second layer,

$SN^* = a_1 D_1 + a_2 D_2$

$SN = a_1 D_1 + a_2 D_2 + a_3 D_3$

and the function g which satisfies the following relation is to be found:

$$1 + g\ a_3 = 10^{0.03973\ \overline{\Delta SS}}$$

The data points from Figures C. 3-1 and C. 4-7 are in Table A.3

TABLE A.3

CORRESPONDING VALUES OF a_3 AND SOIL SUPPORT VALUE

a_3	Soil Support Value	$\overline{\Delta SS}$
0.00	1.60	0.00 (Assumed)
0.05	3.95	2.35
0.11	6.88	5.28
0.14	8.95	7.25

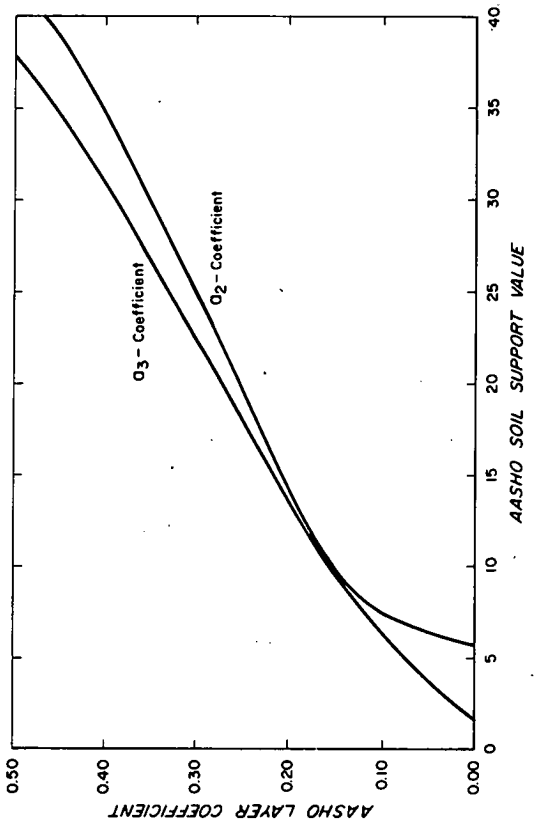


FIGURE A.2. EQUIVALENT SOIL SUPPORT VALUES AND LAYER COEFFICIENTS

TOTAL PERFORMANCE EQUATION

The serviceability loss due to traffic is added to the environmental serviceability loss to produce the total performance equation below.

$$P = P_1 - (P_1 - 1.5)\left(R(N - N_k)\left[\frac{1.051}{(SN + 1)X_j}\right]^{9.3633}\right)^{\beta} + 0.335\, C_1C_2\,(e^{-\theta t} - e^{\theta t_k}) \qquad (A.11)$$

The variables have been defined previously.

STOCHASTIC VARIATIONS OF THE TOTAL PERFORMANCE EQUATION

The purpose of considering stochastic variations in SAMP6 is to allow the pavement designer to take into account in a systematic way the risk he takes by assuming that all variables in the performance equation are at their average value. The critical constraint that the pavement must meet is that it should not require an overlay too soon after construction or after a previous overlay. The "expected" time for an overlay to be placed is calculated with the average values of all of the variables but there is only a 50 per cent certainty that the overlay will actually be required at that time. If the designer wishes to be 90 per cent certain that the overlay will not be needed before a specific time, he must use altered values of the variables to predict the 90 per cent time. The way that the variables are altered in a consistent way is explained below.

Variance of a Multivariate Function

For convenience, only two variables x and y are used for this following illustration which can be generalized. A function can be expanded in the

The curve fitting these points has the following equation.

$$S.S.V._3 = 1.60 + 25.17 \log_{10}(1 + 5.41\, a_3 - 24.06\, a_3^2 + 237.65\, a_3^3) \qquad (A.9)$$

Both curves are plotted in Figure A.2

ENVIRONMENTAL PERFORMANCE EQUATION

Up to the present, this equation has been used to describe the loss of serviceability index due to expansive clay roughness. The equation is based approximately on a diffusion model of the swelling process (9) and because most environmentally-caused pavement deterioration is caused by diffusion of either moisture or temperature, it is expected that the present form of the environmental performance equation will be useful for other forms of environmental serviceability loss. The equation is included in subroutine TIME and is given below.

$$P = P_1 + 0.335\, C_1C_2\,(e^{-\theta t} - e^{-\theta t_k}) \qquad (A.10)$$

where

- P = the serviceability index at time t.
- P_1 = the initial serviceability equation.
- C_1 = the probability of surface activity. This is the percentage of the project length (expressed in decimal form) where environmentally caused roughness is expected to occur.
- C_2 = the maximum differential movement expected to occur on the pavement over a long period of time if the pavement is not overlaid. (In expansive clay areas, this is the potential vertical rise as proposed by McDowell (10)).
- θ = the surface rise rate factor which is roughly proportional to the diffusion constant.

Methods of estimating each of these quantities for expansive clay areas are given in the Users Guide (Appendix C). In SAMP6, the serviceability loss due to traffic is assumed to be independent of the environmental serviceability loss, although there are certainly interactions between them in reality.

form of a Taylor series about the mean (or expected) values of variables $\bar{x}$ and $\bar{y}$.

$$f_{hk} = f + hf_x + kf_y + \frac{h^2}{2} f_{xx} + \cdots$$

where

$x = \bar{x} + h$

$y = \bar{y} + k$

$f_{hk} = f(x,y)$

$f = f(\bar{x},\bar{y})$ which is the expected value of the function.

$f_x = (\partial f/\partial x)$ evaluated at $x = \bar{x}$

$f_y = (\partial f/\partial y)$ evaluated at $y = \bar{y}$

The variance of the function, v(= the standard error squared, σ^2)is

$$v = (f_{hk} - f)^2$$

which is approximately equal to

$$v = (hf_x + kf_y)^2 = h^2f_x^2 + k^2f_y^2 + 2hkf_xf_y \qquad (A.12)$$

if the higher order terms of the expansion can be considered negligible. It is noted that in the above equations:

$v_x = h^2$, the variance of x

$v_y = k^2$, the variance of y

$cov_{xy} = 2hkf_xf_y$, the covariance term

Equation A.12 is used as the variance of a function of two variables and calculations of that sort will be used in what follows.

Pavement Reliability Condition

In the discussion that follows, N is the number of 18-kip equivalent loads which will bring the serviceability index of the pavement down to P_2 (the minimum serviceability index at overlay) and represents a "failure" condition. The actual condition of the pavement is represented by n which is the predicted number of 18-kip equivalent loads that will pass over the pavement in time, t. Each of these quantities, N and n, is assumed to be log-normally distributed. The reliability of the pavement is the probability that at any time t, log N is greater than log n. In equation form, this is

$$R = P(\log_{10} N > \log_{10} n)$$

With the assumption of log-normality of both N and n, it can be shown that this is equivalent to

$$R = P[(\log_{10} N - \log_{10} n) > 0]$$

The difference of the two distributions if a distribution D such that

$$D = \log_{10} N - \log_{10} n \qquad (A.13)$$

which has a variance equal to

$$\sigma_D^2 = \sigma^2_{\log N} + \sigma^2_{\log n} \qquad (A.14)$$

and the reliability R is a function of $x=(\bar{D}/\sigma_D)$

$$R = \frac{1}{\sqrt{2\pi}} \int_{-x}^{\infty} e^{-\frac{z^2}{2}} dz \qquad (A.15)$$

where x is selected from a normal distribution table such as given below and $\bar{D}$ is the expected value of D.

TABLE A.4

RELIABILITY FACTORS

Reliability, R (Percent)	Reliability Factor x
50	0.00
90	1.28
95	1.65
99	2.33
99.5	2.58
99.9	3.09

Thus, is it possible to determine the reliability of a pavement at any time t if estimates of the variances of the distributions of N (failure condition) and n (predicted condition) are known.

Variance of the Predicted Condition (n)

The number n is predicted with the traffic Equation (A.1). An estimate of the variance of its log-normal distribution is given below.

$$\sigma^2_{\log n} = \left(\frac{1}{4}[\log_{10}(2n) - \log_{10}(n/2)]\right)^2$$

where

2n = an estimated maximum number of 18-kip equivalent load applications in time t.

n/2 = an estimated minimum number of 18-kip equivalent load applications in time t.

this gives an estimate of the variance of log n as

$$\sigma^2_{\log n} = 0.0227 \qquad (A.16)$$

Variance of the Failure Condition (N)

The number N is calculated from the total performance equation which has been written below.

$$N = \frac{0.62766}{R}[(SN + 1)X_j]^{9.3633}(g - g'')^{1/\beta}e \qquad (A.17)$$

where all terms have been defined previously but the following

$g'' = \frac{-\alpha C_1 C_2 (e^{-\theta t} - e^{-\theta t_k})}{P_1 - 1.5}$, the environmental damage function.

α = usually 0.335, a constant.

e = the multiplicative lack-of-fit error from the AASHO Road Test.

Taking the logarithm to the base 10 of the total performance equation gives

$$\log N = -\log R + \log(0.62766) + 9.363 \log(SN + 1) + \frac{1}{\beta}\log(g - g'') + 0.372(SS - 3) + \log e$$

where in all cases, log x means $\log_{10} x$.

Assuming that all of the terms are independent of each other (no covariance) gives the following equation for the variance of log N.

$$\sigma^2_{\log N} = \sigma_a^2 + \sigma_b^2 + \sigma_c^2 + \sigma_d^2 + \sigma_e^2 \qquad (A.18)$$

where

a = log R

b = 9.363 log (SN + 1)

$c = \frac{1}{\beta}\log(g - g'')$

$d = 0.372(SS - 3)$

e = log e

Each of these variances is derived in the following discussion in which Equation A.12 is used frequently. It is assumed throughout that there is no covariance term to be considered.

The first variance term is found to be:

$$\sigma_a^2 = \left(\frac{0.4343}{R}\right)^2 \sigma_R^2 \qquad (A.19)$$

where

σ_R^2 = the variance of the regional factor, R.

The second variance term is

$$\sigma_b^2 = \left[\frac{9.363 \times 0.4343}{(1 + SN)}\right]^2 \sigma^2_{SN} \qquad (A.20)$$

where

$\overline{SN}$ = the expected value of the structural number.

σ^2_{SN} = the variance of the structural number which is approximately

$= D_1^2 \sigma^2_{a_1} + D_2^2 \sigma^2_{a_2} + D_3^2 \sigma^2_{a_3} + \cdots + D_n^2 \sigma^2_{a_n}$

$\sigma^2_{a_i}$ = the variance of the ith layer material coefficient

$= c_i^2 \bar{a}_i^2$

c_i = the coefficient of variation of the ith layer material coefficient.

The third variance term is

$$\sigma_c^2 = \left[\frac{1}{\beta}\frac{0.4343}{(g - g'')}\sigma_g - \frac{1}{\beta}\frac{0.4343}{(g - g'')}\sigma_{g''_m} - \frac{\log(g - g'')}{\beta^2}\sigma_\beta^2\right]^2 \qquad (A.21)$$

where

$$\sigma_g^2 = \frac{2}{(P_1 - P_2)^2}\ \sigma_{P_2}^2$$

$$\sigma_{g''}^2 = \left(\frac{g''}{P_1 - 1.5}\ \sigma_{P_1}\right)^2 + \left(\frac{g''}{C_1}\ \sigma_{C_1}\right)^2$$

$$+ \left(\frac{g''}{C_2}\ \sigma_{C_2}\right)^2 + \left(\frac{g''}{\alpha}\ \sigma_\alpha\right)^2$$

$$+ \left[\frac{\alpha C_1 C_2}{P_1 - 1.5}\ (te^{-\theta t} - t_k e^{-\theta t_k})\ \sigma_\theta\right]^2$$

$\sigma_{P_1}^2$ = the variance of P_1.

$\sigma_{C_1}^2$ = the variance of C_1, the probability of surface activity.

$\sigma_{C_2}^2$ = the variance of C_2, the maximum differential movement.

σ_α^2 = the variance of α, the constant in the environmental performance equation. Its usual value is 0.335.

σ_θ^2 = the variance of θ, the surface rise rate constant.

$\sigma_\beta^2 = \left[\frac{(0.081)\ (5.19)\ (19)^{3.23}}{(1 + SN)^{6.19}}\right]^2\ \sigma_{SN}^2$, the variance of β.

The fourth variance term is

$$\sigma_d^2 = (0.372)^2\ \sigma_{SS}^2 \qquad (A.22)$$

where

σ_{SS}^2 = the variance of the soil support value.

The fifth variance term is the variance of the lack-of-fit of the AASHO Road Test Equation. The lack-of-fit variance is only part of the total variance of the Road Test Equation: part is due to replication errors in the data and the other part, the lack-of-fit, is due to the inability of the equation to reproduce the data.

$$\sigma_{\log e}^2 \quad = \quad \sigma_{\log e}^2 \quad + \quad \sigma_{\log e}^2$$

Total — Lack-of-Fit — Replication Error (Lack of Control)

The total variance was 0.0961 as reported in (7). The replication error for 117 replicate test sections and serviceability indexes ranging from 1.5 to 3.5, was computed from the Road Test data to be 0.0198. This gives the desired result.

$$\sigma_{\log e}^2 = 0.0763 \qquad (A.23)$$

At this point, the coefficient of variation times the mean-value is inserted in all expressions where variances appear. In general, the coefficient of variation is the ratio of the standard deviation (σ) to the mean value of a given variable. In equation form, this is

$$\sigma_x = c_x\ \bar{x}$$

where

c_x = the coefficient of variation of x.

$\bar{x}$ = the mean value of x.

The factors for which coefficients of variation are inserted are: structural number, regional factor, soil support value, the environmental

performance equation variables C_1, C_2, and θ, and the serviceability indexes P_1 and P_2. Most of these are known with doubtful accuracy. It is assumed, as a further simplification, that all of these have the same value for their coefficient of variation, c. The variance of log N then becomes:

$$\sigma_{\log N}^2 = c^2[0.2649 + \left(\frac{4.0664}{1 + SN}\ SN\right)^2 + 0.1384\ \overline{SS}^2$$

$$\left[\frac{0.6142\ P_2}{\beta(g - g'')\ (P_1 - P_2)} - \frac{\text{Log}\ (g - g'')}{\beta(1 + SN)}\ SN\right.$$

$$\left. - \frac{0.4343}{\beta(g - g'')}\ \left[\left(\frac{g''\ P_1}{P_1 - 1.5}\right)^2 + 3(g'')^2 + (\theta g''_t)^2\right]^{\frac{1}{2}}\right]^2] \qquad (A.24)$$

where

$$g''_t = \frac{\alpha C_1 C_2}{P_1 - 1.5}\ (te^{-\theta t} - t_k e^{-\theta t_k})$$

This equation appears in subroutine PUPY which amplifies n, the predicted number of 18-kip equivalent loads that would occur in time t by a factor which depends upon the desired reliability. This amplified number is then compared with the "failure" condition, N, to determine whether the reliability condition has been met.

Pavement Reliability Equation

A number of equations which have been presented earlier will be given here again for ready reference. The difference density function is given by the following equation.

$$D = \log N - \log n \geq 0 \qquad (A.13)$$

For a certain reliability given by the factor x in Table A.4, the above equation becomes

$$D_x = \log N - \log n - x\sigma_D \geq 0 \qquad (A.25)$$

which implies that

$$\log N \geq \log n + x\sigma_D \qquad (A.26)$$

Since σ_D is given in Equation (A.14) as

$$\sigma_D = [\sigma_{\log N}^2 + \sigma_{\log n}^2]^{\frac{1}{2}} \qquad (A.14)$$

then the condition of the pavement which verifies its reliability is derived from Equation (A.26).

$$N \geq n \cdot 10^{x\sigma_D} = \text{amplified loading} \qquad (A.27)$$

Physically speaking, this means that as long as the number of 18-kip equivalent loads to failure still exceeds the amplified loads up to time t, then the designer is assured with at least a degree of confidence corresponding to x that the pavement will not fail up to that time.

OVERLAY OPTIMIZATION

Subroutine OVRLAY is called by the MAIN program to calculate the optimal overlay policy for each feasible initial pavement design. The optimal overlay policy for an initial design is that overlay policy, of all feasible overlay policies for that design, for which the sum of overlay costs, maintenance coats, and user costs, less the overlay salvage value, is the least. Overlay depths that are considered within an overlay policy include those ranging from the minimum overlay depth (a program input) to the maximum overlay depth (a program input), in overlay increments (a program input). For example, if the minimum overlay depth (not including level-up and wearing surface) is 1/2", the maximum overlay depth is 3", and the overlay increment is 1/2", overlay depths that will be considered are 1/2", 1", 1-1/2", 2", 2-1/2" and 3". A feasible overlay is an overlay, with one of these acceptable depths, that lasts at least the minimum acceptable time between overlays (a program input). A feasible overlay policy is a set of feasible overlays that maintain the pavement serviceability index above some minimum acceptable level (a program input) throughout the analysis period. This minimum-serviceability-index restriction serves as a limiting factor on the time that can elapse before an overlay must be applied and it generally forces at least one overlay to be performed during the analysis period.

All that is required to determine an optimal overlay policy is to determine the feasible overlay policies and determine which of these is least costly.

There are three types of variables associated with an overlay policy: (1) the number of performance periods, K; (2) the times T_k, k = 1, 2,..., K - 1, at which overlays are applied; and (3) the depths O_k of each overlay.

The alternative, feasible overlay policies for a specific initial design can be represented by a tree of the type shown in Figure A-3. Each branch of this tree represents an individual overlay policy. In this example, the minimum O_k is 1/2", the maximum O_k is 3" and the overlay increment is 1/2". The last overlay in each overlay policy must last beyond the end of the analysis period, T_c. Thicker overlay depths are not considered at an overlay time when a thinner, feasible depth will last beyond the end of the analysis period; e.g., in Figure A-3, there is no policy with O_1 = 1/2", O_2 = 1/2", and O_3 = 1", since O_3 = 1/2" lasts beyond the end of the analysis period (given that O_1 = 1/2" and O_2 = 1/2").

Hypothetical performance histories are depicted in Figure A-4 to A-7 for the overlay policies enumerated in Figure A-3. These policies are for one initial design that last approximately six years from initial construction, T_0, to time of first overlay, T_1, and are for an analysis period, T_c, of 20 years. Experience with the SAMP6 program indicates that the actual number of branches on an overlay tree for a 20-year analysis period usually is less than the number shown in the example tree.

Some designs may require no overlays, especially if the analysis period is short, the traffic and environmental deterioration are low, and minimum initial pavement layers are thick. It also might be mentioned that no adjustment is made in the overlay salvage value for the last overlay of an overlay policy lasting to the end of the period. There are several ways such an adjustment could be made, or the program could be modified to calculate the last overlay depth such that it lasts precisely to the end of the analysis period.

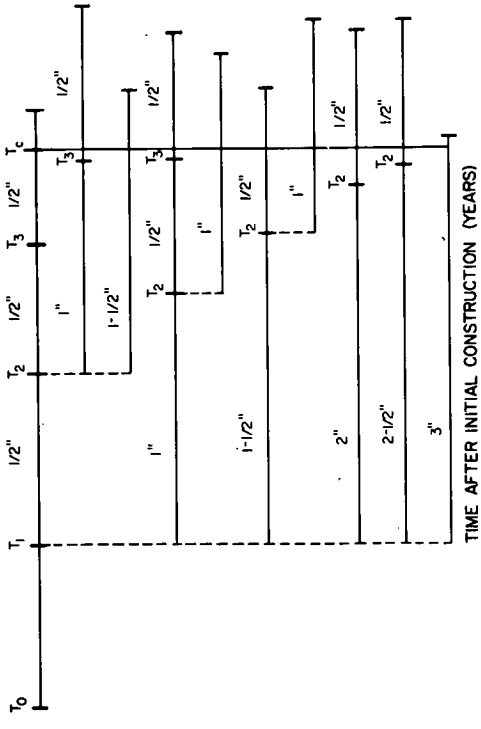


FIGURE A-3. TREE OF OVERLAY POLICIES

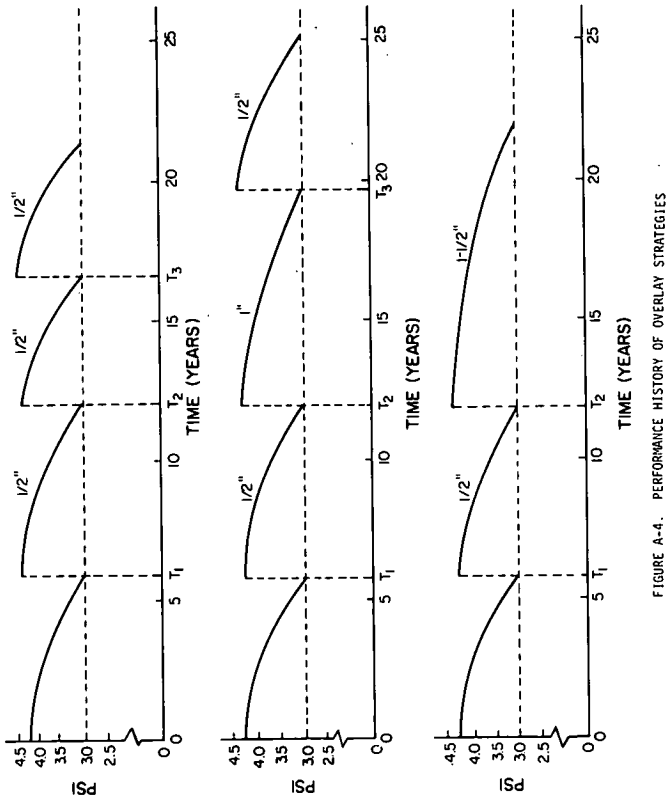


FIGURE A-4. PERFORMANCE HISTORY OF OVERLAY STRATEGIES

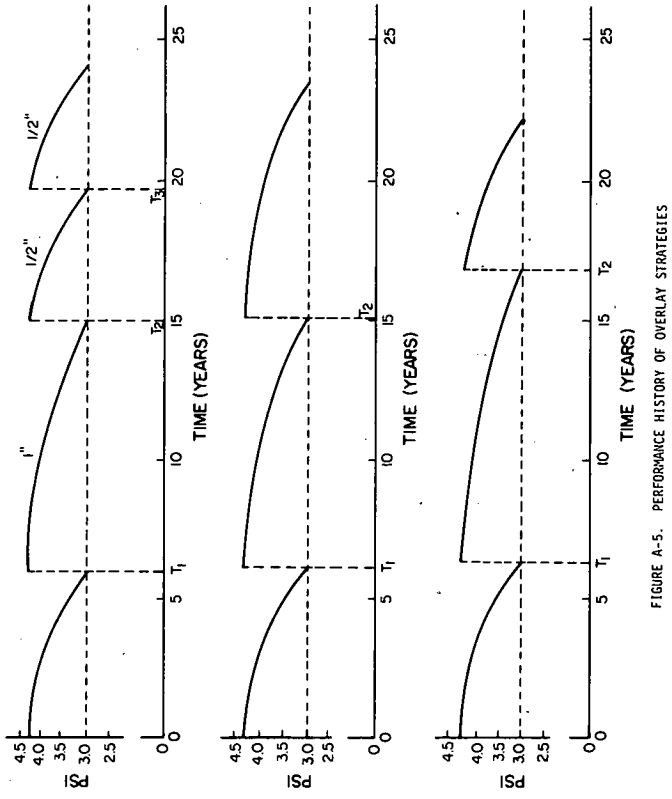


FIGURE A-5. PERFORMANCE HISTORY OF OVERLAY STRATEGIES

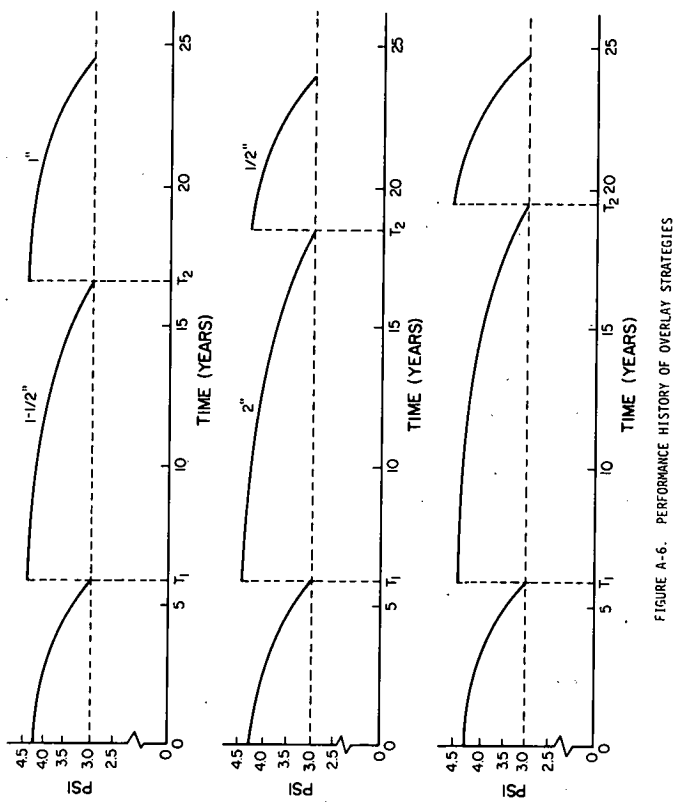


FIGURE A-6. PERFORMANCE HISTORY OF OVERLAY STRATEGIES

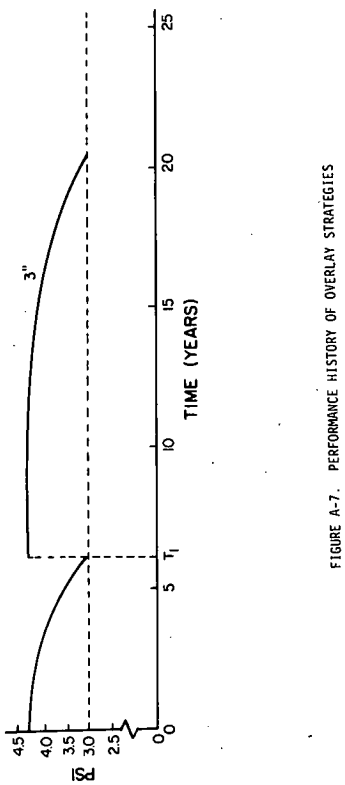


FIGURE A-7. PERFORMANCE HISTORY OF OVERLAY STRATEGIES

CROSS-SECTION VOLUMES AND INITIAL COST

Subroutine INCOST is called by Subroutine SOLVE2 and calculates the material volumes in the initial pavement and shoulders and uses these volumes together with unit costs to calculate the cost of the initial construction per square yard of traffic lane (CT). The salvage value of the initial construction per square yard of traffic lane (SV) also is calculated in Subroutine INCOST.

Cross-Section Models

Two different models, called "0" and "1", are available in SAMP6 for calculating cross-section volumes, and it is anticipated that other models eventually will be developed since these two models do not cover all situations. Cross-section Model No. 0 (i.e., MDXSEC = 0) is in effect the provision for not considering the full cross-section; i.e., a square yard of pavement is considered and pavement layer volumes are assumed to be proportionate to layer depths and shoulders are omitted from all calculations.

Cross-section Model No. 1 (MDXSEC = 1) assumes that pavement and shoulder layers within the pavement are as shown in Figure A-8. The computer program inputs for this cross-section model are explained in the Users' Guide in Appendix C. This general cross-section model is used in SAMP6 to represent both two-lane and multi-lane highways. If the traffic handling model (MODEL) is either 1 or 2, it is assumed in SAMP6 that the cross-section diagram and inputs represent both directions of travel.

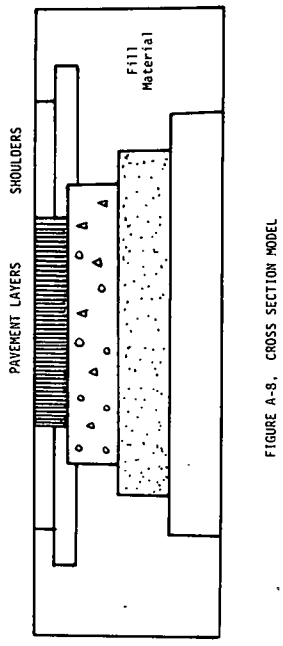


FIGURE A-8. CROSS SECTION MODEL

If the traffic model (MODEL) used in SAMP6 is 3, 4, or 5, the cross-section diagram and inputs are assumed to represent only one direction of travel. For divided highways with wide earth medians, such as most Interstate Highways, the inputs are fairly straightforward with some program inputs representing the configuration of the inside shoulder and other inputs representing the configuration of the outside shoulder. For four-or-more-lane, undivided highways, the inside shoulder layers and the lower pavement layer inputs have zero width.

If a wearing surface is used, it is assumed to be placed across the top pavement layer unless the first shoulder layer also is asphaltic (MASPH = 1), in which case the wearing surface is assumed to cover the inside and outside shoulders also; the wearing surface is not shown in Figure A-8.

Calculations of the volumes of materials, in compacted cubic yards, is simple and straightforward. The volume in each layer is simply the depth (in yards) of that layer multiplied by its width (in yards), multiplied by the length of pavement for which calculations are being made, which always is assumed to be one centerline yard.

The volume of fill material basically is calculated as the volume of the entire cross-section less the volumes of pavement layers and shoulder layers. The cross-section model also provides the ability to reduce the volume of each shoulder layer and the fill material by allowing adjustment volume inputs that are subtracted from these volumes. (See Users' Guide in Appendix C).

Initial Cost and Salvage Value

The initial pavement cost for a particular design is calculated in Subroutine INCOST as the sum of:

(1) the cost of materials other than bitumen in the pavement cross-section, including wearing surface pavement layers, shoulder layers, and fill material,

(2) the cost of bitumen in the wearing surface, pavement layers and shoulder layers,

(3) the cost of tack coats used with the wearing surface, pavement layers, and shoulder layers, and

(4) the cost of prime coats used with the pavement layers and shoulder layers.

Cost and Salvage Value of Materials

The total cost of materials other than bitumen per centerline yard of cross-section, C_n, is the sum of: the cost of such materials in the pavement layers, denoted by C_{np}, the shoulder layers, C_{ps}, the fill material, C_{nf}, and the wearing surface, C_{nw}; i.e.,

$$C_n = C_{np} + C_{ns} + C_{nf} + C_{nw}$$

$$= \sum_{k=1}^{M} Y_k C_k + \sum_{j=1}^{N} Y_j C_j + Y_f C_f + Y_w C_w$$

where all material volumes are measured in cubic yards per centerline yard of cross-section, and:

Y_k = the cubic yards of material in pavement layer k,

C_k = the cost of material in pavement layer k, in dollars per compacted cubic yard,

M = the number of pavement layers,

Y_j = the cubic yards of material in shoulder layer j,

C_j = the cost of material in shoulder layer j, in dollars per compacted cubic yard,

N = the number of shoulder layers,

Y_f = the cubic yards of fill material,

C_f = the cost of fill material, in dollars per compacted cubic yard,

Y_w = the cubic yards of material in the wearing surface, and

C_w = the cost of material in the wearing surface, in dollars per compacted cubic yard.

As was explained previously, the Y_k, Y_j, and Y_f are calculated within INCOST from cross-section inputs. The C_k, C_j, and C_f are calculated with the use of one of two equations, one of which assumes layer material costs per square yard are a linear function of layer thickness (MDCOST = 0); the other assumes the logarithm of pavement material cost per square yard is a function of the log of material thickness (MDCOST = 1). Cost equations are fitted, in SOLVE2, to the costs at the minimum and maximum thicknesses. C_{nw}, the cost of the wearing surface, is calculated in INPUT.

The salvage value of the materials other than bitumen in the initial pavement, S_n, is:

$$S_n = \sum_{k=1}^{M} P_k Y_k C_k + \sum_{j=1}^{N} P_j Y_j C_j + P_f C_{fn} + P_w C_{nw}$$

where:

P_k = the proportion that salvage value is of initial construction cost, for pavement layer k,

P_j = the proportion that salvage value is of initial construction cost for shoulder layer j,

P_f = the proportion that salvage value is of initial construction cost for the fill material,

P_w = the proportion that salvage value is of initial construction cost for the wearing surface,

and where the other variables are as previously defined.

Cost and Salvage Value of Bitumen

The total cost of bitumen per centerline yard of cross-section, C_b, is the sum of: the cost of such bitumen in the pavement layers, denoted by C_{bp}, in the shoulder layers, C_{bs}, and in the wearing surface, C_{bw}; i.e.,

$$C_b = C_{bp} + C_{bs} + C_{bw}$$

$$= \frac{C_{bg}}{8.5}\left(\sum_{k=1}^{M} P_{bk}L_kY_k + \sum_{j=1}^{N} P_{bj}L_jY_j + P_{bw}L_wY_w\right)$$

where:

C_{bg} = the cost of bitumen in dollars per gallon,

P_{bk} = the proportion asphalt content of pavement layer k,

L_k = the pounds of bituminous material per cubic yard of pavement layer k,

P_{bj} = the proportion asphalt content of shoulder layer j,

L_j = the pounds of bituminous material per cubic yard of shoulder layer j,

P_{bw} = the proportion asphalt content of the wearing surface,

L_w = the pounds of bituminous material per cubic yard of wearing surface,

and where Y_j, Y_k, Y_w, M, and N are as previously defined.

The salvage value of bitumen in the initial pavement, S_b, is calculated as:

$$S_b = \frac{C_{bg}}{8.5}\left(\sum_{k=1}^{M} P_kP_{bk}L_kY_k + \sum_{j=1}^{N} P_jP_{bj}L_jY_j + P_wP_{bw}L_wY_w\right)$$

where all variables are as previously defined; i.e., P_k, P_j, and P_w are the same as those used with materials other than bitumen.

Cost of Tack Coats

It is assumed that one tack coat is applied for the wearing surface and that other tack coats are applied in minimum increments, D_i, so long as this minimum exceeds input value D_m. These tack coats are applied to any layer that has a rate of tack coat application that is greater than 0.0.

$$C_t = C_{tg}\left(\sum_{k=1}^{M} K_kW_kR_{tk} + \sum_{j=1}^{N} L_jW_jR_{tj} + W_wR_{tw}\right)$$

where:

C_{tg} = the tack coat cost in dollars per gallon,

K_k = the number of tack coats for pavement layer k,

W_k = the width of pavement layer k, in yards,

R_{tk} = the tack coat application rate for pavement layer k, in gallons per square yard,

L_j = the number of tack coats for shoulder layer j,

W_j = the width of shoulder layer j, in yards,

R_{tj} = the tack coat application rate for shoulder layer j, in gallons per square yard,

W_w = the width of the wearing surface, in yards,

R_{tw} = the tack coat application rate for the wearing surface, in gallons per square yard,

and where M and N are as previously defined.

It is assumed that tack coats in the initial pavement have no salvage value.

Cost of Prime Coats

The method of calculating the cost of prime coats, C_p, is similar to that for tack coats, except that only one prime coat is allowed per layer:

$$C_t = C_{pg}\left(\sum_{k=1}^{M} W_kR_{pk} + \sum_{j=1}^{N} W_jR_{pj}\right)$$

where:

C_{pg} = the prime coat cost in dollars per gallon,

R_{pk} = the prime coat application rate for pavement layer k, in gallons per square yard,

R_{pj} = the prime coat application rate for shoulder layer j, in gallons per square yard,

and where M, N, W_k, and W_j are as previously defined.

It is assumed that prime coats in the initial pavement have no salvage value.

It might be noted that by choosing an appropriate prime coat application rate (R_{pj}) for the top shoulder layer, the cost of adding a special seal to the shoulder can be calculated as a prime coat. R_{pj} for this purpose would equal the cost of the special seal per square yard divided by C_{pg}.

Initial Cost and Salvage Value Per Square Yard

The total initial cost per square yard of traffic lane, C_I, is calculated as:

$$C_I = (C_n + C_b + C_t + C_p)/W_1$$

where these variables are as previously defined. (W_1 is the width of the top pavement layer, in yards). The salvage value of the initial pavement per square yard of traffic lane, S_I, is calculated as:

$$S_I = (S_n + S_b)/W_1$$

where these variables are as previously defined. These two values, C_I and S_I, are calculated for an initial pavement design each time Subroutine SOLVE2 calls Subroutine INCOST.

OVERLAY COST AND SALVAGE VALUE

The overlay cost is calculated in a way similar to that described for calculating initial cost, and includes:

(1) the cost of materials other than bitumen in the wearing surface (which is assumed to have the same thickness as in the initial construction), the level-up, and the overlay,

(2) the cost of bitumen in the wearing surface, the level-up, and the overlay,

(3) the cost of tack coats and prime coats,

(4) the cost of shoulder material other than asphalt, if the shoulders are not paved, and

(5) the cost of upgrading the earth shoulders outside the paved or aggregate shoulders.

Within Subroutine INPUT, the cost of overlaying, excluding level-up but including all other overlay construction coats, is calculated at the minimum and maximum overlay depths; then, a linear cost equation relating overlay cost to overlay depth is estimated using these two costs and their associated depths. This equation is then used to estimate the level-up cost, which is then added into the constant term of the equation. This resulting equation of overlay costs, including level-up, then is used in Subroutine OVRLAY to calculate all overlay construction costs.

The overlay salvage value is calculated as the total overlay construction cost (including all five of the costs enumerated above) multiplied by the proportion that overlay salvage value is of overlay cost.

MAINTENANCE COSTS

Two different models are available for calculating maintenance costs. Each model is used to estimate maintenance costs during a performance period. Within Function RMAINT, maintenance costs are calculated for a performance period and discounted to the beginning of the period using continuous discounting. Each of the two models makes use of four different times, all of which are in years dated from the time the pavement is built:

T_1 = the time at the beginning of the performance period (called TPRIM in the program),

T_2 = the time at the end of the performance period (called T in the program),

C = the length of the analysis period (called CL in the program),

T = the length of the performance period that falls within the analysis period (called TPERF in the program), and $T = \text{Min}(C,T_2) - T_1$ where $\text{Min}(C,T_2)$ denotes that the minimum time of the two times C and T_2 is used.

Each of the models also uses a discount rate, i, expressed as an annual rate in fractional terms (i.e., rate of 6% is .06 per year). In the computer program, i is designated as RATE.

MODEL NO. 1

In Maintenance Model No. 1 (i.e., MNTMOD = 1), the annual rate of routine maintenance cost in dollars per lane, CM_t, is expressed as:

$$CM_t = C_1 + C_2 t$$

where C_1 and C_2 are input constants and t is the time in years from the beginning of the performance period. The RMC for an entire performance period of length T, discounted to the beginning of the performance period is designated as RMC and calculated as follows:

$$RMC = \int_0^T (C_1 + C_2 t)e^{-it}dt$$

$$RMC = C_1 \int_0^T e^{-it}dt + C_2 \int_0^T te^{-it}dt$$

$$RMC = \frac{C_1}{i} + \frac{C_2}{i^2} - \left[\frac{C_1}{i} + \frac{C_2(iT + i)}{i^2}\right]e^{-it}$$

In the case where i = 0.0,

$$RMC = C_1 T + 0.5 C_2 T^2$$

To obtain RMAINT, maintenance cost per square yard of traffic-lane pavement, RMC is divided by the square yards of pavement per lane mile:

$$RMAINT = RMC/1760XLW$$

where XLW is the lane width in yards.

MODEL NO. 2

In Maintenance Model No. 2 (i.e., MNTMOD = 2), the annual rate of routine maintenance cost per centerline mile of four-lane pavement, CM_t, is expressed as:

$$CM_t = YP(CYP)$$

where:

YP = Pavement and shoulder maintenance requirement units for a centerline mile of four-lane highway, and

CYP = the cost in dollars per unit of YP.

The rate of YP units per year YP_t is calculated as follows:

$$YP_t = 183. + 13.72X + 19.72t^2$$

where:

X = the number of days per year when the maximum daily temperature is below 32° Fahrenheit, and

t = age of the pavement surface in years after the beginning of the performance period.

Since CYP and X are constants (program inputs), let A = CYP(-183. + 13.72X) and B = 19.72CYP. Then, the routine maintenance cost per four-lane mile for a performance period, discounted to the beginning of the performance period, is:

$$RMC = \int_0^T (A + Bt^2)\, e^{-it}dt$$

$$= A\left(\frac{1-e^{-iT}}{i}\right) + 2Be^{-iT}\left(\frac{e^{iT} - 1}{i^3} - \frac{T^2}{2i} - \frac{T}{i^2}\right)$$

In the case where i = 0.0,

$$RMC = AT + \frac{1}{3}BT^3$$

The routine maintenance cost per performance period per square yard of traffic-lane pavement, RMAINT, is calculated as:

$$RMAINT = RMC/7040XLW$$

where XLW is the lane width in yards and 7040 is the length of four lanes in yards of lane miles.

CYP, the cost per unit of YP is calculated as follows:

$$CYP = P_l C_l + P_m C_m + P_e C_e$$

where

P_l, P_m, and P_e = the proportion of each YP maintenance unit that is devoted to labor, materials and equipment, respectively, and

C_l, C_m, and C_e = the costs of labor, materials and equipment per maintenance unit.

The values used in the program for P_l, P_m, and P_e are different for urban and rural areas and are as follows (1, p. 54):

	Type of Area	
P_x	Urban	Rural
P_l	0.60	0.44
P_m	0.21	0.35
P_e	0.19	0.21

C_l, C_m, and C_e are inputs to the computer program if Maintenance Model No. 2 is used. Explanations of these inputs are given in NCHRP Report No. 42.

Maintenance Model No. 1 was added to SAMP6 and was not in SAMP5. Also, both maintenance models were changed to continuous discounting to increase mathematical accuracy and to reduce computer time.

USER COSTS

Increases in motorists' costs, or user costs, because of disruption during overlay operations are calculated in Function USER. Function USER in

SAMP6 is basically the same as Subroutine USER in SAMP5, which was developed by one of the authors of this report with the assistance of Mr. James L. Brown of the Texas Highway Department. In SAMP6, the cost and capacity tables have been updated and extended and an interpolation and extrapolation scheme was added for increasing accuracy of calculations. The following description of Function USER relies on descriptions of the Subroutine USER, AS originally published in 1968 (11) and later changed and updated (12). It also has been used and documented elsewhere (13).

This section is divided into four sub-sections, the first of which describes the assumed speed profiles of vehicles in the vicinity of the overlay operation. The second sub-section gives the time and operating costs associated with the different movements described by the speed profiles. In the third sub-section the five methods of handling traffic are described and equations are given for calculating the proportion of vehicles stopped and the average time stopped for conditions where traffic congestion arises because of the overlay operation. The final sub-section gives formulas for calculating total user cost and total user cost per square yard of pavement.

Speed Profiles

It is assumed that all vehicles approach the overlay area at the same speed, called the "approach speed". It is further assumed that there is a "restricted area", the length of which is LSØ or LSN, through which vehicles travel at a reduced speed. For some methods of handling traffic this reduced speed may be the same for vehicles traveling in both directions but for other methods it may be different for each direction; it is assumed to

always be the same for all vehicles going in the same direction. Generally, the vehicles traveling in the "overlay direction" will have their speed reduced as much or more than will those traveling in the "non-overlay direction", LSØ and LSN respectively.

The length LSØ of the restricted area generally will be longer than the length LØ of the actual overlay operation. The amount by which LSØ is longer than LØ will be determined by the road geometrics and the method of handling traffic. This is discussed more fully below in the section on methods of handling traffic.

As was mentioned above it is assumed that vehicles approach the restricted area at an "approach speed" denoted by SA. If there were no overlay taking place then the vehicles would travel through the area which is restricted during overlay at the "approach speed". During overlay, however, most vehicles travel through the restricted area at a reduced speed called the "through speed, overlay direction" denoted by SO or the "through speed, non-overlay direction" denoted by SN. It is assumed that vehicles maintain these "through speeds" all the way through the restricted area.

A proportion (called PO_1 in the overlay direction and PN_1 in the non-overlay direction) of all vehicles will be stopped as they approach the restricted area. It is assumed that these vehicles stop and then accelerate back to the through speed which is reached at the moment they enter the restricted area of length LSØ or LSN; the vehicles then travel at the reduced speed (SO or SN) through the restricted area for a distance, and as soon as they leave the restricted area they return to a speed which is the same as their approach speed.

Figure A-9 shows the speed profile for such a vehicle which is stopped. The letters along the horizontal axis denote points where speeds are changed. The vehicle approaches the restricted area at a speed of SA, begins decelerating at point A and is stopped by the time it reaches point B, remains stopped for a time (DO_1 in the overlay direction and DN_1 in the non-overlay direction) at point B, then accelerates back to the through speed SO or SN which is reached at point C which is the beginning of the restricted area of length LSØ or LSN, then travels from point C to point D at the through speed, and at point D begins accelerating back to the approach speed which is reached at point E.

Vehicles which do not stop are slowed down when they pass through the restricted area and it is assumed that their deceleration is such that they reach the through speed (SO or SN) at the moment they enter the restricted area. The proportion of vehicles which do not stop equals one minus PO_1 for the overlay direction and one minus PN_1 for the non-overlay direction.

Figure A-10 shows the speed profile for a vehicle which is not stopped but is slowed by the overlay operation. The letters along the horizontal axis denote points where speeds are changed. The vehicle approaches the restricted area at a speed of SA, begins decelerating at point A, decelerates to the through speed SO or SN which is reached at point B which is the beginning of the restricted area of length LSØ, continues at the through speed from point B to point C which is at the end of the restricted are, then at point C begins accelerating back to the approach speed which is reached at point D.

Because of overlay operations, vehicles will travel through the overlay area with speed profiles as shown in Figures A-9 and A-10. In the absence

of overlay operations they would have traveled at the approach speed through the overlay area. The excess traffic costs due to overlay include the excess time and operating costs due to reducing from the approach speed to a stop (from A to B in Figure A-9), returning back to that speed (from B to C and from D to E in Figure A-9), the excess time and operating (idling) costs due to being stopped (at point B in Figure A-9), the excess time and operating costs due to reducing from the approach speed to the through speed (from A to B in Figure A-10) and returning to the approach speed (from C to D in Figure A-10), and the excess time and operating costs due to traveling distance LSØ or LSN (from C to D in Figure A-9 and from B to C in Figure A-10 at a reduced speed (SO or SN) instead of traveling at the approach speed (SA).

Time and Operating Costs

The excess user costs because of an overlay include the excess cost of stopping and slowing down, the cost of delay while stopped, and the excess cost of traveling at a reduced speed through the restricted area. The information needed for calculating these costs is given in Tables A-5 through A-8. The program user must stipulate whether the overlay operation is in an urban or rural area and this determines which tables or which columns in the table are used. The difference between the urban and rural costs is the vehicle distributions used to derive the costs. The operating costs for different types of vehicles were taken from a publication by Winfrey (14), and this same source was used for the excess time of making speed changes. The values of time used in calculations were based on information in studies by the Stanford Research Institute (15), Lisco (16), and Adkins (17). Pro-

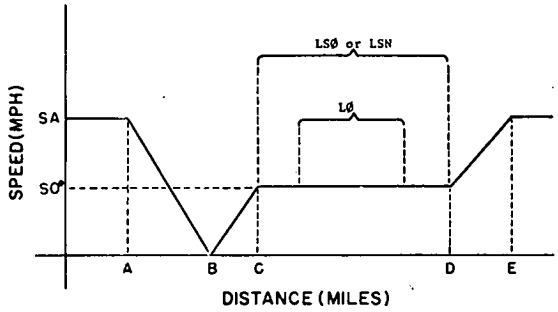


FIGURE A-9. SPEED PROFILE FOR VEHICLES WHICH ARE STOPPED DURING OVERLAY.

* This speed is SO in the overlay direction but would be SN in the non-overlay direction. LØ is length of overlay work. LSØ or LSN is the length of restricted area in the overlay direction or non-overlay direction as applicable.

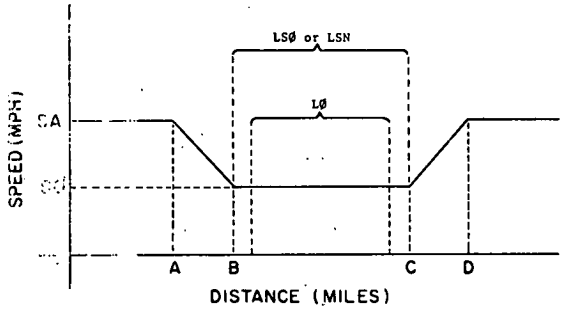


FIGURE A-10. SPEED PROFILE FOR VEHICLES WHICH ARE NOT STOPPED BUT ARE SLOWED DURING OVERLAY.

* This speed is SO in the overlay direction but would be SN in the non-overlay direction. LØ is length of overlay. LSØ or LSN is the length of restricted area overlay or non-overlay direction respectively.

portions of vehicles of different types for urban and rural areas are used to derive weighted time and vehicle operating costs. The reason that the costs are higher for rural area than for urban areas is that there is a higher proportion of trucks in rural areas and their costs are higher than those for passenger cars.

Tables A-5 and A-6 give the excess time and operating costs for stopping (in the first columns) and for slowing down (in the other columns). Table A-7 gives the time and operating costs for operating at a uniform (constant) speed. Table A-8 gives the time and operating costs of delay (or idling).

Methods of Handling Traffic

There are several methods of handling traffic during an overlay operation. The method used depends mainly on highway geometrics, especially the number of lanes, the type of median (if any), and the presence of absence of pavement shoulders, frontage roads, or other alternate routes. In the two following subsections are described the five methods of handling traffic which are most commonly used and the way of calculating average delay and proportion of vehicles stopped for each method.

The five methods. The first two methods of handling traffic are for two-lane roads (with or without shoulders) and the other three methods are for roads with four or more lanes. Figures A-11 through A-15 depict in general way the five situations. In each figure LØ, LSØ, and LSN are shown. LØ is the amount of road which is overlayed at any one time -- not the total overlay job length. LSØ is the distance over which traffic is slowed down by the overlay by the overlay operation at any one time in the overlay direction, LSN is the non-overlay direction. In the situations depicted in

TABLE A-5

DOLLARS OF EXCESS OPERATING AND TIME
COST OF SPEED CHANGE CYCLES - EXCESS COST ABOVE
CONTINUING AT INITIAL SPEED, FOR RURAL ROADS

Initial Speed MPH	Dollars Per 1000 Cycles Speed Reduced To and Returned From (MPH) 0	10	20	30	40	50
10	10.676					
20	22.932	11.860				
30	39.753	27.079	14.306			
40	63.454	49.907	35.812	19.902		
50	98.194	93.454	67.935	50.326	28.491	
60	151.888	134.793	116.527	95.788	71.070	40.931

TABLE A-6

DOLLARS OF EXCESS OPERATING AND TIME
COST OF SPEED CHANGE CYCLES - EXCESS COST ABOVE
CONTINUING AT INITIAL SPEED, FOR URBAN ROADS

Initial Speed MPH	Dollars Per 1000 Cycles Speed Reduced To and Returned From (MPH) 0	10	20	30	40	50
10	7.395					
20	14.829	7.059				
30	24.570	16.200	8.191			
40	37.838	28.896	20.130	10.845		
50	56.703	47.046	37.309	27.024	14.939	
60	85.514	74.330	61.884	50.705	36.994	20.704

TABLE A-7

DOLLARS OF OPERATING AND TIME COST
PER 1000 VEHICLE MILES AT UNIFORM SPEEDS

Uniform Speed MPH	Dollars Per 1000 Miles Rural Roads	Urban Roads
10	495.77	456.66
20	270.31	248.30
30	196.62	179.64
40	162.58	147.22
50	145.54	130.08
60	138.80	121.88

TABLE A-8

DOLLARS OF OPERATING AND TIME COST OF DELAY
(OR IDLING) PER 1000 VEHICLE HOURS

Type Of Delay Cost	Dollars Per 1000 Hours Rural Roads	Urban Roads
Operating	$ 166.60	$ 154.84
Time	4,243.10	3,956.68
Total	4,409.70	4,111.52

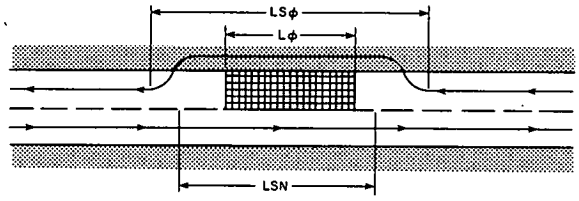


FIGURE A-11. MODEL=1: TRAFFIC ROUTED TO SHOULDER.

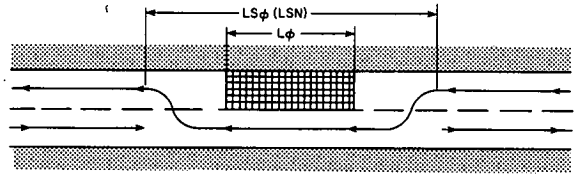


FIGURE A-12. MODEL=2: ALTERNATING TRAFFIC IN ONE LANE.

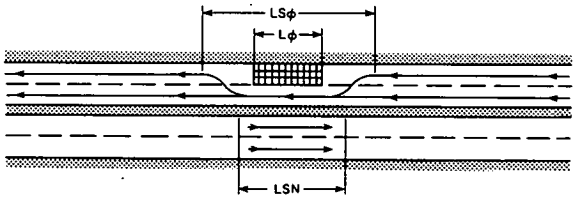


FIGURE A-13. MODEL=3: TWO LANES MERGE, NON-OVERLAY DIRECTION NOT AFFECTED.

Figures A-11 through A-14, LSØ and LSN are only slightly longer than LØ by say one-tenth of a mile, but in the situations depicted in Figure A-15, LSØ may be considerably longer than LØ. LSØ and LSN are input variables provided by the program user. LØ is not used in the calculation of user costs and is included only for illustration. (Note: The variable LO used as a subscript in subroutine USER is not LØ as illustrated in these figures.) In the figures, the "overlay direction" is always to the left.

MODEL = 1 (Figure A-11). For two-lane roads with shoulders, one lane of traffic can be diverted onto a shoulder. Traffic going "west" in the "overlay direction" can be diverted onto the shoulder as shown in Figure A-11 and such traffic will generally be slowed down. Traffic in the non-overlay direction proceeds as usual but also must slow down though probably not by as much as the traffic going in the overlay direction. Another version of this method is to divert the traffic in the non-overlay direction onto their shoulder and divert the traffic going in the overlay direction into the eastward lane. In addition to the delay due to traveling at a reduced speed, traffic may be additionally delayed by having to stop due to movement of overlay personnel and equipment in the overlay area and by the inability to overtake other traffic in the overlay area.

MODEL = 2 (Figure A-12). For two-lane roads without shoulders, it is sometimes necessary to post flagmen at each end of the overlay operation and to stop traffic in one direction while traffic from the other direction proceeds through the overlay area. The flagmen determine from which direction traffic is let through the overlay area at any one time. The vehicle arriving first usually has priority. If an additional vehicle arrives while other vehicles going in the same direction are proceeding through the overlay area

except that it will be stopped when the vehicles in the queue from the other direction are a number or have been waiting a time which justifies priority for them. Traffic from each direction travels through the overlay area at a reduced speed. Some vehicles from each direction are stopped to give way to vehicles from the opposite direction, or because of the movement of overlay personnel and equipment in the overlay area, or because vehicles do not have the ability to overtake other vehicles in the overlay area. Generally speaking, the proportion of traffic stopped to give way to vehicles from the opposite direction will be higher the longer is LSØ and the larger is the traffic volume.

MODEL = 3 (Figure A-13). For roads with two or more lanes in each direction and with a non-transversable median, it is assumed that traffic in only one direction will be affected by the overlay operation. It is also assumed that at least one lane in the overlay direction remains open for traffic. For low traffic volumes the effects on traffic in the overlay direction will be that of reduced speed through the area, stops due to movement of overlay personnel and equipment, and inability to overtake other vehicles as easily. For higher volumes for which the flow of traffic is above the capacity of the restricted roadway, a queue will result upstream of the overlay operation and will lead to vehicles being stopped due to congestion.

MODEL = 4 (Figure A-12). For roads with two or more lanes in each direction and with no medians or with medians which can be crossed at any point or which have median openings, it may sometimes be desirable to block all lanes in the overlay direction and divert the overlay direction traffic to non-overlay-direction lanes. MODEL = 1 depicts the situation and those

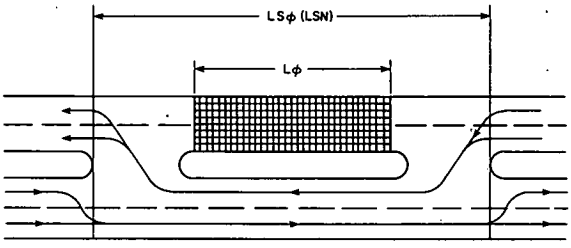


FIGURE A-14. MODEL=4: OVERLAY DIRECTION TRAFFIC ROUTED TO NON-OVERLAY LANES.

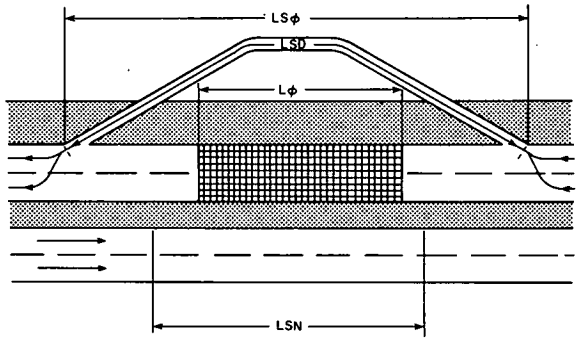


FIGURE A-15. MODEL=5: OVERLAY DIRECTION TRAFFIC ROUTED TO FRONTAGE ROAD OR OTHER PARALLEL ROUTE.

with either no median, or situations for which it is intended that traffic will cross the median immediately in front and behind the overlay job, is that LSØ and LSN in these latter two cases would bear approximately the same relation to LØ as is the relation where MODEL = 1, 2, or 3 instead of being the distance between median openings at each end of the overlay job as when MODEL = 4. For these situations both lanes of traffic will be affected, and the method of calculating average delay and proportion of vehicles stopped is the same as that used for MODEL = 3, but in MODEL = 4 traffic going in both directions is affected.

MODEL = 5 (Figure A-15). In some situations traffic in the overlay direction is diverted to an alternate route such as a frontage road or some other parallel road or street. The addition variable of LSD is the distance traveled by detour in the overlay direction.

Average Delay and Proportion of Vehicles Stopped. The delay to traffic due to overlay is of four basic types which are related to vehicles:

(1) traveling at a reduced "uniform" speed in the restricted area,

(2) not having the ability to overtake and pass other vehicles traveling in the same direction,

(3) Having to stop because of the movement of overlay personnel and equipment in the overlay area, and

(4) having to stop because of congestion when the traffic demand exceeds the capacity of the restricted area.

The delay per vehicle due to traveling at a reduced speed equals the travel time at the reduced speed through the restricted area minus the travel vehicles would have had through the restricted area had it not been restricted.

The delay due to vehicles not having the ability to overtake and pass other vehicles traveling in the same direction because of the overlay operation may result both in the restricted area and outside the restricted area. This delay when it occurs in the restricted area is included in the delay discussed in the preceding paragraph if accurate estimates of speeds through the restricted area are used. The delay due to the inability to pass outside the restricted area because of the overlay is a more complicated calculation and is probably largest in the cases where the capacity of the restricted area is smaller than the demand (or input) for use of the area. In such cases wherein demand exceeds capacity there will be congestion and queueing of vehicles. These queues must disperse after leaving the restricted area and before such dispersion occurs there probably will be some inability to pass outside the restricted area. Such effects probably will be small in all cases except MODEL = 2 with considerable queueing. If the length of the restricted area is fairly long and/or the traffic volumes are fairly large, then when MODEL = 2, there will arise fairly long queues of vehicles. Such queues arise in one direction while vehicles are traveling through the restricted area from the other direction; then, when this queue is allowed to proceed through the restricted area it will emerge as a moving queue, sometimes of considerable length, and extra delay will result outside the restricted area until the queue disperses. The rate of dispersion of this moving queue will depend mainly upon the amount of traffic from the opposite direction, the road geometrics, and the type of vehicles in the queue. This moving queue will also impede passing by traffic from the opposite direction; however, there will be a considerable length of road in front of this queue

in which there will be no (or very few) vehicles which will somewhat offset the effects of the moving queue on traffic in the opposite direction. Since the type of delay discussed in this paragraph probably is small in most cases and since it is difficult to calculate, it is ignored (i.e., assumed to be zero).

The third type of delay, that resulting from vehicles having to stop because of the movement of overlay personnel and equipment in the overlay area, is calculated by multiplying the number of vehicles stopped by the excess delay of stopping. The program user must estimate (1) PO_2 and PN_2, the proportion of vehicles stopped due to the movement of overlay personnel and equipment and (2) DO_2 and DN_2, the average time that each vehicle stopped (because of such movement) remains stopped. It is expected that the overlay operation will be conducted in a way such that the number of vehicles stopped due to the movement of overlay personnel and equipment will be small. Therefore, in the absence of information on the number of such stops, the program user probably should estimate that number to be near or equal to zero.

The last type of delay (denoted by DO_1 in the overlay direction and by DN_1 in the non-overlay direction) results when a proportion of vehicles (denoted by PO_1 in the overlay direction and PN_1 in the non-overlay direction) have to stop because of congestion which results when traffic demand or input per hour (Q) exceeds the hourly capacity or output (Ø) of the restricted area.

When MODEL = 1 (shoulder routed traffic model) is used, congestion stopping delay should be almost nonexistent and is assumed to be zero: i.e., $DO_1 = DN_1 = 0$ and $PO_1 = PN_1 = 0$ for MODEL = 1.

When MODEL = 2 (alternating traffic model) is used, it is assumed that the hourly traffic is evenly divided between directions. It is also assumed

that vehicle arrivals from each direction are Poisson. The proportion of vehicles stopped due to congestion from each direction (PO_1 or PN_1) is estimated by the following equation:

$$PO_1 \ (= PN_1) = \frac{(1-e^{-aQ})2}{2}$$

where a = the time that it takes a vehicle to travel through the restricted area, in hours, and

Q = the number of vehicles arriving at the overlay area per hour in the overlay direction.

An equation for estimating the average delay per stopped vehicle (DO_1 or DN_1) for MODEL = 2 is developed from equations formulated by Tanner (18) and given by:

$$DO_1 \ (= DN_1) = \frac{(1+e^{2aQ})\ (e^{aQ}-aQ-1)}{2Q(e^{2aQ}-e^{aQ}+1)\ PO_1}$$

where a, Q, and PO_1 are as previously defined.

If MODEL = 3 or 5, both PN_1 and DN_1 will equal zero. If MODEL = 3, 4, or 5 is used to handle traffic DO_1 for all three methods and DN_1 for MODEL = 4 are calculated using the following equation developed and verified by the California Division of Highways (19):

$$DO_1 = \frac{H(Q-\emptyset)\ (R-\emptyset)}{2Q\ PO_1\ (R-Q)} \quad \text{if } Q > \emptyset$$

$$DO_1 = \emptyset \quad \text{if } Q \leq \emptyset$$

where H = the number of hours per day that overlay construction takes place,

R = the recovery rate in vehicles per hour,

$\emptyset$ = the restricted output rate in vehicles per hour, and

Q and PO_1 are as previously defined.

It is assumed that the input rate Q is the same for both directions of travel and equals 6 percent of average daily traffic in rural areas and 5 percent of average daily traffic in urban areas. The output rate $\emptyset$ and recovery rate R are taken from the California study (19) and are given in Table A-9. The California study also gives the number of vehicles which will be stopped at the time when recovery begins, i.e., when all lanes are reopened for travel, and this number equals $H(Q-\emptyset)$. The average number of vehicles which will be stopped at any one time during overlay will be $H(Q-\emptyset)/2$. By assuming that each vehicle which is stopped stays stopped for some average amount of time D, which is assumed to equal 1/12 hour, not including the time stopped after recovery begins, and assuming that no vehicles are stopped after recovery begins, the total number of vehicles stopped can be estimated as $H^2(Q-\emptyset)/2D$ if $Q > \emptyset$ and is zero if $Q \leq \emptyset$. Thus, for MODEL = 3, 4, or 5, the proportion of vehicles stopped PO_1 (and also PN_1 for MODEL = 4) is estimated by dividing the total number of vehicles stopped by the total input of vehicles during overlay (H x Q):

$$PO_1 = \frac{H(Q-\emptyset)}{2DQ} \quad \text{if } Q > \emptyset$$

$$PO_1 = \emptyset \quad \text{if } Q \leq \emptyset$$

with the constraint that: if this value exceeds 1.0, it is assigned a value of 1.0.

More research, including field observations, needs to be done on the precise number of stops under stop-and-go operation which results from congestion. Use of the above formulas gives reasonable accurate estimates of hours of delay but may underestimate the vehicle operating costs associated with stop-and-go operation.

TABLE A-9

OUTPUT AND RECOVERY RATES FOR RURAL AND URBAN ROADS WITH DIFFERENT NUMBERS OF LANES, FOR USE WITH TRAFFIC MODELS 3, 4, AND 5

Variable Name (FORTRAN)	% Trucks	Rural or Urban	Overlay or Recovery Zone	Lane Capacities in Vehicles per Hour Lanes (one direction) 1	2	3	4	5	6	7
RUTFOV	10+	RU	Ø	1350	2700	4350	6000	7650	9300	na
RUTFRV	10+	RU	R	na	3000	4500	6200	7900	9600	11300
URTFOV	0 - 10	UR	Ø	1400	2800	4500	6200	7900	9620	na
URTFRV	0 - 10	UR	R	na	3000	4700	6400	8100	9800	11500

Note: In SUBROUTINE USER additional lanes are ignored if beyond the table limits of 6 lanes for the overlay zone and 7 lanes for the recovery zone.

Calculation of User Cost Per Square Yard of Overlay

Subroutine OVRLAY calculates the time in hours (HPSY) for overlaying a square yard of pavement, as follows (in FORTRAN):

HPSY = ACCD*(DELD + OVLEVL)/ACPR + (ACCD*WSTHK/WSPR)*SHFCTR

where:

ACCD = density of overlay and level-up materials (tons per cubic yard),

DELD = overlay thickness (yards),

OVLEVL = "level-up" increment (yards),

ACPR = production rate of overlay and level-up (tons per hour),

WSTHK = thickness of wearing surface (yards),

WSPR = production rate of wearing surface (tons per hour),

SHFCTR = shoulder factor (ratio of width of traffic lanes and paved shoulders to width of traffic lanes).

OVRLAY supplies Function USER with HPSY and the hourly traffic (ADT*PROP). Function USER calculates the user cost per hour of overlay (TUCH), multiplies TUCH times HPSY and returns the multiplicand, called USER, which is the total user cost per square yard of traffic lane that is overlaid.

Within Function USER, TUCH is calculated as follows (in FORTRAN):

TUCH = TIPH*(PO1*(CO1+CO2+CO3) + (1.0-PO1)*(CO3+CO4) + PO2*CO5)
+ TIPH*(PN1*(CN1+CN2+CN3) + (1.0-PN1)*(CN3+CN4) + PN2*CN5)

where "O" in a variable name denotes overlay direction and "N" denotes non-overlay direction, and where:

TIPH = vehicles per hour from each direction,

PO1 & PN1 = proportions of traffic stopped because of congestion,

PO2 & PN2 = proportion of traffic stopped due to overlay personnel and equipment,

CO1 & CN1 = excess costs of stopping from highway speeds,

CO2 & CN2 = excess costs of vehicle idling time while stopped,

CO3 & CN3 = excess costs for reduced speed,

CO4 & CN4 = excess costs of changing speed,

CO5 & CN5 = excess costs due to delays from overlay personnel and equipment (stopping plus idling).

TOTAL DESIGN COST

The total cost, per square yard of traffic lane, for each pavement design considered in SAMP6 is calculated as:

$$C_T = C_I + C_M + C_O + C_U - S_I - S_O$$

where all costs and salvage values are discounted to present value terms and are in dollars per square yard of traffic lane, and where:

C_I = the cost of the initial pavement and shoulders,

C_M = the cost of routine maintenance over the analysis period,

C_O = the cost of all pavement overlays (including level-up and wearing course) placed during the analysis period,

C_U = the users', or motorists', costs associated with overlays made during the analysis period,

S_I = the salvage value of the initial pavement and shoulders, and

S_O = the salvage value of all overlays placed during the analysis period.

Subroutine INCOST calculates C_T (called CT) and S_I (called SV). Subroutine OVRLAY calculates C_M (called PRM), C_O (called POCCT), C_U (called PTUC), and S_O (called PSAL). Subroutine OVRLAY calls Function RMAINT to calculate the routine maintenance cost for each performance period. (A performance period is the length of time from initial construction to first overlay; from first overlay to second overlay; and so forth, with the last performance period being the length of time between the last overlay and the end of the analysis period). OVRLAY discounts the maintenance costs for each performance period and sums them to obtain C_M. Similarly, OVRLAY calls Function USER to calculate the user costs associated with each overlay and discounts and sums these costs to obtain C_U.

A-65

APPENDIX B
SAMP6 COMPUTER PROGRAM DOCUMENTATION

(See Note below.)

APPENDIX C
SAMP6 USERS' GUIDE

(See Note below.)

NOTE

Appendices B, C, G, and H of the agency report, which cover SAMP6 computer program documentation, the Users' Guide, and data feedback systems, are not published in this report. They will be of value primarily to persons directly involved in implementation of the SAMP6 program and are available on a loan basis or for the cost of reproduction from the Program Director, NCHRP, Transportation Research Board, 2101 Constitution Ave., N.W., Washington, D.C. 20418. Loan copies of the SAMP6 program on magnetic tape are also available from the same source.

APPENDIX D
SAMP6 SENSITIVITY ANALYSIS

APPENDIX D

SAMP6 SENSITIVITY ANALYSIS

INTRODUCTION

There are two major purposes for sensitivity analyses, one in a detailed study and the other in a more general study. Detailed studies are made to improve mathematical models contained within a computer program or to establish priorities for research and implementation or to derive reliable simulation models to replace more complicated computation schemes. On the other hand, a general sensitivity analysis is made to acquaint the user with operating characteristics of the computer program. The user is generally not interested in the intricacies usually required of the detailed sensitivity analysis. He is concerned mainly with the most significant variables that are input to the computer program and what effect they have on the final results of the computations made. In the SAMP6 computer program for example, one of the major results of interest to designers is the total cost of the pavement per square yard. This cost is affected significantly by the cost of materials used, by the length of time over which the road is analyzed, by the amount of traffic that passes over the road, and by the traffic loading. These are significant variables, and the designer is interested in how they affect the cost of the final design.

TECHNIQUES OF SENSITIVITY ANALYSIS

A sensitivity analysis is usually done by selecting a typical problem and determining its normal input values. Then, each of the input values is varied one at a time to determine its effect upon the output results. A thorough sensitivity analysis would assign several values to each--for example, high, medium and low values--and use each of these with each

combination of all of the other variables at their high, medium, and low values. Such combinations would lead to a full factorial study, and the number of times a problem must be worked amounts to 3^n where n is the total number of variables. The numbers of problems to be run for a full factorial study quickly becomes unmanageable. Experimental design of the sensitivity analysis may reduce the total number of runs to something that is more manageable. But as the number of problems run decreases, there is a sacrifice in the accuracy of the knowledge of how different variables interact with each other. Instead of taking three levels--high, medium, and low--only two levels may be chosen--high and low. If it is further assumed that some calculated output result such as the total cost per square yard is at most a quadratic function of the input variables, then a large reduction in the total number of problems that must be run is possible. The quadratic function is composed of linear terms of the variables, their squares, and products of each of the variables two at a time. If there are two variables, x_1 and x_2, the quadratic function associated with them would be as follows:

$$y = a_0 + a_1x_1 + a_2x_2 + a_{11}x_1^2 + a_{22}x_2^2 + a_{12}x_1x_2$$

Since there are around 120 variables in the SAMP6 computer program, around 8,400 different problems would be required to determine all of the coefficients of the quadratic function. Not all of the interactions between the variables, such as in x_1 and x_2 in the equation shown above, would be interesting or significant, and much of the effort and cost of running the 8,400 problems would be wasted. Furthermore, it is known that there are several variables which interact in a more complicated fashion than simply as $(x_1 \cdot x_2)$. For example, there are a number of variables which interact three or four at a time, and these interactions would not be considered by an assumed quadratic function.

USE OF RESULTS OF SENSITIVITY ANALYSIS

If the results of the sensitivity analysis can be fit reliably by an assumed function such as the quadratic function discussed above, then one can proceed to determine sensitivity coefficients by taking the partial derivative of the dependent variable with respect to each of the independent variables in turn. For example, in the equation below

$$dy/dx_1 = a_1 + 2a_{11}x_1 + a_{12}x_2.$$

For any given value of x_1 and x_2, the rate of change of the dependent variable y can be found. The larger the size of this derivative, the more important the variable is in determining the value of the dependent variable. This derivative is the sensitivity coefficient.

A simpler method of displaying the importance of different variables is to plot the results of runs of several problems on a piece of graph paper. That way the most important variables can be seen visually to have the higher slopes. A third way of using the results of the sensitivity analysis are by calculating the percentage change in a result with the variation of the single input variable. This technique is used here.

SENSITIVITY ANALYSIS OF SAMP6

Eleven different studies were made using the problems proposed by the cooperating states, Kansas, Louisiana, and Florida. The reference problems included variations of (1) structural number,

(2) soil support value,

(3) projections of expected 18-kip equivalent loads applied,

(4) confidence levels due to stochastic variations of material and pavement properties,

(5) interest rate,

(6) analysis period,

(7) user costs due to congestion and traffic delay,

(8) environmentally caused loss of serviceability,

(9) unit costs of materials,

(10) pavement strategy as affected by material costs which vary with volume,

(11) pavement strategy as affected by considering the cost of the full cross section,

(12) design and total cost variation with soil support option,

(13) thickness design and total cost variations with minimum serviceability index.

Tables D-1, D-2, and D-3 show the significant features of the pavement sections used in these sensitivity analyses.

TABLE D-1. LOUISIANA PAVEMENT SECTIONS

	Acadia St. Proj. 801-32-05	Calcasieu 1 - 10	Pointe Coupee La. 1	Rapides St. Proj. 8-09-20
Initial Average Daily Traffic	40	5,635	1,820	6,560
Final Average Daily Traffic	85	8,635	3,200	14,760
18-kip Equivalent Loading	14,535	6,700,000	1,974,000	17,860,000
Analysis Period	20	20	20	20
Layers Above Subgrade	2	4	2	3,4

TABLE D-2. KANSAS PAVEMENT SECTIONS

	Douglas Co. S.H. K-10	Kingman Co. U.S. 54
Initial Average Daily Traffic	3,230	1,990
Final Average Daily Traffic	5,150	3,250
18-kip Equivalent Loading	380,000	1,440,000
Analysis Period	20	20
Layers Above Subgrade	2	2

TABLE D-3. FLORIDA PAVEMENT SECTIONS

	Florida Sec. 6	Florida Sec. 17	Florida Sec. 19
Initial Average Daily Traffic	485	6,655	6,655
Final Average Daily Traffic	1,193	27,555	27,555
18-kip Equivalent Loading	102,000	17,408,032	17,408,032
Analysis Period	20	40	40
Layers Above Subgrade	3,1	3	3
Number of Lanes	2	4	6

Another item of note in this portion of the sensitivity analysis is that the optimum thicknesses for each of the designs did not change, that is, there was one inch of surface course, twelve inches of base course, and twenty-four inches of subbase course which proved to be the least expensive design no matter what the material coefficient happened to be. This is not the case when the material coefficients of the base course and subbase courses are varied.

Table D-5 shows the results of the sensitivity analysis of the material coefficients of the base course material. The optimum thickness design remained the same as long as the material coefficient was around .10 and .13, but it changed significantly when the material coefficient rose to .20. In this case the strength to cost ratio exceeded that of the other two layers, and so the computer program indicated that the least expensive strategy would be to use surface and subbase courses at their minimum thicknesses and use the greatest amount of base course material available. The total cost per square yard dropped steadily as the material coefficient for the base course rose.

TABLE D-5. TOTAL COSTS -- BASE COURSE MATERIAL COEFFICIENT (FLORIDA, SEC. 17)

Material Coefficient	Optimum Thickness Design	Total Cost per Square Yard	Percent Variation from Medium
0.10	1" - 12" - 20"	$8.686	+5.3
0.13	1" - 12" - 20"	$8.245	-
0.20	1" - 15" - 4"	$7.127	-13.6

Table D-6 shows the results of sensitivity analysis of the material coefficient of the subbase course material. Here again as in the base course material, the optimum thickness design changed. In making the slight change

Sensitivity Analysis No. 1 -- Structural Number

The first section chosen for sensitivity analysis of structural number was from Florida and termed their Section 17. The traffic was moderate to high, beginning at around 6,700 vehicles per day and arriving at the end of the 40-year analysis period at around 28,000 vehicles per day. Total 18-kip equivalents over the life of the pavement would be about seventeen million. Each of the designs considered three layers on top of the subgrade. The surface course material coefficient was varied from .44 to .40 to .30. The base course material coefficient was varied from .20 to .13 to .10. The subbase material coefficient had only two variations, .10 and .08. The subgrade in all cases was maintained at a soil support value of about 6.50. The assumed medium value for each of the courses in this three-layer pavement system was .40 for the surface course, .13 for the base course, .08 for the subbase, and 6.50 for the soil support value of the subgrade.

Table D-4 shows the results of varying the material coefficients of the surface course while keeping the material coefficients of all other courses the same. Because there is so little of the surface course material in the optimum designs, the total cost of the pavement per square yard was affected very little.

TABLE D-4. TOTAL COSTS -- SURFACE COURSE MATERIAL COEFFICIENT (FLORIDA, SEC. 17)

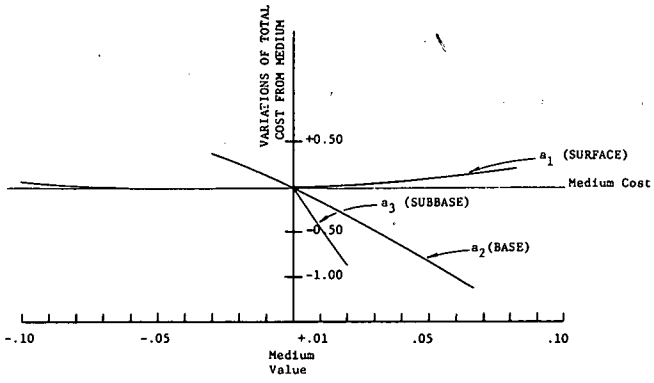
Material Coefficient	Optimum Thickness Design	Total Cost per Square Yard	Percent Variation from Medium
0.30	1" - 12" - 24"	$7.023	+0.38
0.40	1" - 12" - 24"	$6.996	-
0.44	1" - 12" - 24"	$7.003	nil

of material coefficient from .08 to .10, the cost to strength ratio of the subbase material became dominant, and the computer program indicates that the best strategy is to use the maximum amount of subbase material while keeping the surface and base course materials at their minimum levels. The total cost per square yard dropped sharply as the material coefficient for subbase material was raised.

TABLE D-6. TOTAL COSTS -- SUBBASE COURSE MATERIAL COEFFICIENT (FLORIDA, SEC. 17)

Material Coefficient	Optimum Thickness Design	Total Cost per Square Yard	Percent Variation from Medium
0.08	1" - 12" - 20"	$8.245	-
0.10	1" - 4" - 20"	$7.410	-10.1

Figure D-1, on which the percent variation from the medium cost is plotted against variations of material coefficients from their medium values, indicates that the greatest reduction in the total cost per square yard comes from an increase in the subbase course material coefficient. This presumes, of course, that the subbase course still costs the same. A certain degree of caution must be exercised in applying the results of this sensitivity analysis over a broad scale. For example, it is significant that this Fla. section 17 had a moderate to high degree of traffic. On Florida section 6, which is characterized by low traffic and a small number of 18-kip equivalent single axle loads, the material coefficient of the surface course became important, as shown in Table D-7. As the material coefficient changed from .30 to .40, there was less subbase material required, its thickness changing from twenty-four to twenty inches. But as the material coefficient changed from .40 to .44, the strength to cost ratio for the surface course material passed



VARIATIONS OF MATERIAL COEFFICIENTS FROM THE MEDIUM

FIG. D-1. COSTS VERSUS MATERIAL COEFFICIENT CHANGES

soil support value to 6.5 results in a further decrease in thickness of the surface course and also a decrease in the thickness of the base course. The soil support values indicate the strength of the untreated natural subgrade soil, and consequently, this is a material over which the pavement designer has little control. Nevertheless, this table indicates that there are considerable benefits to pavement design in moving from one location where the soil is poor to another location where it is much better.

TABLE D-8. TOTAL COSTS -- SOIL SUPPORT VALUE (FLORIDA, SEC. 17)

Soil Support Value	Optimum Thickness Design	Total Cost per Square Yard	Percent Variation from Medium
3.50	4" - 14" - 20"	$11.714	+8.0
4.00	2" - 14" - 20"	$10.851	-
6.50	1" - 12" - 20"	$8.245	-24.0

Sensitivity Analysis No. 3 -- Projection of 18-kip Equivalencies

This sensitivity analysis was done on two sections — one in Florida, section 17, over a 40-year analysis period and the other in Kingman Co., Kansas, over a 20-year analysis period. The purpose of these sensitivity analyses was to determine in what way the total cost per square yard and the optimum designs varied as the estimate of 18-kip equivalent single axle loads changed. All other input variables remain the same in both Fla. section 17 and the Kingman Co. runs. Florida section 17 data have been discussed in sensitivity analysis number 1. However, to repeat briefly, it consists of moderate to high traffic and fairly high total 18-kip equivalents over its 40-year analysis period. The optimum designs were always three layers on top of the subgrade. By way of contrast, Kingman Co., Kansas,

through that critical value which then made it the most cost-effective pavement material to use. Consequently, the cheapest pavement designs switch from a three layer to a one layer design using six inches of the surface course material. The total cost per square yard dropped steadily as the material coefficient for the surface course rose. The major difference between the results shown in Table D-6 and those in Table D-7 could be ascribed to the traffic. There was high traffic on section 17 and low traffic and low loads on section 6.

TABLE D-7. TOTAL COSTS -- SURFACE COURSE MATERIAL COEFFICIENT (FLORIDA, SEC. 6)

Material Coefficient	Optimum Thickness Design	Total Cost per Square Yard	Percent Variation from Medium
0.30	1" - 4" - 24"	$5.053	+4.0
0.40	1" - 4" - 20"	$4.858	-
0.44	6"	$4.379	-9.9

Sensitivity Analysis No. 2 -- Soil Support Value

The problem selected for a sensitivity analysis of the soil support value was again Florida section 17. The details of Florida section 17 are given in the text above; it is characterized mainly by moderate to high traffic and fairly heavy 18-kip equivalent loads. As shown in Table D-8, the thickness for the optimum design changes as the soil support value rises, and the total cost per square yard drops. The way the thicknesses change as the soil support value rises indicates which of the materials have the better cost-to-strength ratios. As the soil support value rises from 3.5 to 4.0, the optimum design keeps the thicknesses of the base course and subbase the same but reduces the thickness of the surface course. A further increase of

on U. S. Highway 54, had an estimated traffic beginning at about 2,000 vehicles per day and ending after twenty years at about 3,300 vehicles per day. Optimum designs for that pavement section generally resulted in two layers on top of the subgrade.

In each of the problems the estimated number of 18-kip equivalents was doubled and halved to see what effect this would have upon the total cost per square yard and the optimum design. Table D-9 shows the results for the Florida problem. Because the subbase layer has the highest strength-to-cost ratio, the major variations in thickness design will be found there. The changes in structural number indicate that although the 18-kip equivalents have been halved, there has been only a 15.6 percent decrease of structural number. Similarly, when the 18-kip equivalents have been doubled, there was only an 8.6 percent increase of structural number. The total cost per square yard varied less than these. Having 18-kip equivalents cut the cost by 6.9 percent. Doubling the 18-kip equivalents raised the cost by 5.5 percent. These results indicate a rather general rule that although the 18-kip equivalents may change widely, neither the optimum structural number nor the total cost per square yard will usually vary nearly as much. However, the thickness of the most cost-effective layer may be changed considerably.

TABLE D-9. TOTAL COSTS -- OPTIMUM DESIGN -- 18-KIP EQUIVALENTS (FLORIDA SEC. 17, 40-YEAR ANALYSIS PERIOD)

18-Kip Equivalents (Millions)	Optimum Thickness Design	Structural Number	Percent Variation from Medium	Total Cost per Square Yard	Percent Variation from Medium
8.704	1" - 12" - 16"	3.14	15.6	$7.792	-6.9
17.408	1" - 14" - 20"	3.72	-	$8.371	-
34.816	1" - 14" - 24"	4.04	+8.6	$8.832	+5.5

Table D-10 shows the results of the sensitivity analysis on the Kingman Co., Kansas, U. S. Highway 54 problem. As the 18-kip equivalents increase, so does the optimum thickness design. The lower layer has the highest strength-to-cost ratio, and thus it is the one that changes from one optimum design to another. The structural number is more greatly affected in this problem than it was in the Florida problem, whereas the total cost per square yard varies about as before. This indicates another fairly general rule that at the lower level of 18-kip equivalents, there will be a larger variation of optimum structural number.

TABLE D-10. TOTAL COSTS -- OPTIMUM DESIGN -- 18-KIP EQUIVALENTS (KINGMAN CO., KANSAS, U. S. 54, 20-YEAR ANALYSIS PERIOD)

18-Kip Equivalents (Millions)	Optimum Thickness Design	Structural Number	Percent Variation from Medium	Total Cost per Square Yard	Percent Variation from Medium
1.44	2" - 12"	3.28	-15.5	$6.082	-7.4
4.32	2" - 15"	3.88	-	$6.569	-
12.96	2" - 19"	4.68	+20.6	$7.119	+8.4

Sensitivity Analysis No. 4 -- Stochastic Variations of Material and Riding Quality Properties

There are several sources of error in the values of material coefficients, soil support values, initial and final serviceability index levels, and environmental roughness. Some of the error is due to the failure of lab tests to measure the actual properties of the soil in the field. Another source of error is the random variation of these material properties along a project length. There is still another error that is involved in using the AASHO Road Test equation for flexible pavements to try to predict when the serviceability index drops below an acceptable level. There is yet another error

in estimating the total 18-kip equivalent loading that has been applied to a given stretch of road up to a particular time. All of these errors have been considered in deriving this method for making certain within confidence limits that an overlay will not be applied within the specified minimum period of time. Sensitivity analyses were made on the Florida section 17 which is by now familiar, a section of Douglas Co., Kansas, State Highway K-10, and a section of Interstate Highway 10 near Lake Charles, Louisiana, in Calcasieu Parish. The Florida section 17 is characterized by moderate to high traffic and heavy 18-kip equivalents and an analysis period of 40 years. Douglas Co., Kansas, is characterized by moderate to low traffic, low 18-kip equivalents, and a 20-year analysis period. Calcasieu, La. has moderate traffic and 18-kip equivalent loading. In using the SAMP6 program the designer specifies a minimum time to first overlay and a minimum time between overlays. There are a variety of reasons for doing this, some of them being related to the frequency of complaints from the public if pavement rehabilitation work is done too frequently on any one stretch of highway. The stronger the initial design, the more certain the designer is that the pavement will last at least the minimum period of time before requiring additional work. Obviously, where there is high traffic, the designer will require a higher level of confidence than he would on some rural section of road. For this reason the SAMP6 computer program includes several levels of confidence, and Table D-11 indicates their meaning. Confidence level 1 indicates that the chances that an overlay will have to be placed sooner than desired are one in two, which means a fifty-fifty chance. Confidence level 5 indicates that the chances are only one in one hundred that an overlay will have to be placed sooner than desired. Table D-12 shows some of the results of the sensitivity analysis of Florida section 17. As the confidence

TABLE D-11. CONFIDENCE LEVELS

Confidence Levels	Chances That An Overlay Will Have To Be Placed Sooner Than Desired
1	1 in 2
2	3 in 10
3	1 in 10
4	1 in 20
5	1 in 100
6	1 in 200
7	1 in 1000

TABLE D-12. OPTIMUM DESIGN AND TOTAL COST VARIATIONS WITH CONFIDENCE LEVEL (FLORIDA, SEC. 17, 40-YEAR ANALYSIS PERIOD)

Confidence Level	Optimum Thickness Design	Initial Structural Number	Percent Increase	Total Cost per Square Yard	Percent Increase	Number of Overlays Required
1	1" - 12" - 24"	3.78	-	$7.02	-	1
2	1" - 14" - 24"	4.04	6.9	$7.27	3.6	1
3	2" - 14" - 24"	4.34	14.8	$7.72	10.0	0
4	4" - 14" - 24"	4.94	30.7	$8.91	26.9	0

level rose, the optimum thickness design changed. First the base course reached its maximum allowable thickness, and then additional thicknesses were added to the surface course at confidence levels 3 and 4. The initial structural numbers climbed steadily, with percent increases of about seven, fifteen, and thirty percent. The total cost per square yard increased steadily, being about 26.9 percent greater at confidence level 4 than at confidence level 1. This increase would not have been as great had not the base and subbase layers reached their maximum-permitted depths. The number of overlays required at confidence levels 1 and 2 were only one, whereas at confidence levels 3 and 4, no overlays were required for the entire 40-year analysis period.

Table D-13 shows that in Calcasieu Parish, Louisiana, the optimum thickness design remained the same for confidence levels 1 and 2 although the minimum initial structural number for the top thirty designs rose steadily. The total cost per square yard rose to fourteen percent greater than at confidence level 1, and the number of overlays required was one at confidence levels 1 and 2. Overall, the pattern is generally the same as for the Florida section 17 result.

TABLE D-13. OPTIMUM DESIGN AND TOTAL COST VARIATIONS WITH CONFIDENCE LEVEL (CALCASIEU PARISH, LOUISIANA, I-10, 20-YEAR ANALYSIS PERIOD)

Confidence Level	Optimum Thickness Design	Minimum Initial Structural Number	Percent Increase	Total Cost per Square Yard	Percent Increase	Number of Overlays Required
1	1½" - 7" - 10"	4.14	-	$12.753	-	1
2	1½" - 7" - 10"	4.44	7.2	$12.753	0.0	1
3	1½"-8"-10"-6"	5.00	20.8	$14.172	11.1	0
4	1½"-8"-10"-12"	5.30	28.0	$14.573	14.3	0

Table D-14 shows the results of the sensitivity analysis of the Douglas Co., Kansas, State Highway K-10 project. Although the optimum thickness design did not change very much until the final confidence level was reached, the minimum initial structural number for the top thirty designs rose steadily. The 3/4 inch surface course thickness was an HMR asphaltic concrete. It remained the optimum surface course until confidence level number 6 was reached. There an HM3 asphaltic concrete took over with its minimum thickness of two inches. It is significant that in this problem three layers were allowed, the third and bottom layer being specified as six inches of lime-treated soil. Despite this provision, the optimum design always included only two layers above the subgrade, the third being deleted. Beyond confidence level number 2 the total cost per square yard rose steadily, the difference between the result in confidence level 2 and 3 being the thickness of the overlay required. No overlay was required at confidence level number 6.

TABLE D-14. OPTIMUM DESIGN AND TOTAL COST VARIATIONS WITH CONFIDENCE LEVEL (DOUGLAS CO., KANSAS, S.H. K-10, 20-YEAR ANALYSIS PERIOD)

Confidence Level	Optimum Thickness Design	Minimum Initial Structural Number	Percent Increase	Total Cost per Square Yard	Percent Increase	Number of Overlays Required
1	3/4" - 14"	2.56	-	$5.110	-	½"
2	3/4" - 14"	2.76	7.8	$5.110	0.0	½"
3	3/4" - 14"	2.76	15.6	$5.340	4.5	1"
4	3/4" - 15"	3.20	25.0	$5.699	11.5	1½"
6	*2" - 18"	4.56	78.1	$6.790	32.9	0

* Material for surface course changed from HM-R to HM-3 asphaltic concrete.

six lanes. The soil support value in each case was varied from 6.5 to 4.0 to 3.5, and analysis periods of twenty and forty years were used. Results for the four-lane highway are shown in Table D-16 where the percent increases of total costs per square yard were around six percent when the analysis period was raised from twenty to forty years.

TABLE D-16. TOTAL COST VARIATIONS WITH ANALYSIS PERIOD (FLORIDA, SEC. 17, 4 LANES)

Soil Support Value	Analysis Period Years	Total Cost per Square Yard	Percent Increase
6.50	20	$7.797	-
	40	$8.245	+5.7
4.00	20	$10.257	-
	40	$10.851	+5.8
3.50	20	$10.976	-
	40	$11.714	+6.7

As shown in Table D-17, results of the six-lane pavement problems varied from about five to eleven percent increase for an increase of analysis period from twenty to forty years. These figures indicate that it takes only five to eleven percent more money at its present value to provide a pavement that is serviceable over a period that is twice as long as the usual analysis period of twenty years. The quality of the subgrade soil makes some difference in this percentage and the number of lanes to be built also has a certain amount of significance.

Sensitivity Analysis No. 5 -- Interest Rates

Sensitivity analysis was made of the variations in interest rates on the Kingman Co., Kansas, pavement design problem. The major effect of a variation of interest rates is to reduce the total cost per square yard as the interest rate goes up. Kingman Co., Kansas, was selected for this analysis because it has a moderate amount of traffic, a moderate amount of 18-kip equivalents over a 20-year analysis period, and has an optimum design of two layers over the subgrade. The interest rate is used to discount future costs to the present time. Of course, the higher the interest rate, the lower will be the present value of funds that will be expended in the future. Table D-15 shows the results of this sensitivity analysis of interest rates.

TABLE D-15. TOTAL COST VARIATIONS WITH INTEREST RATES (KINGMAN CO., KANSAS, U.S. 54)

Interest Rate	Optimum Thickness Design	Total Cost per Square Yard	Percent Variation
5	2" - 12"	$6.082	-
7	2" - 12"	$5.833	-4.1
10	2" - 12"	$5.551	-8.7

Sensitivity Analysis No. 6 -- Analysis Period

Two extra variables were included in this sensitivity analysis to see what would be the effects of four lanes or six lanes and the effects of various soil support values on the total cost per square yard. The sections chosen for this sensitivity analysis were the Florida Sections 17 and 19. The 18-kip equivalent loadings are identical on each of these pavements, the only difference being that section 17 has four lanes and section 19 has

TABLE D-17. TOTAL COST VARIATIONS WITH ANALYSIS PERIOD (FLORIDA, SEC. 19, 6 LANES)

Soil Support Value	Analysis Period Years	Total Cost per Square Yard	Percent Increase
6.50	20	$6.727	-
	40	$7.051	+4.8
4.00	20	$8.625	-
	40	$9.536	+10.6
3.50	20	$9.192	-
	40	$9.966	+8.4

Sensitivity Analysis No. 7 -- User Costs Due to Congestion and Traffic Delay

In the SAMP6 computer program congestion is assumed to begin when a certain flow rate of vehicles per hour occurs. Table D-18 shows these rates which are slightly higher for urban situations than for rural. This is based upon the fact that usually there is a lower percentage of trucks in typical urban traffic. When the product of the average daily traffic and the percent of ADT passing through the overlay zone each hour rises above the appropriate number in Table D-18, then congestion and traffic delay costs begin to accumulate. Table D-19 shows the results of the sensitivity analysis run on the Rapides Parish, La., pavement design problem. The first level of initial and final ADT were the ones specified by Louisiana for this problem. The vehicles arriving per hour were well below those specified in Table D-17 for the beginning of congestion. Consequently, the user costs were due only to the delay of traffic stopped by construction equipment. The next level which was twice that specified by Louisiana began to accumulate user costs due to

traffic delay because the final vehicles per hour count rose above the rural congestion rate for one lane left open in the overlay direction as shown in Table D-18. The third level of ADT, which was three times that originally specified by Louisiana's Department of Highway Designers quickly became congested, and the user costs more than doubled the total cost of the pavement per square yard.

TABLE D-18. VEHICLES PER HOUR WHEN CONGESTION BEGINS (FOR TRAFFIC MODELS 3, 4, AND 5)

RURAL		URBAN*	
Number Of Lanes Left Open	Vehicles per Hour	Number Of Lanes Left Open	Vehicles per Hour
1	1350	1	1400
2	2700	2	2800
3	4350	3	4500
4	6000	4	6200
5	7650	5	7900
6	9300	6	9600

* Higher urban rates are based on a lower percentage of trucks in typical urban traffic.

TABLE D-19. USER COSTS DUE TO CONGESTION AND TRAFFIC DELAY (RAPIDES PARISH, LA., ST. PROJ. 8-09-20, 1 LANE LEFT OPEN IN OVERLAY DIRECTION)

Initial Average Daily Traffic	Initial Vehicles per Hour	Final Average Daily Traffic	Final Vehicles per Hour	Optimum Thickness Design	Total Cost per Square Yard	Users Cost per Square Yard
6560	394	14760	886	1½" - 10" - 10"	$13.686	$ 0.034
13120	787	29520	1771	1½" - 10" - 10"	$13.774	$ 0.122
19680	1181	44260	2657	1½"-10"-6"-12"	$28.381	$14.378

TABLE D-20. EFFECT OF EXPANSIVE CLAY ON TOTAL COSTS AND OVERLAY SCHEDULING (ACADIA PARISH, LA., ST. PROJ. 801-32-05)

Maximum Surface Rise, Inches	Surface Rise, Rate	Optimum Thickness Design	Time(s) to Overlay, Years	Total Cost per Square Yard
NO EXPANSIVE CLAY		1½" - 6"	10.7	$4.418
24	0.03	1½" - 6"	8.8	$4.446
10	0.12	1½" - 6"	7.8	$4.503

The effects of expansive clay on the total costs and overlay scheduling in Douglas Co., Kansas, St. Highway K-10 are shown in Table D-21. This location is in the Kansas River Valley and is known for a moderate amount of expansive clay activity. The traffic on this state highway is moderate, and the 18-kip equivalent loadings are low. There was a twenty-year analysis period and although three layers were permitted in this design, two layers consistently proved to be the optimum. With no expansive clay present, the first time to overlay was 9.9 years. With the expansive clay present, the optimum thickness design did not change, but the time to overlay was shortened considerably. In fact, during the twenty-year analysis period there were two overlays, one at 3.9 years and the other at 11.0 years. The total cost rose by more than ten percent.

TABLE D-21. EFFECT OF EXPANSIVE CLAY ON TOTAL COSTS AND OVERLAY SCHEDULING (DOUGLAS CO., S.H. K-10)

Maximum Surface Rise, Inches	Surface Rise, Rate	Optimum Thickness Design	Time(s) to Overlay, Years	Total Cost per Square Yard	Percent Increase
NO EXPANSIVE CLAY		3/4" - 14"	9.9	$5.110	-
6.0	0.12	3/4" - 14"	3.9, 11.0	$5.632	+10.2

Sensitivity Analysis No. 8 -- Environmentally Caused Loss of Serviceability

Loss of serviceability due to expansive clay activity is widespread throughout the United States. There is a direct analogy between the kind of roughness caused by expansive clay and that caused by frost heave. Only expansive clay roughness was considered in this sensitivity analysis. Problems were selected from areas of Louisiana and Kansas which are known to have expansive clay, and typical values were used to determine the effect on pavement costs and design strategy that would be caused by expansive clay activity. The Acadia Parish, La. pavement section was chosen for the first sensitivity analysis (see Table D-20). It is characterized by very low traffic and low 18-kip loading. Over a twenty-year analysis period, the two layers above the subgrade were at their minimum thickness. When no expansive clay was considered to be acting on this stretch of road, the first overlay would be expected around 10.7 years after initial construction. Two cases of expansive clay activity are considered here, one in which there is potentially a very large amount of heaving (24") which occurs over a long period of time. The second case is where there is only a moderate amount of heaving that may occur (10") but the rate of heaving is moderate (0.12). In the first case with the slow heaving rate (0.03), the optimum thickness design did not change. It remained at the minimum thickness, but the time to overlay was shortened to 8.8 years, and the total cost per square yard rose slightly. In the third problem run, although a maximum surface rise of only ten inches was assumed, the moderate surface rise rate of 0.12 had a dominating effect. Although it did not change the optimum thickness design, it shortened the time to overlay still farther to 7.8 years.

Sensitivity Analysis No. 9 -- Unit Costs of Materials

The section of highway in Rapides Parish, Louisiana, State Project No. 8-09-20, was selected for this sensitivity analysis because it had a moderate amount of traffic and a heavy 18-kip equivalent loading over a twenty-year analysis period and because there were a number of materials available for use in this pavement section. Four layers were permitted in this problem, and depending upon the variation tried, either three or four layers proved to be the optimum thickness design. The first sensitivity analysis was made varying all unit costs of materials above and below the normal level expected in Louisiana. Table D-22 shows that although the optimum thickness design didn't change, the percent variation in the total cost per square yard was less than the variation in the unit cost level. One additional problem was run in this sensitivity analysis keeping the unit cost level at 75 percent and raising the traffic to a point where congestion was likely to occur. In this case the optimum thickness design was altered considerably and the total cost per square yard was raised significantly as could be expected with the congested user costs.

TABLE D-22. VARIATIONS OF UNIT COSTS OF ALL MATERIALS (RAPIDES PARISH, LA., ST. PROJ. 8-07-20)

Unit Cost Level, Percent	Optimum Thickness Design	Total Cost per Square Yard	Percent Variation
75	1½" - 10" - 10"	$11.109	-18.8
100	1½" - 10" - 10"	$13.686	-
150	1½" - 10" - 10"	$18.921	+38.3
75*	1½" - 10" - 6" - 12"	$25.770	+88.3

* With high traffic

Since much of the material that was used in the design was a base course or a subbase course, a further sensitivity analysis was done to see what effect the variation of simply base course prices would cause on thickness design and total cost. As shown in Table D-23, when the unit cost level dropped to 75 percent, a different optimum thickness design was dictated although the percent variation of total cost was rather small. When the unit cost level of base course materials rose to 150 percent, the optimum thickness design remained the same, and the percent variation in total costs again remained fairly small. On the basis of these two sensitivity analyses which are summarized in Tables D-22 and D-23 and upon other such sensitivity analyses, it has become apparent that the most important unit cost is that of the surface course material.

TABLE D-23. VARIATIONS OF UNIT COSTS OF BASE MATERIALS

Unit Cost Level, Percent	Optimum Thickness Design	Total Cost per Square Yard	Percent Variation
75	1½" - 9" 10" - 6"	$12.885	- 5.9
100	1½" - 10" - 10"	$13.686	-
150	1½" - 10" - 10"	$15.272	+11.6

Sensitivity Analysis No. 10 -- Pavement Strategy Affected by Variable Unit Costs of Materials

Unit costs of materials generally decrease with an increasing volume of material placed. This sensitivity analysis was done on a section of Interstate 10 in Calcasieu Parish, Louisiana, where the traffic and the 18-kip equivalent loading were moderate. The analysis period was twenty years, and there were four layers above the subgrade. This sensitivity

Sensitivity Analysis No. 11 -- Pavement Strategy Variations With Full Cross Section Design

Full cross section design includes the costs of pavement layers as well as materials used in the shoulder and considers the future costs of overlaying the shoulders. The effect of including the costs of these shoulder materials becomes more pronounced as the level of 18-kip equivalent loading is increased. Higher loads require thicker pavements and thus a greater amount of shoulder material. Because variable costs tend to place a premium upon the use of greater quantities of material in initial construction, the thickness of the optimum pavement section will generally prove to be greater when full cross section design is used. If the 18-kip equivalent loading is light to moderate as in the case of La. Hwy. 1 in Pointe Coupee Parish, there will be an increase of total cost per square yard of paving area once the shoulder materials are included. However, as is shown to be the case in Table D-25, the optimum thickness design may not change. When the 18-kip equivalent

TABLE D-25. TOTAL COST VARIATIONS WITH FULL CROSS SECTION DESIGN (POINTE COUPEE, LA., LA. 1)

Cross Section	Optimum Thickness Design	Total Cost per Square Yard	Percent Increase
Pavement Layers	5" - 2"	$5.101	-
Full Cross Section	5" - 2"	$6.178	+21.1

loadings become moderate to high as in the case of Florida Section 17, there is a substantial amount of shoulder material that is to be considered. Consequently, full cross section design gives a large increase in total costs per square yard. The optimum thickness design is changed, the thickness becomes

analysis was carried out to determine whether the optimum thickness design changed with the level of 18-kip loading applied to the pavement. Less material would be required with light loading than with heavier loadings, and the way that unit costs of these materials vary with the amount of material required could change the optimum design. Table D-24 shows the results of this sensitivity analysis. The constant unit costs used in this study were exactly halfway between the maximum and minimum variable unit costs. The

TABLE D-24. VARIATIONS OF OPTIMUM THICKNESS DESIGN WITH VARIABLE COSTS (CALCASIEU PARISH, LA., I-10)

18-kip Equivalents, Millions	Costs	Total Cost per Square Yard	Percent Change	Design Summary of the Top 30 Designs Number of Layers 2	3	4
0.67	Constant	$ 9.979	-	1	10	19
	Variable	$ 9.801	-1.18	2	11	17
6.7	Constant	$13.483	-	0	8	22
	Variable	$12.753	-5.4	2	10	18
20.1	Constant	$15.242	-	0	8	22
	Variable	$14.422	-5.4	0	11	19

total cost per square yard was always smaller than that produced by constant unit costs. Since variable unit costs are generally a more realistic representation of the actual cost structure, it would appear that use of constant unit costs results in a conservative estimate of the total cost per square yard. The discrepancy between the estimated total costs grows larger as the level of 18-kip equivalent loads is increased. Because variable unit costs place a premium upon the use of larger quantities of material, there is a tendency to use fewer layers in the design. The greater the variation of cost with volume, the more this tendency will predominate.

greater, and the average thickness of the top ten designs is also thicker. These data are shown in Table D-26. A further increase in 18-kip equivalent loading or a wider variation of unit costs of materials will show still greater changes in optimum thickness design and total costs per square yard.

TABLE D-26. PAVEMENT STRATEGY VARIATION WITH FULL CROSS SECTION DESIGN (FLORIDA, SEC. 17)

Cross Section	Optimum Thickness Design	Total Cost per Square Yard	Percent Increase	Average Thickness of Top 10 Designs, Inches
Pavement Layers Only	1" - 8" - 24"	$5.167	-	33.1
Full Cross Section	1" - 14" - 20"	$8.371	62.0	33.7

Sensitivity Analysis No. 12 -- Design and Total Cost Variation with Soil Support Option

The SAMP6 computer program allows the pavement designer to choose one of three options for selecting layer thicknesses. (These options are internal within the program and the option is not a program input. They are described in more detail within the computer program and in Appendix A.) For the purposes of the discussion here it is sufficient to say that options one and two reject from consideration those designs in which it would be expected that the initial failure would occur above the subgrade level. Option three allows the designer to put in any combination of materials and thicknesses he desires exactly as specified in the AASHO Interim Guide. Options one and two are also specified as alternate procedures for determining thickness of layers in the AASHO Interim Guide (page 95). Options one and two are used to screen out those designs in which large thicknesses

of weak material have been specified by the designer. Usually, pavement designers have chosen not to specify such combinations and have preferred to use option three. Nevertheless, options one and two are available within SAMP6 as alternate procedures. In Table D-27 a weak material was specified and the computer program predicted that there was a weak layer interface between layers two and three. The designs produced by options one and two are more realistic for the conditions in Florida on Section 17 but are more costly.

TABLE D-27. DESIGN AND TOTAL COST VARIATION WITH SOIL SUPPORT OPTION (Florida, Section 17)

Soil Support Option	1	2	3
Total Cost/Square Yard	$12.893	$12.893	$8.371
Optimum Thickness (inches)	5½ - 8	5½ - 8	1-14*-20
Structural Number	3.01	3.01	3.72
Initial Life (years)	11.6	11.6	25.6
Total Feasible Designs	5	4	465

* Weak layer interface between layers 2 and 3

Sensitivity Analysis No. 13 -- Thickness Design and Total Cost Variations With Minimum Serviceability Index

There is a question of design strategy that is not completely answered by this sensitivity analysis. SAMP6 results indicate that it is less expensive to overlay at lower serviceability indexes, but a major factor has not been considered. The general trend of speed vs. serviceability index data collected on a number of speed monitored sections in different states, indicates that traffic will slow down as the pavement gets rougher. This

reduction in speed can be converted into a time cost of delay due to roughness. This factor is not included in the current version of SAMP6. If these costs were included and the traffic on the road were moderate to heavy, it is expected that the results would show that there is an optimum serviceability index at which to overlay. The provision for computing delay costs due to roughness is not included in the current version of SAMP6. Therefore, the results of this sensitivity analysis indicate that the lower the serviceability index at overlay the lower is the overall total cost of the pavement. If the pavement riding quality is allowed to deteriorate to a serviceability index of 2.0, then the total cost of the pavement, as shown in Table D-28, will be 6.6% less than if the pavement had been overlaid at a serviceability index of 3.0.

TABLE D-28. DESIGN AND COST VARIATION WITH MINIMUM SERVICEABILITY INDEX (Florida, Section 17)

Minimum Serviceability Index	Optimum Thickness Design (inches)	Initial Life (years)	Total Cost/Per Square Yard	Percent Increase
2.0	1-8-20	24.2	$7.851	-
3.0	1-14-20	25.6	$8.371	+6.6

APPENDIX E
STATES' EVALUATIONS AND EXPECTED USE OF SAMP6

APPENDIX E

STATES' EVALUATIONS AND EXPECTED USE OF SAMP6

INTRODUCTION

The three pilot implementation states provided detailed evaluations of the SAMP6 subsystems, inputs, computer program, documentation, and related information. These evaluations were made with point ratings from 1 to 5 and the states also gave reasons for most of their ratings. This appendix summarizes these evaluations. Evaluations of the adequacy of data input and data feedback are given in Appendix F.

SAMP6 SUBSYSTEMS

The results of the states' evaluations of SAMP6 subsystems are summarized in Table E-1. The lowest average evaluations were given to the environmental and structural subsystems, and some of the other subsystems received fairly low ratings from one or two states.

Structural Subsystem

Since Louisiana personnel have extensive experience with the AASHO structural subsystem used in SAMP6 and plans to use it in the future, they gave it a high rating. Neither Kansas nor Florida is satisfied with the AASHO structural subsystem, however. Kansas personnel feel that they need better correlation for AASHO design parameters and would like to develop a new structural subsystem that utilizes the Kansas Design Method directly.

TABLE E-1

PILOT STATES' EVALUATION OF ADEQUACY OF SAMP6 SUBSYSTEMS

Type of Subsystem	Rating of Sufficiency for Design from Low(1) to High(5)			
	Florida	Kansas	Louisiana	Average
Structural	2	2	4	2.7
Environmental	2	2	1	1.7
User Costs-Traffic Delay	5	4	3	4
Maintenance Costs	5	4	3	4
Initial Unit Costs	5	1	5	3.7
Cross-Section Geometry	5	2	5	4
Traffic Prediction	3	4	5	4
Salvage Value	5	5	2	4
Average	4.0	3.0	3.5	3.5

One of the principal difficulties encountered in using the Kansas Design Method directly is that designs giving estimated initial lives other than ten years cannot be considered at present. Kansas has extensive data and experience with their triaxial testing procedures and it would be desirable to make better use of this information than can be done with the current SAMP6 structural subsystem. Although Florida plans to make interim use of

SAMP6 with the AASHO structural subsystem, they are not satisfied with it and want to change the entire structural subsystem to a layered systems approach. They are especially interested in predicting pavement cracking and rut depth. Overall, the structural subsystem received one of the lowest subsystem ratings since only one of the three states was satisfied with it.

Environmental Subsystem

The SAMP6 environmental subsystem was ranked low by all states and had the lowest average of any subsystem. None of the states has a significant problem with swelling clay and only Kansas has frost-heave deterioration. Florida's main environmental problem is with pavement cracking allowing water to penetrate to their limerock base materials. Therefore, they believe environmental effects should consider cracking and might best be considered in material characterization. Kansas needs better values for the regional factor and would like a provision in SAMP6 for applying swelling soil parameters to only the portion of the project that is affected. Although this can be accomplished in SAMP6 by dividing the project into several sections, it cannot be done within a specific SAMP6 problem.

Users Cost-Traffic Delay Subsystem

Kansas would like a provision within SAMP6 that would allow the introduction of a variable to reduce the effect of users cost. Florida noted that the user cost subsystem needs verification in Florida and user costs developed specifically for Florida.

Maintenance Cost Subsystem

Kansas and Louisiana believed that better information should be developed on maintenance costs, although the concern was more with the data inputs than with the structure of the subsystem.

Unit Cost Subsystem

Kansas gave a low rating to the unit cost-calculation methods in SAMP6. They noted that the program, as written, does not allow for variation of soil support or traffic within a project. Therefore, each project must be divided into sections each time the soil support or traffic changes and each section must be run as a separate problem. The variation of unit cost with thickness then becomes meaningless since each section will have a different thickness and therefore use different unit cost. The shoulder quantity will also increase the volume sufficiently to reduce the unit cost but this is not considered.

Cross-Section Geometry

Kansas cross-sections are not accurately represented by the current SAMP6 cross-section model. They would like to have different cross-section models using the pavement width and sideslope and shoulder width and sideslope. Such models also would be useful for some of Louisiana's cross-sections.

Traffic Prediction Subsystem

Both Kansas and Florida would like to have modifications in the traffic prediction subsystem of SAMP6. Kansas would like to be able to change the rate of traffic growth at given times within the analysis period, instead of assuming that traffic growth is linear. Florida would like to have restraints

in the program based on roadway geometry such that the traffic growth rate would decrease when the "E" level of service (congestion) is reached.

Salvage Value

Louisiana would like to have a different method of considering salvage value or better guidelines for determining the salvage value percentages in different situations.

SUBSYSTEM INPUTS

Another way of evaluating the adequacy of SAMP6 subsystems is by rating the comprehensiveness of inputs within different groups and subsystems. Such an evaluation was provided by the cooperating states and is given in Table E-2. These evaluations basically confirm the evaluations given in Table E-1. Louisiana would like to consider additional inputs in the environmental and maintenance cost subroutines. Kansas would like to have modifications in the method of calculating cross-section (including shoulder) volumes and also would like to have unit initial costs related to volumes instead of to layer thicknesses. Kansas noted that the cross-section geometry inputs were awkward for their cross-sections and should utilize side slopes. Kansas and Florida would like to have the ability to consider a seal on the shoulder that would not be on the roadway. Florida would like to have the ability to consider skid resistance, fatigue characteristics, and fundamental strength characteristics in the initial pavement, shoulders, and overlay materials.

Overall, the states believed that most of the important pavement design variables were included as inputs in SAMP6 and that the overall approach was a fairly realistic synthesis of the pavement design process--although, as the preceding discussion has indicated, they noted several limitations and desired additional changes in SAMP6.

TABLE E-2

PILOT STATES' EVALUATION OF EXTENT TO WHICH INPUTS WITHIN EACH GROUP OR SUBROUTINE ARE COMPREHENSIVE

Type of Input	Rating of Comprehensiveness of Inputs from Low(1) to High(5)			
	Florida	Kansas	Louisiana	Average
Program Control	5	4	5	4.7
Environmental	5	4	3	4
Serviceability	5	5	5	5
Traffic	5	5	5	5
Time and Thickness Constraints	5	5	5	5
Traffic Delay	5	5	5	5
Maintenance	5	4	3	4
Cross-Section Geometry	5	2	4	3.7
Cost Models	5	2	4	3.7
Bitumen Variables	5	5	4	4.7
Wearing Surface	5	3	4	4
Overlay	5	3	4	4
Pavement Materials	5	5	4	4.7
Shoulder Materials	5	1	4	3.3
Shoulder Geometry	5	2	4	3.7
Overall-Realistic Synthesis	5	4	3	4
Overall-Includes Main Variables	5	5	4	4.7

SAMP6 COMPUTER PROGRAM

The cooperating states had little difficulty with the SAMP6 computer program and rated it fairly high as is shown by the ratings in Table E-3. There were some problems with interim versions of the program associated with soil support values for layers other than the subgrade and with problems run with very low and very high traffic. It is believed that all of these difficulties have been resolved satisfactorily in the latest version of the program. The only computer program ratings of less than 5 were associated with data coding effort and keypunch effort, particularly with respect to the way data cards are punched. This resulted from confusion with the format statements: for example, Kansas noted that some inputs which will always be whole numbers are shown in the input formats as being read in on F10.2 format while others are read in on I10, F10.0, F10.5, etc. A statement has been added in the users manual to clarify this ambiguity. All cards which do not have alphanumeric description fields are either "real" variables or "integer" variables. The "real" variables begin with letters A-H or O-Z; even though the formats read F10.0, F10.2, etc. for these variables, they may be punched anywhere in the field so long as the decimal is punched. "Integer" variables (with first letter of I-N) must be right-justified in the field and no decimal is punched.

SAMP6 PROGRAM DOCUMENTATION

Evaluations of the SAMP6 program documentation that was provided to the states is summarized in Table E-4. The states indicated that additional documentation would facilitate their use of the program. Kansas specifically noted that they need additional explanations of variables and their expected

TABLE E-3

PILOT STATES' EVALUATION OF COMPUTER PROGRAM

Type of Evaluation	Rating from Low(1) to High(5)			
	Florida	Kansas	Louisiana	Average
Flexibility	5	5	5	5
Ease of Making Changes	-	5	5	5
Ease to Get Running	5	5	5	5
Data Coding Effort	5	4	4	4.3
Keypunch Effort	5	3	4	4

Note: Types of Computers are as follows: Florida - IBM 360/65
Kansas - IBM 370/155
Louisiana - IBM 370/145.

TABLE E-4

PILOT STATES' EVALUATION OF PROGRAM DOCUMENTATION

Type of Evaluation	Rating from Low(1) to High(5)			
	Florida	Kansas	Louisiana	Average
Comprehensiveness	5	4	5	4.7
Dictionary of Terms	5	4	5	4.7
Cross Reference Tables	5	5	4	4.7
Program Listing	5	4	4	4.3
Helpful to Programmer	5	3	4	4

values, documentation of formulas, subroutine identifications, and a program flow chart. A flow-charted program with subroutine identification has been added to the program documentation in response to their comments.

SAMP6 USERS MANUAL

Evaluations of the SAMP6 Users Manual are summarized in Table E-5. Kansas and Louisiana would like additional explanation of some inputs and of the output and would like additional figures in the manual.

SAMP6 OPTIMUM DESIGNS

The cooperating states were asked for evaluations of how well the optimum pavement design strategies given by SAMP6 matched with their usual practice and experience in comparable situations. These evaluations are summarized in Table E-6. The optimum thicknesses matched the states usual designs fairly well if they constrained such thicknesses within reasonable limits. Unrealistic designs were given by SAMP6 when a weak subbase, such as lime-treated soil, was not constrained to a reasonably thin depth (such as 6 to 12 inches, as opposed to, say, 24 to 30 inches). Examples of these unreasonable designs are plentiful in the sensitivity analyses, most of which were run without constraining the weak subbase layers. Florida noted that their design strategies were not confirmed because skid resistance concern dominates their current strategies and the wear characteristics and structural value of their skid mixes presently are unknown. Kansas noted that, "by adjusting the SAMP6 inputs, the results can be made to match our design but this can hardly be construed to mean that it confirms our strategy. Any desired results can be obtained by putting in the right inputs."

TABLE E-5

PILOT STATES' EVALUATION OF USERS MANUAL

Type of Evaluation	Rating from Low(1) to High(5)			
	Florida	Kansas	Louisiana	Average
Explanation of Inputs	5	4	3	4
Organization of Inputs	5	4	5	4.7
Ease of Use	5	4	5	4.7
Helpful Figures	5	4	2	3.7
Interpretation of Output	5	5	2	4

TABLE E-6

PILOT STATES' EVALUATION OF EXTENT TO WHICH OPTIMUM DESIGNS GIVEN BY COMPUTER PROGRAM MATCH WITH EXPERIENCE

Type of Results	Rating From Low (1) to High (5)			
	Florida	Kansas	Louisiana	Average
Optimum Thicknesses	4	4	4	4
Optimum Material Combinations	5	4	3	4
Weighting of Costs	4	3	4	3.7
Overlay Scheduling	4	4	2	3.3

The SAMP6 program gave optimum material combinations that differed from what Louisiana normally used. The source of this discrepancy was not immediately obvious. It might be due to material unit costs or material coefficients being inaccurately estimated or used within the SAMP6 program. Louisiana also noted that the overlay schedule given by SAMP6 optimum designs did not agree well with their present practice. Both Kansas and Florida use inflation adjustments in calculating the cost of future overlays and this presently is not considered in SAMP6; and thus, the weighting of costs does not agree with their normal practice. As noted previously, Kansas unit costs are not accurately estimated in SAMP6 since such costs are considered as a function of thickness and not of volume.

EXPECTED USE OF SAMP6

The cooperating states were asked to evaluate the probability of their using SAMP6 for different uses and these are given in Table E-7. The most probable immediate use of the program is for preliminary pavement design. Florida indicated that they would begin using the SAMP6 program for preliminary design and Louisiana indicated that this would be their probable use of the program. Florida also plans to use the SAMP6 program as a building block for a future design system by replacing the SAMP6 structural subsystem. Kansas indicated that they might use the SAMP6 program for preliminary and final design if the program could consider rigid as well as flexible pavement. Kansas also noted that, "since present policy does not favorably consider frequent overlays and no means exists for programming them, probable use of SAMP6 for the immediate future will be as a research tool."

TABLE E-7

PILOT STATES' EVALUATION OF PROBABILITY OF USING SAMP6 FOR THIS PURPOSE

Type of Use	Probability of Use (0% to 100%)		
	Florida	Kansas	Louisiana
Cost Estimating	80	20	0
Preliminary Design	100	20	60
Sensitivity Analysis	100	40	40
Final Design	40	20	20
Design Strategy Studies	80	20	20
Building Block for Future Design System	100	40	0

APPENDIX F
STATES' EVALUATIONS OF SAMP6 DATA INPUTS AND PAVEMENT FEEDBACK DATA SYSTEMS

APPENDIX F

STATES' EVALUATIONS OF SAMP6 DATA INPUTS AND PAVEMENT FEEDBACK DATA SYSTEMS

INTRODUCTION

The purpose of this appendix is to give the cooperating states' evaluations of SAMP6 data inputs and pavement feedback data systems. Each of the cooperating states rated the ease of obtaining input data for SAMP6 and rated the adequacy of their present data systems for developing inputs for SAMP6. Also, each states gave a subjective evaluation of the expected benefits of developing a more comprehensive pavement feedback data system.

EASE OF OBTAINING DATA

Table F-1 presents the states' evaluations of the ease of obtaining input data for the SAMP6 computer program. The lowest average rating was placed on the traffic delay inputs because the states do not collect such information on a systematic basis. Fortunately, the Federal Highway Administration has recently funded research on user cost subsystems for pavement design and better estimates of the inputs should be developed within a year or so. The environmental inputs also received low ratings including the lowest possible rating from Florida. This should not be a problem in Florida, however, because they do not plan to use the environmental roughness model since they have no swelling-clay or frost-heave problems. The overlay and wearing surface inputs also were difficult to obtain, especially the estimate of the AASHO strength coefficients for these layers.

TABLE F-1

PILOT STATES' EVALUATION OF EASE OF OBTAINING INPUT DATA

Type of Input	Rating of Ease of Obtaining Data from Low(1) to High(5)			
	Florida	Kansas	Louisiana	Average
Program Control	5	5	4	4.7
Environmental	1	3	3	2.3
Serviceability	1	5	4	3.3
Traffic	3	5	4	4
Time and Thickness Constraints	5	5	4	4.7
Traffic Delay	1	3	2	2
Maintenance	3	2	3	2.7
Cross-Section Geometry	5	3	5	4.3
Cost Models	5	3	3	3.7
Bitumen	5	5	3	4.3
Wearing Surface	3	3	3	3
Overlay	2	3	3	2.7
Pavement Materials	4	3	3	3.3
Shoulder Materials	4	5	4	4.3
Shoulder Geometry	5	3	3	3.7

Even though all of the states have information on pavement maintenance costs, it was difficult for them to estimate the cost for a specific pavement. Partially as a result of the difficulty of estimating the maintenance cost inputs for the maintenance cost model in SAMP5, another maintenance cost model was added to SAMP6 as an alternative. Kansas specifically mentioned that they had no way of making acceptable estimates of the regional factor and layer coefficients needed in the AASHO structural subsystem.

ADEQUACY OF DATA SYSTEMS

Each of the states evaluated the adequacy of their current data systems for obtaining inputs needed in the SAMP6 computer program. These ratings are presented in Table F-2. As might be expected, these ratings are somewhat similar to those in Table F-1. However, there is a difference in meaning since it might be fairly easy to obtain an input, but it might be considered quite inadequate if a state had little confidence in it. Two types of subsystem inputs that are not now in SAMP6 , but will probably be added to it in the future, also were evaluated -- skid number and pavement cracking. Each of these was rated low by most of the states. Overall, it can be concluded that none of the states considers its current data system to be completely adequate for developing inputs for SAMP6.

EXPECTED BENEFITS VERSUS COSTS FOR PAVEMENT FEEDBACK DATA SYSTEMS

Each of the states gave estimates of the expected benefit-to-cost ratio, from -5 to +5, of developing a pavement feedback data system

TABLE F-2

PILOT STATES' EVALUATION OF ADEQUACY OF CURRENT DATA SYSTEM FOR DERIVING PAVEMENT DESIGN INPUTS FOR EACH SUBSYSTEM

Type of Subsystem	Rating of Adequacy from Low (1) to High (5)			
	Florida	Kansas	Louisiana	Average
Structural	3	2	4	3
Environmental	--	2	2	2
Users Cost-Traffic Delay	3	2	2	2.3
Maintenance Costs	2	2	2	2
Materials	1	2	4	2.3
Unit Costs	5	4	4	4.3
Cross-Section Geometry	5	5	4	4.7
Traffic Prediction	3	4	4	3.7
Loads	3	3	4	3.3
Skid Number	3	2	4	3
Weather Data	5	5	4	4.7
Roughness	5	3	4	4
Cracking	5	3	1	3

covering different types of inputs. These estimates are given in Table F-3.

Both Florida and Kansas estimated that the benefits to them of developing pavement feedback data systems would considerably exceed the cost of such a system. Louisiana estimated that they would benefit from establishing a limited pavement feedback data system covering some subsystems. Both Florida and Kansas ranked the structural subsystem high because they are not satisfied with the current SAMP6 version. Louisiana, on the other hand, ranked it low because they plan to continue using the AASHO structural subsystem.

Florida estimated high benefit/cost ratios for all subsystems except environmental, which they do not plan to use or further develop, and cross-section geometry, which is standardized and thus needs no further development. They also ranked unit costs relatively low since they already have developed a comprehensive procedure for estimating unit costs. Kansas gave highest ratios for structural, environmental, materials, traffic prediction, and loads because they believe their principal design problems are associated with developing better estimates and inputs for these subsystems. For similar reasons, Louisiana gave high ratios for the environmental, users cost, maintenance costs, and cracking subsystems.

TABLE F-3

PILOT STATES' EVALUATION OF EXPECTED VALUE, IN TERMS OF SUBJECTIVE BENEFIT/COST RATIO, OF DEVELOPING A PAVEMENT FEEDBACK DATA SYSTEM COVERING DIFFERENT DESIGN SUBSYSTEMS

Type of Data by Subsystem	Expected Benefit/Cost Ratio Ranging from -5 to +5			
	Florida	Kansas	Louisiana	Average
Structural	5	5	0	3.3
Environmental	-	5	2	3.5
Users Cost-Traffic Delay	5	1	2	2.7
Maintenance Costs	5	4	2	3.7
Materials	4	5	0	3
Unit Costs	3	4	0	2.3
Cross-Section Geometry	0	3	0	1
Traffic Prediction	4	5	0	3
Loads	4	5	0	3
Skid Number	3	4	0	2.3
Weather Data	4	5	0	3
Roughness	5	2	0	2.3
Cracking	5	2	2	3

APPENDIX G
PAVEMENT FEEDBACK DATA SYSTEMS *

APPENDIX H
COMPUTER SOFTWARE FOR PAVEMENT FEEDBACK DATA SYSTEMS *

* See footnote on page 4 and Note on page 40.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Rep. No.	*Title*
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20
7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80
8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00
18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
28	Surveillance Methods and Ways and Means of Communicating with Drivers (Proj. 3-2), 66 p., $2.60
29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00
32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00
33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60
34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
35	Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $5.00
36	Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., $1.60
37	Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., $3.60
38	Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., $2.00
39	Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., $5.00
40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00
41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60
42	Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60
43	Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00
44	Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
46	Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60
47	Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40
48	Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
49	National Survey of Transportation Attitudes and Behavior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20

* Highway Research Board Special Report 80.

Rep. No. Title

50 Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20
51 Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00
52 Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $3.80
53 Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., $3.20
54 Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., $2.60
55 Research Needs in Highway Transportation (Proj. 20-2), 66 p., $2.80
56 Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $6.40
57 Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., $3.20
58 Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., $3.60
59 Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., $3.20
60 Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2) 148 p., $6.00
61 Evaluation of Studded Tires—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., $3.00
62 Urban Travel Patterns for Hospitals, Universities, Office Buildings, and Capitols (Proj. 7-1), 144 p., $5.60
63 Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., $4.00
64 Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., $3.60
65 One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., $1.40
66 Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., $2.80
67 Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., $2.20
68 Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., $2.00
69 Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., $2.80
70 Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., $3.00
71 Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., $2.80
72 Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., $2.20
73 Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5/1), 55 p., $2.80
74 Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., $2.80
74A Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., $8.00
74B Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., $4.00
75 Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $3.60

Rep. No. Title

76 Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2)), 37 p., $2.00
77 Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., $3.80
78 Highway Noise—Measurement, Simulation, and Mixed Reactions (Proj. 3-7), 78 p., $3.20
79 Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., $6.40
80 Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., $5.20
81 Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., $5.60
82 National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., $4.00
83 Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $2.80
84 Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., $2.40
85 Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., $1.80
86 Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., $3.20
87 Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., $2.00
88 Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., $2.00
89 Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., $3.20
90 Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., $4.00
91 Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research (Proj. 16-1), 70 p., $3.20
92 Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., $2.60
93 Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., $6.20
94 Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., $1.80
95 Highway Fog (Proj. 5-6), 48 p., $2.40
96 Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., $5.40
97 Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., $2.60
98 Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p. $5.00
99 Visual Requirements in Night Driving (Proj. 5-3), 38 p., $2.60
100 Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $3.40
101 Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., $3.60
102 Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., $5.40
103 Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $5.00
104 Rules of Compensability and Valuation Evidence for Highway Land Acquisition (Proj. 11-1), 77 p., $4.40

Rep. No. Title

105 Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $5.00
106 Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., $3.40
107 New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., $2.40
108 Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., $4.00
109 Elastomeric Bearing Research (Proj. 12-9), 53 p., $3.00
110 Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., $4.40
111 Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., $5.20
112 Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., $2.60
113 Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., $15.60
114 Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., $2.60
115 Guardrail Performance and Design (Proj. 15-1(2)), 70 p., $3.60
116 Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., $6.40
117 Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., $4.60
118 Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., $5.20
119 Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., $3.60
120 Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., $4.80
121 Protection of Highway Utility (Proj. 8-5), 115 p., $5.60
122 Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., $13.60
123 Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12), 239 p., $9.60
124 Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5), 86 p., $4.80
125 Optimization of Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5A), 86 p., $4.40
126 Divergencies in Right-of-Way Valuation (Proj. 11-4), 57 p., $3.00
127 Snow Removal and Ice Control Techniques at Interchanges (Proj. 6-10), 90 p., $5.20
128 Evaluation of AASHO Interim Guides for Design of Pavement Structures (Proj. 1-11), 111 p., $5.60
129 Guardrail Crash Test Evaluation—New Concepts and End Designs (Proj. 15-1(2)), 89 p., $4.80
130 Roadway Delineation Systems (Proj. 5-7), 349 p., $14.00
131 Performance Budgeting System for Highway Maintenance Management (Proj. 19-2(4)), 213 p., $8.40
132 Relationships Between Physiographic Units and Highway Design Factors (Proj. 1-3(1)), 161 p., $7.20

Rep. No. Title

133 Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (Proj. 7-8), 127 p., $5.60
134 Damages Due to Drainage, Runoff, Blasting, and Slides (Proj. 11-1(8)), 23 p., $2.80
135 Promising Replacements for Conventional Aggregates for Highway Use (Proj. 4-10), 53 p., $3.60
136 Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds (Proj. 15-4), 85 p., $4.60
137 Roadside Development—Evaluation of Research (Proj. 16-2), 78 p., $4.20
138 Instrumentation for Measurement of Moisture—Literature Review and Recommended Research (Proj. 21-1), 60 p., $4.00
139 Flexible Pavement Design and Management—Systems Formulation (Proj. 1-10), 64 p., $4.40
140 Flexible Pavement Design and Management—Materials Characterization (Proj. 1-10), 118 p., $5.60
141 Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways (Proj. 19-3), 184 p., $8.40
142 Valuation of Air Space (Proj. 11-5), 48 p., $4.00
143 Bus Use of Highways—State of the Art (Proj. 8-10), 406 p., $16.00
144 Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures (Proj. 3-7), 80 p., $4.40
145 Improving Traffic Operations and Safety at Exit Gore Areas (Proj. 3-17) 120 p., $6.00
146 Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis. (Proj. 8-9), 68 p., $4.00
147 Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments (Proj. 12-7), 85 p., $4.80
148 Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach (Proj. 20-7), 64 p., $4.00
149 Bridge Rail Design—Factors, Trends, and Guidelines (Proj. 12-8), 49 p., $4.00
150 Effect of Curb Geometry and Location on Vehicle Behavior (Proj. 20-7), 88 p., $4.80
151 Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques (Proj. 1-12(2)), 100 p., $6.00
152 Warrants for Highway Lighting (Proj. 5-8), 117 p., $6.40
153 Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances (Proj. 22-2), 19 p., $3.20
154 Determining Pavement Skid-Resistance Requirements at Intersections and Braking Sites (Proj. 1-12), 64 p., $4.40
155 Bus Use of Highways—Planning and Design Guidelines (Proj. 8-10), 161 p., $7.60
156 Transportation Decision-Making—A Guide to Social and Environmental Considerations (Proj. 8-8(3)), 135 p., $7.20
157 Crash Cushions of Waste Materials (Proj. 20-7), 73 p., $4.80
158 Selection of Safe Roadside Cross Sections (Proj. 20–7), 57 p., $4.40
159 Weaving Areas—Design and Analysis (Proj. 3-15), 119 p., $6.40

Rep. No. *Title*

160 Flexible Pavement Design and Management—Systems Approach Implementation (Proj. 1-10A), 53 p., $4.00

Synthesis of Highway Practice

No. *Title*

1 Traffic Control for Freeway Maintenance (Proj. 20-5, Topic 1), 47 p., $2.20

2 Bridge Approach Design and Construction Practices (Proj. 20-5, Topic 2), 30 p., $2.00

3 Traffic-Safe and Hydraulically Efficient Drainage Practice (Proj. 20-5, Topic 4), 38 p., $2.20

4 Concrete Bridge Deck Durability (Proj. 20-5, Topic 3), 28 p., $2.20

5 Scour at Bridge Waterways (Proj. 20-5, Topic 5), 37 p., $2.40

6 Principles of Project Scheduling and Monitoring (Proj. 20-5, Topic 6), 43 p., $2.40

7 Motorist Aid Systems (Proj. 20-5, Topic 3-01), 28 p., $2.40

8 Construction of Embankments (Proj. 20-5, Topic 9), 38 p., $2.40

No. *Title*

9 Pavement Rehabilitation—Materials and Techniques (Proj. 20-5, Topic 8), 41 p., $2.80

10 Recruiting, Training, and Retaining Maintenance and Equipment Personnel (Proj. 20-5, Topic 10), 35 p., $2.80

11 Development of Management Capability (Proj. 20-5, Topic 12), 50 p., $3.20

12 Telecommunications Systems for Highway Administration and Operations (Proj. 20-5, Topic 3-03), 29 p., $2.80

13 Radio Spectrum Frequency Management (Proj. 20-5, Topic 3-03), 32 p., $2.80

14 Skid Resistance (Proj. 20-5, Topic 7), 66 p., $4.00

15 Statewide Transportation Planning—Needs and Requirements (Proj. 20-5, Topic 3-02), 41 p., $3.60

16 Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 3-08), 23 p., $2.80

17 Pavement Traffic Marking—Materials and Application Affecting Serviceability (Proj. 20-5, Topic 3-05), 44 p., $3.60

18 Erosion Control on Highway Construction (Proj. 20-5, Topic 4-01), 52 p., $4.00

19 Design, Construction, and Maintenance of PCC Pavement Joints (Proj. 20-5, Topic 3-04), 40 p., $3.60

20 Rest Areas (Proj. 20-5, Topic 4-04), 38 p., $3.60

21 Highway Location Reference Methods (Proj. 20-5, Topic 4-06), 30 p., $3.20

22 Maintenance Management of Traffic Signal Equipment and Systems (Proj. 20-5, Topic 4-03) 41 p., $4.00

23 Getting Research Findings into Practice (Proj. 20-5, Topic 11) 24 p., $3.20

24 Minimizing Deicing Chemical Use (Proj. 20-5, Topic 4-02), 58 p., $4.00

25 Reconditioning High-Volume Freeways in Urban Areas (Proj. 20-5, Topic 5-01), 56 p., $4.00

26 Roadway Design in Seasonal Frost Areas (Proj. 20-5, Topic 3-07), 104 p., $6.00

27 PCC Pavements for Low-Volume Roads and City Streets (Proj. 20-5, Topic 5-06), 31 p., $3.60

28 Partial-Lane Pavement Widening (Proj. 20-5, Topic 5-05), 30 p., $3.20

29 Treatment of Soft Foundations for Highway Embankments (Proj. 20-5, Topic 4-09), 25 p., $3.20

30 Bituminous Emulsions for Highway Pavements (Proj. 20-5, Topic 6-10), 76 p., $4.80

31 Highway Tunnel Operations (Proj. 20-5, Topic 5-08), 29 p., $3.20

THE TRANSPORTATION RESEARCH BOARD is an agency of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 150 committees and task forces composed of more than 1,800 administrators, engineers, social scientists, and educators who serve without compensation. The program is supported by state transportation and highway departments, the U.S. Department of Transportation, and other organizations interested in the development of transportation.

The Transportation Research Board operates within the Commission on Sociotechnical Systems of the National Research Council. The Council was organized in 1916 at the request of President Woodrow Wilson as an agency of the National Academy of Sciences to enable the broad community of scientists and engineers to associate their efforts with those of the Academy membership. Members of the Council are appointed by the president of the Academy and are drawn from academic, industrial, and governmental organizations throughout the United States.

The National Academy of Sciences was established by a congressional act of incorporation signed by President Abraham Lincoln on March 3, 1863, 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. It is a private, honorary organization of more than 1,000 scientists elected on the basis of outstanding contributions to knowledge and is supported by private and public funds. Under the terms of its congressional charter, the Academy is called upon to act as an official—yet independent—advisor to the federal government in any matter of science and technology, although it is not a government agency and its activities are not limited to those on behalf of the government.

To share in the tasks of furthering science and engineering and of advising the federal government, the National Academy of Engineering was established on December 5, 1964, under the authority of the act of incorporation of the National Academy of Sciences. Its advisory activities are closely coordinated with those of the National Academy of Sciences, but it is independent and autonomous in its organization and election of members.

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 42970

000015M003
MATERIALS ENGR
IDAHO TRANS DEPT DIV OF HWYS
P O BOX 7129
BOISE ID 83707

DONE

SYSTEMS APPROACH TO PAVEMENT DESIGN

IMPLEMENTATION PHASE

APPENDICES B,C,G,H

Supplement to NCHRP REPORT 160, "Flexible Pavement Design and Management–Systems Approach Implementation"

Prepared for

Transportation Research Board

National Cooperative Highway Research Program

National Academy of Sciences

R. L. Lytton and W. F. McFarland
Texas Transportation Institute
College Station, Texas

SYSTEMS APPROACH TO PAVEMENT DESIGN

IMPLEMENTATION PHASE

APPENDICES B,C,G,H

Supplement to NCHRP REPORT 160, "Flexible Pavement Design and Management–Systems Approach Implementation"

Prepared for

Transportation Research Board

National Cooperative Highway Research Program

National Academy of Sciences

R. L. Lytton and W. F. McFarland
Texas Transportation Institute
College Station, Texas

PREFACE

NCHRP Report 160, "Flexible Pavement Design and Management--Systems Approach Implementation," describes an operational computer program (SAMP6) that provides a basis for selecting flexible pavement design and management strategies with the lowest predicted total cost over a prescribed analysis period when considering such cost elements as initial construction, routine maintenance, periodic rehabilitation, interest on investment, salvage value, and roadway user costs. The program uses the AASHTO Interim Guides as its structural subsystem and the predicted decrease in serviceability with time and traffic as developed at the AASHO Road Test. It has been pilot tested in three states and found to be implementable where suitable computer facilities and personnel are available. A certain amount of modification of the current system is likely to be needed to reflect the unique facets of an individual agency's approach to pavement design. The report will be of particular interest to administrators who must make policy decisions concerning use of the systems approach to pavement design and management; to pavement designers who will be involved in its implementation; and to materials, soils, maintenance, and traffic engineers who provide the input information for its operation.

Appendices B, C, G, and H of the agency report for NCHRP Project 1-10A were not published in Report 160 but are reproduced in this supplement for the use of persons directly involved in the operation of the SAMP6 program. Report 160 is available from the Transportation Research Board, Publications Office, 2101 Constitution Ave., N.W., Washington, DC 20418.

APPENDIX B

SAMP6 COMPUTER PROGRAM DOCUMENTATION

INTRODUCTION

THE SAMP6 COMPUTER PROGRAM IS THE SIXTH OF A SERIES CALLED A SYSTEMS ANALYSIS MODEL FOR PAVEMENTS.

THE SAMP SERIES IS BASED ON A PAVEMENT SYSTEMS ANALYSIS MODEL CONCEPT AND COMPUTER PROGRAM DEVELOPED BY F.H. SCRIVNER, G.R. CAREY, W.F. MCFARLAND, AND W.M. MOORE AS REPORTED IN TEXAS TRANSPORTATION INSTITUTE RESEARCH REPORT 32-11, 'A SYSTEMS APPROACH TO THE FLEXIBLE PAVEMENT DESIGN PROBLEM.'

IN COMPARISON WITH EARLIER VERSION, THE SAMP6 VERSION HAS EXTENSIVE REVISIONS TO PROVIDE A MODULAR PROGRAM TO ALLOW MODIFICATION FOR CUSTOMIZING TO THE NEEDS AND REQUIREMENTS OF A PARTICULAR USING ORGANIZATION. THE MODULES ARE DESIGNED TO ALLOW MODIFICATION OF PARTICULAR SUBPROGRAM MODULES FOR CUSTOM REQUIREMENTS WITH AN UNDERSTANDING OF POSSIBLE INTERACTIONS WITH OTHER PORTIONS OF THE PROGRAM. THE DOCUMENTATION ITEMIZES AND DEFINES THE THE VARIABLES WHICH INTERACT BETWEEN DIFFERENT MODULES OF THE PROGRAM.

THE PURPOSE OF THIS DOCUMENTATION IS TO AID THE SYSTEMS ANALYST OR PROGRAMER TO MAINTAIN OR MODIFY THE PROGRAM. INCLUDED WITHIN THIS PROGRAM DOCUMENTATION SECTION ARE ADDITIONAL AIDS TO ENABLE THE ANALYST TO MAINTAIN AN UPDATED DOCUMENTATION USING THE SAME MATERIALS AND PROCEDURES USED IN MAINTAINING THE SAMP COMPUTER PROGRAM. THE PRIMARY AID FOR A CONTINUING DOCUMENTATION IS THE 'TEXLIS' COMPUTER PROGRAM USED TO PRODUCE AN EDITED LISTING OF A DOCUMENTATION DECK.

THE SAMP6 COMPUTER PROGRAM AND THIS DOCUMENTATION ARE AVAILABLE ON TAPE AS 80 CHARACTER CARD IMAGES FROM THE ADDRESSES BELOW. EACH USING ORGANIZATION MAY MAINTAIN AN INDEPENDENT DOCUMENTATION UTILIZING THE 'TEXLIS' PROGRAM FOR FUTURE CHANGES.

SAMP6 COMPUTER PROGRAM AND DOCUMENTATION AVAILABLE FROM . . .

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
HIGHWAY RESEARCH BOARD
2101 CONSTITUTION AVENUE NW
WASHINGTON, D.C. 20418

OR

PAVEMENT DESIGN DEPARTMENT
TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS 77843

DEFINITION OF TERMS

A BRIEF DEFINITION OF THE FOLLOWING TERMS IS GIVEN BELOW TO AID IN UNDERSTANDING THIS DOCUMENTATION AND THE OUTPUT OF SAMP6.

1. PROBLEM
   A PROBLEM IS DEFINED BY ONE SET OF DATA AS INPUT FOR THE SAMP6 COMPUTER PROGRAM AND ON OUTPUT BY PAGES WITH THE SAME HEADING. A COMPUTER RUN MAY CONSIST OF ONE OR MORE PROBLEMS.

2. DESIGN TYPE
   WITHIN A PROBLEM, A UNIQUE SET OF INITIAL DESIGN MATERIALS IS A DESIGN TYPE. EACH DESIGN TYPE PRODUCES AN OPTIMUM DESIGN ON OUTPUT OR A STATEMENT THAT NO DESIGN WAS POSSIBLE FOR THAT DESIGN TYPE.

3. INITIAL DESIGN
   WITHIN EACH DESIGN TYPE, EACH COMBINATION OF DIFFERENT LAYER THICKNESS POSSIBLE WITH THE GIVEN LIMITS ON THICKNESSES AND INCREMENTS MAKES AN INITIAL DESIGN. IF THE INITIAL DESIGN MEETS ALSO CONSTRAINTS OF COST AND TOTAL INITIAL DESIGN THICKNESS, IT IS A FEASIBLE INITIAL DESIGN.

4. FEASIBLE
   THE WORD FEASIBLE USUALLY SHOULD BE COMBINED WITH A MODIFIER SUCH AS 'FEASIBLE INITIAL DESIGN', 'FEASIBLE OVERLAY', OR 'FEASIBLE OVERLAY POLICY'. IF A DESIGN OR POLICY IS FEASIBLE, IT HAS MET ONE OR MORE CONSTRAINTS. IT MAY BE REJECTED IF WHEN COMPARED TO OTHER FEASIBLE DESIGNS IT IS OF HIGHER COST.

5. BEST OVERLAY POLICY
   FOR A GIVEN INITIAL DESIGN, THE OPTIMUM OVERLAY POLICY OBTAINED BY COMPARING COSTS BETWEEN ALL FEASIBLE OVERLAYS IS KNOWN AS THE BEST OVERLAY POLICY WITH A PARTICULAR INITIAL DESIGN.

EXTERNAL CROSS-REFERENCE TABLES

THE FOLLOWING TWO CROSS-REFERENCE TABLES ARE DESIGNED TO AID THE PROGRAMER OR ANALYST TO ALTER ONE PORTION OF THE PROGRAM WITHOUT CAUSING UNKNOWN OR DISASTROUS EFFECTS ON OTHER PORTIONS OF THE PROGRAM.

1. SUBPROGRAM AND MAIN CROSS-REFERENCE TABLE.

EACH SUBROUTINE AND FUNCTION CALL IS LISTED DOWN THE LEFT WITH AN 'X' UNDER THE COLUMN FOR THE MAIN OR SUBPROGRAM WHICH REFERENCES THAT SUBPROGRAM WHICH WAS CALLED.

IN ADDITION TO THE SUBROUTINES AND FUNCTIONS INCLUDED WITH THE PROGRAM, OTHER STANDARD FORTRAN FUNCTIONS USED ARE LISTED WITH THE EXTERNAL REFERENCES. OTHER STANDARD FORTRAN FUNCTIONS ARE REFERENCED, BUT ARE COMPILED 'IN-LINE' SUCH AS AMAX1, AMIN1, MAX0, MAX1, AND FLOAT.

THE FORTRAN LANGUAGE ALSO IMPLIES CERTAIN FUNCTION CALLS AND THEIR NAMES MAY DIFFER DEPENDING ON THE COMPUTER SYSTEM. THE NAMES SHOWN ARE THOSE BY THE IBM OS/360 SYSTEM. IBCOM IS THE IBM FORTRAN INPUT-OUTPUT SUBPROGRAM. FRXPR IS AN IMPLICIT FUNCTION CALLED FOR FLOATING POINT EXPONENT CALCULATIONS.

2. COMMON VARIABLES CROSS-REFERENCE TABLE.

THIS TABLE LISTS EACH OF THE VARIABLES IN COMMON AND IDENTIFIES THE PROGRAM OR PROGRAMS WHICH USE THOSE VARIABLES AND WHETHER THEY ARE JUST REFERENCED (FETCHED) AND/OR IF THE PROGRAM STORES A NEW VALUE. SUBROUTINE CALLING ARGUMENTS WHICH ARE ALSO IN COMMON ARE IDENTIFIED.

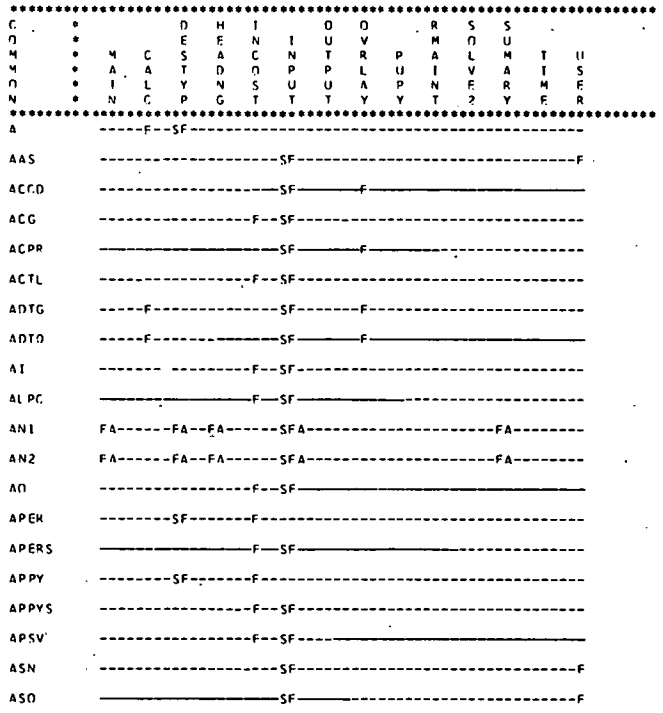
SUBPROGRAM AND MAIN CROSS-REFERENCE TABLE

BELOW IS A TABLE SHOWING THE EXTERNAL REFERENCES OF EACH OF THE PROGRAMS.

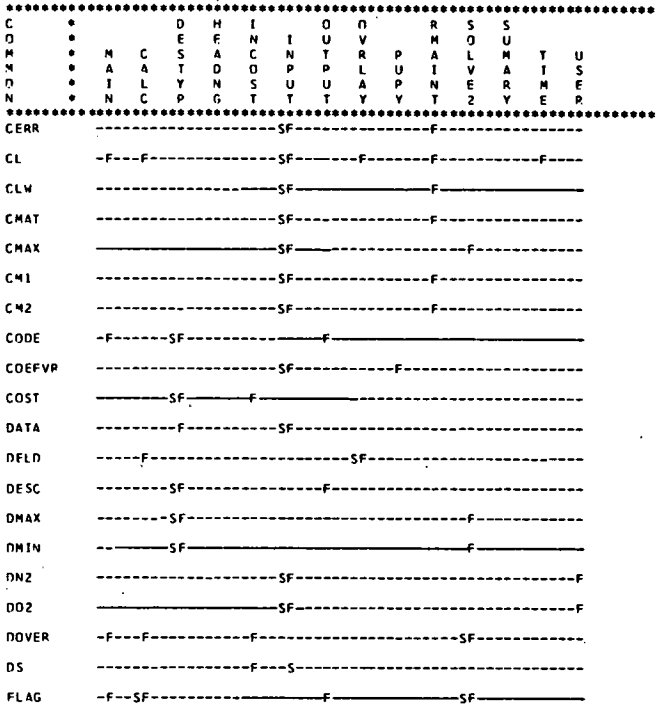
CALLED \ CALLING PROGRAM NAME	DESTYP	HEADNG	INCOST	INPUT	OUTPUT	OVRLAY	PUPY	RMAINT	SOLVE2	SUMARY	TIME	USER
CALC							X					
DESTYP				X								
HEADNG							X			X		
INCOST												
INPUT				X						X		
OUTPUT				X								
OVRLAY				X								
PUPY												
RMAINT												
SOLVE2				X								
SUMARY				X								
TIME												
USER												
/ / / / / / / / EXPLICIT FORTRAN AND LIBRARY REFERENCE / / / / / / /												
ALOG		X										
ALOG10												
EXP		X										
SQRT												
/ / / / / / / / / / IBM IMPLIED FORTRAN LIBRARY REFFRENCES / / / / / /												
FRXPR		X		X						X		
IBCOM		X		X						X		

COMMON VARIABLES CROSS-REFERENCE TABLE

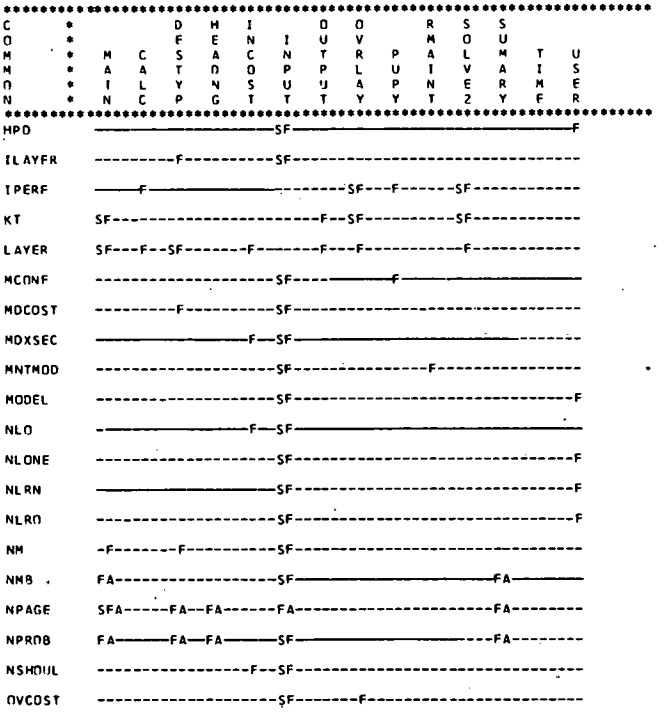
F = FETCH FOR COMPUTATION OR PRINTING
S = STORE A NEW VALUE IN CORE
A = CALLING ARGUMENT USED IN A SUBROUTINE OR FUNCTION



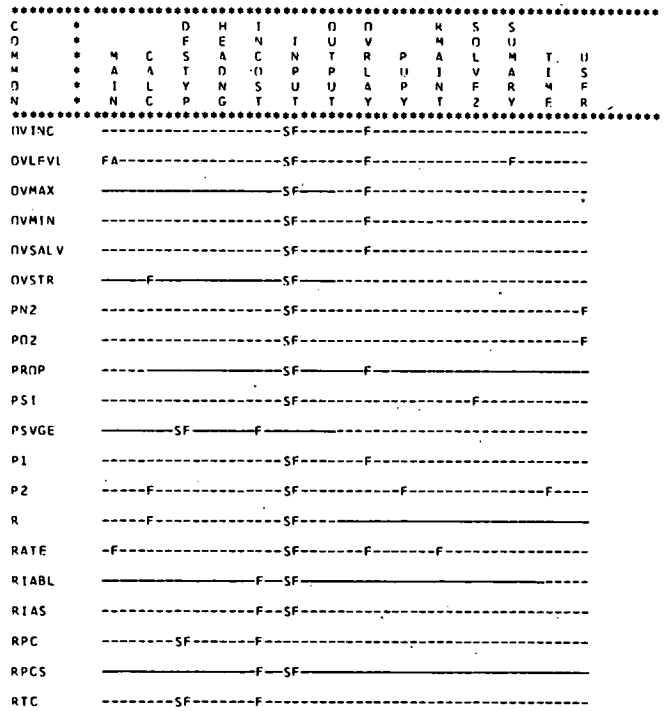
COMMON VARIABLES CROSS-REFERENCE TABLE (CONTINUED)



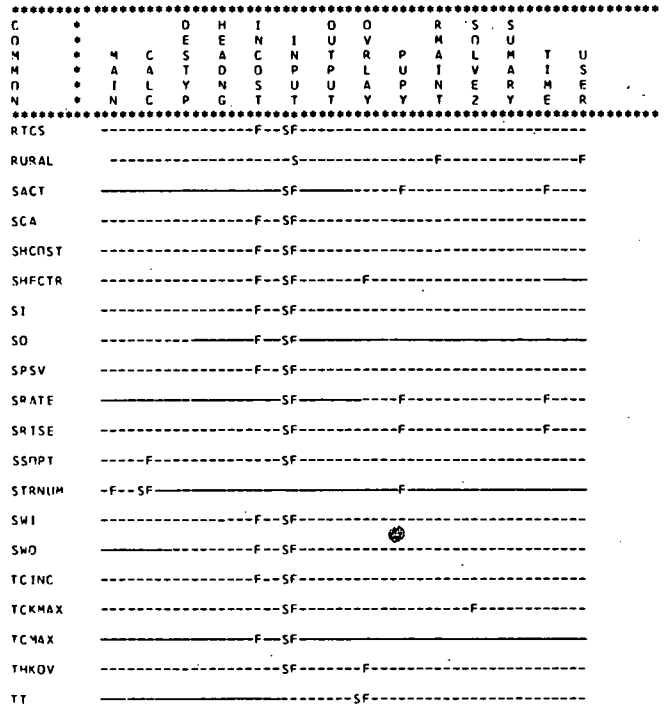
REFERENCES TO COMMON CONT'D.



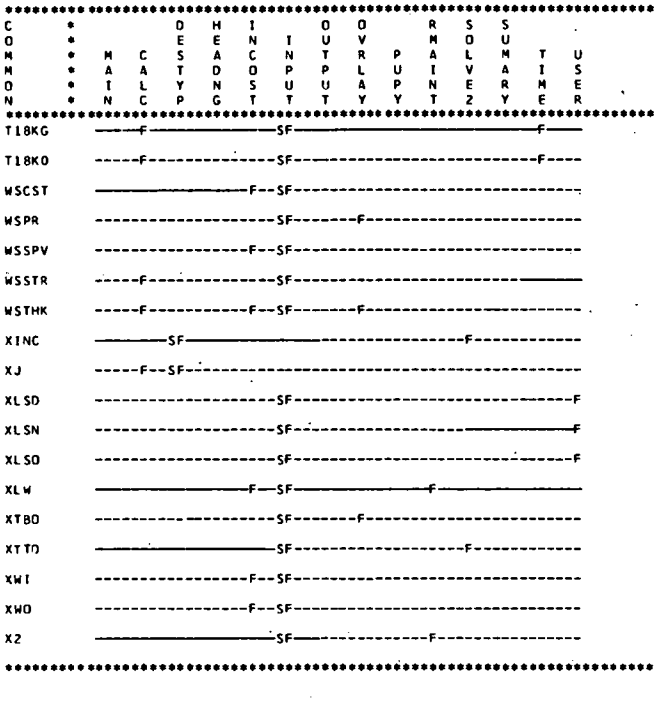
REFERENCES TO COMMON CONT'D.



REFERENCES TO COMMON CONT'D.



REFERENCES TO COMMON CONT'D.



NAME DICTIONARY

THE NAME DICTIONARY DOCUMENTS WITH A DESCRIPTION AND THE UNITS OF MEASURE THE INPUT VARIABLES, VARIABLES IN COMMON, AND VARIBLES PASSED AS SUBROUTINE AND FUNCTION ARGUMENTS. DOCUMENTATION OF IMPORTANT VARIABLES LOCAL WITHIN A GIVEN SUBPROGRAM MAY BE DOCUMENTED WITH COMMENT CARDS WITHIN THAT PROGRAM. IT MAY BE NOTED THAT ESSENTIALLY ALL THE VARIBLES PASSED BETWEEN PROGRAMS ARE IN YARDS, SQUARE YARDS, OR CUBIC YARDS, WITH THE EXCEPTION OF DETOUR AND OVERLAY OPERATIONS WHICH ARE IN MILES. INPUT VARIABLES ARE IN UNITS WHICH ARE DESIGNED TO BE CONVENIENT FOR THE USER.

****

A A VECTOR OF STRENGTH COEFFICIENTS FOR EACH MATERIAL IN A DESIGN.

AAS THE AVERAGE APPROACH SPEED TO THE OVERLAY AREA, ASSUMED TO BE THE SAME IN BOTH DIRECTIONS (MILES PER HOUR).

ACCD ASPHALTIC CONCRETE COMPACTED DENSITY (TONS PER COMPACTED CUBIC YARD).

ACG BITUMINOUS MATERIAL COST ($/GALLON).

ACPR ASPHALTIC CONCRETE PRODUCTION RATE(TONS PER HOUR).

ACTL TACK COAT COST ($/GALLON).

ADDWID ADDITIONAL WIDTH, OUTSIDE AND INSIDE, PAVEMENT LAYERS AND SHOULDER LAYERS RESPECTIVELY. ADDITIONAL WIDTH IS RELATIVE TO LAYER ONE.

ADT AVERAGE DAILY TRAFFIC AT A GIVEN POINT IN TIME.

ADTG AVERAGE DAILY TRAFFIC GROWTH RATE, THE INCREASE IN ANNUAL AVERAGE DAILY TRAFFIC PER YEAR.

ADTO AVERAGE DAILY TRAFFIC VOLUME AT THE BEGINNING OF THE ANALYSIS PERIOD (VEHICLES/DAY,ONE WAY).

AI THE INSIDE WIDTH OF A LAYER, RELATIVE TO LAYER ONE (YARDS).

ALPC PRIME COAT COST ($/GALLON).

AMINCT THE TOTAL COST OF THE CURRENT OVERLAY POLICY FOR A DESIGN ($/SQ.YD.).

AN1 AN ARRAY(20 WORDS) OF ALPHANUMERIC CHARACTERS ASSOCIATED WITH THE PAVEMENT SYSTEM,USED FOR PAGE HEADINGS.

AN2 AN ARRAY(19 WORDS) OF ALPHANUMERIC CHARACTERS ASSOCIATED WITH THE PAVEMENT SYSTEM, USED FOR PAGE HEADINGS.

NAME DICTIONARY (CONTINUED)

AO OUTSIDE WIDTH OF A LAYER RELATIVE TO LAYER ONE(YARDS).

APER ASPHALTIC CONTENT OF PAVEMENT LAYER(PROPORTION).

APCT SALVAGE VALUE OF OTHER FILL MATERIAL(PERCENT).

APERS ASPHALT CONTENT OF SHOULDER LAYER (PROPORTION).

APPY POUNDS OF BITUMINOUS MATERIAL PER CU. YD. FOR A PAVEMENT LAYER.

APPYS POUNDS OF BITUMINOUS MATERIAL PER CUBIC YARD FOR A SHOULDER LAYER.

ASN THE AVERAGE SPEED THROUGH THE OVERLAY AREA, IN THE NON-OVERLAY DIRECTION (MILES PER HOUR).

ASO THE AVERAGE SPEED THROUGH THE OVERLAY AREA,IN THE OVERLAY DIRECTION (MILES PER HOUR).

BALL AN ARRAY CONTAINING THE OPTIMAL DESIGN.

BBPOCC OVERLAY COST FOR THE LEAST COSTLY(OVERALL) DESIGN FOR A PARTICULAR SET OF MATERIALS ($/SQ.YD.).

BBPRM ROUTINE MAINTENANCE COST FOR THE LEAST COSTLY (OVERALL) DESIGN FOR A PARTICULAR SET OF MATERIALS ($/SQ.YD.).

BBPTUC USER COST FOR THE LEAST COSTLY (OVERALL) DESIGN FOR A PARTICULAR SET OF MATERIALS

BBSAL OVERLAY SALVAGE VALUE FOR THE LEAST COSTLY (OVERALL) DESIGN FOR A PARTICULAR SET OF MATERIALS ($).

BBTT AN ARRAY OF OVERLAY SCHEDULES IN SUBROUTINE OUTPUT (YEARS).

BCOST THE TOTAL COST OF THE BEST DESIGN FOR THE SET OF MATERIALS UNDER CONSIDERATION. IF AMINCT IS LESS THAN BCOST THIS BEST IS REPLACED BY THE CURRENT DESIGN UNDER CONSIDERATION.

BDEXT AN ARRAY OF OVERLAY THICKNESSES FOR THE BEST OVERLAY POLICY (YARDS).

BICC INITIAL COST FOR THE LEAST COSTLY (OVERALL) DESIGN FOR A PARTICULAR SET OF MATERIALS ($/SQ.YD.).

BPOCCT THE OVERLAY COST FOR A PARTICULAR DESIGN ($/SQ.YD.).

BPRM THE PRESENT WORTH VALUE OF THE ROUTINE MAINTENANCE FOR THE BEST OVERLAY POLICY (PRESENT VALUE DOLLARS PER SQUARE YARD).

RPTUC THE PRESENT WORTH VALUE OF TOTAL USER-COSTS FOR THE BEST OVERLAY POLICY. (PRESENT WORTH DOLLARS PER SQUARE YARD).

BSAL THE PRESENT WORTH OF THE SALVAGE VALUE TO BE SUBTRACTED FROM OTHER COSTS FOR THE BEST OVERLAY POLICY OF A DESIGN.

BTT AN ARRAY OF PERFORMANCE TIME PERIODS (SET EQUAL CORRESPONDING TT ITEM) FOR THE BEST OVERLAY POLICY (YEARS).

CERR THE COMPOSITE EQUIPMENT RENTAL RATE.

CL THE LENGTH OF THE ANALYSIS PERIOD IN YEARS.

CLW THE COMPOSITE LABOR WAGE.

CMAT THE RELATIVE MATERIAL COST BASED ON A VALUE OF 1.00 FOR A ROAD OF THE INTERSTATE TYPE.

CMAX MAXIMUM FUNDS AVAILABLE FOR INITIAL CONSTRUCTION.

CM1 INITIAL ANNUAL ROUTINE MAINTENANCE COST($/LANE MILE,MNTMOD=1)

CM2 ANNUAL INCREMENTAL INCREASE IN ROUTINE MAINTENANCE COSTS ($/LANE MILE/YEAR,MNTMOD=1)

CODE AN ALPHANUMERIC CODE LETTER TO IDENTIFY A PAVEMENT MATERIAL MATERIAL AND IS ASSOCIATED WITH 'DESC' FOR THAT LAYER.

COEFVR COEFFICIENT OF VARIATION.

COST THE COST VECTOR FOR CALCULATION OF DOLLARS PER SQUARE YARD GIVEN THE YARDS OF THICKNESS FOR EACH LAYER.

COSTIN COST OF THE INITIAL DESIGN ($).

CT TOTAL COST OF INITIAL CONSTRUCTION ($).

DATA AN ARRAY WITH A ROW(1ST SUBSCRIPT) FOR EACH MATERIAL. SEE ALSO ILAYER.
DATA(,1) A CODE LETTER IDENTIFYING THE MATERIAL.
DATA(,2 3 4 5) NAME OF THE MATERIAL (16 CHARACTER ALPH).
DATA(,6) THE STRENGTH COEFFICIENT.
DATA(,7) SOIL SUPPORT VALUE.
DATA(,8) MINIMUM LAYER THICKNESS.
DATA(,9) AT MIN., IN-PLACE COST/COMPACTED CU. YD.
DATA(,10) MAXIMUM LAYER THICKNESS.
DATA(,11) AT MAX THICKNESS,IN PLACE COST/CU. YD.
DATA(,12) SALVAGE VALUE PERCENTAGE OF THE MATERIAL.
DATA(,13) MINIMUM LAYER INCREMENT IN INCHES.
DATA(,14) THE TACK COAT APPLICATION RATE (GAL/SQ YD).
DATA(,15)THE PRIME COAT APPLICATION RATE (GAL/SQ YD).
DATA(,16) ASPHALTIC CONCRETE DENSITY(LB./IN/./SQ.YD.).
DATA(,17) THE ASPHALT CONTENT (PER CENT).

DELD THE OVERLAY THICKNESS IN YARDS.

DESC NAME OF THE MATERIAL.

DMAX AN ARRAY, ONE MAXIMUM LAYER THICKNESS PER LAYER, FOR THE CURRENT DESIGN (YARDS).

DMIN AN ARRAY, ONE MINIMUM LAYER THICKNESS PER LAYER, FOR THE CURRENT DESIGN (YARDS).

DN2 AVERAGE DELAY PER VEHICLE STOPPED IN THE NON-OVERLAY DIRECTION DUE TO THE OVERLAY CONSTRUCTION (HOURS).

DOVER AN ARRAY OF CALAULATED LAYER THICKNESSES FOR A DESIGN.

DO2 AVERAGE DELAY PER VEHICLE STOPPED IN THE OVERLAY DIRECTION DUE TO OVERLAY CONSTRUCTION (HOURS)

DS DEPTH OF A SHOULDER LAYER (YARDS).

FLAG USED AS AN INDICATOR OF POTENTIAL INTERFACE PROBLEMS. SUBROUTINE CALC SUBROUTINE 'CALC' WILL PLACE AN '*' IN FLAG,PRINTED IN INPUT AND SUMARY.

HPD THE NUMBER OF HOURS PER DAY THAT OVERLAY CONSTRUCTION TAKES PLACE.THE PRODUCT OF PROP*HPD SHOULD NOT BE GREATER THAN 1.00 IF THE STRIP IS UNDER CONSTRUCTION FOR 24 HOURS EACH DAY, THEN (PROP * HPD) IS EQUAL ONE.

IBBT THE OPTIMAL NUMBER OF PERFORMANCE PERIODS.

ILAYER AN ARRAY, ASSOCIATED WITH A MATERIAL PROPERTY IN THE DATA ARRAY, WHICH IS THE LAYER NUMBER IN WHICH THE MATERIAL MAY BE USED. (LAYER 1 IS THE TOP LAYER)

INDEX AN ARRAY USED FOR LAYER INDEXING AND POINTS TO THE MATERIAL IN THE DATA ARRAY FOR EACH LAYER USED IN A DESIGN.

IPERF THE PERFORMANCE PERIOD NUMBER.

ITYPE A CODE FOR THE TYPE OF ROAD UNDER CONSIDERATION
ITYPE = 1 DESIGNATES A RURAL ROAD
ITYPE = 2 DESIGNATES AN URBAN ROAD.

KDESGN A COUNTER OF THE NUMBER OF COMPLETE DESIGNS WITHIN A DESIGN TYPE.

KNTOL IS A COUNTER THAT KEEPS TRACK OF THE TOTAL NUMBER OF FEASIBLE DESIGNS INCLUDED IN ALL COMBINATIONS OF MATERIALS.

KSKIP A VECTOR SET NONZERO TO INDICATE CONSTRAINTS WHICH PREVENT A DESIGN.

KT A COUNTER VECTOR PRINTED IN OUTPUT.

LAST THIS FLAG IS SET NONZERO IN INPUT TO INDICATE THE LAST DATA THAT HAVE BEEN USED.

LAYER A COUNTER USED FOR THE NUMBER OF LAYERS (EXCLUDING SUBGRADE) FOR EACH DESIGN.

MASPHS THE MODEL FOR ASPHALTIC SHOULDERS(1 FOR ASPHALTIC SHOULDERS, 0 OTHERWISE)

MCONF CONFIDENCE LEVEL INDICATOR.

MDCOST THE MODEL USED TO CALCULATE CROSS SECTION COSTS.

MDXSEC THE MODEL USED TO CALCULATE CROSS SECTION AREAS.

MODEL THE MODEL NUMBER WHICH DESCRIBES THE TRAFFIC SITUATION.

MNTMOD THE MAINTENANCE MODEL.

NDP THE NUMBER OF DESIGNS PER PAGE.

NL NUMBER OF LANES ON THE HIGHWAY IN BOTH DIRECTIONS.

NLO THE NUMBER OF TRAFFIC LANES PER PAIR OF SHOULDERS, FOR EXAMPLE, A FOUR-LANE HIGHWAY WITH A MEDIAN, NLO=2, BUT WITHOUT A MEDIAN, NLO=4.

NLONE THE ONE DIRECTION NUMBER OF TRAFFIC LANES.

NLRN THE NUMBER OF LANES LEFT OPEN TO TRAFFIC IN THE RESTRICTED ZONE IN THE NON-OVERLAY DIRECTION.

NLRO THE NUMBER OF LANES LEFT OPEN TO TRAFFIC IN THE RESTRICTED ZONE IN THE OVERLAY DIRECTION.

NM THE TOTAL NUMBER OF MATERIALS AVAILABLE, EXCLUDING SUBGRADE.

NMB THE NUMBER OF OUTPUT PAGES FOR THE PROBLEM SUMMARY TABLE (10 DESIGNS / PAGE).

NMDGNT THE MAXIMUM NUMBER OF DESIGNS.

NPAGE PAGE NUMBER USED FOR THE HEADING.

NPG NUMBER OF OUTPUT PAGES FOR THE SUMMARY TABLE(10 DESIGNS/PAGE), THE MAXIMUM 'NPG' IS THREE.

NPROB AN ALPHANUMERIC LITERAL ASSOCIATED WITH THE PROBLEM, USED FOR PAGE HEADINGS.

NSHOUL THE NUMBER OF SHOULDER LAYERS EXCLUDING FILL MATERIALS.

NUMBER A COUNTER OF THE NUMBER OF FEASIBLE INITIAL DESIGNS.

OAPP ASPHALTIC CONCRETE DENSITY (LB/SQ.YD. PER INCH THICKNESS).

OMAXIN MAXIMUM THICKNESS OF EACH OVERLAY (INCHES).

OMININ MINIMUM THICKNESS OF EACH OVERLAY (INCHES).

OPC PRIME COAT APPLICATION RATE (GALLON/SQ. YD.).

OPCT ASPHALTIC CONTENT (PERCENT).

OTC TACK COAT APPLICATION RATE (GALLONS/SQ.YD).

OVCOST A VECTOR OF CONSTANTS IN THE OVERLAY COST EQUATION.

OVDESC OVERLAY MATERIAL DESCRIPTION.

OVINC THE OVERLAY INCREMENT DEPTH (YARDS).

OVINCI INCREMENT IN OVERLAY THICKNESS (INCHES).

OVLEVL THE AMOUNT OF OVERLAY LEVEL-UP (YARDS).

OVMAX THE ACCUMULATED MAXIMUM THICKNESSES OF ALL OVERLAYS.

OVMAXC IN PLACE COST OF OVERLAY AT MAXIMUM THICKNESS ($/CU.YD).

OVMIN THE MINIMUM THICKNESS OF AN INDIVIDUAL OVERLAY(YARDS).

OVMINC IN PLACE COST OF OVERLAY AT MINIMUM THICKNESS ($/CU.YD.).

OVSALV THE PROPORTION OF THE OVERLAY COST WHICH HAS A SALVAGE VALUE (LESS THAN OR EQUAL ONE).

OVSTR OVERLAY STRENGTH COEFFICIENT

PCTRAT ANNUAL INTEREST RATE OR TIME VALUE OF MONEY (PERCENT).

PERFB A CONSTANT USED IN THE PERFORMANCE EQUATION.

PN2 THE PROPORTION OF VEHICLES THAT WILL BE STOPPED IN THE NON-OVERLAY DIRECTION BECAUSE OF PERSONNEL OR EQUIPMENT.

POLICY-AN ARRAY OF INFORMATION ON THE BEST DESIGNS SELECTED. THE POLICY ARRAY IS FILLED IN 'OUTPUT'. ONE COLUMN IS FILLED FOR EACH NEW DESIGN STORED IN THE POLICY ARRAY. THE ROWS OF THE POLICY ARRAY ARE AS GIVEN BELOW.

POLICY(2,)	THE INITIAL CONSTRUCTION COST.
POLICY(3,)	THE OVERLAY CONSTRUCTION COST.
POLICY(4,)	THE USER COST.
POLICY(5,)	THE STRUCTURAL NUMBER.
POLICY(6,)	THE ROUTINE MAINTENANCE COST.
POLICY(7,)	THE SALVAGE VALUE.
POLICY(8,)	THE TOTAL COST.
POLICY(9,)	THE NUMBER OF LAYERS.
POLICY(L+9,)	DEPTH OF EACH LAYER.
POLICY(20,)	THE NUMBER OF PERFORMANCE PERIODS.
POLICY(I+20,)	LENGTH OF EACH PERFORMANCE PERIOD (YEARS).
POLICY(I+30,)	THE THICKNESS OF EACH OVERLAY (YARDS).
POLICY(L+40,)	FLAG SET TO * FOR A CRITICAL LAYER INTERFACE.
POLICY(L+49,)	CODE LETTER FOR EACH LAYER.

PONE VALUE OF THE SERVICEABILITY INDEX AT THE BEGINNING OF A PERFORMANCE PERIOD, SET EQUAL TO P1 OR PSI.

PO2 THE PROPORTION OF VEHICLES STOPPED IN THE OVERLAY DIRECTION DUE TO OVERLAY CONSTRUCTION.

PPN2 THE PERCENT OF VEHICLES THAT WILL BE STOPPED IN THE NON-OVERLAY DIRECTION DUE TO OVERLAY CONSTRUCTION.

PPO2 THE PERCENT OF VEHICLES THAT WILL BE STOPPED IN THE OVERLAY DIRECTION DUE TO OVERLAY CONSTRUCTION ACTIVITIES.

PROP THE PROPORTION OF THE AVERAGE DAILY TRAFFIC PASSING THROUGH THE OVERLAY ZONE EACH HOUR.

PROPCT PERCENT OF 'ADT' PASSING THROUGH OVERLAY ZONE EACH HOUR.

PSI THE SERVICEABILITY INDEX OF THE INITIAL STRUCTURE.

PSVGE THE PROPORTION OF THE ORIGINAL COST WHICH CAN BE DEDUCTED FOR SALVAGE VALUE (MAGNITUDE LESS THAN ONE, BUT MAY BE POSITIVE, NEGATIVE, OR ZERO.

P1 THE BEGINNING SERVICEABILITY INDEX OF THE PAVEMENT AFTER AN OVERLAY.

P2 THE MINIMUM ALLOWED VALUE OF THE SERVICEABILITY INDEX (POINT AT WHICH AN OVERLAY MUST BE APPLIED).

R THE REGIONAL FACTOR.

RATE THE INTEREST RATE OR TIME VALUE OF MONEY (PERCENT/100.0).

RC THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE END OF THE ANALYSIS PERIOD.

RIABL FILL ADJUSTMENT VOLUME(CU YDS).

RIAS SHOULDER LAYER ADJUSTMENT VOLUME (CU YDS).

RPC THE RATE OF APPLICATION OF THE PRIME COAT (GALLON/SQ YD)

RPCS THE RATE OF APPLICATION OF THE PRIME COAT FOR THE SHOULDER (GALLON / SQ YD)

RTC RATE OF APPLICATION OF TACK COAT (GALLON / SQ YD)

RTCS RATE OF APPLICATION OF TACK COAT FOR THE SHOULDER (GALLON/SQ YD)

RURAL A LOGICAL TYPE VARIABLE,SET.TRUE.IF (ITYPE=1), OTHERWISE .FALSE.

RO THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE BEGINNING OF THE ANALYSIS PERIOD.

SACT THE PROPORTION OF THE PROJECT'S LENGTH WHICH IS LIKELY TO EXPERIENCE SWELL.

SALVIN SALVAGE VALUE OF INITIAL DESIGN ($/SQ YD).

SCA IN PLACE COST / CU YD OF OTHER FILL MATERIALS

SDESC NAME OF SHOULDER MATERIAL FOR EACH SHOULDER LAYER.

SHCOST THE SHOULDER MATERIAL COST ($/CU YD).

SHFCTR RATIO OF (LANE WIDTHS + SHOULDER WIDTHS) TO (LANE WIDTHS). IF 'MASPHS' IS EQUAL ONE , THIS NUMBER CAN BE GREATER THAN ONE.

SI ADDITIONAL WIDTH OF AN INSIDE SHOULDER LAYER RELATIVE TO SHOULDER LAYER ONE (YARDS).

SIWID WIDTH OF INSIDE SHOULDER (FEET).

SO ADDITIONAL WIDTH OF AN OUTSIDE SHOULDER LAYER RELATIVE TO SHOULDER LAYER ONE (YARDS).

SOWID WIDTH OF OUTSIDE SHOULDER (FEET).

SPSV SHOULDER PERCENT SALVAGE VALUE.

SRATE THE SWELL RATE,VARIES BETWEEN 0.04 AND 0.20.IT IS USED TO CALCULATE HOW FAST SWELLING TAKES PLACE.IT IS LARGER WHEN THE SOIL IS CRACKED AND OPEN AND WHEN A LARGE MOISTURE SUPPLY IS AVAILABLE DUE TO POOR DRAINAGE CONDITIONS,UNDERGROUND SEEPAGE OR OTHER SOURCES OF WATER.WHEN DRAINAGE CONDITIONS ARE GOOD AND THE SOIL IS TIGHT,THEN SRATE BECOMES SMALLER.

SRISE A MEASURE (INCHES) OF HOW MUCH A SURFACE OF A BED OF CLAY CAN RISE IF IT IS SUPPLIED WITH ALL OF THE MOISTURE IT CAN TAKE.IT CAN BE ESTIMATED IN A PARTICULAR LOCALITY FROM THE TOTAL AMOUNT OF DIFFERENTIAL HEAVE THE ENGINEER WOULD EXPECT TO OBSERVE OVER A LONG PERIOD OF TIME.

SSOPT AN OPTION FOR DETERMINATION OF PROGRAM ACTION, IF DURING THE CALCULATIONS OF PAVEMENT LIFE USING THE SOIL-SUPPORT VALUES OF INTERMEDIATE LAYERS, A POTENTIAL LAYER INTERFACE PROBLEM IS INDICATED.
SSOPT=1 DESIGN LIFE ESTIMATES BASED ON THE SHORTEST CALCULATED LAYER INTERFACE.
SSOPT=2 CAUSES ANY DESIGN WITH A CALCULATED LAYER FAILURE TO BE ELIMINATED,IN EFFECT INCREASING LAYER THICKNESSES UNTIL NO CALCULATED LAYER FAILURE EXISTS ABOVE THE SUBGRADE.
SSOPT=3 DESIGN LIFE ESTIMATES BASED ON SUBGRADE SOIL SUPPORT, OTHER SOIL SUPPORT VALUES ONLY FOR LOCATING THE ' * ' .

STRNUM STRUCTURAL NUMBER FOR THE I-TH PERFORMANCE PERIOD.

SV OVERALL SALVAGE VALUE OF INITIAL CONSTRUCTION ($/SQ YD).

SWI THE WIDTH OF THE INSIDE SHOULDER(YARDS).

SWO THE WIDTH OF THE OUTSIDE SHOULDER (YARDS).

T TIME TO LOSS OF SERVICEABILITY OF A DESIGN, CALCULATED BY 'TIME'.

TCINC THE MAXIMUM DEPTH ABOVE TLMAX FOR A TACK COAT BETWEEN LIFTS. (YDS).

TCKMAX THE MAXIMUM ALLOWABLE TOTAL THICKNESS OF INITIAL CONSTRUCTION.

TCMAX THE MAXIMUM DEPTH AT WHICH A PAVEMENT LAYER WILL BE APPLIED WITHOUT TACKCOATS BETWEEN LIFTS.

THKOV THE MAXIMUM THICKNESS ALLOWABLE FOR ALL OVERLAYS COMBINED, NOT INCLUDING WEAR-COATS AND LEVEL-UPS (YARDS).

TK OVERALL THICKNESS OF INITIAL CONSTRUCTION EXCLUDING WEARING SURFACE (YARDS).

TLINC THE MAXIMUM DEPTH ABOVE TLMAX FOR A TACK COAT BETWEEN LIFTS. (INCHES).

TLMAX MAXIMUM LAYER DEPTH NOT REQUIRING A TACK COAT (INCHES).

TMAXIN ALLOWABLE THICKNESS FOR ALL COMBINED OVERLAYS EXCLUDING WEAR COAT AND LEVEL-UP (INCHES).

TMOVIN THE MAXIMUM ALLOWABLE THICKNESS FOR ALL OVERLAYS COMBINED (INCHES).

TPRIM TIME FROM INITIAL CONSTRUCTION TO THE PRESENT PERFORMANCE PERIOD OR OVERLAY (YEARS).

TRPRIM THE TRAFFIC LOAD AT TIME TPRIM (18 KIP EQUIVALENTS).

TT AN ARRAY OF T'S, FOR EACH PERFORMANCE PERIOD, THE TIME TO THE NEXT OVERLAY (YEARS).

T18KG THE GROWTH RATE OF 18-KIP EQUIVALENTS PER YEAR.

T18KO TRAFFIC LOAD RATE IN 18-KIP EQUIVALENTS PER YEAR AT TIME=0.0.

UPGCST COST OF UPGRADE AFTER AN OVERLAY ($/CU.YD.).

UPLVL AMOUNT OF OVERLAY LEVEL-UP THICKNESS REQUIRED PER OVERLAY (INCHES).

WAPP THE ASPHALTIC CONCRETE DENSITY FOR THE WEARING SURFACE (LB./IN./SQ.YD.).

WIDUPG WIDTH OF SHOULDERS UPGRADED AT OVERLAY (FEET).

WPC PRIME COAT APPLICATION RATE (GALLONS/SQ.YD.).

WPCT ASPHALTIC CONTENT (PER CENT).

WSCOST IN PLACE COST OF WEARING SURFACE MATERIAL ($/CU. YD)

WSCST WEARING SURFACE MATERIAL COST ($/SQ YD).

WSPR WEARING SURFACE MATERIAL PRODUCTION RATE(TONS PER HOUR)

WSSPCT WEARING SURFACE SALVAGE VALUE (PERCENT)

WSSPV WEARING SURFACE SALVAGE VALUE ($/SQ YD).

WSSTR WEARING SURFACE STRENGTH COEFFICIENT.

WSTHK WEARING SURFACE THICKNESS (YDS).

WSTMIN WEARING SURFACE THICKNESS (INCHES).

WTC TACK COAT APPLICATION RATE (GALLONS/SQ.YD.).

XINC A VECTOR WITH THE INCREMENT IN LAYER THICKNESS FOR EACH LAYER OF AN INITIAL DESIGN(YDS).

XJ AN ARRAY OF CONSTANTS CALCULATED FROM SOIL SUPPORT VALUES FOR EACH LAYER.

NAME DICTIONARY (CONTINUED)

XJAY A CONSTANT FOR A LAYER OF AN INITIAL DESIGN, CALCULATED FROM THE SOIL SUPPORT VALUE OF THE LAYER.

XIWID CROSS SECTION WIDTH OUTSIDE OF INSIDE SHOULDER (FEET).

XLSD THE DISTANCE, MEASURED ALONG THE DETOUR, AROUND THE OVERLAY ZONE (MILES).

XLSN THE DISTANCE, MEASURED ALONG THE C.L.,OVER WHICH TRAFFIC IS SLOWED IN THE NON-OVERLAY DIRECTION (MILES).

XLSO THE DISTANCE, MEASURED ALONG THE C.L.,OVER WHICH TRAFFIC IS SLOWED IN THE OVERLAY DIRECTION (MILES).

XLW THE WIDTH OF EACH LANE (YARDS).

XLWFT WIDTH OF EACH HIGHWAY LANE (FEET).

XNC THE ONE-DIRECTION ACCUMULATED NUMBER OF EQUIVALENT 18-KIP AXLE EQUIVALENTS DURING THE ANALYSIS PERIOD.

XOWID CROSS SECTION WIDTH OUTSIDE OF OUTSIDE SHOULDER (FEET).

XTBO THE MINIMUM ALLOWED TIME BETWEEN OVERLAYS PERMITTED (YEARS).

XTTO THE MINIMUM ALLOWED TIME TO THE FIRST OVERLAY (YEARS).

XWI CROSS SECTION WIDTH OUTSIDE OF INSIDE SHOULDER (YARDS).

XWO CROSS SECTION WIDTH OUTSIDE OF OUTSIDE SHOULDER (YARDS).

X2 THE NO. OF DAYS PER YEAR THAT THE TEMPERATURE REMAINS BELOW 32 DEGREES FAHRENHEIT.

CRITICAL DIMENSION STATEMENTS

THE FOLLOWING VARIABLES WITH FORTRAN DIMENSION AND COMMON STATEMENTS SHOULD BE CHECKED WHEN PLANNING CHANGES TO THE SAMP6 PROGRAM TO PREVENT POTENTIAL ILLEGAL SUBSCRIPT VALUES AND STORING NUMBERS OUTSIDE THEIR ASSIGNED ARRAYS.

IF DIMENSIONS OF THE ARRAYS ARE DEFINED AS . . .
LAYD = MAXIMUM NUMBER OF LAYERS IN A DESIGN, EXCLUDING SUBGRADE.
NMD = NUMBER OF MATERIALS EXCLUDING SUBGRADE.
NPERFD = MAXIMUM NUMBER OF PERFORMANCE PERIODS.
NPD = NUMBER OF ITEMS ALLOWED FOR EACH BETTER DESIGN(55 IN SAMP6).
NSHD = MAXIMUM NUMBER OF SHOULDER LAYERS (EXCLUDING FILL MATERIAL) IN A DESIGN.
NSUMD = MAXIMUM NUMBER OF SUMMARY DESIGNS (BETTER DESIGNS).

THE FOLLOWING ARRAYS SHOULD BE DIMENSIONED AS . . .
A(LAYD)
AI(LAYD)
AO(LAYD)
APERS(NSHD)
APPY(LAYD)
APPYS(NSHD)
CODE(LAYD)
COST(LAYD,3)
DATA(NMD,20)
DESC(LAYD+1,4)
DMAX(LAYD)
DMIN(LAYD)
DOVER(LAYD)
DS(NSHD)
FLAG(LAYD)
ILAYER(NMD+1)
INDEX(LAYD+1)
IPOSS(NKD)
NMBMAT(LAYD)
NN(LAYD)
POLICY(NPD,NSUMD)
PSVGE(LAYD)
RIAS(NSHD)
RPC(LAYD)
RPCS(NSHD)
RTC(LAYD)
SHCOST(NSHD,3)
ST(NSHD)
SO(NSHD)
SPSV(NSHD)
STRNUM(NPERFD)
TT(NPERFD)
XINC(LAYD)
XJ(LAYD+1)

COMPUTER PROGRAM MACHINE REQUIREMENTS AND TIMING ESTIMATES.

THE SAMP6 IS WRITTEN IN FORTRAN IV WITH A DELIBERATE EFFORT TO AVOID FEATURES WHICH ARE NOT STANDARD FORTRAN. THE PROGRAM HAS BEEN COMPILED AND RUN WITH COMPARABLE RESULTS USING THE FOLLOWING FORTRAN COMPILERS. IBM' FORTRAN G, IBM'S FORTRAN H BOTH WITH AND WITHOUT OPTIMIZATION OPTION(OPT=2), AND ALSO WATFIV, A COMPILER DEVELOPED AT THE UNIVERSITY OF WATERLOO. THE PROGRAM HAS RUN WITHOUT MODIFICATION ON SEVERAL MODELS OF IBM 360 AND 370 COMPUTERS. THE FIRST 'READ' STATEMENT IN SUBROUTINE INPUT HAS AN 'END=' OPTION TO BE REMOVED IF NOT AVAILABLE ON ANOTHER MANUFACTURER'S COMPUTER. NO OTHER CHANGE IS NEEDED IF A BLANK CARD IS USED AFTER THE LAST SET OF DATA. SOME CASES OF MIXED MODE ARITHMETIC AND ARITHMETIC EXPRESSIONS AS SUBSCRIPTS ARE NON-STANDARD, BUT ARE COMMONLY AVAILABLE, HOWEVER THESE INSTANCES ARE EASILY LOCATED USING KNOWN COMPILERS FOR MANUFACTURER'S MACHINES WHEN THESE EXTENSIONS OF FORTRAN IV ARE NOT AVAILABLE.

PROGRAM RUNNING TIME (CPU SECONDS) ON IBM 360/65

THE TEST DATA DISTRIBUTED WITH THE PROGRAMS REQUIRED TEN TO TWENTY SECONDS EXECUTION TIME EACH. EXECUTION TIME FOR OTHER PROBLEMS IS DEPENDENT ON THE CONSTRAINTS IN THE INPUT DATA AND ON THE INCREMENTS SELECTED FOR PAVEMENT AND OVERLAY MATERIALS.

'TEXLIS' USER'S GUIDE

'TEXLIS'

A COMPUTER PROGRAM
AID FOR DOCUMENTATION

VERSION 73266

CORE REQUIREMENTS (8 BIT BYTES, IBM 360)

COMPUTER MEMORY REQUIREMENTS WITH THE PROGRAM COMPILED WITH FULL OPTIMZATION (OPT=2) USING IBM'S FORTRAN H COMPILER IS 76 K BYTES. THIS WOULD BE ROUGHLY EQUIVALENT TO 20,000 TO 30,000 WORDS OF A WORD ORIENTED COMPUTER.

'TEXLIS' USER'S GUIDE -SUMMARY-

TEXLIS

THE PROGRAM 'TEXLIS' IS USEFUL AS A DOCUMENTATION AID FOR COMPUTER PROGRAMS, LISTING OF PROGRAMS, OR AS A SIMPLE TEXT EDITOR. TEXLIS PROVIDES A USEFUL AID FOR DOCUMENTATION OF FORTRAN COMPUTER PROGRAMS BECAUSE THE DOCUMENTATION MAY BE CHANGED, EITHER LINE BY LINE OR WITH EXTENSIVE REVISIONS AND INSERTIONS WITH AN UPDATED REPORT GENERATED IMMEDIATELY, COMPLETE WITH PAGE NUMBERS, BY SUBMITTING 'TEXLIS' AND THE UPDATED DECK OF COMPUTER CARDS USING SIMILAR EQUIPMENT AND PROCEDURES AS USED IN CHANGING THE PROGRAM WHICH IS BEING DOCUMENTED.

ACKNOWLEDGEMENT

THE PROGRAM TEXLIS IS BASED ON AN EARLIER PROGRAM TXTLST BY LARRY BRISTOL, TEXAS A&M UNIVERSITY, COLLEGE STATION, TEXAS.

SHOULD ANY PROBLEMS ARISE WHEN USING THIS PROGRAM, PLEASE DIRECT THE INQUIRY TO . . .

DALE L. SCHAFER
TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS
PHONE 713 845-1717

PROGRAM ACTION

THIS PROGRAM IS USED TO LIST ALPHABETIC TEXT TO FORM AN EDITED LISTING OF PROGRAM DOCUMENTATION. THIS LISTING WAS PRINTED BY THE PROGRAM. THE PROGRAM PROVIDES FOR CHANGING THE PAGE SIZE, AND ALLOWS FOR THREE BASIC OUTPUT FORMATS.

THE PROGRAM READS INPUT CARDS SEQUENTIALLY AND PRODUCES SEQUENTIAL LISTINGS AS DIRECTED BY THE INPUT CARDS. ANY CARD WITH A DOLLAR SIGN ($) IN COLUMN 1 IS TREATED AS A COMMAND CARD. OTHER CARDS ARE TEXT CARDS. THE PROGRAM PRINTS EACH TEXT CARD ON A LINE SINGLE SPACING. IT AUTOMATICALLY DETECTS THE END OF A PAGE AS SET BY A PAGE LINE LIMIT, AND PRODUCES FOOTINGS AND HEADINGS AT THESE POINTS. TEXT CARDS ARE PUNCHED IN COLUMNS 1-72 AND ARE OUTPUT FOR 8 1/2 BY 11 UNLESS THE FULL SIZE OPTION IS REQUESTED FOR PRINTING ON FULL WIDTH 11 BY 14 PAGE SIZE (SEE CARD FORMAT UNDER PROGRAM OPTIONS).

'TEXLIS' USER'S GUIDE -COMMAND CARDS (CONTINUED)-

3) $FOOTING - THIS CARD SPECIFIES TEXT TO BE PRINTED AS A AS A PAGE FOOTING. THE FOOTING TEXT IS PUNCHED STARTING IN COLUMN 10. THIS TEXT IS PRINTED CENTERED ON THE SPECIFIED FOOTING LINE OF EACH PAGE UNTIL CHANGED.

4) $PAGE - THIS CARD CAUSES A NEW PAGE TO BE STARTED BY GENERATING A FOOTING FOR THE CURRENT PAGE, PRODUCING THE HEADING ON THE NEXT PAGE, AND POSITIONING TO THE FIRST TEXT LINE SPECIFIED.

5) $LINE - THIS CARD SPECIFIES AN ABSOLUTE LINE ON A PAGE TO BE SKIPPED TO. THE SKIP IS MADE IN A FORWARD DIRECTION ONLY. IF THE SPECIFIED LINE HAS BEEN PASSED ON THE CURRENT PAGE, THE PROGRAM SKIPS TO THE LINE ON THE FOLLOWING PAGE, GENERATING FOOTING AND HEADING. IF THE LINE SPECIFIED IS OUTSIDE THE TEXT RANGE (FIRST LINE TO LAST LINE) THE EFFECT IS THE SAME AS THE $PAGE CARD. THE LINE NUMBER IS SPECIFIED IN COLUMNS 10-11.

6) $SKIP - THIS CARD CAUSES A SPECIFIED NUMBER OF LINES TO BE SKIPPED. FIELD 1 (COLUMNS 10-11) SPECIFIES THESE NUMBER OF LINES. FIELD 2 (COLUMNS 12-13) SPECIFIES THE NUMBER OF LINES THAT MUST REMAIN ON THE CURRENT PAGE AFTER THE SKIP. IF THE SKIP WOULD RESULT IN FEWER THAN THE SPECIFIED LINES TO REMAIN, THE ACTION TAKEN IS THE SAME AS A $PAGE CARD.

7) $CENTER THIS IS THE SAME AS A TEXT CARD EXCEPT THAT THE TEXT (STARTING IN COLUMN 10) IS CENTERED IN THE PRINTED LINE. THIS COMMAND IS USEFUL FOR TITLES AND HEADINGS IN THE TEXT.

8) $END - THIS CARD IS THE LAST CARD OF THE DECK. SUCCESSFUL EXECUTION OF THE PROGRAM WILL BE INDICATED ON THE LAST PAGE OF THE OUTPUT.

'TEXLIS' USER'S GUIDE -COMMAND CARDS-

COMMAND CARD FORMATS

THERE ARE EIGHT COMMAND TYPES. A COMMAND CARD IS INDICATED BY A DOLLAR SIGN ($) IN COLUMN 1. THE COMMAND TYPE IS PUNCHED IN COLUMNS 2-9. STARTING IN COLUMN 10 ADDITIONAL DATA MAY BE PUNCHED TO FURTHER PROVIDE CONTROL INFORMATION.

1) $START - THIS CARD ENDS ONE DATA GROUP, AND INDICATES THE START OF A NEW GROUP. SIX ADDITIONAL FIELDS ARE READ FROM THE CARD IN THE FORMAT (9X, 4I2,2L1)

FIELD 1 - PAGE NUMBER OF THE FIRST PAGE OF
10-11 THE LISTING. IF ZERO THE PAGE COUNTER WILL NOT BE CHANGED.

FIELD 2 - LINE NUMBER FOR THE FIRST TEXT
12-13 LINE OF EVERY PAGE.

FIELD 3 - LINE NUMBER FOR THE LAST TEXT
14-15 LINE ON EVERY PAGE.

FIELD 4 - LINE NUMBER TO PUT FOOTING.
16-17

FIELD 5 - PUNCH T TO TAKE FULL SIZE OPTION.
18

FIELD 6 - PUNCH T TO TAKE CARD 2 OPTION.
19

NOTE THE DEFAULT VALUES SELECTED IF ANY OF THE FIELDS ARE BLANK OR ZERO ARE (00, 03, 56, 58, F, F).

2) $HEADING - THIS CARD SPECIFIES TEXT TO BE PRINTED AS A PAGE HEADING ON ALL SUBSEQUENT PAGES. THE HEADING TEXT IS PUNCHED STARTING IN COLUMN 10. THIS TEXT IS PRINTED CENTERED ON LINE ONE OF EACH PAGE.

'TEXLIS' USER'S GUIDE -COMMAND CARDS (CONTINUED)-

NOTE . . . ONLY THE FIRST TWO CHARACTERS (AND THIRD IN THE CASE OF $START) ARE CHECKED ON COMMAND CARDS, THEREFORE $SPACE, $SKIP, OR $S ARE EQUIVALENT COMMANDS.

TEXT CARD AND PAGE SIZE OPTIONS

THE TWO OPTIONS AS SPECIFIED ON THE $START CARD HAVE THE FOLLOWING EFFECTS (NOTE THAT THEY WORK IN COMBINATION.)

1) NO FULL SIZE AND NO CARD 2 - EACH INPUT CARD IS A SEPARATE LINE IN THE LISTING. THE PAGE FORMAT FOR 8 1/2 X 11 FORMS IS ASSUMED.

2) NO FULL SIZE WITH CARD 2 - THIS COMBINATION IS ILLEGAL.

3) FULL SIZE WITH NO CARD 2 - EACH INPUT CARD IS A SEPARATE LINE. THE PAGE FORMAT IS ASSUMED TO FIT 132 CHARACTER (14 X 11) FORMS.

4) FULL SIZE AND CARD 2 - TWO TEXT CARDS FORM A SINGLE PRINT LINE. THE FIRST 72 OF CARD 1 AND 60 FROM COLUMNS 7-66 OF CARD 2 FORM A 132 CHARACTER LINE. NOTE THAT CONTROL CARDS STILL USE ONLY ONE CARD.

TEXT CARD FORMAT

THERE ARE TWO FORMATS FOR TEXT CARDS, DEPENDING ON THE USE OF CARD 2 OPTION. IF THE OPTION IS NOT USED, TEXT IS READ FROM COLUMNS 1-72 OF EACH CARD. COLUMNS 73-80 ARE IGNORED. IF THE OPTION IS USED, THE FIRST 72 CHARACTERS OF THE LINE COME FROM COLUMNS 1-72 OF CARD 1, AND THE REMAINING 60 COME FROM COLUMNS 7-66 OF CARD 2. THE REMAINING COLUMNS ARE IGNORED. NOTE, HOWEVER, THAT COLUMNS 1-6 OF CARD 2 MUST BE BLANK.

MULTI-PRINTING ON ONE LINE

THE FOLLOWING PARAGRAPH ON OVERPRINTING APPLIES IF A '+' IN COLUMN ONE AS CARRIAGE CONTROL WILL CAUSE THE PRINTER TO PRINT WITHOUT SKIPPING TO A NEW LINE.

MULTIPLE TEXT CARDS CAN BE OVER-PRINTED ON A SINGLE LINE BY PLACING A DOLLAR SIGN '$' IN COLUMN 72 FOR NO CARD 2, OR IN COLUMN 66 OF CARD 2 FOR USE WITH THE CARD 2 OPTION.

'TEXLIS' USER'S GUIDE -PROGRAM REVISIONS-

. CHANGES INCORPORATED IN THIS VERSION OF THE PROGRAM.

THE FOLLOWING CHANGES HAVE BEEN MADE FROM 'TXTLST'. EARLIER DATA WILL RUN UNDER THIS VERSION, HOWEVER CENTERING OF HEADINGS AND FOOTINGS WILL BE DIFFERENT. THE ADDITIONAL COMMANDS WILL BE CONSIDERED ILLEGAL IF USED AND RUN UNDER EARLIER VERSIONS.

1. ONLY THE FIRST FEW CHARACTERS OF COMMAND CARDS ARE CHECKED TO ALLOW OPTIONAL SPELLING.

2. $END COMMAND HAS BEEN ADDED

3. $CENTER COMMAND HAS BEEN ADDED AND CENTERING OF HEADINGS AND FOOTINGS HAS BEEN INCORPORATED.

4. THE PROGRAM HAS BEEN CHANGED TO BE LESS COMPUTER AND INSTALLATION DEPENDENT BY REMOVING 'REREAD' AND OTHER SPECIAL ROUTINES.

4. PAGE NUMBERING HAS BEEN CHANGED FROM THE UPPER RIGHT TO THE BOTTOM CENTER OF THE PAGE.

5. THE OVERPRINT OPTION REQUIRES A DOLLAR SIGN '$', INSTEAD OF THE PLUS '+' IN THE LAST USABLE COLUMN OF THE CARD.

TEXLIS PROGRAM SOURCE LISTING

```
C-------------------------------------------------------------------
C
C              PROGRAM TEXLIS, A TEXT LISTING PROGRAM
C
C       ACKNOWLEDGEMENT   BASED ON 'TXTLST' BY LARRY BRISTOL
C                                      TEXAS A&M UNIVERSITY
C
C-------------------------------------------------------------------
      INTEGER   LINE1(72), LINE2(64), HEADNG(64), FOOTNG(64), PAGE,
     *   SLINE, FLINE
      INTEGER HT, CHK1, CHK2, PLUS, BLANK, DOLLAR, COMND(7)
      LOGICAL   FULLSZ, CARD2, FIRST
      COMMON     HEADNG, FOOTNG, LINE1, LINE2, LINE, PAGE, SLINE, MLINE,
     1   FLINE, FULLSZ, CARD2, FIRST
      DATA BLANK /1H /, DOLLAR /1H$/, HT/1HT/
      DATA COMND/1HS, 1HH, 1HF, 1HP, 1HL, 1HC, 1HE/
C---INITIALIZE HEADING AND FOOTING AT BLANK.
      DO 20 I = 1,64
      HEADNG(I) = BLANK
      FOOTNG(I) = BLANK
      LINE2(I) = BLANK
   20 CONTINUE
      FULLSZ= .FALSE.
      CARD2= .FALSE.
      FIRST= .TRUE.
      LINE = 10 000
      PAGE = 0
      SLINE = 3
      MLINE = 58
      FLINE = 56
C
C*****           FOR OTHER THAN IBM MACHINES,                    *****
C*****  EXCHANGE THE 'C' ON THE FOLLOWING TWO STATEMENTS.        *****
C    1 READ(5,501          ) LINE1
     1 READ(5,501,END=170) LINE1
      IF (LINE1(1) .EQ. DOLLAR) GO TO 100
      FIRST = .FALSE.
      IF (.NOT. CARD2) GO TO 10
      READ(5,502)          CHK1, CHK2, (LINE2(I), I=1,60)
      IF( CHK1.NE.BLANK .OR. CHK2.NE.BLANK )GO TO 1000
C---WRITE A LINE
   10 CALL WRITE
      GO TO 1
C--EDIT COMMAND CONTROL CARD, CHECK FOR TYPE
  100 DO 101 IGO = 1, 7
      IF( LINE1(2).EQ.COMND(IGO)  )
     1    GO TO(110, 120, 130, 140, 150, 160, 170), IGO
  101 CONTINUE
      GO TO 1002
C--$START
C--$SKIP IF THIRD CHARACTER NOT A 'T'
  110 IF( LINE1(3) .NE. HT ) GO TO 115
      IF( .NOT. FIRST) CALL FOOT
      NPAGE=INTG(LINE1, 72, 10, 2)
```


TEXLIS PROGRAM SOURCE LISTING (CONTINUED)

```
      PAGE = 0
      SLINE=INTG(LINE1,72,12,2)
      MLINE=INTG(LINE1,72,14,2)
      FLINE=INTG(LINE1,72,16,2)
      FULLSZ = .FALSE.
      IF( LINE1(18) .EQ. HT )FULLSZ = .TRUE.
      CARD2 = .FALSE.
      IF( LINE1(19) .EQ. HT )CARD2 = .TRUE.
      IF (NPAGE .NE. 0) PAGE = NPAGE - 1
      IF (CARD2 .AND. .NOT. FULLSZ) GO TO 1001
      IF (SLINE .LT. 3 .OR. SLINE .GT. 24) SLINE = 3
      IF (MLINE .LT. SLINE .OR. MLINE .GT. 56) MLINE = 56
      IF (FLINE .LT. MLINE+1 .OR. FLINE .GT. 58) FLINE = MLINE + 2
      LINE = 10 000
      GO TO 1
C--$SKIP
  115 L =INTG(LINE1,72,10,2)
      M =INTG(LINE1,72,12,2)
      IF (L .LE. 0) L = 1
      L = LINE + L
      IF (L+M .GT. MLINE) GO TO 140
      GO TO 145
C---$HEADING
  120 CALL CENTER
      DO 121 I = 1, 64
  121 HEADNG(I) = LINE1(I+2)
      GO TO 1
C--$FOOTING
  130 CALL CENTER
      DO 131 I = 1,64
  131 FOOTNG(I) = LINE1(I+2)
      GO TO 1
C--$PAGE
  140 CALL FOOT
      CALL HEAD
      GO TO 1
C--$LINE
  150 L =INTG(LINE1,72,10,2)
  145 IF (L .LT. SLINE .OR. L .GT. MLINE) L = SLINE
      IF (LINE .LE. L) GO TO 152
      IF (PAGE .EQ. 0) GO TO 151
      CALL FOOT
  151 CALL HEAD
  152 CALL POS (L)
      GO TO 1
C---$CENTER
  160 CALL CENTER
      IF( .NOT. CARD2  ) GO TO 10
      DO 161 I = 1, 26
      LINE2(I) = LINE1 (I+46)
      LINE1(I+ 46) =LINE1(I+20)
      LINE1(I+20) = BLANK
      IF( I .LE. 6 )     GO TO 161
      LINE1(I+20) = LINE1(I-6)
```


TEXLIS PROGRAM SOURCE LISTING (CONTINUED)

```
      LINE1(I-6) = BLANK
  161 CONTINUE
      DO 162 I =21, 64
      LINE2(I) = BLANK
  162 CONTINUE
      GO TO 10
C--$END OR EOF
  170 CALL FOOT
      WRITE(6,666)
      STOP
 1000 WRITE(6,6000) CHK1, CHK2, (LINE2(I), I=1,60)
      STOP
 1001 WRITE(6,6001)
      STOP
 1002 WRITE(6,6002) LINE1
      STOP
  501 FORMAT (72A1)
  502 FORMAT (A3, A3, 60A1)
  666 FORMAT (23H1PROGRAM - TEXLIS $END /14H MAINTAINED BY /
     *   16H DALE L. SCHAFER / 13H 713 845-1717 )
 6000 FORMAT (
     1      18H1ILLEGAL CARD 2 -  ,A3, A3, 60A1)
 6001 FORMAT(55H1CARD-2  OPTION MUST ALSO HAVE  FULL-SIZE  OPTION
 6002 FORMAT(20H1UNDEFINED COMMAND-- , /1H , 80A1)
      END
      SUBROUTINE CENTER
      INTEGER   LINE1(72), LINE2(64), HEADNG(64), FOOTNG(64), PAGE,
     *   SLINE, FLINE
      LOGICAL   FULLSZ, CARD2, FIRST
      COMMON     HEADNG, FOOTNG, LINE1, LINE2, LINE, PAGE, SLINE, MLINE,
     1   FLINE, FULLSZ, CARD2, FIRST
      INTEGER BLANK/' '/
      K = 1
      DO 1 I = 1, 72
      LINE1(I) = BLANK
      IF( I .LE. 63) LINE1(I) = LINE1(I+9)
 1    IF( LINE1(I) .NE. BLANK ) K = I
      J = 66 -((62-K)/2 )
      DO 2 I = 1, K
      LINE1( J - I) = LINE1(K-I+1)
 2        LINE1(K-I+1) = BLANK
      RETURN
      END
      SUBROUTINE FOOT
      INTEGER   LINE1(72), LINE2(64), HEADNG(64), FOOTNG(64), PAGE,
     *   SLINE, FLINE
      LOGICAL   FULLSZ, CARD2, FIRST
      COMMON     HEADNG, FOOTNG, LINE1, LINE2, LINE, PAGE, SLINE, MLINE,
     1   FLINE, FULLSZ, CARD2, FIRST
      IF( LINE .GT. FLINE) RETURN
      CALL POS (FLINE)
      LINE = LINE + 1
      IF (FULLSZ) WRITE(6,601) FOOTNG, PAGE
      IF (.NOT. FULLSZ) WRITE(6,602) FOOTNG, PAGE
```

```
      RETURN
  601 FORMAT (29X,64A1/  57X, I3)
  602 FORMAT(11X,64A1/  41X, I3)
      END
      SUBROUTINE HEAD
      INTEGER   LINE1(72), LINE2(64), HEADNG(64), FOOTNG(64), PAGE,
     *   SLINE, FLINE
      LOGICAL   FULLSZ, CARD2, FIRST
      COMMON     HEADNG, FOOTNG, LINF1, LINE2, LINE, PAGE, SLINE, MLINE,
     1   FLINE, FULLSZ, CARD2, FIRST
      PAGE = PAGE + 1
      IF (FULLSZ) WRITE(6,601) HEADNG
      IF (.NOT. FULLSZ) WRITE(6,602) HEADNG
      LINE = 2
      CALL POS (SLINE)
      RETURN
  601 FORMAT (1H1,28X,64A1)
  602 FORMAT (1H1, 10X, 64A1 )
      END
      FUNCTION INTGI (ALPHA, NDIM, IBEG, NCHAR)
C--INTG AN INTEGER FROM ALPHA CONVERSION FUNCTION.  ASSUMES ALL NON-
C--NUMERICS TO BE ZEROS.
      DIMENSION NUMBRS( 9), IALPHA(NDIM)
      DATA NUMBRS /1H1, 1H2, 1H3, 1H4, 1H5, 1H6, 1H7, 1H8, 1H9 /
      INTG=0
      ITEN=1
      IEND=IBEG+NCHAR-1
      DO 10 I = IBEG, IEND
         INDEX = IEND + IBEG - I
         DO 8 J = 1, 9
           IF(IALPHA(INDEX) .NE. NUMBRS(J) ) GO TO 8
           INTG = INTG + J * ITEN
           GO TO 10
    8    CONTINUE
   10  ITEN = ITEN * 10
      RETURN
      END
      SUBROUTINE POS (L)
      INTEGER   LINF1(72), LINE2(64), HEADNG(64), FOOTNG(64), PAGE,
     *   SLINE, FLINE
      LOGICAL   FULLSZ, CARD2, FIRST
      COMMON     HEADNG, FOOTNG, LINF1, LINE2, LINE, PAGE, SLINE, MLINE,
     1   FLINE, FULLSZ, CARD2, FIRST
    1 IF (L .LE. LINE) RETURN
      LINE = LINE + 1
      WRITE(6,600)
      GO TO 1
  600 FORMAT (1H )
      END
      SUBROUTINE WRITE
      INTEGER   LINF1(72), LINE2(64), HEADNG(64), FOOTNG(64), PAGE,
     *   SLINE, FLINE
      INTEGER PLUS
      LOGICAL   FULLSZ, CARD2, FIRST
```

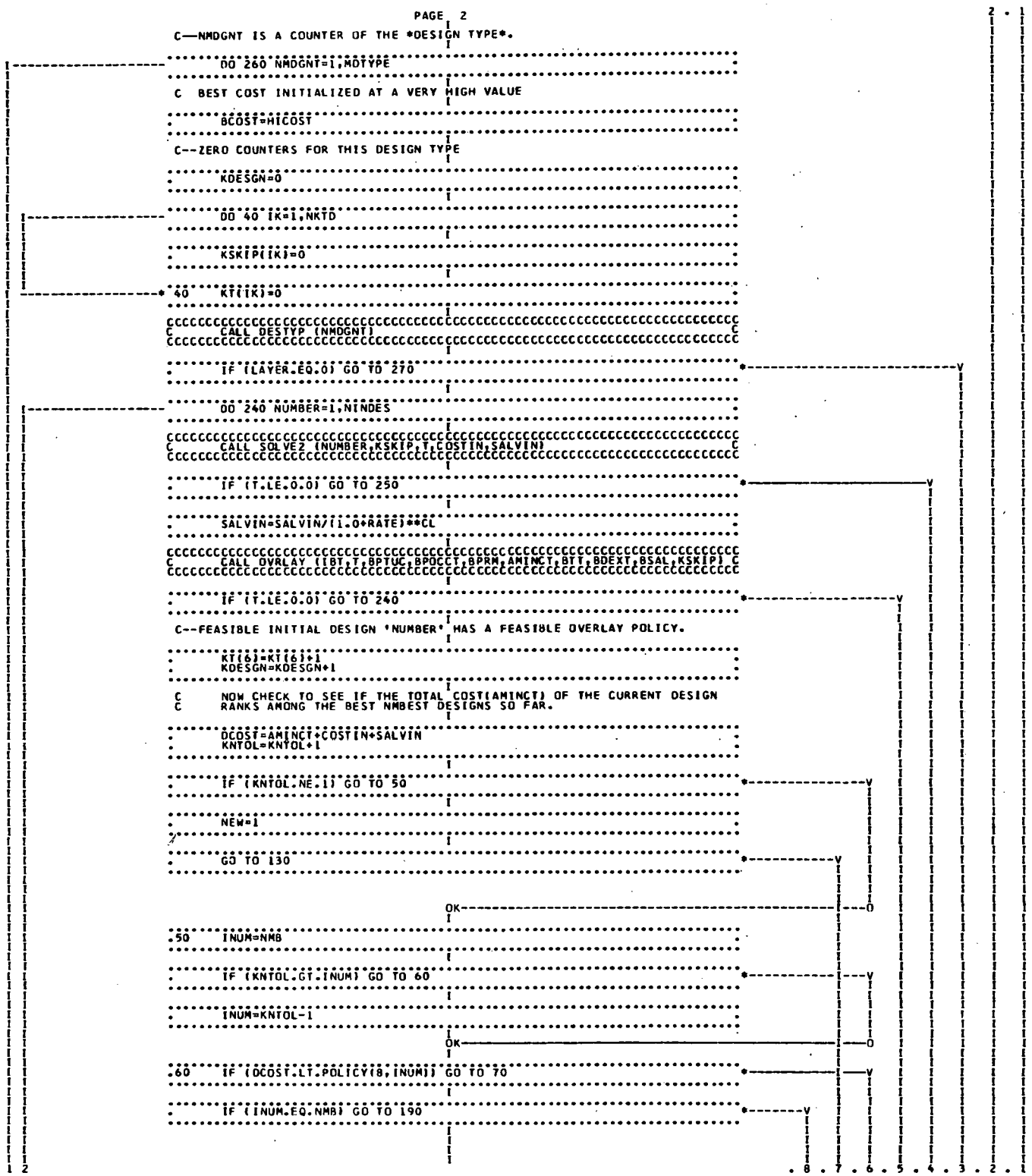


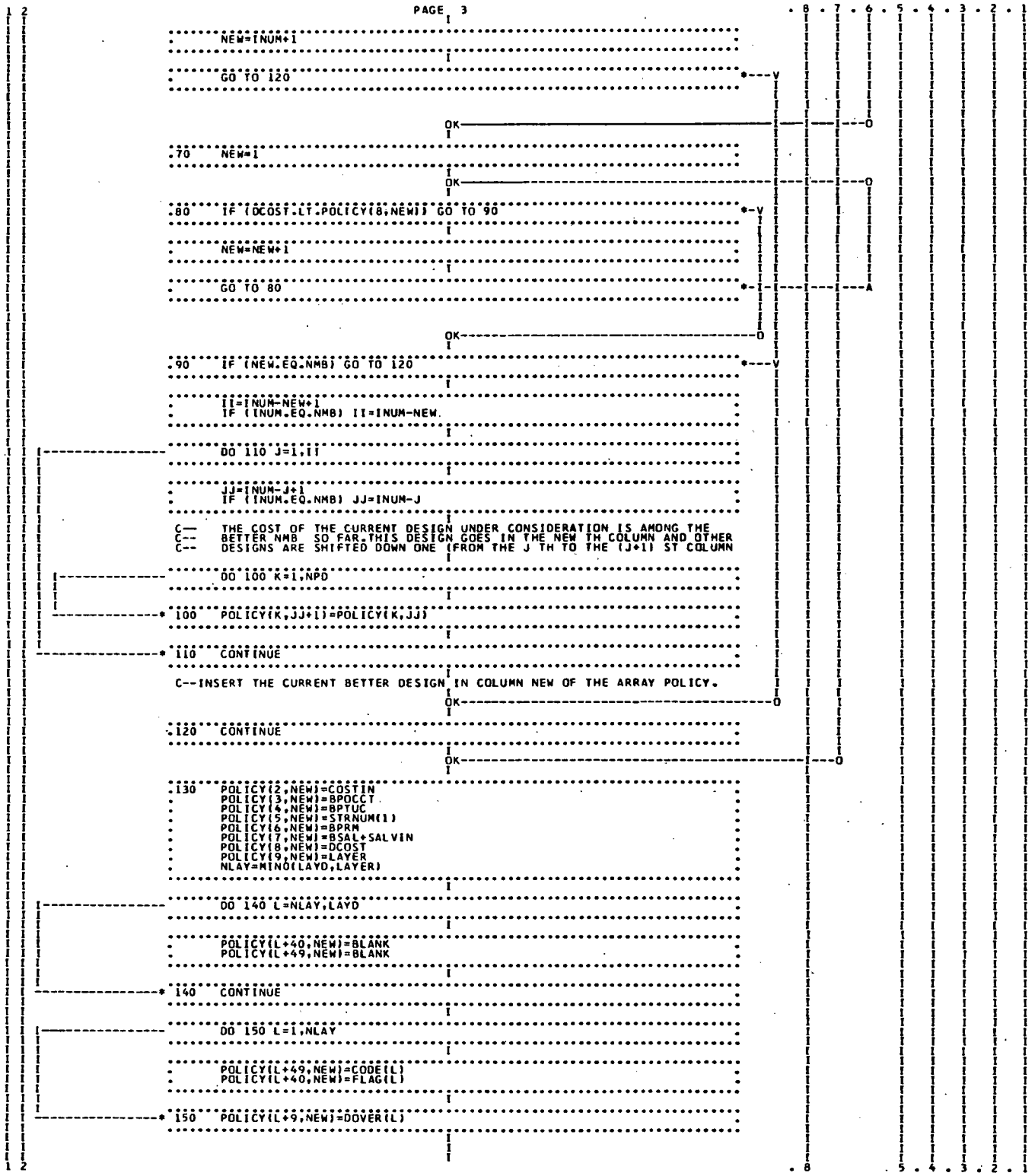
```
      COMMON     HEADNG, FOOTNG, LINE1, LINE2, LINE, PAGE, SLINE, MLINE,
     1   FLINE, FULLSZ, CARD2, FIRST
      DATA PLUS /1H+/
      IF (LINE .LE. MLINE) GO TO 1
      IF (PAGE .NE. 0) CALL FOOT
      CALL HEAD
    1 IF (FULLSZ) GO TO 100
      IF (LINE1(72) .EQ. PLUS) GO TO 10
      WRITE(6,601) LINE1
      LINE = LINE + 1
      RETURN
   10 WRITE(6,602) (LINE1(I), I = 1,71)
      RETURN
  100 IF (CARD2) GO TO 150
      IF (LINE1(72) .EQ. PLUS) GO TO 110
      WRITE(6,603) LINE1
      LINE = LINE + 1
      RETURN
  110 WRITE(6,604) (LINE1(I), I = 1,71)
      RETURN
  150 IF (LINE2(60) .EQ. PLUS) GO TO 160
      WRITE(6,605) LINE1, (LINE2(I), I = 1, 60 )
      LINE = LINE + 1
      RETURN
  160 WRITE(6,606) LINE1, (LINE2(I), I = 1,59)
      RETURN
  601 FORMAT (9X,72A1)
  602 FORMAT (1H+,8X,72A1)
  603 FORMAT (27X,80A1)
  604 FORMAT (1H+,26X,79A1)
  605 FORMAT (1X,132A1)
  606 FORMAT (1H+,131A1)
      END
```

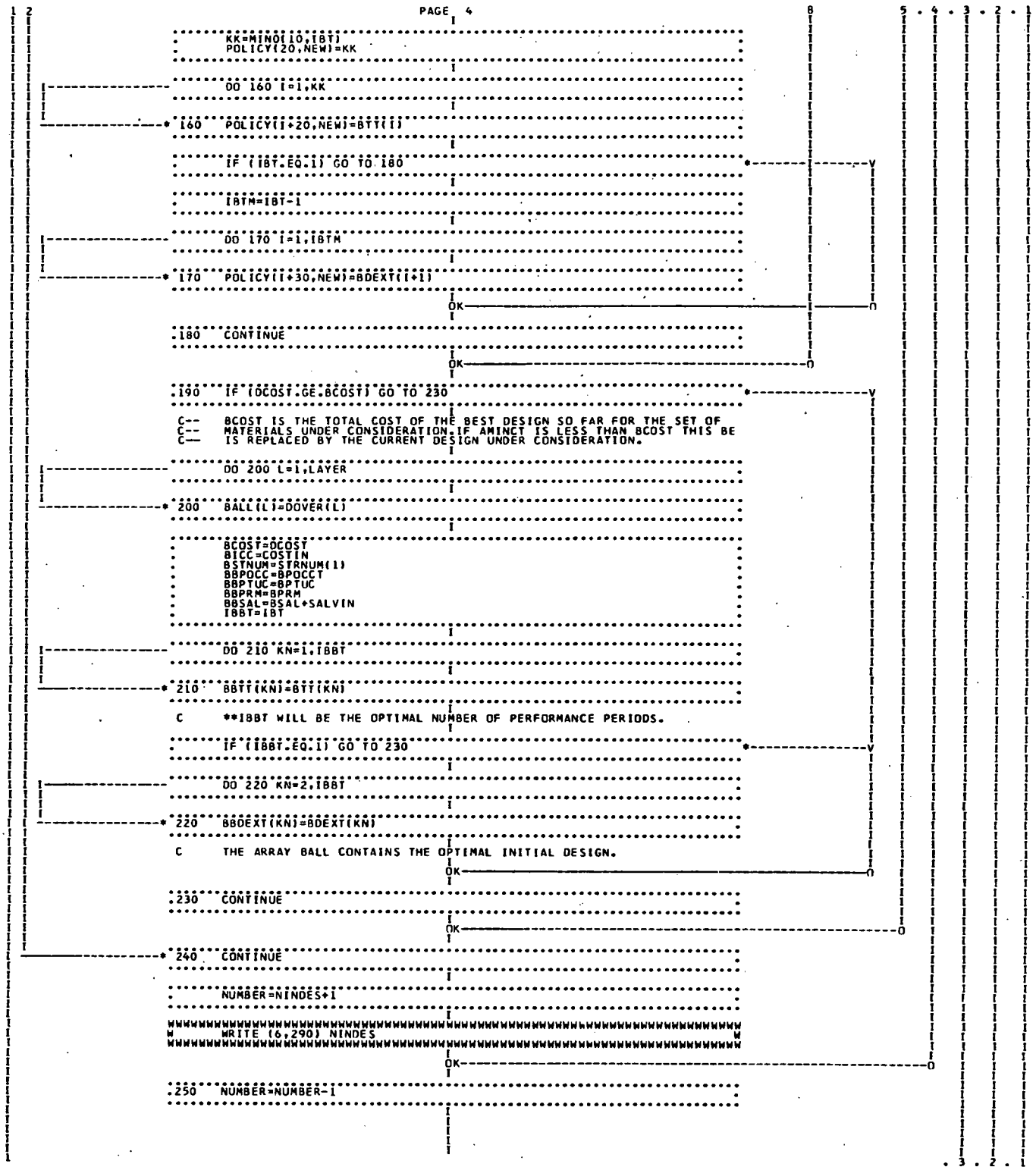
SYMBOL KEY

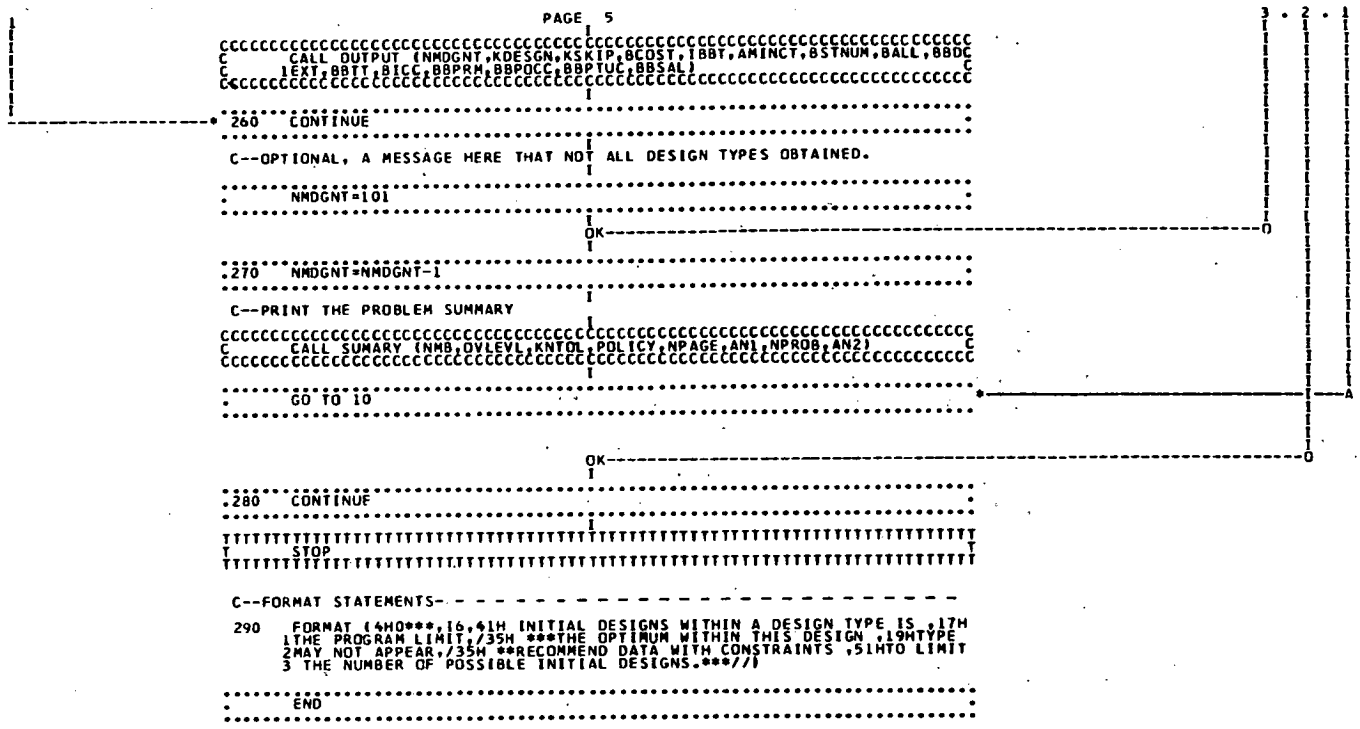
EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C                        S A M P 6
C                        ---------
C
C               SYSTEMS ANALYSIS MODEL FOR PAVEMENTS
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C         PROGRAM SAMP6 IS THE SIXTH IN A SERIES OF COMPUTER
C     PROGRAMS CALLED SYSTEMS ANALYSIS MODEL FOR PAVEMENTS.
C         THE SAMP SERIES IS BASED ON A PAVEMENT SYSTEMS ANALYSIS
C     MODEL CONCEPT AND COMPUTER PROGRAM DEVELOPED BY F H SCRIVNER,
C     G R CAREY, W F MCFARLAND, AND W M MOORE AS REPORTED IN TEXAS
C     TRANSPORTATION INSTITUTE RESEARCH REPORT 32-11, *A SYSTEMS
C     APPROACH TO THE FLEXIBLE PAVEMENT DESIGN PROBLEM.*
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      LOGICAL RURAL
      COMMON A         (6), AAS           , ACCD          , ACG          ,
     1       ACPR           , ACTL          , ADTG          , ADTO         ,
     2       AI       (11), ALPC           , AN1       (20), AN2      (19),
     3       AO       (11), APER       (6), APERS      (5), APPY      (6),
     4       APPYS     (5), APSV           , ASN           , ASO
      COMMON CERR           , CL            ,CLW            , CMAT         ,
     1       CMAX           , CM1           ,CM2            , CODE      (6),
     2       COEFVR         , COST     (6,3), DATA   (11,20), DELD         ,
     3       DESC    (7,4), DMAX       (6), DMIN       (6), DN2          ,
     4       DO2            , DOVER      (6), DS         (5)
      COMMON FLAG      (6), HPD            , ILAYER    (11), IPERF        ,
     1       KT       (10), LAYER          , MCONF          , MDCOST       ,
     2       MDXSEC         , MNTMOD        , MODEL          , NLO          ,
     3       NLONE          , NLRN          , NLRO           , NM           ,
     4       NMB            , NPAGE         , NPROB          , NSHOUL
      COMMON OVCOST    (4), OVINC          , OVLEVL         , OVMAX        ,
     1       OVMIN          , OVSALV        , OVSTR          , PN2          ,
     2       PO2            , PROP          , PSI            , PSVGE     (6),
     3       P1             , P2
      COMMON R              ,RATE           , RIABL          , RIAS      (5),
     1       RPC       (6), RPCS       (6), RTC        (6), RTCS      (5),
     2       RURAL          , SACT          , SHCOST   (5,3), SCA          ,
     3       SHFCTR         , SI         (5), SO         (5), SPSV      (5),
     4       SRATE          , SRISE         , SSOPT          , STRNUM   (20),
     5       SWI            , SWO
      COMMON TCINC          , TCKMAX        , TCMAX          , THKOV        ,
     1       TT       (20), T18KG          , T18KO          , WSCST        ,
     2       WSPR           , WSSPV         , WSSTR          , WSTHK        ,
     3       XINC      (6), XJ         (7), XLSD           , XLSN         ,
     4       XLSO           , XLW           , XTBO           , XTTO         ,
     5       XWI            , XWO           , X2

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      DIMENSION BTT(20), BDEXT(20), POLICY(55,30), KSKIP(10), BBTT(20),
     1BBDEXT(20), BALL(20)
      DATA LAYD/6/,MDTYPE/100/,NPD/55/,NKTD/10/,NINDES/1000/
      DATA BLANK/1H /,HICOST/1.0E30/

C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
E     LAST=0                                                            E
EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
                                   I
      NPAGE=0
                                   I
C--SUBROUTINE INPUT SUPPLIES DATA FOR ANOTHER PROBLEM
                                   I
                                   OK-----------------------------------
                                   I
 10   CONTINUE
                                   I
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     CALL INPUT (LAST)                                                 C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                                   I
      IF (LAST.NE.0) GO TO 280                    *---------------V
                                   I
      DO 30 J=1,NMB
                                   I
      DO 20 I=1,NPD
                                   I
 20   POLICY(I,J)=0.0
                                   I
 30   CONTINUE
                                   I
C--KNTOL IS COUNTER FOR A PROBLEM OF NUMBER OF COMPLETED DESIGNS.
                                   I
      KNTOL=0
                                   I
C--NMP IS THE SUBGRADE IN THE DATA ARRAY
                                   I
      NMP=NM+1
      LAYER=0
                                   I                                 2 .
```


PAGE 2
C—NMDGNT IS A COUNTER OF THE *DESIGN TYPE*.
DO 260 NMDGNT=1,MDTYPE
C BEST COST INITIALIZED AT A VERY HIGH VALUE
BCOST=HICOST
C--ZERO COUNTERS FOR THIS DESIGN TYPE
KDESGN=0
DO 40 IK=1,NKTD
KSKIP(IK)=0
40 KT(IK)=0
C CALL DESTYP (NMDGNT) C
IF (LAYER.EQ.0) GO TO 270
DO 240 NUMBER=1,NINDES
C CALL SOLVEZ (NUMBER,KSKIP,T,COSTIN,SALVIN) C
IF (T.LE.0.0) GO TO 250
SALVIN=SALVIN/(1.0+RATE)**CL
C CALL OVRLAY (IBT,T,BPTUC,BPOCCT,BPRM,AMINCT,BTT,BDEXT,BSAL,KSKIP) C
IF (T.LE.0.0) GO TO 240
C--FEASIBLE INITIAL DESIGN 'NUMBER' HAS A FEASIBLE OVERLAY POLICY.
KT(6)=KT(6)+1
KDESGN=KDESGN+1
C NOW CHECK TO SEE IF THE TOTAL COST(AMINCT) OF THE CURRENT DESIGN
C RANKS AMONG THE BEST NMBEST DESIGNS SO FAR.
DCOST=AMINCT+COSTIN+SALVIN
KNTOL=KNTOL+1
IF (KNTOL.NE.1) GO TO 50
NEW=1
GO TO 130
OK
50 INUM=NMB
IF (KNTOL.GT.INUM) GO TO 60
INUM=KNTOL-1
OK
60 IF (DCOST.LT.POLICY(8,INUM)) GO TO 70
IF (INUM.EQ.NMB) GO TO 190
2 . 1
1 2
. 8 . 7 . 6 . 5 . 4 . 3 . 2 . 1


PAGE 3
NEW=INUM+1
GO TO 120
OK
70 NEW=1
OK
80 IF (DCOST.LT.POLICY(8,NEW)) GO TO 90
NEW=NEW+1
GO TO 80
OK
90 IF (NEW.EQ.NMB) GO TO 120
II=INUM-NEW+1
IF (INUM.EQ.NMB) II=INUM-NEW.
DO 110 J=1,II
JJ=INUM-J+1
IF (INUM.EQ.NMB) JJ=INUM-J
C-- THE COST OF THE CURRENT DESIGN UNDER CONSIDERATION IS AMONG THE
C-- BETTER NMB SO FAR.THIS DESIGN GOES IN THE NEW TH COLUMN AND OTHER
C-- DESIGNS ARE SHIFTED DOWN ONE (FROM THE J TH TO THE (J+1) ST COLUMN
DO 100 K=1,NPD
100 POLICY(K,JJ+1)=POLICY(K,JJ)
110 CONTINUE
C--INSERT THE CURRENT BETTER DESIGN IN COLUMN NEW OF THE ARRAY POLICY.
OK
120 CONTINUE
OK
130 POLICY(2,NEW)=COSTIN
POLICY(3,NEW)=BPOCCT
POLICY(4,NEW)=BPTUC
POLICY(5,NEW)=STRNUM(1)
POLICY(6,NEW)=BPRM
POLICY(7,NEW)=BSAL+SALVIN
POLICY(8,NEW)=DCOST
POLICY(9,NEW)=LAYER
NLAY=MIN0(LAYD,LAYER)
DO 140 L=NLAY,LAYD
POLICY(L+40,NEW)=BLANK
POLICY(L+49,NEW)=BLANK
140 CONTINUE
DO 150 L=1,NLAY
POLICY(L+49,NEW)=CODE(L)
POLICY(L+40,NEW)=FLAG(L)
150 POLICY(L+9,NEW)=DOVER(L)


PAGE 4
KK=MIN0(10,IBT)
POLICY(20,NEW)=KK
DO 160 I=1,KK
160 POLICY(I+20,NEW)=BTT(I)
IF (IBT.EQ.1) GO TO 180
IBTM=IBT-1
DO 170 I=1,IBTM
170 POLICY(I+30,NEW)=BDEXT(I+1)
OK
180 CONTINUE
OK
190 IF (OCOST.GE.BCOST) GO TO 230
C-- BCOST IS THE TOTAL COST OF THE BEST DESIGN SO FAR FOR THE SET OF
C-- MATERIALS UNDER CONSIDERATION.IF AMINCT IS LESS THAN BCOST THIS BE
C— IS REPLACED BY THE CURRENT DESIGN UNDER CONSIDERATION.
DO 200 L=1,LAYER
200 BALL(L)=DOVER(L)
BCOST=OCOST
BICC=COSTIN
BSTNUM=STRNUM(1)
BBPOCC=BPOCCT
BBPTUC=BPTUC
BBPRM=BPRM
BBSAL=BSAL+SALVIN
IBBT=IBT
DO 210 KN=1,IBBT
210 BBTT(KN)=BTT(KN)
C **IBBT WILL BE THE OPTIMAL NUMBER OF PERFORMANCE PERIODS.
IF (IBBT.EQ.1) GO TO 230
DO 220 KN=2,IBBT
220 BBDEXT(KN)=BDEXT(KN)
C THE ARRAY BALL CONTAINS THE OPTIMAL INITIAL DESIGN.
OK
230 CONTINUE
OK
240 CONTINUE
NUMBER=NINDES+1
WRITE (6,290) NINDES
OK
250 NUMBER=NUMBER-1


PAGE 5
C CALL OUTPUT (NMDGNT,KDESGN,KSKIP,BCOST,IBBT,AMINCT,BSTNUM,BALL,BBDC
C 1EXT,BBTT,BICC,BBPRM,BBPOCC,BBPTUC,BBSAL)
260 CONTINUE
C--OPTIONAL, A MESSAGE HERE THAT NOT ALL DESIGN TYPES OBTAINED.
NMDGNT=101
OK
270 NMDGNT=NMDGNT-1
C--PRINT THE PROBLEM SUMMARY
C CALL SUMARY (NMB,OVLEVL,KNTOL,POLICY,NPAGE,AN1,NPROB,AN2)
GO TO 10
A
OK
280 CONTINUE
STOP
C--FORMAT STATEMENTS
290 FORMAT (4H0***,I6,41H INITIAL DESIGNS WITHIN A DESIGN TYPE IS ,17H
1THE PROGRAM LIMIT,/35H ***THE OPTIMUM WITHIN THIS DESIGN ,19HTYPE
2MAY NOT APPEAR,/35H **RECOMMEND DATA WITH CONSTRAINTS ,51HTO LIMIT
3 THE NUMBER OF POSSIBLE INITIAL DESIGNS.***//)
END

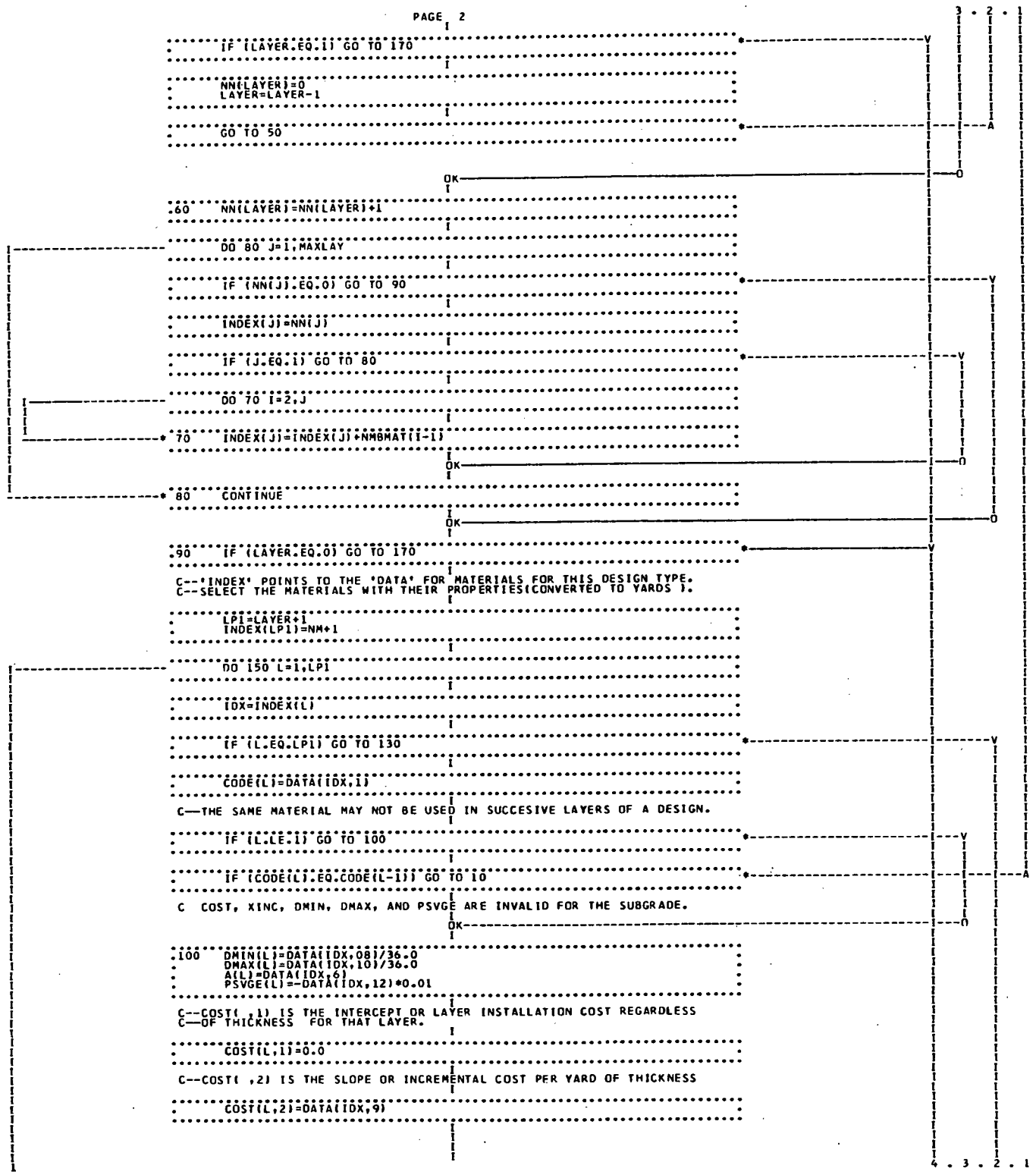
SYMBOL KEY

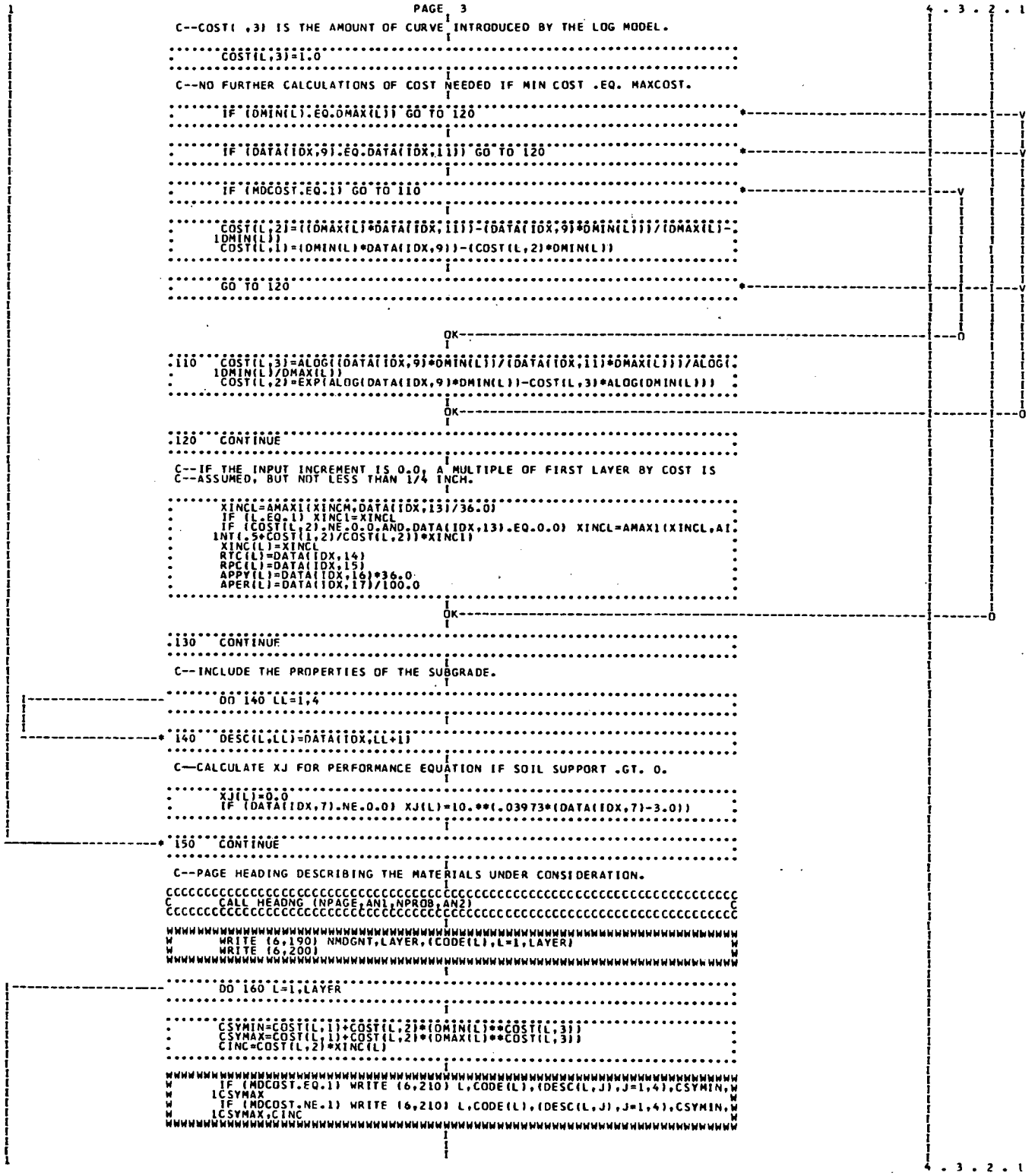
EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

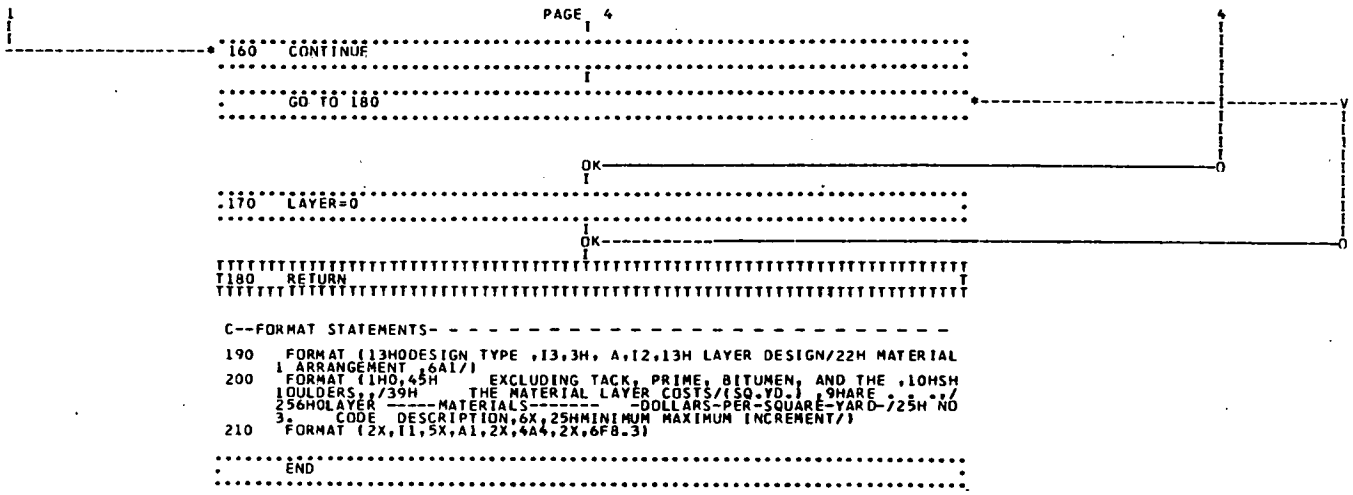
```
      SUBROUTINE CALC (PONE,TPRIM,TRPRIM,PERFB,PERFY,XJAY,TTRAF)

C--CALC CALCULATES CONSTANTS FOR THE PERFORMANCE EQUATION PERFB, PERFY,
C--ALSO RETURNS TTRAF, AN ESTIMATE OF PAVEMENT LIFE WITHOUT ENVIONMENTAL
C--LOSSES.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      LOGICAL RURAL
      COMMON A(6),AAS,ACCD,ACG,ACPR,ACTL,ADTG,ADTO,AI(11),ALPC,AN1(20),A
     1N2(19),AO(11),APER(6),APERS(5),APPY(6),APPYS(5),APSV,ASN,ASO,CERR,
     2CL,CLW,CMAT,CMAX,CM1,CM2,CODE(6),COEFVR,COST(6,3),DATA(11,20),DELD
     3,DESC(7,4),DMAX(6),DMIN(6),DN2,DO2,DOVER(6),DS(5),FLAG(6),HPD,ILAY
     4ER(11),IPERF,KT(10),LAYER,MCONF,MDCOST,MDXSEC,MNTMOD,MODEL,NLO,NLO
     5NE,NLRN,NLRO,NM,NMB,NPAGE,NPROB,NSHOUL
      COMMON OVCOST(4),OVINC,OVLEVL,OVMAX,OVMIN,OVSALV,OVSTR,PN2,PO2,PRO
     1P,PSI,PSVGE(6),P1,P2,R,RATE,RIABL,RIAS(5),RPC(6),RPCS(6),RTC(6),RT
     2CS(5),RURAL,SACT,SHCOST(5,3),SCA,SHFCTR,SI(5),SO(5),SPSV(5),SRATE,
     3SRISE,SSOPT,STRNUM(20),SWI,SWO,TCINC,TCKMAX,TCMAX,THKOV,TT(20),T18
     4KG,T18KO,WSCST,WSPR,WSSPV,WSSTR,WSTHK,XINC(6),XJ(7),XLSO,XLSN,XLSO
     5,XLW,XTBO,XTTO,XWI,XWO,X2

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      DIMENSION SN(6), B(6), TL(6)

C--DIMENSION STATEMENT VECTORS THE NUMBER OF LAYERS(EXCLUDING SUBGRADE)

      DATA XKONST/1093.602/,STAR/1H*/

C--DEFINITION  XKONST = 0.081*19.**3.23

      G=(PONE-P2)/(PONE-1.5)
      TLIM=1.0E75
      TP=(((ADTO+ADTG*CL)**2)+(ADTO**2))/(CL*(T18KO+(CL*T18KG*0.5)))
      LFAIL=LAYER

      DO 20 L=1,LAYER

      SN(L)=WSSTR*WSTHK*FLOAT(IPERF)

C---          -- ADD THE STRENGTH DUE TO OVERLAY

      IF (IPERF.GT.1) SN(L)=SN(L)+OVSTR*DELD*36.0

      DO 10 KK=1,L

   10 SN(L)=SN(L)+A(KK)*(DOVER(KK)*36.0)

      IF (XJ(L+1).EQ.0.0) GO TO 20

      B(L)=0.4+XKONST/(SN(L)+1.)**5.19
      BINV=1./B(L)
      W=(0.62766*(G**BINV)*((SN(L)+1.)*XJ(L+1))**9.3633)/R*TRPRIM

C--TL(L) FOR THAT INTERFACE IS CALCULATED LIFE EXCLUDING SWELLING CLAY.

      TL(L)=(-ADTO+SQRT(ADTO**2+W*TP))/ADTG

      IF (TL(L).GE.TLIM) GO TO 20

C--CALCULATED LIFE AT THIS INTERFACE IS LESS THAN PREVIOUS INTERFACE.

      TLIM=TL(L)
      LFAIL=L

                                  OK

   20 CONTINUE

C--SET A FLAG FOR THE LAYER INTERFACE WHERE POTENTIAL FAILURE EXISTS.

      FLAG(LFAIL+1)=STAR

C--OPTION 3 = IGNORE DESIGN LIFE ESTIMATES BASED ON OTHER THAN SUBGRADE.

      IF (SSOPT.EQ.3) LFAIL=LAYER
      STRNUM(IPERF)=SN(LFAIL)
      XJAY=XJ(LFAIL+1)

C--DEFINITION--PERFB=0.4+0.081*(19.**3.23)/((STRNUM+1.0)**5.19)

      PERFB=B(LFAIL)
      PERFY=R*(1.051/((SN(LFAIL)+1.)*XJAY))**9.3633
      TTRAF=TL(LFAIL)

C--OPTION 2 = DESIGN FAILURE IF     THE SUBGRADE INTERFACE IS NOT THE
C--WEAKEST.

      IF ((SSOPT.EQ.2).AND.(LFAIL.NE.LAYER)) TTRAF=0.0

      RETURN

      END
```

DESTYP

```
                                                                    SYMBOL KEY

                                                                    EEEEE = ENTRY
                                                                    TTTTT = TERMINAL
                                                                    CCCCC = CALL
                                                                    RRRRR = READ
                                                                    WWWWW = WRITF

EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
E      SUBROUTINE DESTYP (NMDGNT)                                       E
EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
                                   I
 C--'DESTYP'  PRINTS THE LAYER MATERIALS  AND NUMBER OF LAYERS OF A
 C--       DESIGN TYPE AND RETURNS WITH THE DESIGN TYPE DATA ASSOCIATED
 C--       WITH THOSE MATERIALS.
 C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                   I
      LOGICAL RURAL
      COMMON A(6),AAS,ACCD,ACG,ACPR,ACTL,ADTG,ADTO,AI(11),ALPC,AN1(20),A
     1N2(19),AO(11),APER(6),APERS(5),APPY(6),APPYS(5),APSV,ASN,ASO,CERR,
     2CL,CLW,CMAT,CMAX,CM1,CM2,CODE(6),COEFVR,COST(6,3),DATA(11,20),DELO
     3,DESC(7,4),DMAX(6),DMIN(6),DN2,DO2,DOVER(6),DS(5),FLAG(6),HPO,ILAY
     4ER(11),IPERF,KT(10),LAYER,MCONF,MDCOST,MDXSEC,MNTMOD,MODEL,NLO,NLO
     5NE,NLRN,NLRO,NM,NMB,NPAGE,NPROB,NSHOUL
      COMMON OVCOST(4),OVINC,OVLEVL,OVMAX,OVMIN,OVSALV,OVSTR,PN2,PO2,PRO
     1P,PSI,PSVGE(6),P1,P2,R,RATE,RIABL,RIAS(5),RPC(6),RPCS(6),RTC(6),RT
     2CS(5),RURAL,SACT,SHCOST(5,3),SCA,SHFCTR,SI(5),SO(5),SPSV(5),SRATE,
     3SRISE,SSOPT,STRNUM(20),SWI,SWO,TCINC,TCKMAX,TCMAX,THKOV,TT(20),T18
     4KG,T18KO,WSCST,WSPR,WSSPV,WSSTR,WSTHK,XINC(6),XJ(7),XLSD,XLSN,XLSO
     5,XLW,XTBO,XTTO,XWI,XWO,X2
                                   I
 C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
 C--GIVEN . . .
 C      NM   THE NUMBER OF MATERIALS, MUST BE GREATER THAN ZERO, NOT
 C           GREATER THAN NMD.
 C      DATA   AN ARRAY WITH A ROW FOR EACH MATERIAL, COLUMNS WITH
 C             INFORMATION USED TO CALCULATE DESIGN TYPE INFORMATION.
 C      ILAYER  AN ARRAY WITH THE LAYERS WHICH EACH MATERIAL MAY
 C              OCCUR.  ILAYER MUST BE SORTED IN ASCENDING ORDER WITH
 C              AT LEAST ONE MATERIAL PER LAYER.
 C      LAYER  MUST BE EQUAL ZERO THE FIRST CALL FOR A GIVEN SET OF
 C             MATERIALS, OTHERWISE MUST BE RETURNED WITH THE VALUE FROM
 C             THE LAST CALL TO LAYIDX.
 C--RETURNED
 C      LAYER  THE NUMBER OF LAYERS FOR THIS DESIGN TYPE, OR LAYER SET
 C             EQUAL ZERO IF NO MORE DESIGN TYPES FOR THIS SET OF
 C             MATERIALS.
 C      CODE, DMIN, DMAX, COST, PSVGE, XINC, RTC, PPC, APPY, APER, ECT.
 C             INFORMATION ABOUT THE DESIGN TYPE SELECTED.
 C--AN OPTIMUM DESIGN IS CALCULATED IF POSSIBLE FOR EACH DESIGN TYPE
 C--WITHIN THIS HIERARCHY UNLESS SUCCESIVE LAYERS HAVE THE SAME
 C--MATERIAL CODE LETTER.  THE ARRAY INDEX POINTS TO THE DATA ARRAY
 C--FOR THE MATERIAL TYPES UNDER CONSIDERATION IN THE CURRENT DESIGN.
 C--THE FOLLOWING DIMENSIONS MUST BE NOT LESS THAN THE MAXIMUM NUMBER
 C--OF LAYERS (THE MAXIMUM VALUE IN THE ILAYER ARRAY)
                                   I
      DIMENSION NN(06), NMBMAT(06), INDEX(6)
                                   I
 C--LAYD IS DIMENSIONED NUMBER OF LAYERS,  XINCM IS INCREMENT MINIMUM
 C--  FOR ANY LAYER MATERIAL (.6444444E-2 IS .25 INCH IN YARDS).
                                   I
      DATA LAYD/6/,XINCM/.6444444E-02/
                                   I
                                   OK-----------------------------------------------O
                                   I                                                I
 .10    IF (LAYER.NE.0) GO TO 40                 *---------------------------V     I
                                   I                                          I     I
 I------------------  DO 20 I=1,LAYD                                          I     I
 I                                 I                                          I     I
 I                  .   NN(I)=0                                               I     I
 I                                 I                                          I     I
 ------------------* 20  NMBMAT(I)=0                                          I     I
                                   I                                          I     I
 I------------------  DO 30 J=1,NM                                            I     I
 I                                 I                                          I     I
 I                  .   LAY=ILAYER(J)                                         I     I
 I                                 I                                          I     I
 I                  C--------OPTIONAL, CHECK OF SORTING AND MAXIMUM VALUES OF ILAYER
 I                                 I                                          I     I
 ------------------* 30  NMBMAT(LAY)=NMBMAT(LAY)+1                            I     I
                                   I                                          I     I
                    .   MAXLAY=LAY                                            I     I
                                   I                                          I     I
                                   OK-----------------------------------------O     I
                                   I                                                I
 .40    IF (LAYER.GE.MAXLAY) GO TO 50            *---------------------------V     I
                                   I                                          I     I
 .      LAYER=LAYER+1                                                         I     I
                                   I                                          I     I
 .      GO TO 60                                 *---------------------V     I     I
                                                                       I     I     I
                                   OK----------------------------------I-----O     I
                                   I                                   I     I     I
 .50    IF (NN(LAYER).LT.NMBMAT(LAYER)) GO TO 60 *---------------------V     I     I
                                   I                                   I     I     I
                                   I                                   I     I     I
                                   I                                 . 3  .  2  .  1
```

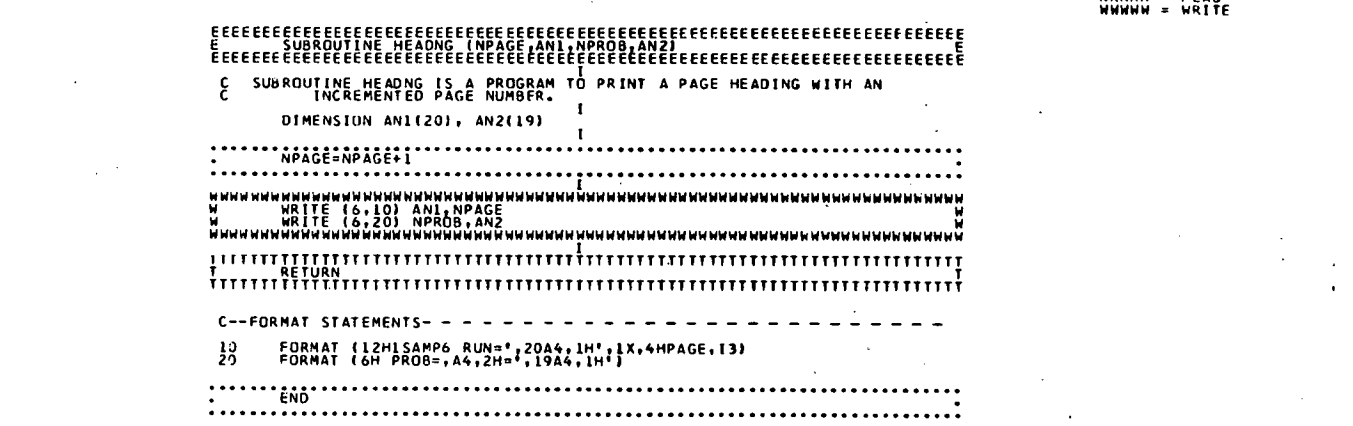

PAGE 2
IF (LAYER.EQ.1) GO TO 170
NN(LAYER)=0
LAYER=LAYER-1
GO TO 50
OK
60 NN(LAYER)=NN(LAYER)+1
DO 80 J=1,MAXLAY
IF (NN(J).EQ.0) GO TO 90
INDEX(J)=NN(J)
IF (J.EQ.1) GO TO 80
DO 70 I=2,J
70 INDEX(J)=INDEX(J)+NMBMAT(I-1)
OK
80 CONTINUE
OK
90 IF (LAYER.EQ.0) GO TO 170
C--'INDEX' POINTS TO THE 'DATA' FOR MATERIALS FOR THIS DESIGN TYPE.
C--SELECT THE MATERIALS WITH THEIR PROPERTIES(CONVERTED TO YARDS).
LP1=LAYER+1
INDEX(LP1)=NM+1
DO 150 L=1,LP1
IDX=INDEX(L)
IF (L.EQ.LP1) GO TO 130
CODE(L)=DATA(IDX,1)
C—THE SAME MATERIAL MAY NOT BE USED IN SUCCESIVE LAYERS OF A DESIGN.
IF (L.LE.1) GO TO 100
IF (CODE(L).EQ.CODE(L-1)) GO TO 10
C COST, XINC, DMIN, DMAX, AND PSVGE ARE INVALID FOR THE SUBGRADE.
OK
100 DMIN(L)=DATA(IDX,8)/36.0
DMAX(L)=DATA(IDX,10)/36.0
A(L)=DATA(IDX,6)
PSVGE(L)=-DATA(IDX,12)*0.01
C--COST(,1) IS THE INTERCEPT OR LAYER INSTALLATION COST REGARDLESS
C—OF THICKNESS FOR THAT LAYER.
COST(L,1)=0.0
C--COST(,2) IS THE SLOPE OR INCREMENTAL COST PER YARD OF THICKNESS
COST(L,2)=DATA(IDX,9)
3 . 2 . 1
4 . 3 . 2 . 1


PAGE 3
C--COST(,3) IS THE AMOUNT OF CURVE INTRODUCED BY THE LOG MODEL.
COST(L,3)=1.0
C--NO FURTHER CALCULATIONS OF COST NEEDED IF MIN COST .EQ. MAXCOST.
IF (DMIN(L).EQ.DMAX(L)) GO TO 120
IF (DATA(IDX,9).EQ.DATA(IDX,11)) GO TO 120
IF (MDCOST.EQ.1) GO TO 110
COST(L,2)=((DMAX(L)*DATA(IDX,11))-(DATA(IDX,9)*DMIN(L)))/(DMAX(L)-DMIN(L))
COST(L,1)=(DMIN(L)*DATA(IDX,9))-(COST(L,2)*DMIN(L))
GO TO 120
OK
110 COST(L,3)=ALOG((DATA(IDX,9)*DMIN(L))/(DATA(IDX,11)*DMAX(L)))/ALOG(DMIN(L)/DMAX(L))
COST(L,2)=EXP(ALOG(DATA(IDX,9)*DMIN(L))-COST(L,3)*ALOG(DMIN(L)))
OK
120 CONTINUE
C--IF THE INPUT INCREMENT IS 0.0, A MULTIPLE OF FIRST LAYER BY COST IS
C--ASSUMED, BUT NOT LESS THAN 1/4 INCH.
XINCL=AMAX1(XINCM,DATA(IDX,13)/36.0)
IF (L.EQ.1) XINC1=XINCL
IF (COST(L,2).NE.0.0.AND.DATA(IDX,13).EQ.0.0) XINCL=AMAX1(XINCL,AINT(.5*COST(L,2)/COST(L,2))*XINC1)
XINC(L)=XINCL
RTC(L)=DATA(IDX,14)
RPC(L)=DATA(IDX,15)
APPY(L)=DATA(IDX,16)*36.0
APER(L)=DATA(IDX,17)/100.0
OK
130 CONTINUE
C--INCLUDE THE PROPERTIES OF THE SUBGRADE.
DO 140 LL=1,4
140 DESC(L,LL)=DATA(IDX,LL+1)
C--CALCULATE XJ FOR PERFORMANCE EQUATION IF SOIL SUPPORT .GT. 0.
XJ(L)=0.0
IF (DATA(IDX,7).NE.0.0) XJ(L)=10.**(.03973*(DATA(IDX,7)-3.0))
150 CONTINUE
C--PAGE HEADING DESCRIBING THE MATERIALS UNDER CONSIDERATION.
CALL HEADNG (NPAGE,AN1,NPROB,AN2)
WRITE (6,190) NMDGNT,LAYER,(CODE(L),L=1,LAYER)
WRITE (6,200)
DO 160 L=1,LAYER
CSYMIN=COST(L,1)*COST(L,2)*(DMIN(L)**COST(L,3))
CSYMAX=COST(L,1)*COST(L,2)*(DMAX(L)**COST(L,3))
CINC=COST(L,2)*XINC(L)
IF (MDCOST.EQ.1) WRITE (6,210) L,CODE(L),(DESC(L,J),J=1,4),CSYMIN,CSYMAX
IF (MDCOST.NE.1) WRITE (6,210) L,CODE(L),(DESC(L,J),J=1,4),CSYMIN,CSYMAX,CINC



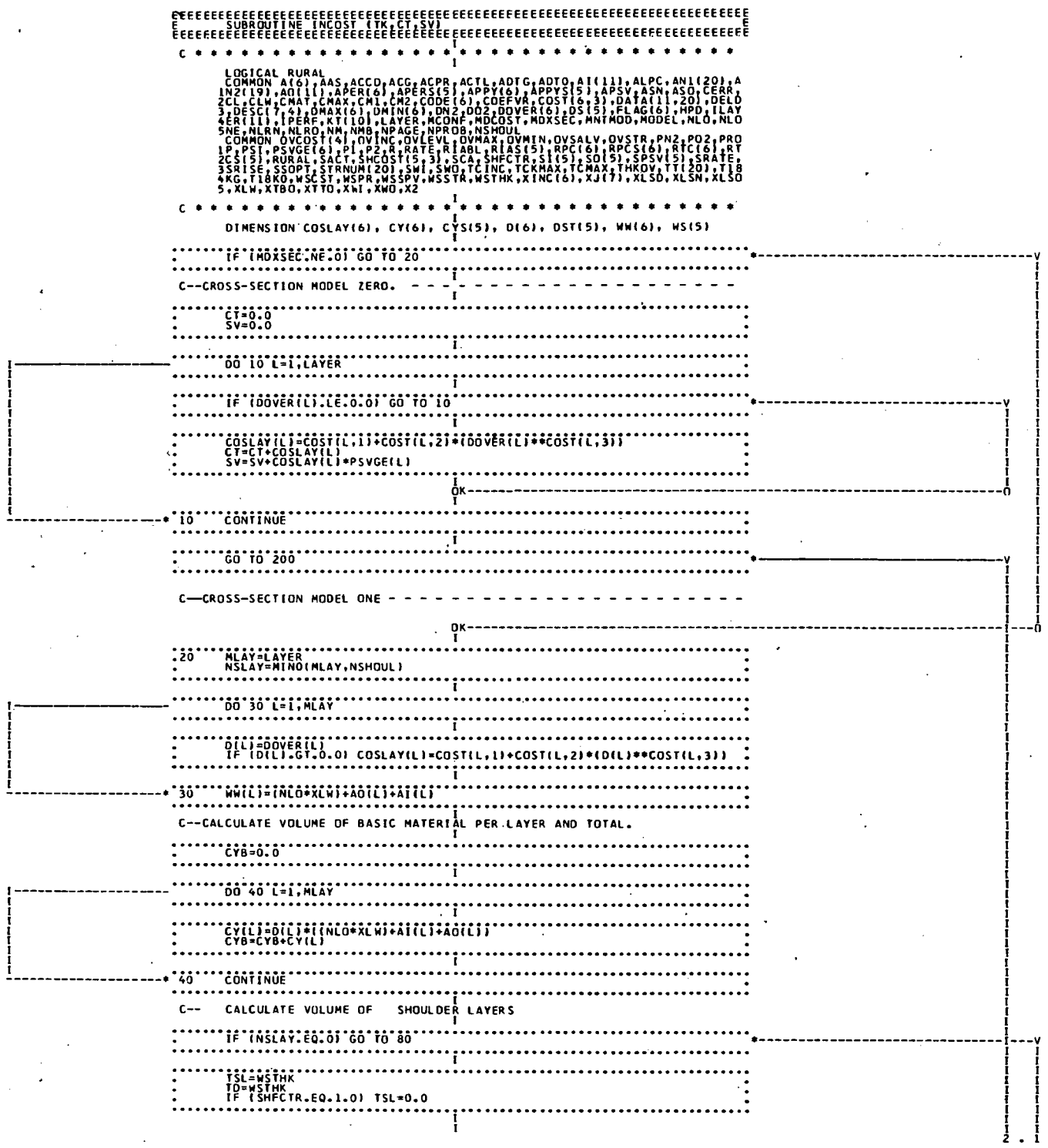
SYMBOL KEY

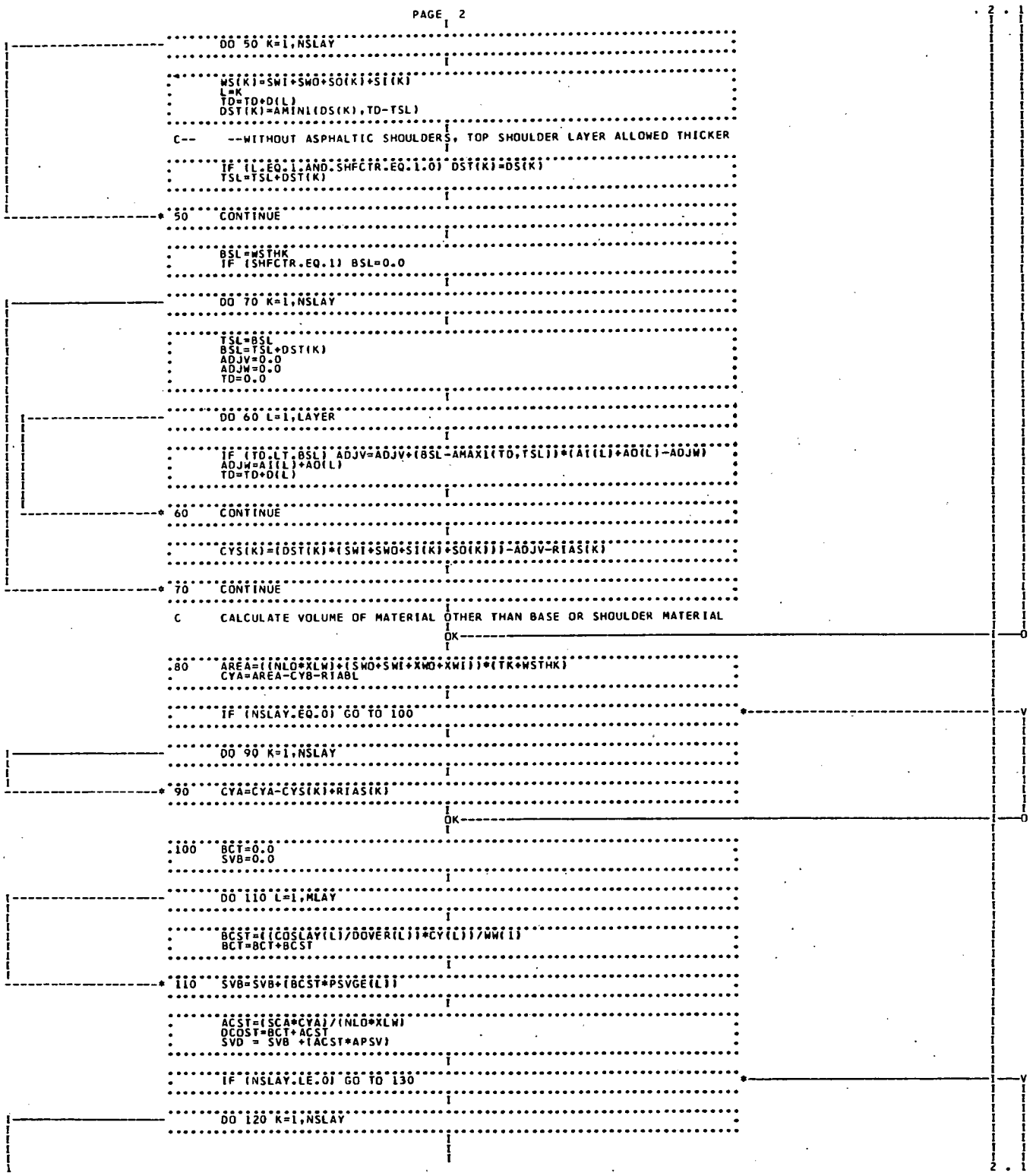
EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

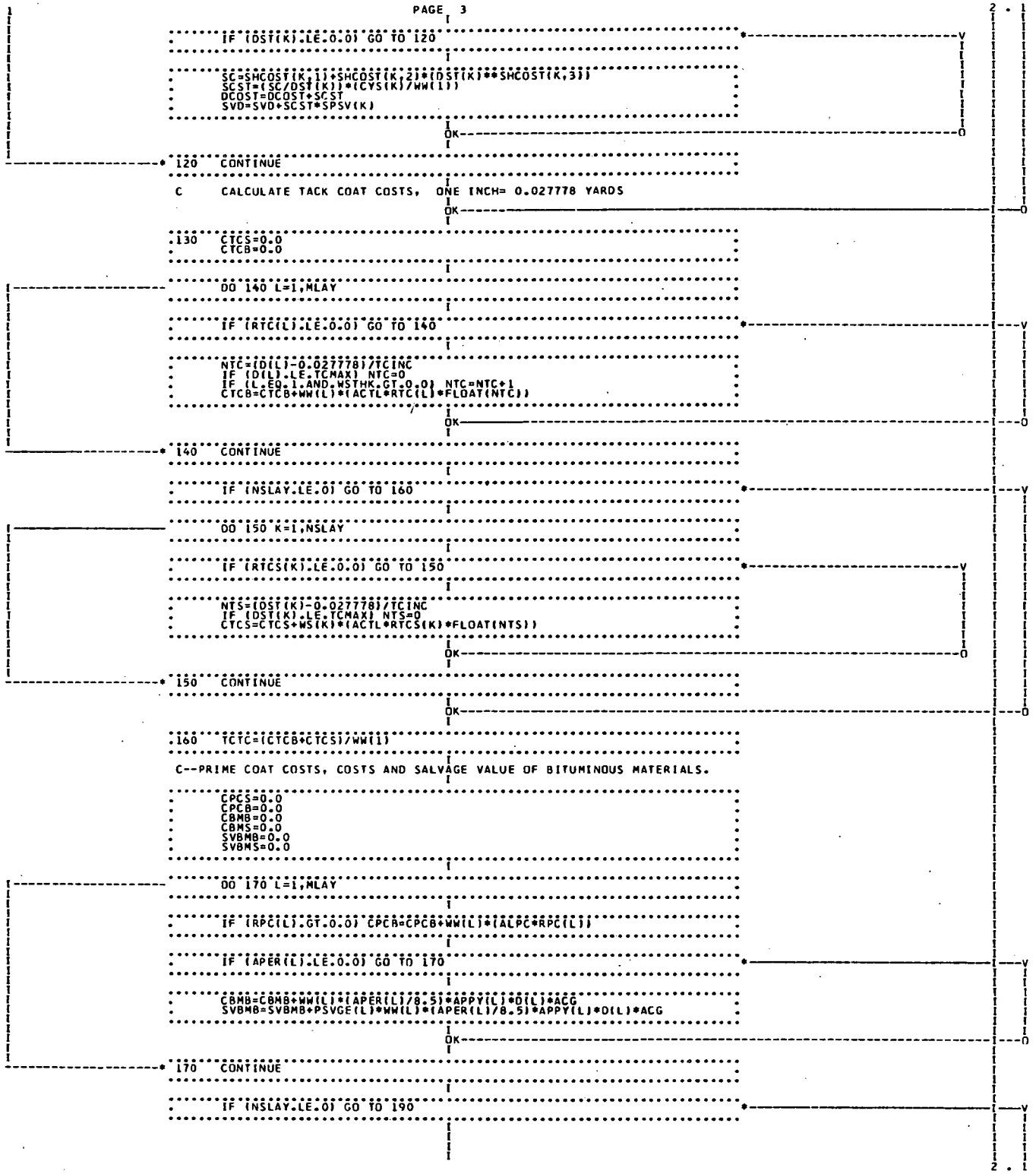


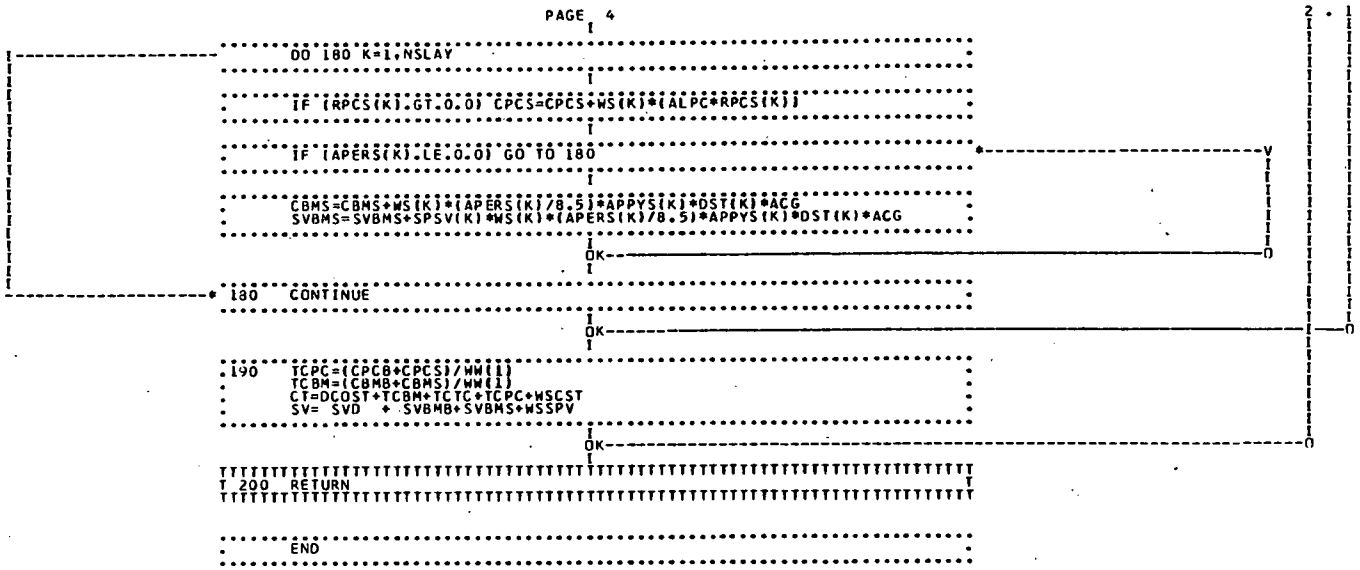
SYMBOL KEY

EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

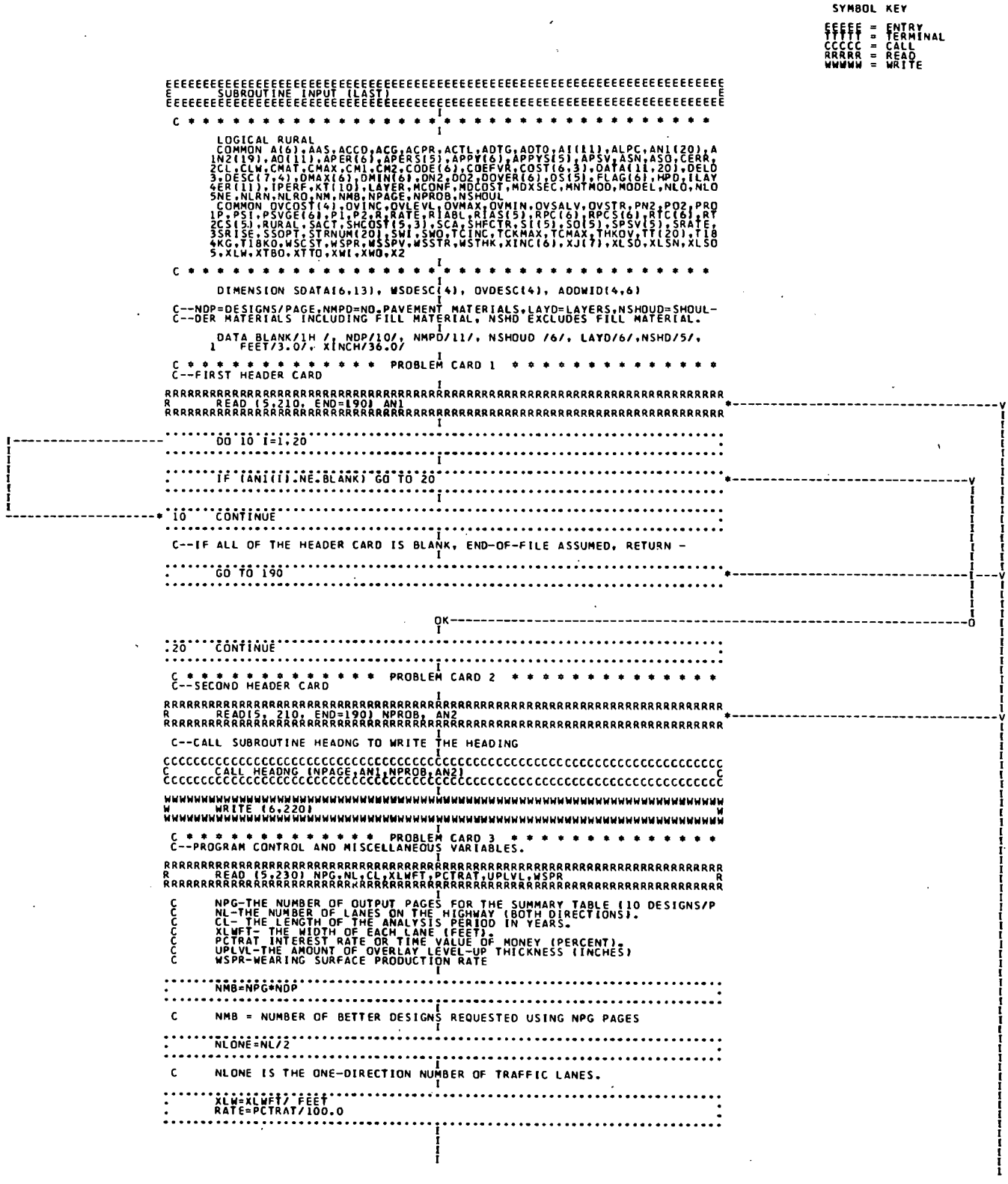



PAGE 2
DO 50 K=1,NSLAY
WS(K)=SWI+SWO+SO(K)+S(K)
L=K
TD=TD+D(L)
DST(K)=AMIN1(DS(K),TD-TSL)
C-- --WITHOUT ASPHALTIC SHOULDERS, TOP SHOULDER LAYER ALLOWED THICKER
IF (L.EQ.1.AND.SHFCTR.EQ.1.0) DST(K)=DS(K)
TSL=TSL+DST(K)
50 CONTINUE
BSL=WSTHK
IF (SHFCTR.EQ.1) BSL=0.0
DO 70 K=1,NSLAY
TSL=BSL
BSL=TSL+DST(K)
ADJV=0.0
ADJW=0.0
TD=0.0
DO 60 L=1,LAYER
IF (TD.LT.BSL) ADJV=ADJV+(BSL-AMAX1(TD,TSL))*(A1(L)+AO(L)-ADJW)
ADJW=A1(L)+AO(L)
TD=TD+D(L)
60 CONTINUE
CYS(K)=(DST(K)*(SWI+SWO+S1(K)+SO(K)))-ADJV-RIAS(K)
70 CONTINUE
C CALCULATE VOLUME OF MATERIAL OTHER THAN BASE OR SHOULDER MATERIAL
OK
80 AREA=((NLO*XLW)+(SWO+SWI+XWO+XWI))*(TK+WSTHK)
CYA=AREA-CYB-RIABL
IF (NSLAY.EQ.0) GO TO 100
DO 90 K=1,NSLAY
90 CYA=CYA-CYS(K)+RIAS(K)
OK
100 BCT=0.0
SVB=0.0
DO 110 L=1,MLAY
BCST=((COSLAY(L)/DOVER(L))*CY(L))/WW(1)
BCT=BCT+BCST
110 SVB=SVB+(BCST*PSVGE(L))
ACST=(SCA*CYA)/(NLO*XLW)
OCOST=BCT+ACST
SVD = SVB +(ACST*APSV)
IF (NSLAY.LE.0) GO TO 130
DO 120 K=1,NSLAY
2 . 1
2 . 1


PAGE 3
IF (DST(K).LE.0.0) GO TO 120
SC=SHCOST(K,1)+SHCOST(K,2)*(DST(K)**SHCOST(K,3))
SCST=(SC/DST(K))*(CYS(K)/WW(1))
DCOST=DCOST+SCST
SVD=SVD+SCST*SPSV(K)
OK
120 CONTINUE
C CALCULATE TACK COAT COSTS, ONE INCH= 0.027778 YARDS
OK
130 CTCS=0.0
CTCB=0.0
DO 140 L=1,MLAY
IF (RTC(L).LE.0.0) GO TO 140
NTC=(D(L)-0.027778)/TCINC
IF (D(L).LE.TCMAX) NTC=0
IF (L.EQ.1.AND.WSTHK.GT.0.0) NTC=NTC+1
CTCB=CTCB+WW(L)*(ACTL*RTC(L)*FLOAT(NTC))
OK
140 CONTINUE
IF (NSLAY.LE.0) GO TO 160
DO 150 K=1,NSLAY
IF (RTCS(K).LE.0.0) GO TO 150
NTS=(DST(K)-0.027778)/TCINC
IF (DST(K).LE.TCMAX) NTS=0
CTCS=CTCS+WS(K)*(ACTL*RTCS(K)*FLOAT(NTS))
OK
150 CONTINUE
OK
160 TCTC=(CTCB+CTCS)/WW(1)
C--PRIME COAT COSTS, COSTS AND SALVAGE VALUE OF BITUMINOUS MATERIALS.
CPCS=0.0
CPCB=0.0
CBMB=0.0
CBMS=0.0
SVBMB=0.0
SVBMS=0.0
DO 170 L=1,MLAY
IF (RPC(L).GT.0.0) CPCB=CPCB+WW(L)*(ALPC*RPC(L))
IF (APER(L).LE.0.0) GO TO 170
CBMB=CBMB+WW(L)*(APER(L)/8.5)*APPY(L)*D(L)*ACG
SVBMB=SVBMB+PSVGE(L)*WW(L)*(APER(L)/8.5)*APPY(L)*D(L)*ACG
OK
170 CONTINUE
IF (NSLAY.LE.0) GO TO 190


PAGE 4
DO 180 K=1,NSLAY
IF (RPCS(K).GT.0.0) CPCS=CPCS+WS(K)*(ALPC*RPCS(K))
IF (APERS(K).LE.0.0) GO TO 180
CBMS=CBMS+WS(K)*(APERS(K)/8.5)*APPYS(K)*DST(K)*ACG
SVBMS=SVBMS+SPSV(K)*WS(K)*(APERS(K)/8.5)*APPYS(K)*DST(K)*ACG
OK
180 CONTINUE
OK
190 TCPC=(CPCB+CPCS)/WW(1)
TCBM=(CBMB+CBMS)/WW(1)
CT=DCOST+TCBM+TCTC+TCPC+WSCST
SV= SVD + SVBMB+SVBMS+WSSPV
OK
T 200 RETURN
END

INPUT

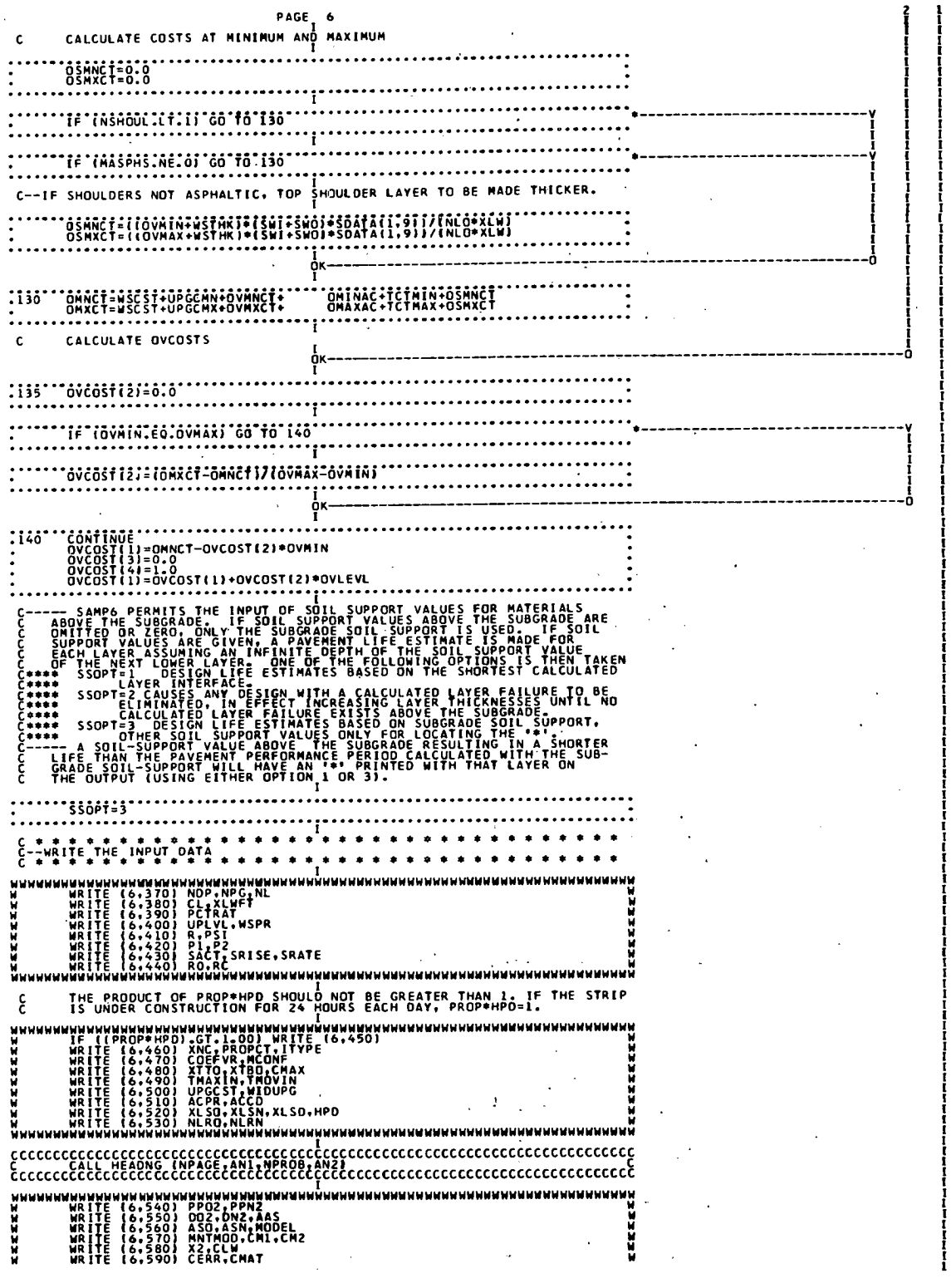

SYMBOL KEY
EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE
SUBROUTINE INPUT (LAST)
LOGICAL RURAL
COMMON A(6),AAS,ACCD,ACG,ACPR,ACTL,ADTG,ADTO,AI(11),ALPC,AN1(20),A
1N2(19),AO(11),APER(6),APERS(5),APPY(6),APPYS(5),APSV,ASN,ASO,CERR,
2CL,CLW,CMAT,CMAX,CM1,CM2,CODE(6),COEFVA,COST(6,3),DATA(11,20),DELO
3,DESC(7,4),DMAX(6),DMIN(6),DN2,DO2,DOVER(6),DS(5),FLAG(6),HPD,ILAY
4ER(11),IPERF,KT(10),LAYER,MCONF,MDCOST,MDXSEC,MNTMOD,MODEL,NLO,NLO
5NE,NLRN,NLRO,NM,NMB,NPAGE,NPROB,NSHOUL
COMMON OVCOST(4),OVINC,OVLEVL,OVMAX,OVMIN,OVSALV,OVSTR,PN2,PO2,PRO
1P,PSI,PSVGE(6),P1,P2,R,RATE,RIABL,RIAS(5),RPC(6),RPCS(6),RTC(6),RT
2CS(5),RURAL,SACT,SHCOST(5,3),SCA,SHFCTR,SI(5),SO(5),SPSV(5),SRATE,
3SRISE,SSOPT,STRNUM(20),SWI,SWO,TCINC,TCKMAX,TCMAX,THKOV,TT(20),T18
4KG,T18KO,WSCST,WSPR,WSSPV,WSSTR,WSTHK,XINC(6),XJ(7),XLSO,XLSN,XLSO
5,XLW,XT80,XTTO,XWI,XWO,X2
DIMENSION SDATA(6,13), WSDESC(4), OVDESC(4), ADDWID(4,6)
C--NDP=DESIGNS/PAGE,NMPD=NO.PAVEMENT MATERIALS,LAYD=LAYERS,NSHOUD=SHOUL-
C--DER MATERIALS INCLUDING FILL MATERIAL, NSHD EXCLUDES FILL MATERIAL.
DATA BLANK/1H /, NDP/10/, NMPD/11/, NSHOUD /6/, LAYD/6/,NSHD/5/,
1 FEET/3.0/, XINCH/36.0/
C * * * * * * * * * * * * * * PROBLEM CARD 1 * * * * * * * * * * * * * *
C--FIRST HEADER CARD
READ (5,210, END=190) AN1
DO 10 I=1,20
IF (AN1(I).NE.BLANK) GO TO 20
10 CONTINUE
C--IF ALL OF THE HEADER CARD IS BLANK, END-OF-FILE ASSUMED, RETURN -
GO TO 190
OK
20 CONTINUE
C * * * * * * * * * * * * * PROBLEM CARD 2 * * * * * * * * * * * * * *
C--SECOND HEADER CARD
READ(5, 210, END=190) NPROB, AN2
C--CALL SUBROUTINE HEADNG TO WRITE THE HEADING
CALL HEADNG (NPAGE,AN1,NPROB,AN2)
WRITE (6,220)
C * * * * * * * * * * * * * PROBLEM CARD 3 * * * * * * * * * * * * * *
C--PROGRAM CONTROL AND MISCELLANEOUS VARIABLES.
READ (5,230) NPG,NL,CL,XLWFT,PCTRAT,UPLVL,WSPR
C NPG-THE NUMBER OF OUTPUT PAGES FOR THE SUMMARY TABLE (10 DESIGNS/P
C NL-THE NUMBER OF LANES ON THE HIGHWAY (BOTH DIRECTIONS).
C CL- THE LENGTH OF THE ANALYSIS PERIOD IN YEARS.
C XLWFT- THE WIDTH OF EACH LANE (FEET).
C PCTRAT INTEREST RATE OR TIME VALUE OF MONEY (PERCENT).
C UPLVL-THE AMOUNT OF OVERLAY LEVEL-UP THICKNESS (INCHES)
C WSPR-WEARING SURFACE PRODUCTION RATE
NMB=NPG*NDP
C NMB = NUMBER OF BETTER DESIGNS REQUESTED USING NPG PAGES
NLONE=NL/2
C NLONE IS THE ONE-DIRECTION NUMBER OF TRAFFIC LANES.
XLW=XLWFT/ FEET
RATE=PCTRAT/100.0

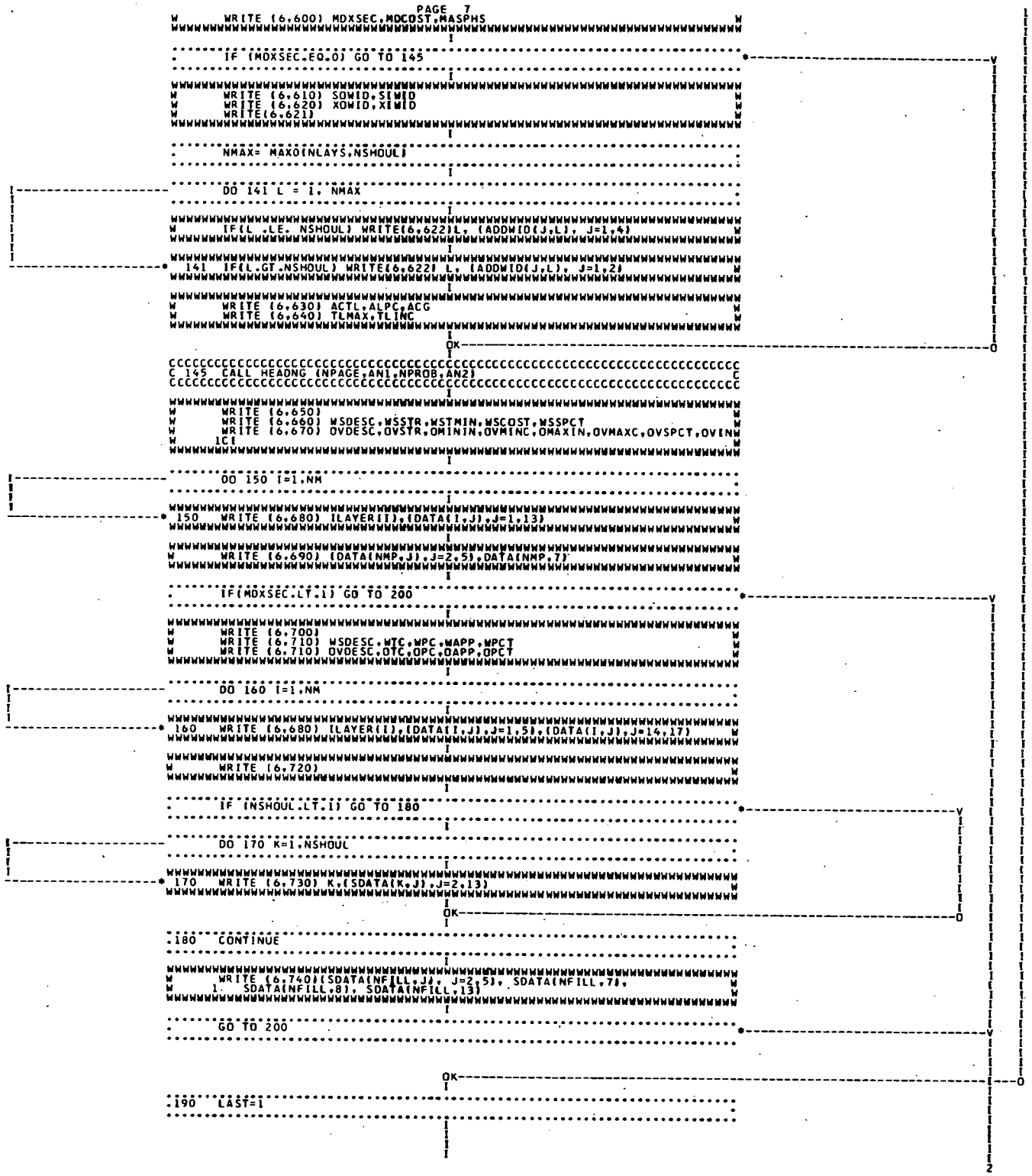
```
                                        PAGE  2
C     RATE-THE INTEREST RATE OR TIME VALUE OF MONEY(PERCENT/100.)
C * * * * * * * * * * * * *  PROBLEM CARD 4  * * * * * * * * * * * * * *
C--ENVIONMENTAL AND SERVICEABILITY VARIABLES
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R       READ (5,240) R,PSI,P1,P2,SACT,SRISE,SRATE                         R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
C     R-THE REGIONAL FACTOR.
C     PSI-THE SERVICEABILITY INDEX OF THE INITIAL STRUCTURE.
C     P1-SERVICEABILITY INDEX AFTER AN OVERLAY.
C     P2-THE MINIMUM ALLOWED VALUE OF THE SERVICEABILITY INDEX
C     (POINT AT WHICH AN OVERLAY MUST BE APPLIED).
C     SACT- A FRACTION BETWEEN 0.0 AND 1.0 WHICH REPRESENTS THE
C     PROPORTION OF THE PROJECT'S LENGTH WHICH IS LIKELY TO
C     EXPERIENCE SWELL.IT IS A PROBABILITY OF SWELL.
C     SRISE- A MEASURE(IN INCHES) OF HOW MUCH THE SURFACE OF A BED OF
C     CLAY CAN RISE IF IT IS SUPPLIED WITH ALL OF THE MOISTURE IT WANTS
C     IT CAN BE ESTIMATED IN A PARTICULAR LOCALITY FROM THE TOTAL AMOUNT
C     OF DIFFERENTIAL HEAVE THE ENGINEER WOULD EXPECT TO OBSERVE OVER A
C     LONG PERIOD OF TIME.
C     SRATE-(SWELL RATE) VARIES BETWEEN 0.04 AND 0.20. IT IS USED TO
C     CALCULATE HOW FAST SWELLING TAKES PLACE.IT IS LARGER WHEN THE
C     SOIL IS CRACKED AND OPEN AND WHEN A LARGE MOISTURE SUPPLY IS
C     AVAILABLE DUE TO POOR DRAINAGE CONDITIONS,UNDERGROUND SEEPS,OR
C     OTHER SOURCES OF WATER.WHEN DRAINAGE CONDITIONS ARE GOOD AND THE
C     SOIL IS TIGHT,THEN SRATE BECOMES SMALLER.
C * * * * * * * * * * * * *  PROBLEM CARD 5  * * * * * * * * * * * * * *
C--LOAD AND TRAFFIC VARIABLES.
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R       READ (5,250) RO,RC,XNC,PROPCT,ITYPE,COEFVR,MCONF                  R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
C     RO-THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE BEGINNING OF THE
C     ANALYSIS PERIOD.
C     RC-THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE END OF THE
C        ANALYSIS PERIOD.
C     XNC-THE ONE-DIRECTION ACCUMULATED NUMBER OF EQUIVALENT 18-KIP AXLE
C     DURING THE ANALYSIS PERIOD.
C   PROPCT-THE PERCENT OF ADT WHICH WILL PASS THROUGH THE OVERLAY ZONE
C     DURING EACH HOUR WHILE OVERLAYING TAKES PLACE(NORMALLY ABOUT
C     6 PERCENT FOR RURAL AREAS AND 5.5 PERCENT FOR URBAN AREAS).
C      ITYPE-IS A CODE FOR THE TYPE OF ROAD UNDER CONSIDERATION.
C     ITYPE=1 DESIGNATES A RURAL ROAD AND ITYPE=2 DESIGNATES AN
C     URBAN ROAD.
C     COEFVR-THE COEFFICIENT OF VARIATION.
C     MCONF-THE CONFIDENCE LEVEL INDICATOR.
.....................................................................
.     PROP=PROPCT*0.01                                              .
.     ADTO=RO                                                       .
.     ADTG=(RC-RO)/CL                                               .
.     TEMP=XNC*2/(CL*(RO+RC))                                       .
.     T18KO=RO*TEMP                                                 .
.     T18KG=((RC-RO)/CL)*TEMP                                       .
.     RURAL=.FALSE.                                                 .
.     IF (ITYPE.EQ.1) RURAL=.TRUE.                                  .
.....................................................................
C * * * * * * * * * * * * *  PROBLEM CARD 6  * * * * * * * * * * * * * *
C--CONSTRAINTS.
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R       READ (5,240) XTTO,XTBO,CMAX,TMAXIN,TMOVIN,UPGCST,WIDUPG           R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
C     XTTO-THE MINIMUM ALLOWED TIME TO THE FIRST OVERLAY.
C     XTBO-THE MINIMUM ALLOWED TIME BETWEEN OVERLAYS PERMITTED.
C     CMAX-MAXIMUM FUNDS AVAILABLE FOR INITIAL CONSTRUCTION.
C     TMAXIN-THICKNESS ALLOWOWED AX MAXIMUM FOR INITIAL CONSTRUCTION
C        (INCHES).
C     TMOVIN-THICKNESS ALLOWABLE FOR ALL OVERLAYS COMBINED(INCHES).
C     UPGCST-COST OF UPGRADING PAVEMENT & SHOULDERS AFTER AN OVERLAY
C     WIDUPG-WIDTH OF PAVEMENT & SHOULDERS UPGRADED AFTER AN OVERLAY, FT
.....................................................................
.     TCKMAX=TMAXIN/36.0                                            .
.     THKOV=TMOVIN/36.0                                             .
.     UPGWID=WIDUPG/3.                                              .
.....................................................................
C * * * * * * * * * * * * *  PROBLEM CARD 7  * * * * * * * * * * * * * *
C--TRAFFIC DELAY VARIABLES.
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R       READ (5,270) ACPR,ACCD,XLSO,XLSN,XLSD,HPD,NLRO,NLRN               R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
C     ACPR-ASPHALTIC CONCRETE PRODUCTION RATE (TONS PER HOUR)
C     ACCO-ASPHALTIC CONCRETE COMPACTED DENSITY(TONS/COMACTED CY)
C     XLSO-THE DISTANCE,MEASURED ALONG THE C.L.,OVER WHICH TRAFFIC IS
C     SLOWED IN THE OVERLAY DIRECTION.
C     XLSN-THE DISTANCE,MEASURED ALONG THE C.L.,OVER WHICH TRAFFIC ISC
C     SLOWED IN THE NON-OVERLAY DIRECTION.
C     XLSD-THE DISTANCE,MEASURED ALONG THE DETOUR,AROUND THE OVERLAY ZON
C     HPD-THE NUMBER OF HOURS PER DAY THAT OVERLAY CONSTRUCTION TAKES PL
C     NLRO-THE NUMBER OF LANES IN THE RESTRICTED ZONE IN THE
C        OVERLAY DIRECTION.
C     NLRN-THE NUMBER OF LANES IN THE RESTRICTED ZONE IN THE
C        NON-OVERLAY DIRECTION.
C * * * * * * * * * * * * *  PROBLEM CARD 8  * * * * * * * * * * * * * *
C--MORE TRAFFIC DELAY AND USER COST VARIABLES.
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R       READ (5,280) PPO2,PPN2,DO2,DN2,AAS,ASO,ASN,MODEL                  R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
C     PPO2-THE PERCENT OF VEHICLES THAT WILL BE STOPPED IN THE OVERLAY
C     DIRECTION BECAUSE OF MOVEMENT OF PERSONNEL OR EQUIPMENT.
C     PPN2-THE PERCENT OF VEHICLES THAT WILL BE STOPPED IN THE
C      NON-OVERLAY DIRECTION BECAUSE OF PERSONNEL OR EQUIPMENT.
C     DO2--THE   AVERAGE DELAY PER VEHICLE STOPPED IN THE OVERLAY DIRECT
C      BECAUSE OF MOVEMENT OF OVERLAY PERSONNEL AND EQUIPMENT IN THE
C     RESTRICTED ZONE.
C     DN2--THE AVERAGE DELAY PER VEHICLE STOPPED IN THE NON-OVERLAY
C     DIRECTION BECAUSE OF MOVEMENT OF PERSONNEL OR EQUIPMENT.
C     AAS-THE AVERAGE APPROACH SPEED TO THE OVERLAY AREA,ASSUMED TO BE
```

```
                                    PAGE  3
C     THE SAME FOR BOTH DIRECTIONS.
C     ASO-THE THE AVERAGE SPEED THROUGH THE OVERLAY AREA,IN THE OVERLAY
C     DIRECTION.
C     ASN-THE THE AVERAGE SPEED THROUGH THE OVERLAY AREA,IN THE
C     NON-OVERLAY DIRECTION.
C     MODEL- THE MODEL NUMBER WHICH DESCRIBES THE TRAFFIC SITUATION.
                                    I
.....................................................................
.     PO2=PPO2/100.                                                 .
.     PN2=PPN2/100.                                                 .
.....................................................................
                                    I
 C * * * * * * * * * * * * * PROBLEM CARD 9  * * * * * * * * * * * * * *
 C--MAINTENANCE VARIABLES.
                                    I
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R      READ (5,290) MNTMOD,CM1,CM2,X2,CLW,CERR,CMAT                     R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
                                    I
 C      MNTMOD-MAINTENANCE MODEL, 1 =  EXPLICIT COSTS PER MILE, 2=NCHRP.
 C      CM1-INITIAL ANNUAL ROUTINE COST($/LANE MILE, MNTMOD=1).
 C      CM2-ANNUAL INCREMENTAL INCREASE IN COSTS($/LANE MI/YR,MNTMOD=1)
 C      X2-DAYS PER YEAR THAT TEMPERATURE IS BELOW FREEZING  (MNTMOD=2).
 C      CLW- THE COMPOSITE LABOR WAGE(MNTMOD=2).
 C      CERR-THE COMPOSITE EQUIPMENT RENTAL RATE(MNTMOD=2).
 C      CMAT-THE RELATIVE MATERIAL COST BASED ON A VALUE OF 1.00 FOR A
 C           ROAD OF INTERSTATE TYPE (MNTMOD=2).
 C      ***FOR INFORMATION ON THESE VARIABLES SEE NCHRP REPORT 42.***
 C * * * * * * * * * * * * * PROBLEM CARD 10 * * * * * * * * * * * * * *
 C-----READ IN XSECTION & COST MODELS, NO. OF SHOULDERS & SHOULDER WIDTHS
                                    I
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R      READ (5,300) MDXSEC,MDCOST,MASPHS,SOWID,SIWID,XOWID,XIWID         R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
                                    I
 C              MDXSEC - THE MODEL USED TO CALCULATE CROSS SECTION AREAS.
 C              MDCOST - THE MODEL USED TO CALCULATE CROSS SECTION COSTS.
 C              MASPHS - MODEL FOR ASPHALTIC SHOULDERS(0=NOT ASPHALTIC)
 C              SOWID - WIDTH OF OUTSIDE SHOULDER IN FEET.
 C              SIWID - WIDTH OF  INSIDE SHOULDER IN FEET.
 C              XOWID - XSECTION WIDTH OUTSIDE OF OUTSIDE SHOULDER, IN FT.
 C              XIWID - XSECTION WIDTH OUTSIDE OF  INSIDE SHOULDER, IN FT.
                                    I
.....................................................................
.     SWO=SOWID/FEET                                                .
.     SWI=SIWID/FEET                                                .
.     XWO=XOWID/FEET                                                .
.     XWI=XIWID/FEET                                                .
.....................................................................
                                    I
 C * * * * * * * * * * *  CARDS 11, 12, 13, AND 14 * * * * * * * * * * *
 C--ADDITIONAL WIDTH OF OUTSIDE AND INSIDE, PAVEMENT AND SHOULDER LAYERS.
 C--OMIT IF MDXSEC=0.  BITUMINOUS MATERIAL COST ZERO FOR MDXSEC=0.
                                    I
.....................................................................
.     ACG=0.0                                                       .
.....................................................................
                                    I
.....................................................................
.     IF(MDXSEC .LT. 1) GO TO 25                                    .
.....................................................................
                                    I
.....................................................................
.     DO 21 I = 1, 4                                                .
.....................................................................
                                    I
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
*  21   READ(5,240)(ADDWID(I,L),L=1, LAYD)                           R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
                                    I
.....................................................................
.     DO 22 L = 1, LAYD                                             .
.....................................................................
                                    I
.....................................................................
.     AO(L) = ADDWID(1,L)/FEET                                      .
.....................................................................
                                    I
.....................................................................
*  22   AI(L) = ADDWID(2,L)/FEET                                    .
.....................................................................
                                    I
.....................................................................
.     DO 23 K=1, NSHD                                               .
.....................................................................
                                    I
.....................................................................
.     SO(K)=ADDWID(3,K)/FEET                                        .
.....................................................................
                                    I
.....................................................................
*  23   SI(K)=ADDWID(4,K)/FEET                                      .
.....................................................................
                                    I
 C * * * * * * * * * * * * * PROBLEM CARD 15  * * * * * * * * * * * * * *
 C--COST/SQ.YD. OF TACK, PRIME, BITMEN, AND LIFT THICKNESS.
 C--OMIT IF MDXSEC=0
                                    I
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R                    READ (5,240) ACTL,ALPC,ACG,TLMAX,TLINC             R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
                                    I
 C              ACTL - TACK COAT COST, $/GAL.
 C              ALPC - PRIME COAT COST, $/GAL.
 C              ACG - BITUMINOUS MATERIAL COST, $/GAL.
 C              TLMAX - MAXIMUM LAYER DEPTH FOR NO TACK COATS, INCHES.
 C              TLINC - MAXIMUM DEPTH OF EACH LIFT ABOVE TLMAX, INCHES.
                                    I
.....................................................................
.     TCMAX=TLMAX/XINCH                                             .
.     TCINC=AMAX1(1.0,TLINC)/XINCH                                  .
.....................................................................
                                    I
 C * * * * * * * * * * * * * PROBLEM CARD 16  * * * * * * * * * * * * * *
 C--WEARING SURFACE PROPERTIES.
                                    I
                                    I
                                    I
```

```
                                      PAGE  4
                                        OK
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R 25    READ (5,310) WSDESC,WSSTR,WSTMIN,WSCOST,WSSPCT,WTC,WPC,WAPP,WPCT    R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
C      WSDESC-16 CHARACTER ALPHA FIELD WITH WEARING SURFACE DESCRIPTION
C      WSSTR-WEAR SURFACE STRENGTH COEFFICIENT.
C      WSTMIN-THICKNESS OF WEARING SURFACE      (INCHES)
C      WSCOST-IN PLACE COST OF WEARING SURFACE(PER CU.YD.)
C      WSSPCT-WEARING SURFACE SALVAGE VALUE
C      WTC-TACK COAT APPLICATION RATE (GAL/SQ. YD.)
C      WPC-PRIME COAT APPLICATION RATE (GAL/SQ. YD.)
C      WAPP-AC APPLICATION RATE (LB/IN.)
C      WPCT-ASPHALT CONTENT PER CENT
.....................................................................................
.      WPPY=WAPP*XINCH                                                              .
.      WPER=WPCT/100.0                                                              .
.      WSTHK=WSTMIN/XINCH                                                           .
.      WSCST=(WSTHK*WSCOST) + (WPPY*WSTHK*WPER/8.5)*ACG                             .
.      WSSPV=-WSSPCT*WSCST/100.                                                     .
.....................................................................................

C * * * * * * * * * * * * *  PROBLEM CARD 17  * * * * * * * * * * * * *
C--OVERLAY PROPERTIES.

RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R      READ (5,320) OVDESC,OVSTR,OMININ,OVMINC,OMAXIN,OVMAXC,OVSPCT,OVINCR    R
R      11,OTC,OPC,OAPP,OPCT                                                    R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
C      OVDESC-16 CHARACTER FIELD WITH OVERLAY DESCRIPTION (ALPHA)
C      OVSTR-OVERLAY STRENGTH COEFFICIENT.
C      OMININ-MINIMUM OVERLAY THICKNESS, INCHES
C      OVMINC-IN PLACE OVERLAY COST/CU YD AT MINIMUM THICKNESS
C      OMAXIN-MAXIMUM OVERLAY THICKNESS, INCHES
C      OVMAXC-IN PLACE COST OF OVERLAY/CU YD AT MAXIMUM THICKNESS
C      OVLPCT-OVERLAY SALVAGE VALUE IN PERCENT
C      OVINCI-OVERLAY INCREMENT IN INCHES
C      OTC-TACK COAT APPLICATION RATE (GAL/SQ. YD.)
C      OPC-PRIME COAT APPLICATION RATE (GAL/SQ. YD.)
C      OAPP-AC APPLICATION RATE (LB/IN.)
C      OPCT-ASPHALT CONTENT PER CENT
.....................................................................................
.      OVMIN=OMININ/XINCH                                                           .
.      OVMAX=OMAXIN/XINCH                                                           .
.      OMNCI = OVMIN*OVMINC                                                         .
.      OMXCI = OVMAX*OVMAXC                                                         .
.      OVSALV=-OVSPCT/100.0                                                         .
.....................................................................................

C--OVINC-OVERLAY INCREMENT IN YARDS, NOT LESS THAN 1/4 INCH

.....................................................................................
.      OVINC=AMAX1(OVINCI,0.25)/XINCH                                               .
.      OPPY=OAPP*XINCH                                                              .
.      OVLEVL=UPLVL/XINCH                                                           .
.      OPER=OPCT/100.0                                                              .
.....................................................................................

C * * * * * * * * * * * * *  PROBLEM CARD GROUP 18 * * * * * * * * * * * * *
C--PAVEMENT MATERIALS AND THEIR PROPERTIES, LAST CARD IS THE SUBGRADE.
C--COL 1, ILAYER( ) THE LAYER NUMBER IN WHICH THE MATERIAL MAY BE USED.
C--   ILAYER FIELD MUST BE BLANK OR ZERO ON SUBGRADE MATERIAL CARD.
C--COL 3, DATA( ,1) A CODE LETTER IDENTIFYING THE MATERIAL.
C--COL 5-20, DATA( , 2 3 4 5) NAME OF THE MATERIAL(16 CHARACTER ALPHA).
C--COL 21-25, DATA( ,6) STRENGTH COEFFICIENT.
C--COL 26-30, DATA( ,7) SOIL SUPPORT VALUE.
C--COL 31-35, DATA( ,8) MINIMUM LAYER THICKNESS.
C--COL 36-40, DATA( ,9) AT MIN., IN-PLACE COST / COMPACTED CUBIC YARD.
C--COL 41-45, DATA( ,10) MAXIMUM LAYER THICKNESS.
C--COL 46-50, DATA( ,11) AT MAX THICKNESS, IN PLACE COST/CUBIC YD.
C--COL 51-55, DATA( ,12) SALVAGE VALUE PERCENTAGE OF THE MATERIAL.
C--COL 56-60, DATA( ,13) IS THE LAYER INCREMENT IN INCHES.
C--COL 61-65, DATA( ,14) IS THE TACK COAT APPLICATION RATE (GAL/SQ.YD.).
C--COL 66-70, DATA( ,15) IS THE PRIME COAT APPLICATION RATE (GAL/SQ.YD.)
C--COL 71-75, DATA( ,16) IS THE AC APPLICATION RATE (LB/IN.).
C--COL 76-80, DATA( ,17) IS THE ASPHALT CONTENT PER CENT.
.....................................................................................
.      NLAYS=0                                                                      .
.....................................................................................

.....................................................................................
.      DO 30 J=1,NMPD                                                               .
.....................................................................................

RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R      READ (5,330) ILAYER(J),(DATA( ,K),K=1,17)                               R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
.....................................................................................
.      IF (ILAYER(J).EQ.0) GO TO 40                                                 .
.....................................................................................
.....................................................................................
.30    NLAYS=MAXO(NLAYS,ILAYER(J))                                                  .
.....................................................................................

WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW
W      WRITE (6,340) NMPD                                                      W
WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW
.....................................................................................
.      GO TO 190                                                                    .
.....................................................................................

                                        OK
.....................................................................................
.40    NM=J-1                                                                       .
.      NMP=NM+1                                                                     .
.      SHFCTR=1.                                                                    .
.      NSHOUL=0                                                                     .
.....................................................................................
```

```
                                                                PAGE  5
      IF (MOXSEC.EQ.0) GO TO 135
C * * * * * * * * * * * * * * *  PROBLEM CARD GROUP 13 * * * * * * * * * * * * * * *
C--SHOULDER MATERIALS AND THEIR PROPERTIES, LAST CARD IS FILL MATERIAL.
C--FILL MATER. HAS ZERO IN DEPTH FIELD, OMIT GROUP IF MOXSEC=0.
C--COL 5-20,SDATA( ,2 3 4 5) NAME OF MATERIAL(16 CHAR. ALPHA).
C--COL 21-25,SDATA( ,6) DEPTH IN INCHES(ZERO OR BLANK FOR FILL MATERIAL)
C--COL 26-30,SDATA( ,7)IN PLACE COST/CU.YD.
C--COL 31-35,SDATA(,8) SALVAGE VALUE(PCT).
C--COL 36-40,SDATA( ,9) TACK COAT APPLICATION RATE (GAL/SQ.YD.).
C--COL 41-45,SDATA( ,10) PRIME COAT APPLICATION RATE(GAL/SQ.YD.).
C--COL 46-50,SDATA( ,11) AC APPLICATION RATE (LB/IN).
C--COL 51-56,SDATA( ,12) ASPHALTIC CONTENT PER CENT.
C--COL 56-60,SDATA( ,13) ADJUSTMENT VOLUME.
      DO 60 NFILL = 1, NSHOUD
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
R     READ (5,350) (SDATA(NFILL,J), J=2, 13)                                  R
RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
      IF(SDATA(NFILL,6) .EQ. 0) GO TO 70
 60   CONTINUE
      NFILL = NSHOUD
                                                                OK
 70   NSHOUL = NFILL-1
      SCA = SDATA(NFILL,7)
      APSV=-SDATA(NFILL,8)/100.0
      RIABL=SDATA(NFILL,13)
      IF (NSHOUL.LT.1) GO TO 100
      DO 90 I=1,NSHOUL
      DS(I)=SDATA(I,6)/XINCH
      SHCOST(I,1)=0.0
      SHCOST(I,3)=1.0
      SHCOST(I,2)=SDATA(I,7)
      SPSV(I)=-SDATA(I,8)/100.
      RTCS(I)=SDATA(I,9)
      RPCS(I)=SDATA(I,10)
      APPYS(I)=SDATA(I,11)*36.
      APERS(I)=SDATA(I,12)/100.
      RIAS(I)=SDATA(I,13)
 90   CONTINUE
                                                                OK
100   CONTINUE
      IF (MODEL.GT.2) UPGWID=UPGWID/2.
      NLO=NLONE
      IF (MODEL.LT.3) NLO=NLONE*2
C--SHFCTR IS THE PROPORTION OF OVERLAY & WEARCOURSE WIDTH TO PAVE. WIDTH
C--SHFCTR .GT. 1 ONLY MOXSEC .EQ.1 AND IF ASPHALTIC SHOULDERS.
      IF (MOXSEC.NE.1.OR.NSHOUL.LT.1) GO TO 120
      IF (MASPHS.NE.0)SHFCTR=1.0+(SWO+SWI)/(FLOAT(NLO)*XLW)
                                                                OK
120   UPGCMN=UPGWID*(WSTHK+OVMIN)*UPGCST/(NLO*XLW)
      UPGCMX=UPGWID*(WSTHK+OVMAX)*UPGCST/(NLO*XLW)
      OVMNCT=(OVMIN*OVMINC)*SHFCTR
      OVMXCT=(OVMAX*OVMAXC)*SHFCTR
      OMINAC=((OPPY*OVMIN*OPER/8.5)*ACG)*SHFCTR
      OMAXAC=((OPPY*OVMAX*OPER/8.5)*ACG)*SHFCTR
C--OVERLAY, WEARING-SURFACE, AND TACK-COAT COSTS. INCLUDE SHOULDERS.
      WSCST = WSCST * SHFCTR
      WSSPV = WSSPV * SHFCTR
      NTCMIN=(OVMIN-0.0277778)/TCINC
      IF (OVMIN.LE.TCMAX) NTCMIN=0
      NWC=0
      IF (WSTHK.GT.0.0) NWC=1
      TCTMIN=(ACTL*OTC*NTCMIN+(ACTL*WTC*NWC))*SHFCTR
      NTCMAX=(OVMAX-0.0277778)/TCINC
      IF (OVMAX.LE.TCMAX) NTCMAX=0
      NWC=0
      IF (WSTHK.GT.0.0) NWC=1
      TCTMAX=(ACTL*OTC*NTCMAX+(ACTL*WTC*NWC))*SHFCTR
```


PAGE 6
C CALCULATE COSTS AT MINIMUM AND MAXIMUM
OSMNCT=0.0
OSMXCT=0.0
IF (NSHOUL.LT.1) GO TO 130
IF (MASPHS.NE.0) GO TO 130
C--IF SHOULDERS NOT ASPHALTIC, TOP SHOULDER LAYER TO BE MADE THICKER.
OSMNCT=((OVMIN+WSTHK)*(SWI+SWO)*SDATA(1,9))/(NLO*XLW)
OSMXCT=((OVMAX+WSTHK)*(SWI+SWO)*SDATA(1,9))/(NLO*XLW)
OK
130 OMNCT=WSCST+UPGCMN+OVMNCT+ OMINAC+TCTMIN+OSMNCT
OMXCT=WSCST+UPGCMX+OVMXCT+ OMAXAC+TCTMAX+OSMXCT
C CALCULATE OVCOSTS
OK
135 OVCOST(2)=0.0
IF (OVMIN.EQ.OVMAX) GO TO 140
OVCOST(2)=(OMXCT-OMNCT)/(OVMAX-OVMIN)
OK
140 CONTINUE
OVCOST(1)=OMNCT-OVCOST(2)*OVMIN
OVCOST(3)=0.0
OVCOST(4)=1.0
OVCOST(1)=OVCOST(1)+OVCOST(2)*OVLEVL
C----- SAMP6 PERMITS THE INPUT OF SOIL SUPPORT VALUES FOR MATERIALS
C ABOVE THE SUBGRADE. IF SOIL SUPPORT VALUES ABOVE THE SUBGRADE ARE
C OMITTED OR ZERO, ONLY THE SUBGRADE SOIL SUPPORT IS USED. IF SOIL
C SUPPORT VALUES ARE GIVEN, A PAVEMENT LIFE ESTIMATE IS MADE FOR
C EACH LAYER ASSUMING AN INFINITE DEPTH OF THE SOIL SUPPORT VALUE
C OF THE NEXT LOWER LAYER. ONE OF THE FOLLOWING OPTIONS IS THEN TAKEN
C**** SSOPT=1 DESIGN LIFE ESTIMATES BASED ON THE SHORTEST CALCULATED
C**** LAYER INTERFACE.
C**** SSOPT=2 CAUSES ANY DESIGN WITH A CALCULATED LAYER FAILURE TO BE
C**** ELIMINATED, IN EFFECT INCREASING LAYER THICKNESSES UNTIL NO
C**** CALCULATED LAYER FAILURE EXISTS ABOVE THE SUBGRADE.
C**** SSOPT=3 DESIGN LIFE ESTIMATES BASED ON SUBGRADE SOIL SUPPORT.
C**** OTHER SOIL SUPPORT VALUES ONLY FOR LOCATING THE '*'.
C----- A SOIL-SUPPORT VALUE ABOVE THE SUBGRADE RESULTING IN A SHORTER
C LIFE THAN THE PAVEMENT PERFORMANCE PERIOD CALCULATED WITH THE SUB-
C GRADE SOIL-SUPPORT WILL HAVE AN '*' PRINTED WITH THAT LAYER ON
C THE OUTPUT (USING EITHER OPTION 1 OR 3).
SSOPT=3
C *
C--WRITE THE INPUT DATA
C *
WRITE (6,370) NDP,NPG,NL
WRITE (6,380) CL,XLWFT
WRITE (6,390) PCTRAT
WRITE (6,400) UPLVL,WSPR
WRITE (6,410) R,PSI
WRITE (6,420) P1,P2
WRITE (6,430) SACT,SRISE,SRATE
WRITE (6,440) RO,RC
C THE PRODUCT OF PROP*HPD SHOULD NOT BE GREATER THAN 1. IF THE STRIP
C IS UNDER CONSTRUCTION FOR 24 HOURS EACH DAY, PROP*HPD=1.
IF ((PROP*HPD).GT.1.00) WRITE (6,450)
WRITE (6,460) XNC,PROPCT,ITYPE
WRITE (6,470) COEFVR,NCONF
WRITE (6,480) XTTO,XTBO,CMAX
WRITE (6,490) TMAXIN,TMOVIN
WRITE (6,500) UPGCST,WIDUPG
WRITE (6,510) ACPR,ACCD
WRITE (6,520) XLSO,XLSN,XLSD,HPD
WRITE (6,530) NLRO,NLRN
CALL HEADNG (NPAGE,AN1,NPROB,AN2)
WRITE (6,540) PPO2,PPN2
WRITE (6,550) DO2,DN2,AAS
WRITE (6,560) ASO,ASN,MODEL
WRITE (6,570) MNTMOD,CM1,CM2
WRITE (6,580) X2,CLW
WRITE (6,590) CERR,CMAT


PAGE 7
WRITE (6,600) MDXSEC,MDCOST,MASPHS
IF (MDXSEC.EQ.0) GO TO 145
WRITE (6,610) SOWID,SIWID
WRITE (6,620) XOWID,XIWID
WRITE(6,621)
NMAX= MAXO(NLAYS,NSHOUL)
DO 141 L = 1, NMAX
IF(L .LE. NSHOUL) WRITE(6,622)L, (ADDWID(J,L), J=1,4)
141 IF(L.GT.NSHOUL) WRITE(6,622) L, (ADDWID(J,L), J=1,2)
WRITE (6,630) ACTL,ALPC,ACG
WRITE (6,640) TLMAX,TLINC
OK
C 145 CALL HEADNG (NPAGE,AN1,NPROB,AN2)
WRITE (6,650)
WRITE (6,660) WSDESC,WSSTR,WSTMIN,WSCOST,WSSPCT
WRITE (6,670) OVDESC,OVSTR,OMININ,OVMINC,OMAXIN,OVMAXC,OVSPCT,OVINC
DO 150 I=1,NM
150 WRITE (6,680) ILAYER(I),(DATA(I,J),J=1,13)
WRITE (6,690) (DATA(NMP,J),J=2,5),DATA(NMP,7)
IF(MDXSEC.LT.1) GO TO 200
WRITE (6,700)
WRITE (6,710) WSDESC,WTC,WPC,WAPP,WPCT
WRITE (6,710) OVDESC,OTC,OPC,OAPP,OPCT
DO 160 I=1,NM
160 WRITE (6,680) ILAYER(I),(DATA(I,J),J=1,5),(DATA(I,J),J=14,17)
WRITE (6,720)
IF (NSHOUL.LT.1) GO TO 180
DO 170 K=1,NSHOUL
170 WRITE (6,730) K,(SDATA(K,J),J=2,13)
OK
180 CONTINUE
WRITE (6,740)(SDATA(NFILL,J), J=2,5), SDATA(NFILL,7),
1 SDATA(NFILL,8), SDATA(NFILL,13)
GO TO 200
OK
190 LAST=1

PAGE 8

OK

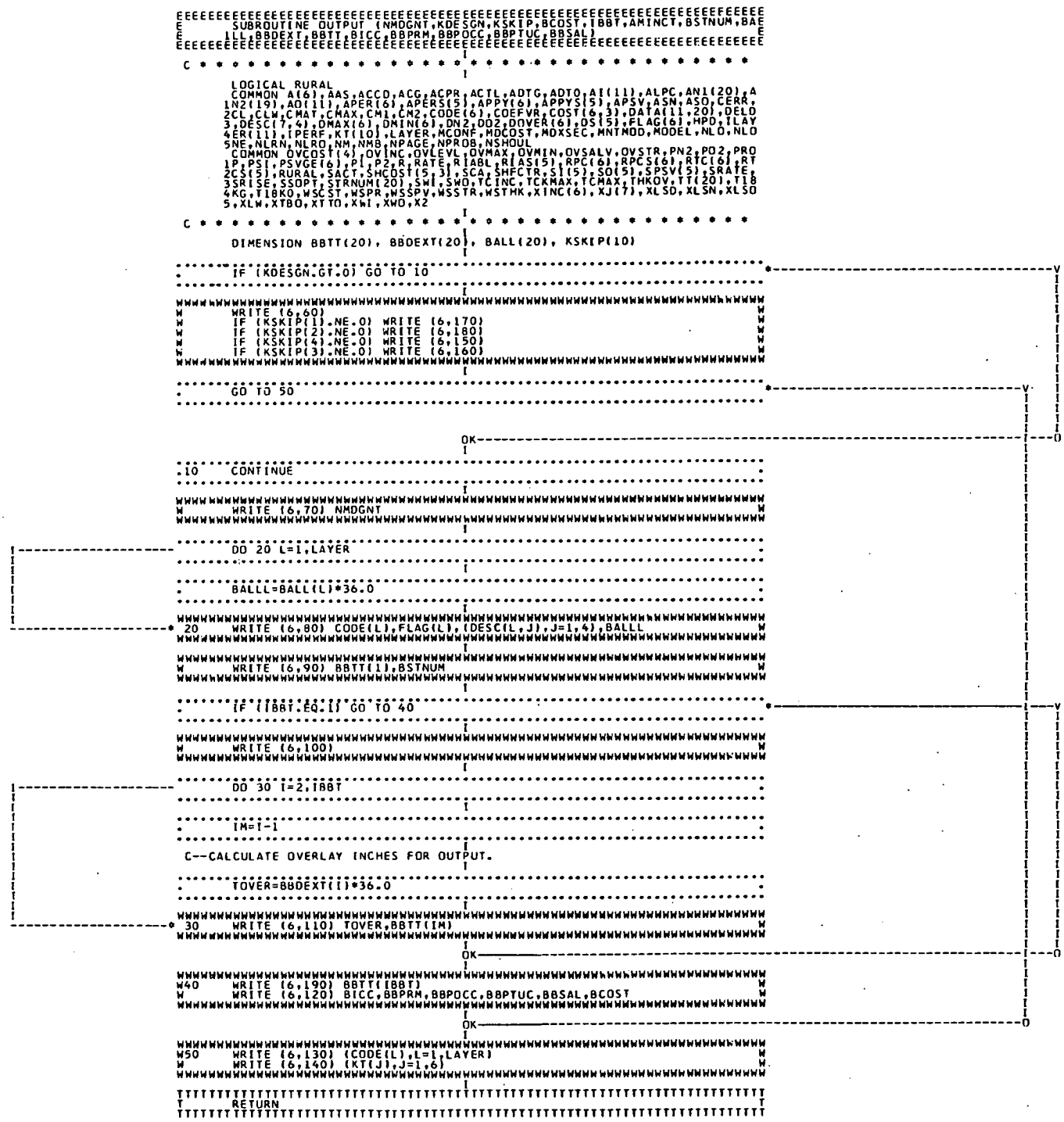
T200 RETURN

```
C--FORMAT STATEMENTS- - - - - - - - - - - - - - - - - - - - - - - - - -

 210   FORMAT (20A4)
 220   FORMAT (1140(INPUT DATA)
 230   FORMAT (2I10,6F10.2)
 240   FORMAT (8F10.2)
 250   FORMAT (4F10.2,I10,F10.2,I10)
 270   FORMAT (6F10.0,2I10)
 280   FORMAT (7F10.2,I10)
 290   FORMAT (I10,7F10.2)
 300   FORMAT (3I10,4F10.2,I10)
 310   FORMAT (4X,4A4,F5.2,5X,2F5.2,10X,F5.2,5X,4F5.2)
 320   FORMAT (4X,4A4,F5.2,5X,10F5.2)
 330   FORMAT (11,1X,A1,1X,4A4,12F5.2)
 340   FORMAT (9H1****ERROR,I5,34HMATERIALS ALLOWED IN A PROBLEM****)
 350   FORMAT (1X,3X,4A4,12F5.2)
 370   FORMAT (1HO,5X,43HPROGRAM CONTROL AND MISCELLANEOUS VARIABLES/,11X
      1,52HNPG-THE NUMBER OF OUTPUT PAGES FOR THE SUMMARY TABLE,1H(,I2,15
      2H DESIGNS/PAGE),,10X,I10,/,11X,26HNL-THE NUMBER OF LANES ON ,33HTH
      3E HIGHWAY (BOTH DIRECTIONS),  ,21X,I10)
 380   FORMAT (11X,45HCL-THE LENGTH OF THE ANALYSIS PERIOD(YEARS),  ,35X,F
      110.0,/,11X,36HXLWFT-THE WIDTH OF EACH LANE (FEET),,44X,F10.0)
 390   FORMAT (11X,47HPCTRAT-THE INTEREST RATE OR TIME VALUE OF MONEY,10H
      1(PERCENT),,23X,F10.2)
 400   FORMAT (11X,65HUPLVL-THE LEVEL-UP THICKNESS REQUIRED PER OVERLAY(I
      1NCHES),  ,15X,F10.1/11X,48HWSPR-WEARING SURFACE PRODUCTION RA
      2TE(TONS/HOUR),,32X,F10.1)
 410   FORMAT (1HO,5X,42HENVIRONMENTAL AND SERVICEABILITY VARIABLES,/,11X
      1,18HR-REGIONAL FACTOR,,62X,F10.1,/,11X,55HPSI-THE SERVICEABILITY I
      2NDEX OF THE INITIAL STRUCTURE,  ,25X,F10.1)
 420   FORMAT (11X,45HP1-THE SERVICEABILITY INDEX OF AN OVERLAY,  ,35X,F
      110.1,/,11X,36HP2-THE MINIMUM ALLOWED VALUE OF THE ,21HSERVICEABILI
      2TY INDEX,,23X,F10.1,/,16X,36HAT WHICH AN OVERLAY WILL BE APPLIED.)
 430   FORMAT (11X,47HSACT-PROPORTION OF THE PROJECT'S LENGTH LIKELY 1X,8
      1HTO SWELL,24X,F10.2,/,11X,60HSRISE-VERTICAL DISTANCE THE SURFACE O
      2F A CLAY LAYER CAN RISE,8H(INCHES),12X,F10.2,/,11X,41HSRATE-CALCUL
      3ATES HOW FAST SWELLING OCCURS,39X,F10.2)
 440   FORMAT (1HO,5X,26HLOAD AND TRAFFIC VARIABLES,/,11X,79HRO-THE ONE-D
      1IRECTION AVERAGE DAILY TRAFFIC AT THE START OF THE ANALYSIS PERIOD
      2.  , F11.0  /  11X,35HRC-THE ONE-DIRECTION AVERAGE D
      3AILY ,38HTRAFFIC AT THE END OF ANALYSIS PERIOD,,7X,F10.0)
 450  FORMAT (  12HO* WARNING *,  49HAS INPUT,THE PRODUCT OF HPD
      1 AND PROPCT IS GREATER,  /,10X,38HTHAN 100.0 PERCENT --PROGRAM CO
      2NTINUES)
 460   FORMAT (11X,44HXNC-THE ONE-DIRECTION ACCUMULATED NUMBER OF ,30HEQU
      1IVALENT 18-KIP AXLES DURING,6X,F10.0,/,16X,20HTHE ANALYSIS PERIOD.
      2,/,11X,54HPROPCT-THE PERCENT OF ADT WHICH WILL PASS THROUGH THE ,2
      30HOVERLAY ZONE DURING ,6X,F10.1,/,16X,15HEACH HOUR WHILE,28H OVERL
      4AYING IS TAKING PLACE.,/,11X,15HITYPE-THE TYPE ,45HOF ROAD UNDER C
      5ONSTRUCTION(1-RURAL,2-URBAN),,20X,I10)
 470   FORMAT (11X,32HCOEFVR-COEFFICIENT OF VARIATION.,48X,F10.2/11X,33HM
      1CONF-CONFIDENCE LEVEL INDICATOR,,47X,I10)
 480   FORMAT (1HO,5X,20HCONSTRAINT VARIABLES,/,11X,51HXTTO-THE MINIMUM A
      1LLOWED TIME TO THE FIRST OVERLAY.,29X,F10.1,/,11X,38HXTBO-THE MINI
      2MUM ALLOWED TIME BETWEEN ,9HOVERLAYS.,33X,F10.1,/,11X,23HCMAX-THE
      3MAXIMUM FUNDS ,35HAVAILABLE FOR INITIAL CONSTRUCTION.,22X,F10.2)
 490   FORMAT (11X,45HTMAXIN-THE MAXIMUM ALLOWABLE TOTAL THICKNESS ,32HOF
      1 INITIAL CONSTRUCTION(INCHES).,3X,F10.2,/11X,57HTMOVIN-THE ACCUMUL
      2ATED THICKNESS MAXIMUM OF ALL OVERLAYS ,10H (INCHES),,13X,F10.2/15
      3X,25H(EXCLUDING WEAR-COAT  AND ,10HLEVEL-UP).)
 500   FORMAT (11X,48HUPGCST-COST/CU. YD. TO UPGRADE AFTER AN OVERLAY.,32
      1X,F10.2/11X,61HWIDUPG-WIDTH OF PAVEMENT & SHOULDERS TO BE UPGRADED
      2(FEET).  ,19X,F10.1)
 510   FORMAT (1HO,5X,47HTRAFFIC DELAY VARIABLES ASSOCIATED WITH OVERLAY,
      121H AND ROAD GEOMETRICS ,/,11X,24HACPR-ASPHALTIC CONCRETE ,27HPROD
      2UCTION RATE(TONS/HOUR).,29X,F10.1,/,11X,5HACCD-,55HASPHALTIC CONCR
      3ETE COMPACTED DENSITY(TONS/COMPACTED CY),20X,F10.2)
 520   FORMAT (11X,47HXLSO-THE DISTANCE OVER WHICH TRAFFIC IS SLOWED ,25H
      1IN THE OVERLAY DIRECTION.,8X,F10.2,/,11X,9HXLSN-THE ,56HDISTANCE O
      2VER WHICH TRAFFIC IS SLOWED IN THE NON-OVERLAY,11H DIRECTION.,4X,F
      310.2,/,11X,25HXLSD-THE  DISTANCE AROUND ,24HTHE OVERLAY ZONE(MILES)
      4.,31X,F10.2,/,11X,8HHPD-THE ,53HNUMBER OF HOURS/DAY OVERLAY CONSTR
      5UCTION TAKES PLACE.,19X,F10.1)
 530   FORMAT (11X,48HNLRD-THE NUMBER OF LANES IN THE RESTRICTED ZONE ,25
      1HIN THE OVERLAY DIRECTION.,I17/11X,19HNLRN-THE NUMBER OF ,58HLANES
      2 IN THE RESTRICTED ZONE IN THE NON-OVERLAY DIRECTION.,I13)
 540   FORMAT (1HO,5X,47HTRAFFIC DELAY VARIABLES ASSOCIATED WITH TRAFFIC,
      119H SPEEDS AND DELAYS ,/,16X,24HTHE PERCENT OF VEHICLES ,27HSTOPPE
      2D DUE TO MOVEMENT OF ,23HPERSONNEL OR EQUIPMENT.,/,11X,20HPPO2-IN
      3THE OVERLAY ,10HDIRECTION.,50X,F10.2,/,11X,24HPPN2-IN THE NON-OVER
      4LAY ,10HDIRECTION.,46X,F10.2)
 550   FORMAT (16X,45HTHE AVERAGE DELAY PER VEHICLE STOPPED DUE TO ,30HMO
      1VEMENT OF PERSONNEL & EQUIP.,/,11X,37HDO2 -IN THE OVERLAY DIRECTIO
      2N(HOURS),,43X,F10.3,/,11X,41HDN2 -IN THE NON-OVERLAY DIRECTION(HOU
      3RS).,39X,F10.3,/,11X,45HAAS-THE AVERAGE APPROACH SPEED TO THE OVER
      4LAY,6H AREA.,29X,F10.0)
 560   FORMAT (16X,42HTHE AVERAGE SPEED THROUGH THE OVERLAY AREA,/,11X,34
      1HASO-IN THE OVERLAY DIRECTION(MPH).,46X,F10.0,/,11X,38HASN-IN THE
      2NON-OVERLAY DIRECTION(MPH).,42X,F10.0,/,11X,38HMODEL-THE TRAFFIC H
      3ANDLING MODEL USED.,42X,I10)
 570   FORMAT (1HO,5X,21HMAINTENANCE VARIABLES,/,11X,49HMNTMOD-THE MAINTE
      1NANCE MODEL(EXPLICIT=1,NCHRP=2).,31X,I10/11X,55HCM1-INITIAL ANNUAL
      2 ROUTINE COST($/LANE MILE, MNTMOD=1).,25X,F10.2/,11X,40HCM2-ANNUAL
      3INCREMENTAL INCREASE IN COSTS,27H($/LANE MILE/YR, MNTMOD=1).,13X,F
      410.2)
 580   FORMAT (11X,47HX2-DAYS THE TEMPERATURE REMAINS BELOW 32F.(DAYS,17H
      1/YEAR, MNTMOD=2).,16X,F10.0/11X,35HCLW-THE COMPOSITE LABOR WAGE($/
      2HR).,45X,F10.2)
 590   FORMAT (11X,41HCERR-THE COMPOSITE EQUIPMENT RENTAL RATE.,39X,F10.2
      1,/,11X,49HCMAT-THE RELATIVE MATERIAL COST(1.00 IS AVERAGE).,F41.2)
 600   FORMAT (1HO,5X,48HCROSS SECTION MODEL, COST AND SHOULDER VARIABLES
      1 /11X,36HMDXSEC-THE CROSS SECTION MODEL USED.,44X,I10/11X,27HMDCO
      2ST-THE COST MODEL USED.,  163  /11X, 63HMASPHS-ASPHALTIC SHOULDER
      2MODEL (0 IF NOT ASPHALTIC SHOULDERS).,  127)
 610   FORMAT (11X,40HSOWID-WIDTH OF OUTSIDE SHOULDER, IN FEET,40X,F10.2/
      111X,40HSIWID-WIDTH OF  INSIDE SHOULDER, IN FEET,40X,F10.2)
 620   FORMAT (11X,62HXOWID-CROSS SECTION WIDTH OUTSIDE OF OUTSIDE SHOULD
      1ER(FEET)  ,18X,F10.2/11X,62HXIWID-CROSS SECTION WIDTH OUTSIDE OF
      2 INSIDE SHOULDER(FEET)  ,18X,F10.2)
  621  FORMAT(61HO     ADDITIONAL WIDTH(FEET) OF LAYERS RELATIVE TO LAYER
      1 ONE. / 1HO, 10X, 41HLAYER   PAVEMENT-LAYERS   SHOULDER-LAYERS /
```

```
                                    PAGE  9
     2   11X, 41H  NO.     OUTSIDE INSIDE     OUTSIDE INSIDE    )
 622  FORMAT(6X, I10, F10.2, F8.2, F10.2, F8.2)
 630  FORMAT (1H0,5X,38HTACK, PRIME, AND BITUMINOUS VARIABLES /11X,28HAC
     1TL-TACK  COAT COST($/GAL).,52X,F10.2/11X,28HALPC-PRIME COAT COST($
     2/GAL).,52X,F10.2/11X,36HACG-BITUMINOUS MATERIAL COST($/GAL).,44X,F
     310.2)
 640  FORMAT (11X,51HTLMAX-MAXIMUM LAYER DEPTH FOR NO TACK COATS, INCHES
     1,29X,F10.2/11X,52HTLINC-MAXIMUM DEPTH OF EACH LIFT ABOVE TLMAX, IN
     2CHES,28X,F10.2)
 650  FORMAT (1H0,20X,41HTHE CONSTRUCTION MATERIALS UNDER CONSIDER,10HAT
     1ION ARE ,/,40HOLAYER  -PAVEMENT MATERIALS-  STRENGTH  ,47HSOIL   -
     2---MINIMUM----  ----MAXIMUM---- SALVAGE,/,47H NO.    CODE  DESCRIP
     3TION        COEFF.  SUPPORT,2(16H DEPTH  $/CU.YD.),8H   VALUE,2X,9H
     4INCREMENT)
 660  FORMAT (1H ,1X,1H-,5X,1H-,2X,4A4,2X,F8.2,8H  ------,2F8.2,1X,2(8H
     1 ------),2X,F8.2,8H  ------)
 670  FORMAT (1H ,1X,1H-,5X,1H-,2X,4A4,2X,F8.2,8H  ------,2F8.2,1X,2F8.2
     1,2X,3F8.2)
 680  FORMAT (1H ,1X,I1,5X,A1,2X,4A4,2X,F8.2,F8.2,2F8.2,1X,2F8.2,2X,3F8.
     12)
 690  FORMAT (1H ,1X,1H-,5X,1H-,2X,4A4,2X,8H  ------,F8.2,2(2(8H  ------
     1),1X),1X,8H  ------,F8.2)
 700  FORMAT (1H0,28X,32H---APPLICATION RATES---- ASPHALT/1X,5HLAYER,2X,
     120H-PAVEMENT MATERIALS-,5X,30HTACK   PRIME ASPHALT CONTENT
     2          /1X,3HNO.,4X,17HCODE  DESCRIPTION,8X,30HCOAT    COAT (LB/
     3IN)   (PCT)                 )
 710  FORMAT (1H ,1X,1H-,5X,1H ,2X,4A4,2X,4F8.2)
 720  FORMAT (/1H0,52X,32H---APPLICATION RATES---- ASPHALT/1X,5HLAYER,2X
     1,45H-SHOULDER MATERIALS- ---------------- SALVAGE,4X,28HTACK   PRI
     2ME ASPHALT CONTENT,8H ADJUST./4H NO.,5X,11HDESCRIPTION,12X,61HDEPT
     3H $/CU.YD.  VALUE    COAT    COAT (LB/IN)   (PCT)  VOLUME)
 730  FORMAT (1H ,1X,I1,5X,1H-,2X,4A4,2X,8F8.2)
 740  FORMAT (1H ,2H -,5X,1H-,2X,4A4,2X,8H  ------,2F8.2,8H  ------,2(8H
     1  ------),8H  ------,F8.2)

.......................................................................
.     END                                                             .
.......................................................................
```

SYMBOL KEY

EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

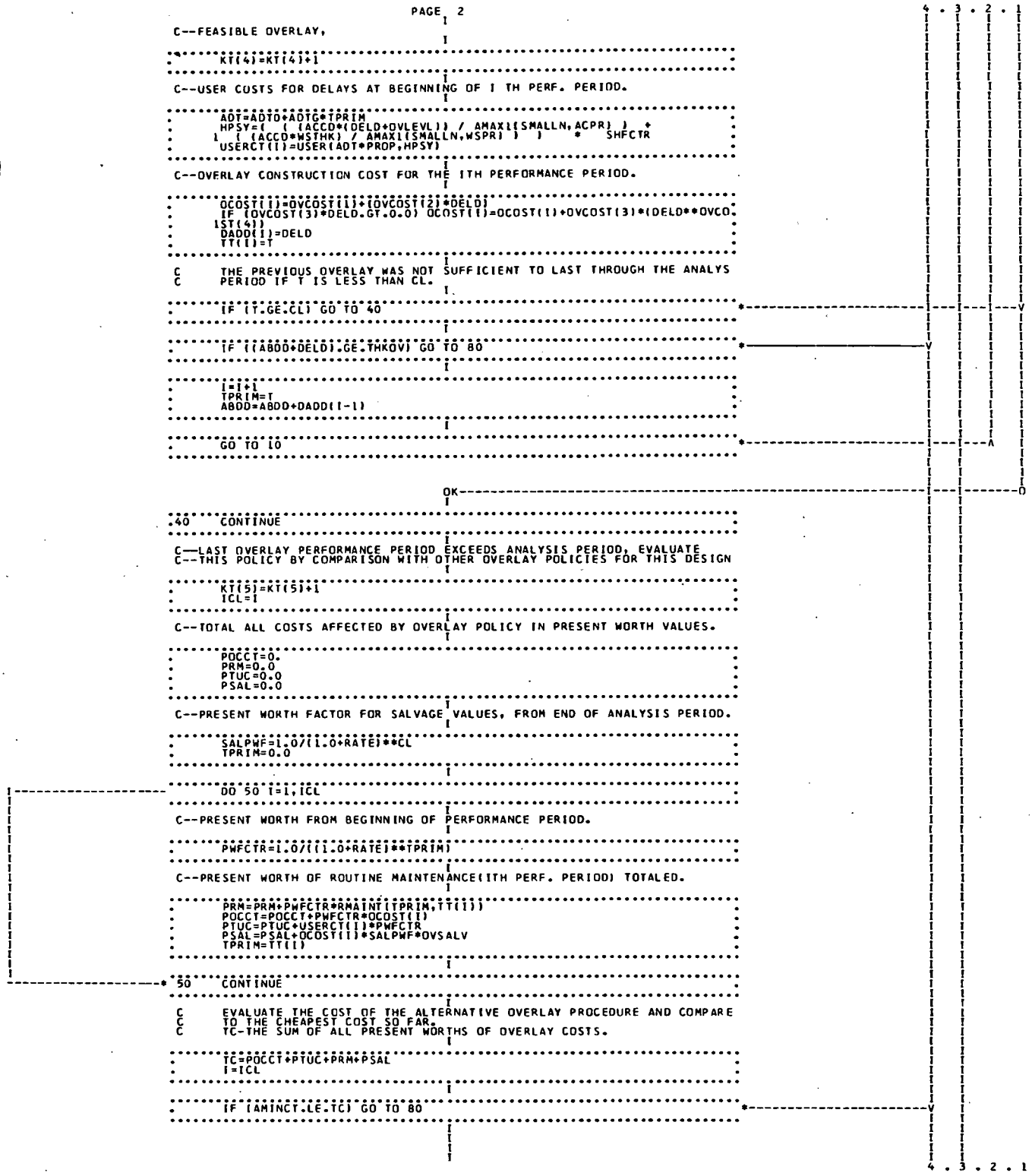


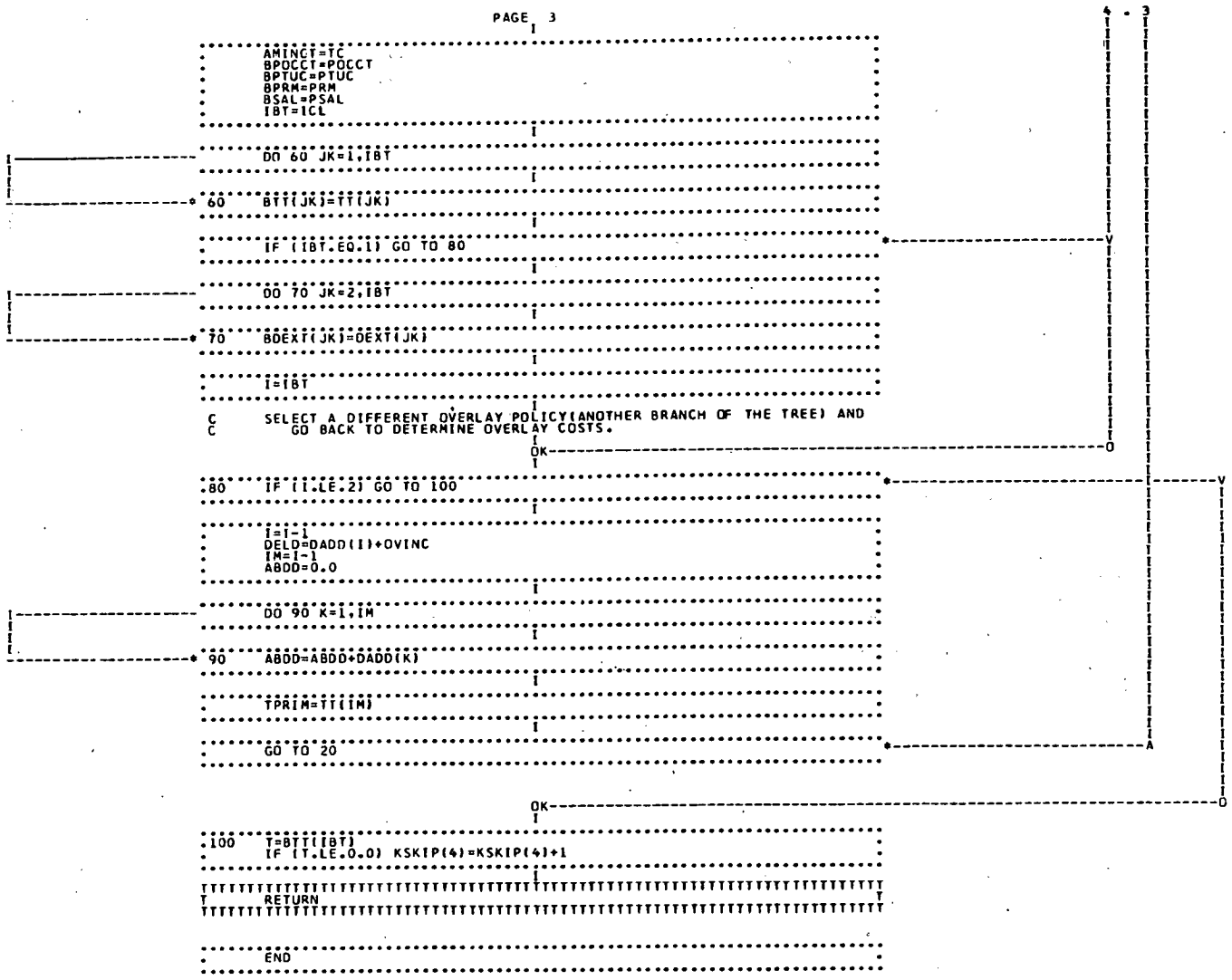
```
C--FORMAT STATEMENTS- - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 60    FORMAT (50HOTHE FOLLOWING CONSTRAINTS PREVENTED A DESIGN WITH,/43H
     1   THIS SET OF MATERIALS (THIS DESIGN TYPE).)
 70    FORMAT (/2X,I2,3X,58HTHE OPTIMAL DESIGN FOR THE MATERIALS UNDER CO
     1NSIDERATION--/8X,45HFOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE)
 80    FORMAT (15X,A3,A2,4A4,F8.2,7H INCHES)
 90    FORMAT (8X,35HTHE LIFE OF THE INITIAL STRUCTURE =,F6.1,6H YEARS,5X
     1,17HSTRUCTURAL NUMBER,F6.2)
100    FORMAT (8X,23HTHE OVERLAY SCHEDULE IS)
110    FORMAT (15X,F5.2,4HINCH(ES) (EXCLUSIVE OF LEVEL-UP AND WEAR-,13HC
     1OURSE) AFTER,F6.1,7H YEARS.)
120    FORMAT (/8X,56HTHE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATION
     1S ARE/15X,25HINITIAL CONSTRUCTION COST,9X,F6.3/15X,30HTOTAL ROUTIN
     2E MAINTENANCE COST,4X,F6.3/15X,31HTOTAL OVERLAY CONSTRUCTION COST,
     33X,F6.3/15X,22HTOTAL USER COST DURING/25X,20HOVERLAY CONSTRUCTION,
     43X,F7.3,/,15X,13HSALVAGE VALUE,20X,F7.3,/,15X,18HTOTAL OVERALL COS
     5T,15X,F7.3)
130    FORMAT (44HOSAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE ,10A1)
140    FORMAT (2X,15HINITIAL DESIGNS/1X,19,17H WITHIN COST AND ,21HTHICKN
     1ESS CONSTRAINTS/1X,19,26H FEASIBLE TO FIRST OVERLAY/2X,8HOVERLAYS/
     21X,19,11H CONSIDERED/1X,19,9H FEASIBLE/4X,16,27H FEASIBLE OVERLAY
     3POLICIES ,/2X,16HCOMPLETE DESIGNS/4X,16,9H FEASIBLE)
150    FORMAT (//4X,52HTHE MINIMUM TIME BETWEEN OVERLAYS IS TOO LONG AND/
     1OR/4X,52HTHE MAXIMUM ALLOWABLE TOTAL OVERLAY THICKNESS IS TOO/4X,5
     22HSMALL TO OBTAIN A FEASIBLE OVERLAY POLICY FOR ANY OF/4X,20HTHE I.
     3NITIAL DESIGNS.)
160    FORMAT (//4X,67HTHE CONSTRUCTION RESTRICTIONS ARE TOO BINDING TO O
     1BTAIN A STRUCTURE/4X,65HTHAT WILL MEET THE MINIMUM TIME TO THE FIR
     2ST OVERLAY RESTRICTION.)
170    FORMAT (61HOFOR THE DESIGN UNDER CONSIDERATION THE FUNDS AVAILABLE
     1 TO BE/54H SPENT PER SQ. YD. ARE NOT ENOUGH TO COVER THE DESIGN.)
180    FORMAT (//4X,46HTHE DEPTH OF EACH MATERIAL RESULTED IN A TOTAL,/4X
     1,51HPAVEMENT THICKNESS GREATER THAN THE MAXIMUM ALLOWED,/4X,16HTOT
     2AL THICKNESS.)
190    FORMAT (8X,17HTHE TOTAL LIFE = ,F6.1,7H YEARS.)

      END
```

SYMBOL KEY

EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

```
      SUBROUTINE OVRLAY (IBT,T,BPTUC,BPOCCT,BPRM,AMINCT,BTT,BDEXT,BSAL,KE
     1SKIP)

C--IBT=NUMBER OF PERFORMANCE PERIODS
C--T=TIME AT END OF FIRST PERFORMANCE PERIOD AT SUBPROGRAM ENTRY,
C--       BUT RETURNED AS TIME AT END OF LAST PERFORMANCE PERIOD OF THE
C--       OPTIMUM OVERLAY POLICY., ELSE 0.0 IF NO SUCCESSFUL POLICIES.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      LOGICAL RURAL
      COMMON A(6),AAS,ACCD,ACG,ACPR,ACTL,ADTG,ADTO,AI(11),ALPC,AN1(20),A
     1N2(19),AO(11),APER(6),APERS(5),APPY(6),APPYS(5),APSV,ASN,ASO,CERR,
     2CL,CLW,CMAT,CMAX,CM1,CM2,CODE(6),COEFVR,COST(6,3),DATA(11,20),DELD
     3,DESC(7,4),DMAX(6),DMIN(6),DN2,DO2,DOVER(6),DS(5),FLAG(6),HPD,ILAY
     4ER(11),IPERF,KT(10),LAYER,MCONF,MDCOST,MDXSEC,MNTMOD,MODEL,NLO,NLO
     5NE,NLRN,NLRO,NM,NMB,NPAGE,NPROB,NSHOUL
      COMMON OVCOST(4),OVINC,OVLEVL,OVMAX,OVMIN,OVSALV,OVSTR,PN2,PO2,PRO
     1P,PSI,PSVGE(6),P1,P2,R,RATE,RIABL,RIAS(5),RPC(6),RPCS(6),RTC(6),RT
     2CS(5),RURAL,SACT,SHCOST(5,3),SCA,SHFCTR,SI(5),SO(5),SPSV(5),SRATE,
     3SRISE,SSOPT,STRNUM(20),SWI,SWO,TCINC,TCKMAX,TCMAX,THKOV,TT(20),T18
     4KG,T18KO,WSCST,WSPR,WSSPV,WSSTR,WSTHK,XINC(6),XJ(7),XLSD,XLSN,XLSO
     5,XLW,XTBO,XTTO,XWI,XWO,X2
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      DIMENSION DADD(20), OCOST(20), DEXT(20), USERCT(20), KSKIP(10), BT
     1T(20), BDEXT(20)
      DATA HICOST/1.0E30/, SMALLN/1.0E-30/

      LP1=LAYER+1

C--MINIMUM COST OF OVERLAY POLICY SET AT A VERY HIGH NUMBER.

      AMINCT=HICOST

C--           --INITIALIZE USER FUNCTION FOR THIS INITIAL DESIGN.

      USERCT(1)=USER(0.0,0.0)
      OCOST(1)=0.
      DADD(1)=0.0
      BTT(1)=0.0
      I=1
      IBT=1
      TT(1)=T

      IF (T.GE.CL) GO TO 40

C     THE REMAINDER OF THE OVERLAY OPTIMIZATION RESEMBLES A **TREE**.IT
C     IS NECESSARY TO SELECT THE OVERLAY POLICY WITH THE LEAST COST.

      ABDD=0.0

C     ABDD IS THE ACCUMULATED DEPTH OF ALL PREVIOUS OVERLAYS.

      TPRIM=T
      I=I+1
                                  OK
10    DELD=OVMIN

C     THE DEPTH OF LAYER 1 IS = ORIGINAL D(1) + SUM OF PREVIOUS OVERLAYS
C     CURRENT OVERLAY DEPTH.
                                  OK
20    IF (((ABDD+DELD).GT.THKOV).OR.(DELD.GT.OVMAX)) GO TO 80

      KT(3)=KT(3)+1
      IPERF=I
      T=TIME(TPRIM,P1,TPRIM+XTBO)

      IF (T.GT.0.0) GO TO 30

      DELD=DELD+OVINC

      GO TO 20
                                  OK
30    DEXT(I)=DELD

                                                     4 . 3 . 2 . 1
```

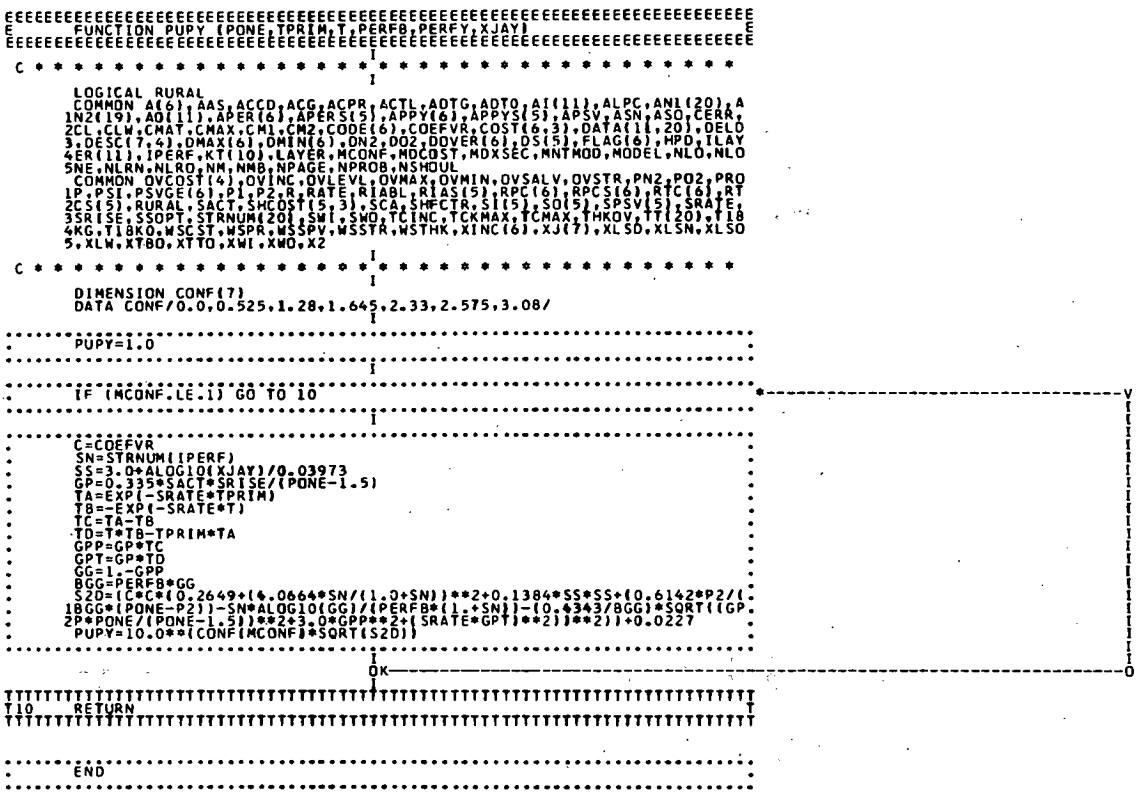

PAGE 2
C--FEASIBLE OVERLAY,
KT(4)=KT(4)+1
C--USER COSTS FOR DELAYS AT BEGINNING OF I TH PERF. PERIOD.
ADT=ADTO+ADTG*TPRIM
HPSY=(((ACCD*(DELD+OVLEVL)) / AMAX1(SMALLN,ACPR)) +
1 ((ACCD*WSTHK) / AMAX1(SMALLN,WSPR))) * SHFCTR
USERCT(I)=USER(ADT*PROP,HPSY)
C--OVERLAY CONSTRUCTION COST FOR THE ITH PERFORMANCE PERIOD.
OCOST(I)=OVCOST(1)+(OVCOST(2)*DELD)
IF (OVCOST(3)*DELD.GT.0.0) OCOST(I)=OCOST(I)+OVCOST(3)*(DELD**OVCO.
1ST(4))
DADD(I)=DELD
TT(I)=T
C THE PREVIOUS OVERLAY WAS NOT SUFFICIENT TO LAST THROUGH THE ANALYS
C PERIOD IF T IS LESS THAN CL.
IF (T.GE.CL) GO TO 40
IF ((ABDD+DELD).GE.THKOV) GO TO 80
I=I+1
TPRIM=T
ABDD=ABDD+DADD(I-1)
GO TO 10
OK
40 CONTINUE
C--LAST OVERLAY PERFORMANCE PERIOD EXCEEDS ANALYSIS PERIOD, EVALUATE
C--THIS POLICY BY COMPARISON WITH OTHER OVERLAY POLICIES FOR THIS DESIGN
KT(5)=KT(5)+1
ICL=I
C--TOTAL ALL COSTS AFFECTED BY OVERLAY POLICY IN PRESENT WORTH VALUES.
POCCT=0.
PRM=0.0
PTUC=0.0
PSAL=0.0
C--PRESENT WORTH FACTOR FOR SALVAGE VALUES, FROM END OF ANALYSIS PERIOD.
SALPWF=1.0/(1.0+RATE)**CL
TPRIM=0.0
DO 50 I=1,ICL
C--PRESENT WORTH FROM BEGINNING OF PERFORMANCE PERIOD.
PWFCTR=1.0/((1.0+RATE)**TPRIM)
C--PRESENT WORTH OF ROUTINE MAINTENANCE(ITH PERF. PERIOD) TOTALED.
PRM=PRM+PWFCTR*RMAINT(TPRIM,TT(I))
POCCT=POCCT+PWFCTR*OCOST(I)
PTUC=PTUC+USERCT(I)*PWFCTR
PSAL=PSAL+OCOST(I)*SALPWF*OVSALV
TPRIM=TT(I)
50 CONTINUE
C EVALUATE THE COST OF THE ALTERNATIVE OVERLAY PROCEDURE AND COMPARE
C TO THE CHEAPEST COST SO FAR.
C TC-THE SUM OF ALL PRESENT WORTHS OF OVERLAY COSTS.
TC=POCCT+PTUC+PRM+PSAL
I=ICL
IF (AMINCT.LE.TC) GO TO 80
4 . 3 . 2 . 1
4 . 3 . 2 . 1


PAGE 3
AMINCT=TC
BPOCCT=POCCT
BPTUC=PTUC
BPRM=PRM
BSAL=PSAL
IBT=ICL
DO 60 JK=1,IBT
60 BTT(JK)=TT(JK)
IF (IBT.EQ.1) GO TO 80
DO 70 JK=2,IBT
70 BDEXT(JK)=DEXT(JK)
I=IBT
C SELECT A DIFFERENT OVERLAY POLICY(ANOTHER BRANCH OF THE TREE) AND
C GO BACK TO DETERMINE OVERLAY COSTS.
OK
O
80 IF (I.LE.2) GO TO 100
I=I-1
DELD=DADD(I)+OVINC
IM=I-1
ABDD=0.0
DO 90 K=1,IM
90 ABDD=ABDD+DADD(K)
TPRIM=TT(IM)
GO TO 20
A
OK
O
100 T=BTT(IBT)
IF (T.LE.0.0) KSKIP(4)=KSKIP(4)+1
RETURN
END

PUPY

SYMBOL KEY

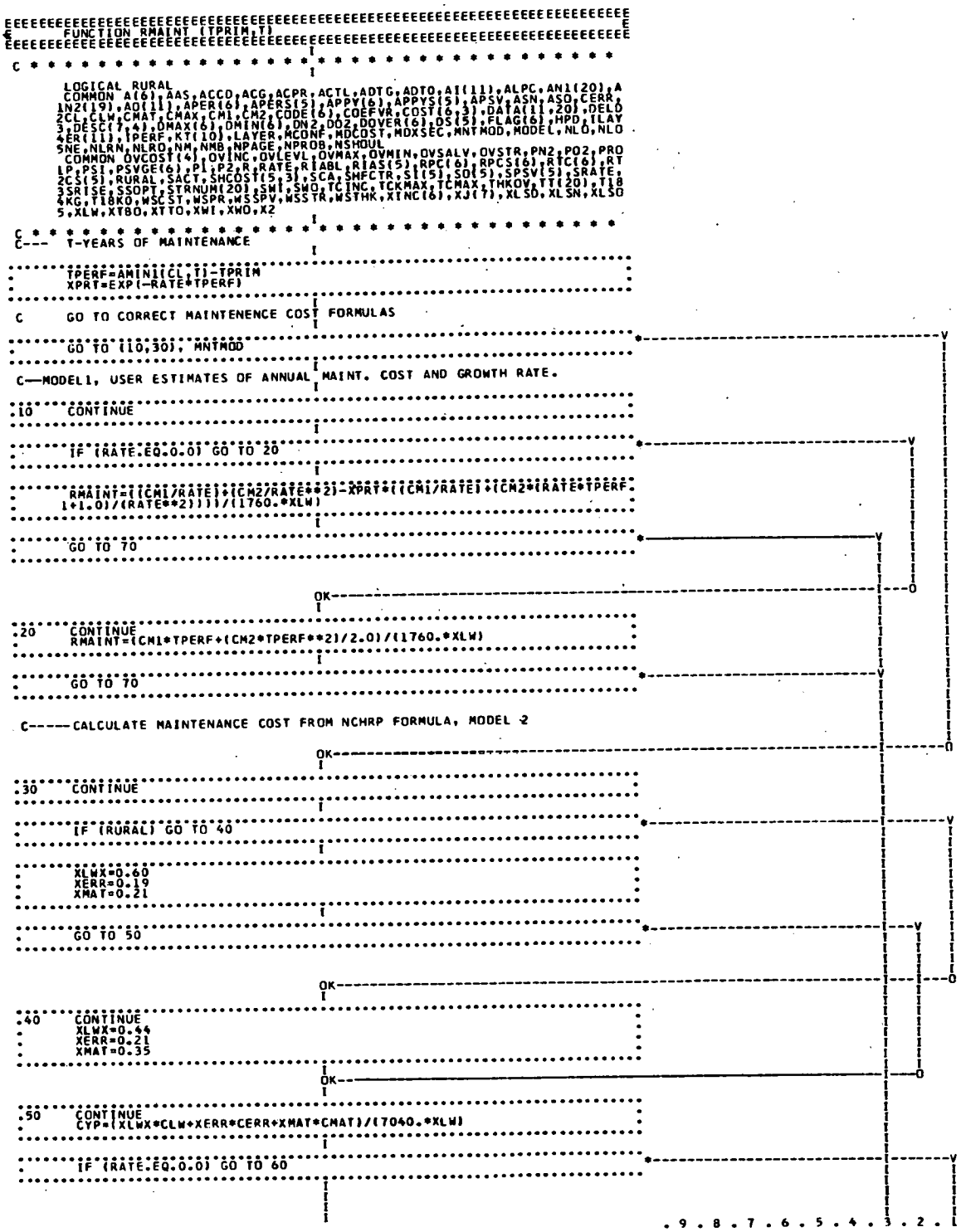
EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE



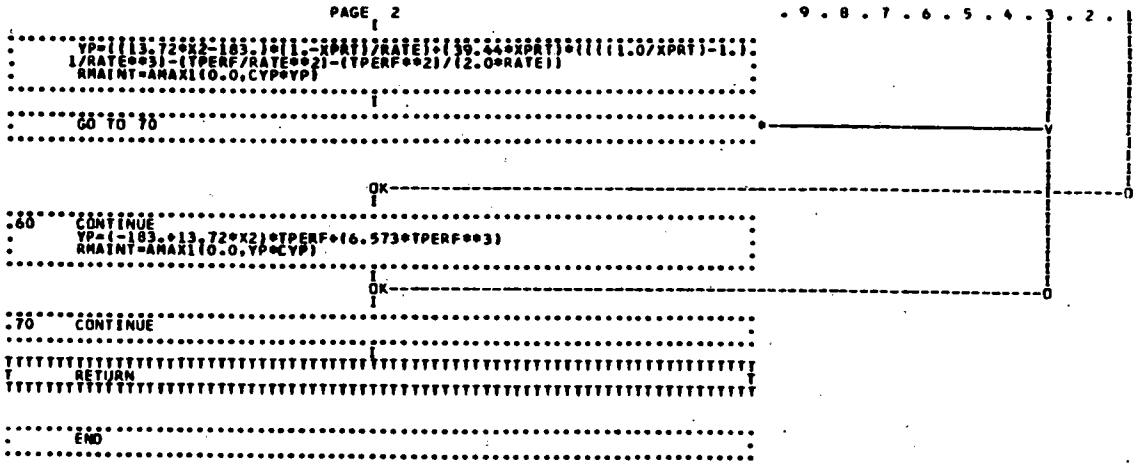
RMAINT

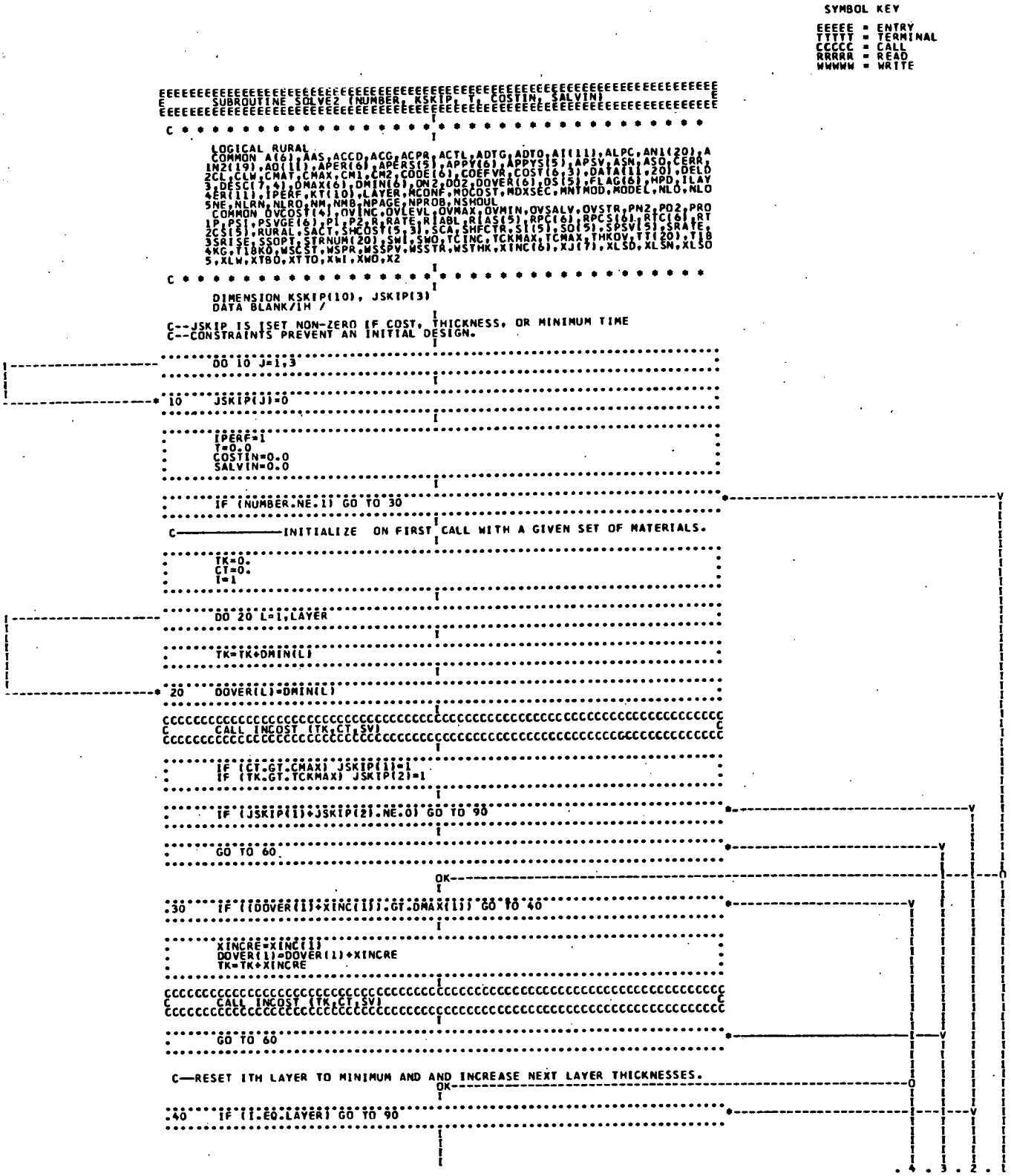
SYMBOL KEY

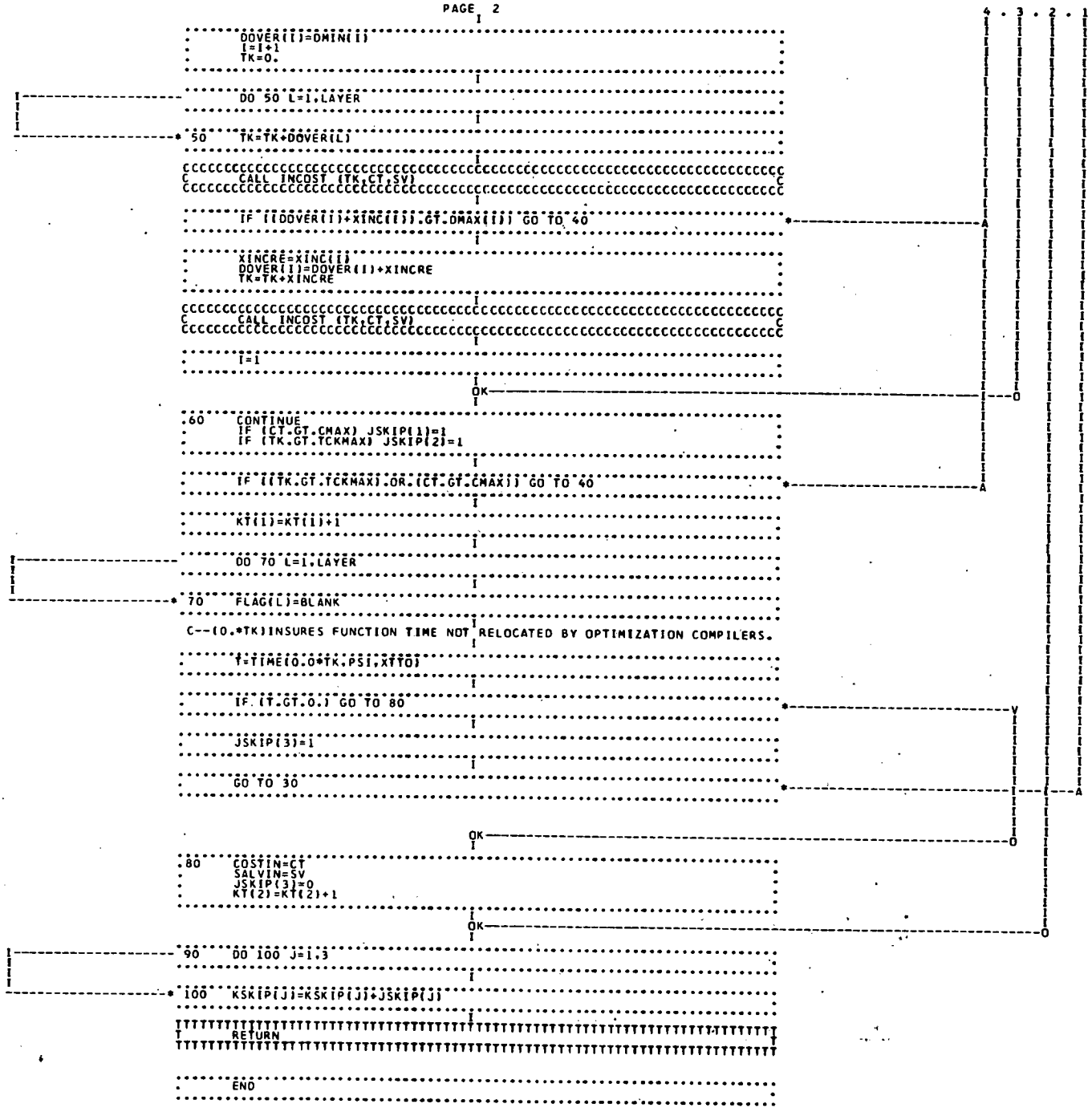
EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE



RMAINT


PAGE 2
YP=((13.72*X2-183.)*(1.-XPAT)/RATE)+(39.44*XPAT)*(((1.0/XPAT)-1.)
1/RATE**3)-(TPERF/RATE**2)-(TPERF**2)/(2.0*RATE))
RMAINT=AMAX1(0.0,CYP*YP)
GO TO 70
OK
.60 CONTINUE
YP=(-183.+13.72*X2)*TPERF+(6.573*TPERF**3)
RMAINT=AMAX1(0.0,YP*CYP)
OK
.70 CONTINUE
RETURN
END

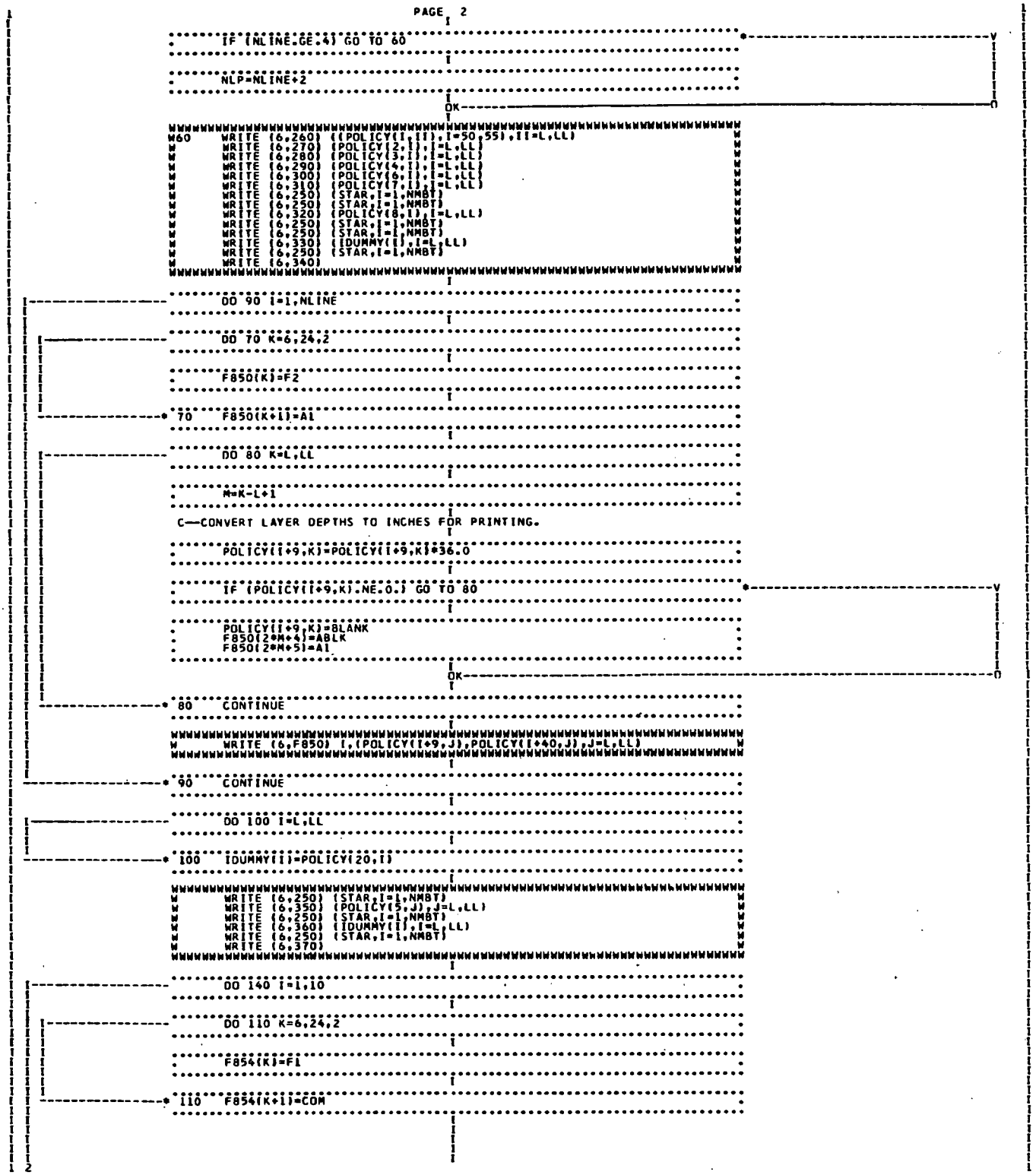

SYMBOL KEY
EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE
SUBROUTINE SOLVE2 (NUMBER, KSKIP, T, COSTIN, SALVIN)
LOGICAL RURAL
COMMON A(6),AAS,ACCD,ACG,ACPR,ACTL,ADTG,ADTO,AI(11),ALPC,AN1(20),A
IN2(19),AO(11),APER(6),APERS(5),APPY(6),APPYS(5),APSV,ASN,ASO,CERR,
2CL,CLW,CMAT,CMAX,CM1,CM2,CODE(6),COEFVR,COST(6,3),DATA(11,20),DELD
3,DESC(7,4),DMAX(6),DMIN(6),DN2,DO2,DOVER(6),DS(5),FLAG(6),HPD,ILAY
4ER(11),IPERF,KT(10),LAYER,MCONF,MDCOST,MDXSEC,MNTMOD,MODEL,NLO,NLO
5NE,NLRN,NLRO,NM,NMB,NPAGE,NPROB,NSHOUL
COMMON OVCOST(4),OVINC,OVLEVL,OVMAX,OVMIN,OVSALV,OVSTR,PN2,PO2,PRO
1P,PSI,PSVGE(6),P1,P2,R,RATE,RIABL,RLAS(5),RPC(6),RPCS(6),RTC(6),RT
2CS(5),RURAL,SACT,SHCOST(5,3),SCA,SHFCTR,SI(5),SO(5),SPSVL(5),SRATE,
3SRISE,SSOPT,STRNUM(20),SWI,SWO,TCINC,TCKMAX,TCMAX,THKOV,TT(20),T18
4KG,T18KO,WSCST,WSPR,WSSPV,WSSTR,WSTHK,XINC(6),XJ(7),XLSD,XLSN,XLSO
5,XLW,XTBO,XTTO,XWI,XWO,X2
DIMENSION KSKIP(10), JSKIP(3)
DATA BLANK/1H /
C--JSKIP IS ISET NON-ZERO IF COST, THICKNESS, OR MINIMUM TIME
C--CONSTRAINTS PREVENT AN INITIAL DESIGN.
DO 10 J=1,3
10 JSKIP(J)=0
IPERF=1
T=0.0
COSTIN=0.0
SALVIN=0.0
IF (NUMBER.NE.1) GO TO 30
C----------INITIALIZE ON FIRST CALL WITH A GIVEN SET OF MATERIALS.
TK=0.
CT=0.
I=1
DO 20 L=1,LAYER
TK=TK+DMIN(L)
20 DOVER(L)=DMIN(L)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C CALL INCOST (TK,CT,SV) C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
IF (CT.GT.CMAX) JSKIP(1)=1
IF (TK.GT.TCKMAX) JSKIP(2)=1
IF (JSKIP(1)+JSKIP(2).NE.0) GO TO 90
GO TO 60
OK
30 IF ((DOVER(I)+XINC(I)).GT.DMAX(I)) GO TO 40
XINCRE=XINC(I)
DOVER(I)=DOVER(I)+XINCRE
TK=TK+XINCRE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C CALL INCOST (TK,CT,SV) C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
GO TO 60
C--RESET ITH LAYER TO MINIMUM AND AND INCREASE NEXT LAYER THICKNESSES.
OK
40 IF (I.EQ.LAYER) GO TO 90
.4 .3 .2 .1

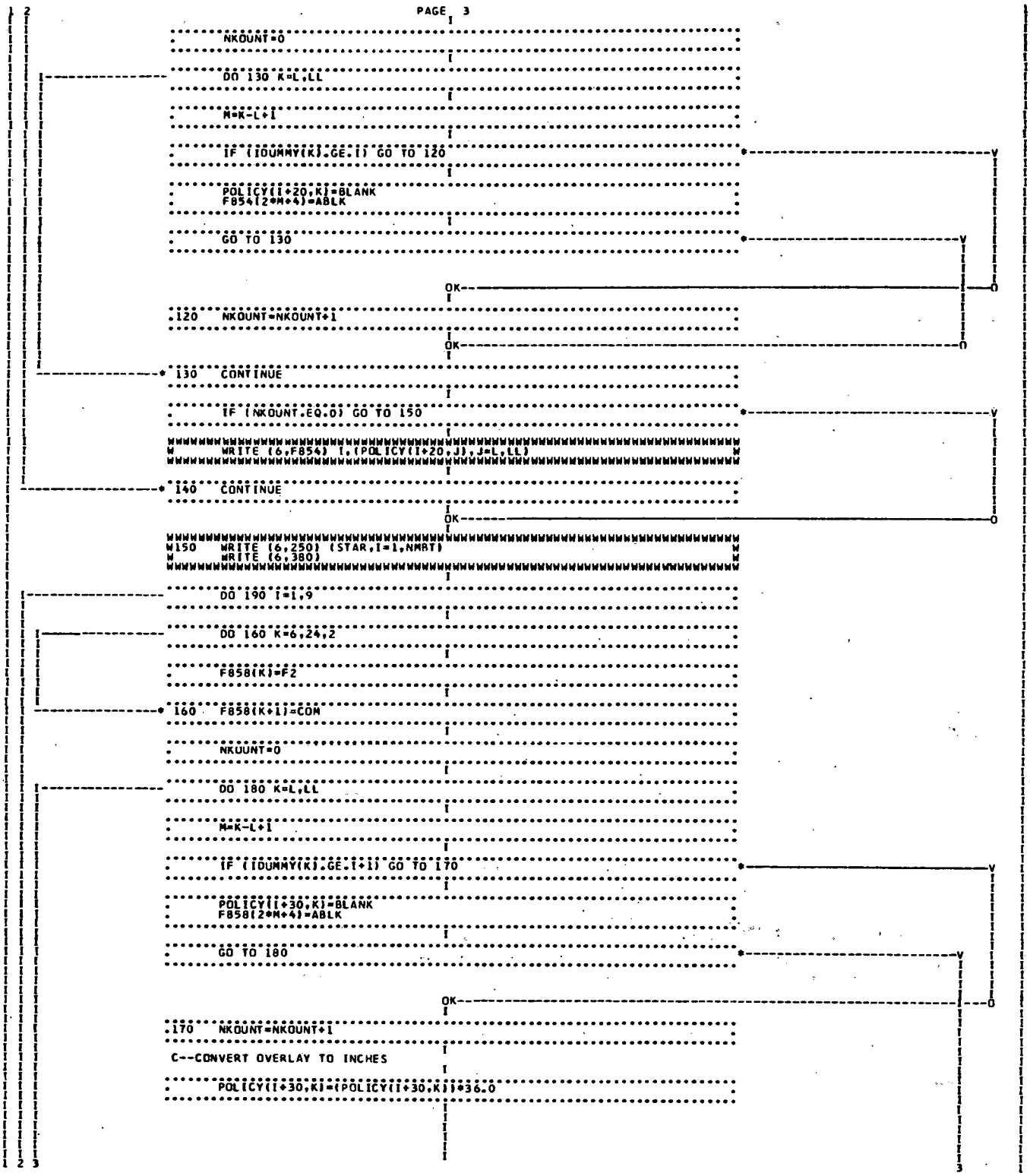

PAGE 2
DOVER(I)=DMIN(I)
I=I+1
TK=0.
DO 50 L=1,LAYER
50 TK=TK+DOVER(L)
CALL INCOST (TK,CT,SV)
IF ((DOVER(I)+XINC(I)).GT.DMAX(I)) GO TO 40
XINCRE=XINC(I)
DOVER(I)=DOVER(I)+XINCRE
TK=TK+XINCRE
CALL INCOST (TK,CT,SV)
I=1
OK
O
60 CONTINUE
IF (CT.GT.CMAX) JSKIP(1)=1
IF (TK.GT.TCKMAX) JSKIP(2)=1
IF ((TK.GT.TCKMAX).OR.(CT.GT.CMAX)) GO TO 40
KT(I)=KT(I)+1
DO 70 L=1,LAYER
70 FLAG(L)=BLANK
C--(0.*TK)INSURES FUNCTION TIME NOT RELOCATED BY OPTIMIZATION COMPILERS.
T=TIME(0.0*TK,PSI,XTTO)
IF (T.GT.0.) GO TO 80
JSKIP(3)=1
GO TO 30
OK
O
80 COSTIN=CT
SALVIN=SV
JSKIP(3)=0
KT(2)=KT(2)+1
OK
O
90 DO 100 J=1,3
100 KSKIP(J)=KSKIP(J)+JSKIP(J)
RETURN
END
4 3 2 1

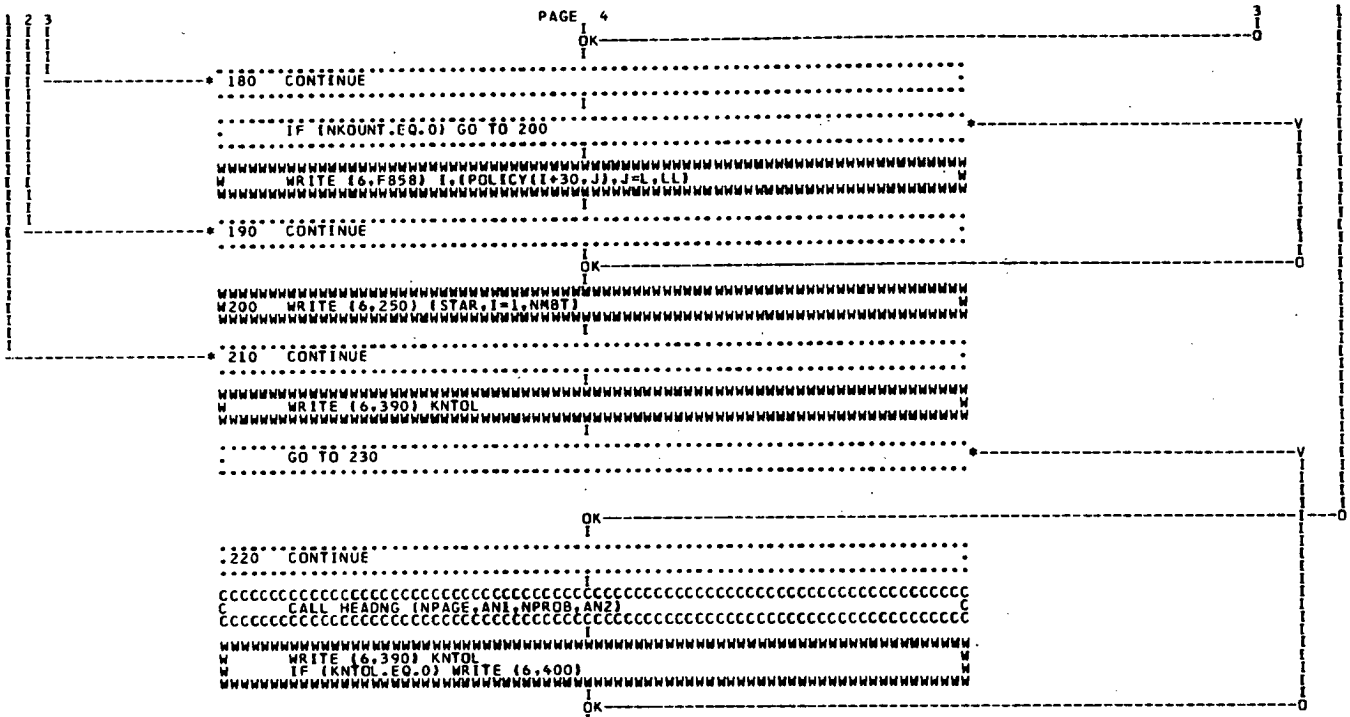
SYMBOL KEY

EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

```
      SUBROUTINE SUMARY (NMB,OVLEVL,KNTOL,POLICY,NPAGE,AN1,NPROB,AN2)
C--A SUMMARY OF THE BETTER(LOWEST COST) DESIGNS ARE PRINTED FOR PROBLEM.
      DIMENSION IDUMMY(34), POLICY(55,30), AN1(20), AN2(19)
      DIMENSION F850(26), F854(26), F858(26)
      DATA F850(1)/4H(7X,/,  F850(2)/4H2HD(/,  F850(3)/4H,I1,/,
     1     F850(4)/4H1H),/,  F850(5)/4H12X,/,  F850(26)/3H1X)  /
      DATA F854(1)/4H(7X,/,  F854(2)/4H2HT(/,  F854(3)/4H,I1,/,
     1     F854(4)/4H1H),/,  F854(5)/4H11X,/,  F854(26)/3H1X)  /
      DATA F858(1)/4H(7X,/,  F858(2)/4H2HO(/,  F858(3)/4H,I1,/,
     1     F858(4)/4H1H),/, F858(5)/4H11X,/, F858(26)/3H1X) /
      DATA  ABLK/2HA7/,  F1/4HF7.1/,  COM/4H,1X,/, F2/4HF7.2/,A1/4H,A1,/
      DATA BLANK/1H /, STAR/4H****/, NDP/10/, LAYD/6/
      IF (NMB*KNTOL.EQ.0) GO TO 220
      NMBEST=MINO(NMB,KNTOL)
      DO 210 L=1,NMBEST,NDP
      LL=MINO(L+NDP-1,NMBEST)
C--LL-THE NO. DESIGNS THIS PAGE, NMBT-WORDS OF '****' REQUIRED.
      NMBT=((LL-L)*8+31)/4
      CALL HEADNG (NPAGE,AN1,NPROB,AN2)
      WRITE (6,240) (I,I=L,LL)
      DO 10 I=L,LL
10    IDUMMY(I)=POLICY(9,I)
      DO 40 I=1,LAYD
      NKOUNT=0
      DO 30 K=L,LL
      IF (IDUMMY(K).GE.I) GO TO 20
      POLICY(I+9,K)=0.0
      GO TO 30
20    NKOUNT=NKOUNT+1
30    CONTINUE
      IF (NKOUNT.EQ.0) GO TO 50
      NLINE=I
40    CONTINUE
50    WRITE (6,250) (STAR,I=1,NMBT)
```


PAGE 2
IF (NLINE.GE.4) GO TO 60
NLP=NLINE+2
OK
W60 WRITE (6,260) ((POLICY(I,II),I=50,55),II=L,LL)
W WRITE (6,270) (POLICY(2,I),I=L,LL)
W WRITE (6,280) (POLICY(3,I),I=L,LL)
W WRITE (6,290) (POLICY(4,I),I=L,LL)
W WRITE (6,300) (POLICY(6,I),I=L,LL)
W WRITE (6,310) (POLICY(7,I),I=L,LL)
W WRITE (6,250) (STAR,I=1,NMBT)
W WRITE (6,250) (STAR,I=1,NMBT)
W WRITE (6,320) (POLICY(8,I),I=L,LL)
W WRITE (6,250) (STAR,I=1,NMBT)
W WRITE (6,250) (STAR,I=1,NMBT)
W WRITE (6,330) (IDUMMY(I),I=L,LL)
W WRITE (6,250) (STAR,I=1,NMBT)
W WRITE (6,340)
DO 90 I=1,NLINE
DO 70 K=6,24,2
F850(K)=F2
70 F850(K+1)=A1
DO 80 K=L,LL
M=K-L+1
C—CONVERT LAYER DEPTHS TO INCHES FOR PRINTING.
POLICY(I+9,K)=POLICY(I+9,K)*36.0
IF (POLICY(I+9,K).NE.0.) GO TO 80
POLICY(I+9,K)=BLANK
F850(2*M+4)=ABLK
F850(2*M+5)=A1
OK
80 CONTINUE
W WRITE (6,F850) I,(POLICY(I+9,J),POLICY(I+40,J),J=L,LL)
90 CONTINUE
DO 100 I=L,LL
100 IDUMMY(I)=POLICY(20,I)
W WRITE (6,250) (STAR,I=1,NMBT)
W WRITE (6,350) (POLICY(5,J),J=L,LL)
W WRITE (6,250) (STAR,I=1,NMBT)
W WRITE (6,360) (IDUMMY(I),I=L,LL)
W WRITE (6,250) (STAR,I=1,NMBT)
W WRITE (6,370)
DO 140 I=1,10
DO 110 K=6,24,2
F854(K)=F1
110 F854(K+1)=COM

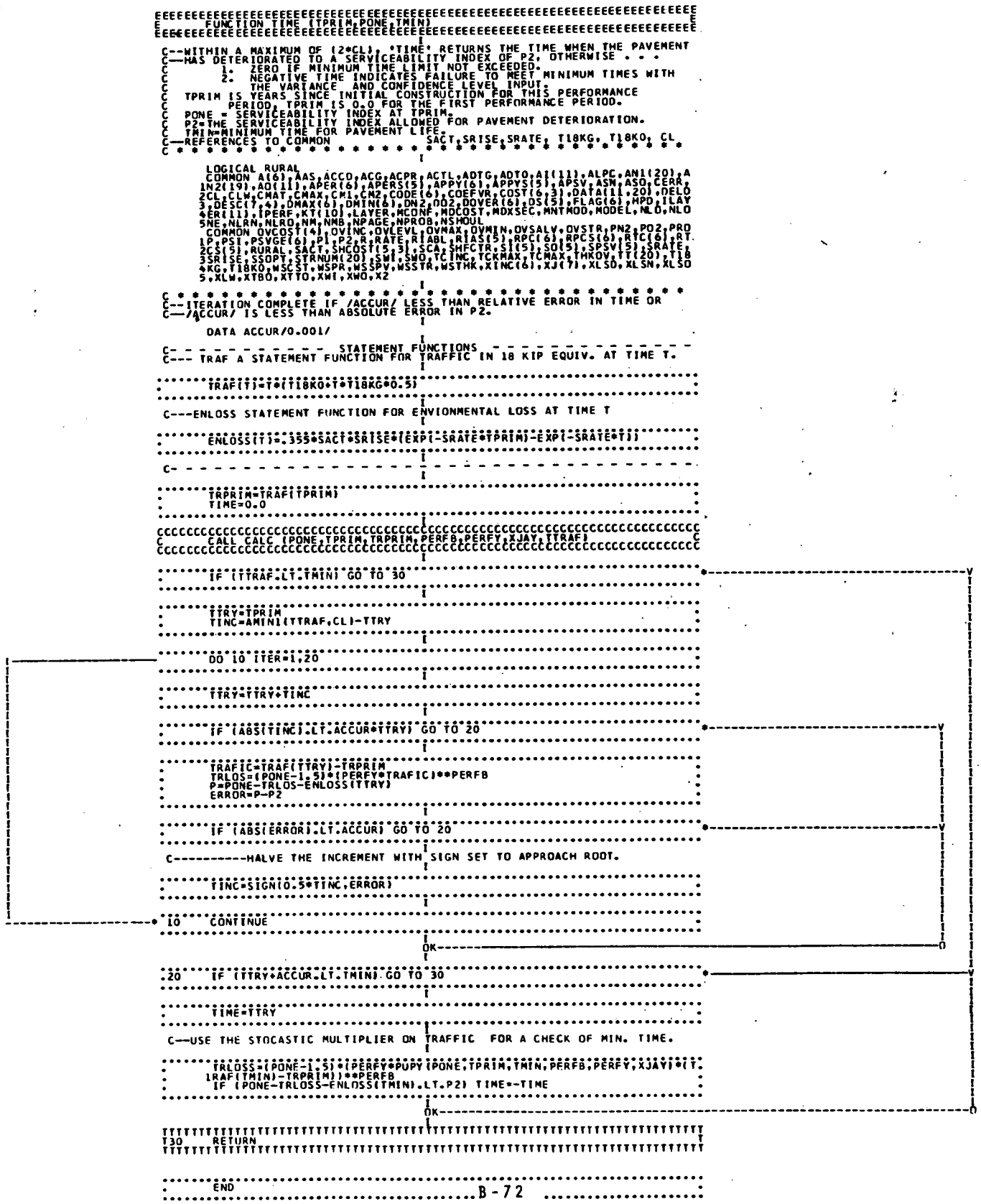

PAGE 3
NKOUNT=0
DO 130 K=L,LL
M=K-L+1
IF (IDUMMY(K).GE.I) GO TO 120
POLICY(I+20,K)=BLANK
F854(2*M+4)=ABLK
GO TO 130
OK
120 NKOUNT=NKOUNT+1
OK
130 CONTINUE
IF (NKOUNT.EQ.0) GO TO 150
WRITE (6,F854) I,(POLICY(I+20,J),J=L,LL)
140 CONTINUE
OK
150 WRITE (6,250) (STAR,I=1,NMRT)
WRITE (6,380)
DO 190 I=1,9
DO 160 K=6,24,2
F858(K)=F2
160 F858(K+1)=COM
NKOUNT=0
DO 180 K=L,LL
M=K-L+1
IF (IDUMMY(K).GE.I+1) GO TO 170
POLICY(I+30,K)=BLANK
F858(2*M+4)=ABLK
GO TO 180
OK
170 NKOUNT=NKOUNT+1
C--CONVERT OVERLAY TO INCHES
POLICY(I+30,K)=(POLICY(I+30,K))+36.0



```
                                                                    PAGE  4
                                                                      OK
  180   CONTINUE
        IF (NKOUNT.EQ.0) GO TO 200
        WRITE (6,F858) I,(POLICY(I+30,J),J=L,LL)
  190   CONTINUE
                                                                      OK
  200   WRITE (6,250) (STAR,I=1,NMBT)
  210   CONTINUE
        WRITE (6,390) KNTOL
        GO TO 230
                                                                      OK
  220   CONTINUE
C       CALL HEADNG (NPAGE,ANI,NPROB,ANZ)
        WRITE (6,390) KNTOL
        IF (KNTOL.EQ.0) WRITE (6,400)
                                                                      OK
  230   RETURN

 C--FORMAT STATEMENTS- - - - - - - - - - - - - - - - - - - - - - -

  240   FORMAT (19X,46HPROBLEM SUMMARY OF THE BETTER FEASIBLE DESIGNS/26X,
       133HIN ORDER OF INCREASING TOTAL COST//20X,10I8)
  250   FORMAT (2X,32A4,A2)
  260   FORMAT (2X,20HMATERIAL ARRANGEMENT,3X,10(6A1,2X))
  270   FORMAT (2X,17HINIT. CONST. COST,3X,10F8.3)
  280   FORMAT (2X,19HOVERLAY CONST. COST,1X,10F8.3)
  290   FORMAT (2X,9HUSER COST,11X,10F8.3)
  300   FORMAT (2X,19HROUTINE MAINT. COST,1X,10F8.3)
  310   FORMAT (2X,13HSALVAGE VALUE,7X,10F8.3)
  320   FORMAT (2X,10HTOTAL COST,10X,10F8.3)
  330   FORMAT (2X,16HNUMBER OF LAYERS,3X,10I8)
  340   FORMAT (2X,20HLAYER DEPTH (INCHES))
  350   FORMAT (2X,20HSTRUCTURAL NUMBER   ,10F8.2)
  360   FORMAT (2X,18HNO.OF PERF.PERIODS,1X,10I8)
  370   FORMAT (2X,18HPERF. TIME (YEARS))
  380   FORMAT (2X,20HOVERLAY POLICY(INCH)/2X,23HEXCLUSIVE OF LEVEL-UP C,1
       13H WEAR-COURSE))
  390   FORMAT (///10X,51HTHE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED W
       1AS,I10////)
  400   FORMAT (////10X,60HTHERE WERE NO FEASIBLE DESIGNS FOR THE CONDITIO
       1NS SPECIFIED.////)

        END
```

SYMBOL KEY

EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

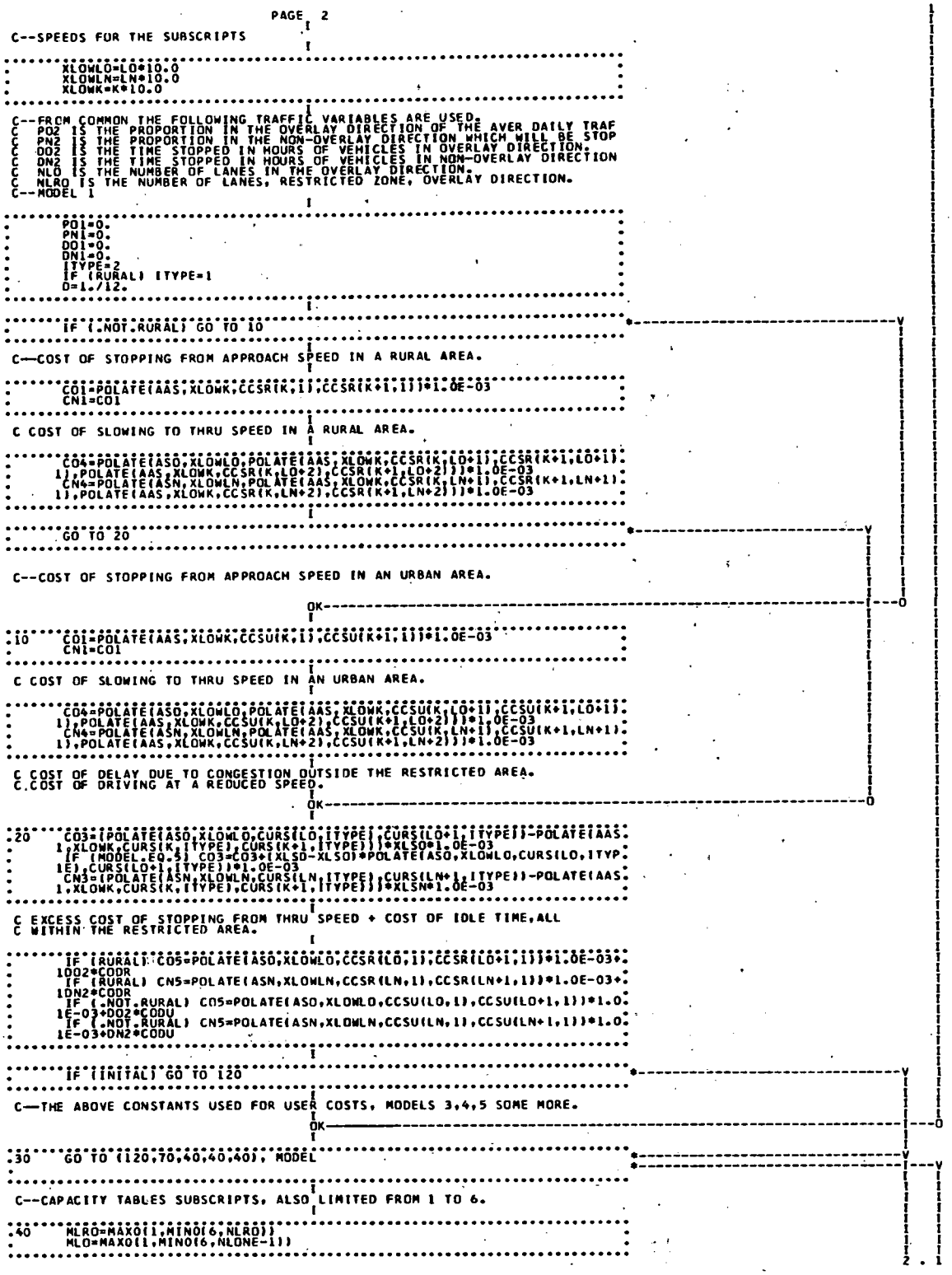


USER

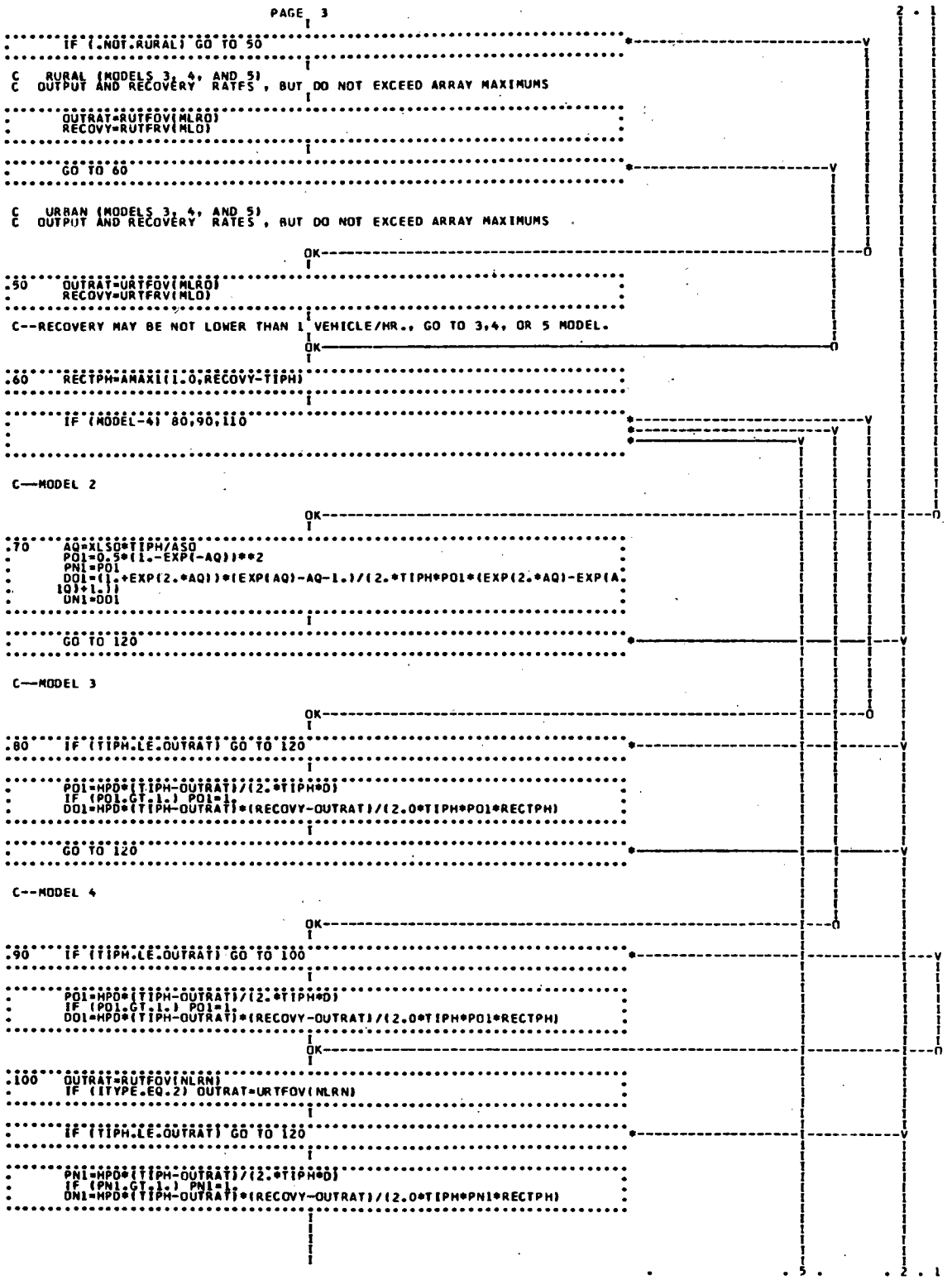
SYMBOL KEY

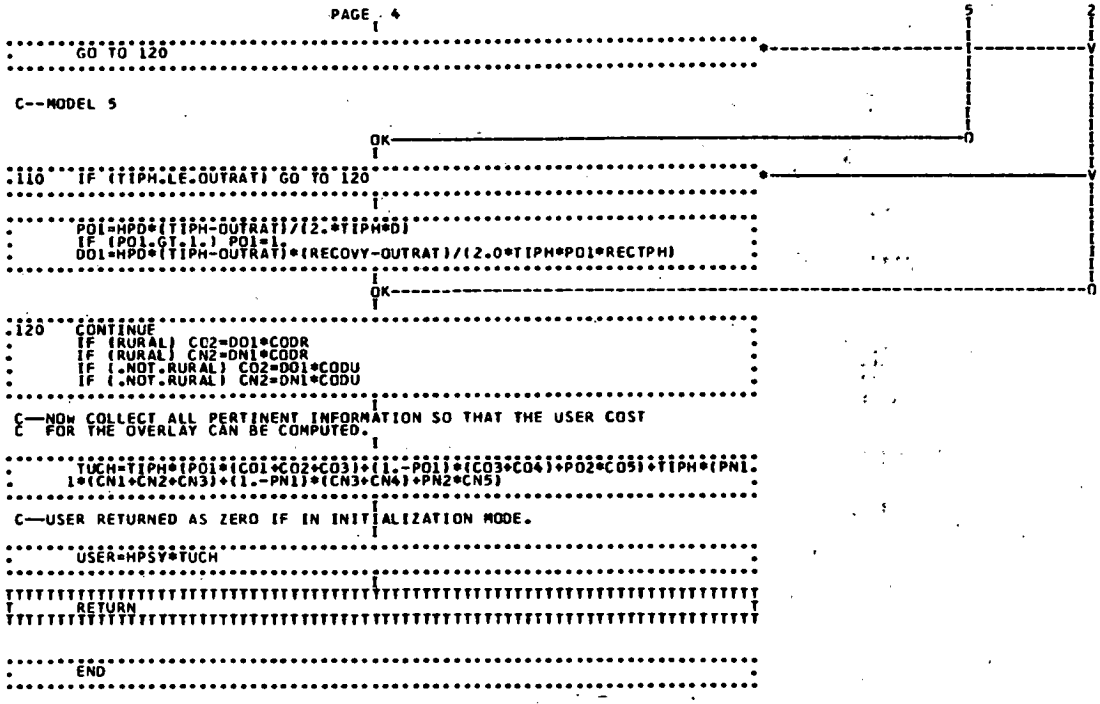
EEEEE = ENTRY
TTTTT = TERMINAL
CCCCC = CALL
RRRRR = READ
WWWWW = WRITE

```
      FUNCTION USER (TIPH,HPSY)

C--THIS SUBROUTINE OPERATES IN TWO MODES, NORMAL AND INITIALIZATION.
C-- FOR NORMAL USE, TIPH SHOULD NEVER BE ZERO.
C--  THE INITIALIZATION MODE CAN BE EFFECTIVE IN SAVING COMPUTER TIME
C--IF THE REFERENCED VALUES IN COMMON ARE NOT CHANGED FOR SEVERAL
C--  CALLS TO THIS FUNCTION.  USER(0.0,0.0) WILL REFERENCE THE VALUES IN
C--  COMMON AND CALULATE INTERMEDIATE VALUES USED BY THE FUNCTION.
C--  USER(0.0,0.0) WILL AGAIN RE-INITIALIZE THE INTERMEDIATE VARIABLES.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      LOGICAL RURAL
      COMMON A(6),AAS,ACCO,ACG,ACPR,ACTL,ADTG,ADTO,AI(11),ALPC,AN1(20),A
     1N2(19),AO(11),APER(6),APERS(5),APPY(6),APPYS(5),APSV,ASN,ASO,CERR,
     2CL,CLW,CMAT,CMAX,CM1,CM2,CODE(6),COEFVR,COST(6,3),DATA(11,20),DELO
     3,DESC(7,4),DMAX(6),DMIN(6),DN2,DO2,DOVER(6),DS(5),FLAG(6),HPD,ILAY
     4ER(11),IPERF,KT(10),LAYER,MCONF,MDCOST,MDXSEC,MNTMOD,MODEL,NLO,NLO
     5NE,NLRN,NLRO,NM,NMB,NPAGE,NPROB,NSHOUL
      COMMON OVCOST(4),OVINC,OVLEVL,OVMAX,OVMIN,OVSALV,OVSTR,PN2,PO2,PRO
     1P,PSI,PSVGE(6),P1,P2,R,RATE,RIABL,RIAS(5),RPC(6),RPCS(6),RTC(6),RT
     2CS(5),RURAL,SACT,SHCOST(5,3),SCA,SHFCTR,SI(5),SO(5),SPSV(5),SRATE,
     3SRISE,SSOPT,STRNUM(20),SWI,SWO,TCINC,TCKMAX,TCMAX,THKOV,TT(20),T18
     4KG,T18KO,WSCST,WSPR,WSSPV,WSSTR,WSTHK,XINC(6),XJ(7),XLSD,XLSN,XLSO
     5,XLW,XTBO,XTTO,XWI,XWO,X2

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      DIMENSION CCSR(6,7), CCSU(6,7), CURS(6,2)
      DIMENSION RUTFOV(6), RUTFRV(6), URTFOV(6), URTFRV(6)

C--USER COSTS AND MODELS IN TTI REPORT 123-11, APPENDIX II-PART 2.
C--THE FORTRAN ARRAY IS AS FOLLOWS . . .
C--CCSR(1,1), CCSR(2,1), . . ., CCSR(6,1), CCSR(1,2), CCSR(2,2), . . .,
C--CCSR(6,6), CCSR(1,7), CCSR(2,7), . . ., CCSR(6,7).
C  COST OF SLOWING DOWN IN A RURAL AREA

      DATA CCSR/ 10.676, 22.932, 39.753, 63.454, 98.194, 151.888,
     *   0.0, 11.860, 27.079, 49.907, 83.454, 134.793,
     *   0.0, 0.0, 14.306, 35.812, 67.935, 116.527,
     *   0.0, 0.0, 0.0, 19.902, 50.326, 95.788,
     *   0.0, 0.0, 0.0, 0.0, 28.491, 71.070,
     *   0.0, 0.0, 0.0, 0.0, 0.0, 40.931, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0/

C  COST OF SLOWING DOWN IN AN URBAN AREA

      DATA CCSU/ 7.395, 14.829, 24.570, 37.838, 56.703, 85.514,
     *   0.0, 7.059, 16.200, 28.896, 47.046, 74.330,
     *   0.0, 0.0, 8.191, 20.130, 37.309, 61.884,
     *   0.0, 0.0, 0.0, 10.845, 27.024, 50.705,
     *   0.0, 0.0, 0.0, 0.0, 14.939, 36.994,
     *   0.0, 0.0, 0.0, 0.0, 0.0, 20.704, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0/

C  COST OF OPERATING AT A REDUCED SPEED

      DATA CURS/ 495.77, 270.31, 196.62, 162.58, 145.54, 138.80,
     *   456.66, 248.30, 179.64, 147.22, 130.08, 121.88   /

C--COST OF DELAY, RURAL AND URBAN

      DATA CODR/ 4.409 70/, CODU/4.111 52/

C  TRAFFIC MODELS AND THEIR ASSOCIATED CAPACITY TABLES DOCUMENTED BY
C       REPORT 123-11,APPENDIX II, PART 3.
C  RUTFOV-RURAL TRAFFIC IN OVERLAY ZONE(NO. OF LANES OPEN SUBSCRIPT)

      DATA RUTFOV/1350., 2700., 4350., 6000., 7650., 9300./

C  RUTFRV-RURAL TRAFFIC IN RECOVERY ZONE(ONE LESS THAN NUMBER OF LANES,
C          ONE-DIRECTION (NORMAL TRAFFIC) FOR A SUBSCRIPT)

      DATA RUTFRV/3000., 4500., 6200., 7900., 9600., 11300./

C  URTFOV AND URTFRV-SIMILAR TO ABOVE FOR URBAN TRAFFIC.

      DATA URTFOV/1400., 2800., 4500., 6200., 7900., 9600./
      DATA URTFRV/3000., 4700., 6400., 8100., 9800., 11500./
      LOGICAL INITAL
      DATA INITAL/.FALSE./

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C--'POLATE', A STATEMENT FUNCTION FOR LINEAR INTERPOLATION,EXTRAPOLATION
C--WHERE XLOW IS NEXT LOWER TABLE VALUE BELOW DESIRED X,
C--10. IS THE INCREMENT IN X VALUES ON THE TABLE,
C--YLOW IS THE TABLE VALUE CORRESPONDINT TO XLOW,
C--YHI CORRESPONDS TO XLOW + 10. ON THE TABLE,
C--POLATE WILL BE THE INTERPOLATED Y VALUE FOR X, HOWEVER, IF X IS NOT
C--BETWEEN XLOW AND XLOW+10., POLATE WILL BE AN EXTRAPOLATED VALUE.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

      POLATE(X, XLOW, YLOW, YHI) = YLOW  + (X-XLOW) * 0.1 * (YHI-YLOW)

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C--GO BELOW  TO USE PREVIOUS VALUES IF INITIALIZATION MODE AND NON-ZERO

      IF (INITAL.AND.TIPH.GT.0.0) GO TO 30

      IF (TIPH.EQ.0.0) INITAL=.TRUE.

C--RESTRICTED SPEED SUBSCRIPTS FOR STOPPING-SLOWING TABLES.
C--SUBSCRIPTS GREATER THAN ZERO, LESS THAN 6 FOR YLOW.

      LO=MAXO(1,MINO(5,IFIX(ASO)/10))
      LN=MAXO(1,MINO(5,IFIX(ASN)/10))
      K=MAXO(1,MINO(5,IFIX(AAS)/10))
```




```
C--SPEEDS FOR THE SUBSCRIPTS

      XLOWLO=LO*10.0
      XLOWLN=LN*10.0
      XLOWK=K*10.0

C--FROM COMMON THE FOLLOWING TRAFFIC VARIABLES ARE USED.
C  PO2 IS THE PROPORTION IN THE OVERLAY DIRECTION OF THE AVER DAILY TRAF
C  PN2 IS THE PROPORTION IN THE NON-OVERLAY DIRECTION WHICH WILL BE STOP
C  DO2 IS THE TIME STOPPED IN HOURS OF VEHICLES IN OVERLAY DIRECTION.
C  DN2 IS THE TIME STOPPED IN HOURS OF VEHICLES IN NON-OVERLAY DIRECTION
C  NLO IS THE NUMBER OF LANES IN THE OVERLAY DIRECTION.
C  NLRO IS THE NUMBER OF LANES, RESTRICTED ZONE, OVERLAY DIRECTION.
C--MODEL 1

      PO1=0.
      PN1=0.
      DO1=0.
      DN1=0.
      ITYPE=2
      IF (RURAL) ITYPE=1
      D=1./12.

      IF (.NOT.RURAL) GO TO 10

C--COST OF STOPPING FROM APPROACH SPEED IN A RURAL AREA.

      CO1=POLATE(AAS,XLOWK,CCSR(K,1),CCSR(K+1,1))*1.0E-03
      CN1=CO1

C COST OF SLOWING TO THRU SPEED IN A RURAL AREA.

      CO4=POLATE(ASO,XLOWLO,POLATE(AAS,XLOWK,CCSR(K,LO+1),CCSR(K+1,LO+1).
     1),POLATE(AAS,XLOWK,CCSR(K,LO+2),CCSR(K+1,LO+2)))*1.0E-03
      CN4=POLATE(ASN,XLOWLN,POLATE(AAS,XLOWK,CCSR(K,LN+1),CCSR(K+1,LN+1).
     1),POLATE(AAS,XLOWK,CCSR(K,LN+2),CCSR(K+1,LN+2)))*1.0E-03

      GO TO 20

C--COST OF STOPPING FROM APPROACH SPEED IN AN URBAN AREA.

10    CO1=POLATE(AAS,XLOWK,CCSU(K,1),CCSU(K+1,1))*1.0E-03
      CN1=CO1

C COST OF SLOWING TO THRU SPEED IN AN URBAN AREA.

      CO4=POLATE(ASO,XLOWLO,POLATE(AAS,XLOWK,CCSU(K,LO+1),CCSU(K+1,LO+1).
     1),POLATE(AAS,XLOWK,CCSU(K,LO+2),CCSU(K+1,LO+2)))*1.0E-03
      CN4=POLATE(ASN,XLOWLN,POLATE(AAS,XLOWK,CCSU(K,LN+1),CCSU(K+1,LN+1).
     1),POLATE(AAS,XLOWK,CCSU(K,LN+2),CCSU(K+1,LN+2)))*1.0E-03

C COST OF DELAY DUE TO CONGESTION OUTSIDE THE RESTRICTED AREA.
C.COST OF DRIVING AT A REDUCED SPEED.

20    CO3=(POLATE(ASO,XLOWLO,CURS(LO,ITYPE),CURS(LO+1,ITYPE))-POLATE(AAS.
     1,XLOWK,CURS(K,ITYPE),CURS(K+1,ITYPE)))*XLSO*1.0E-03
      IF (MODEL.EQ.5) CO3=CO3+(XLSD-XLSO)*POLATE(ASO,XLOWLO,CURS(LO,ITYP.
     1E),CURS(LO+1,ITYPE))*1.0E-03
      CN3=(POLATE(ASN,XLOWLN,CURS(LN,ITYPE),CURS(LN+1,ITYPE))-POLATE(AAS.
     1,XLOWK,CURS(K,ITYPE),CURS(K+1,ITYPE)))*XLSN*1.0E-03

C EXCESS COST OF STOPPING FROM THRU SPEED + COST OF IDLE TIME,ALL
C WITHIN THE RESTRICTED AREA.

      IF (RURAL) CO5=POLATE(ASO,XLOWLO,CCSR(LO,1),CCSR(LO+1,1))*1.0E-03+.
     1DO2*CODR
      IF (RURAL) CN5=POLATE(ASN,XLOWLN,CCSR(LN,1),CCSR(LN+1,1))*1.0E-03+.
     1DN2*CODR
      IF (.NOT.RURAL) CO5=POLATE(ASO,XLOWLO,CCSU(LO,1),CCSU(LO+1,1))*1.0.
     1E-03+DO2*CODU
      IF (.NOT.RURAL) CN5=POLATE(ASN,XLOWLN,CCSU(LN,1),CCSU(LN+1,1))*1.0.
     1E-03+DN2*CODU

      IF (INITAL) GO TO 120

C--THE ABOVE CONSTANTS USED FOR USER COSTS, MODELS 3,4,5 SOME MORE.

30    GO TO (120,70,40,40,40), MODEL

C--CAPACITY TABLES SUBSCRIPTS, ALSO LIMITED FROM 1 TO 6.

40    MLRO=MAX0(1,MIN0(6,NLRO))
      MLO=MAX0(1,MIN0(6,NLONE-1))
```


PAGE 3
IF (.NOT.RURAL) GO TO 50
C RURAL (MODELS 3, 4, AND 5)
C OUTPUT AND RECOVERY RATES, BUT DO NOT EXCEED ARRAY MAXIMUMS
OUTRAT=RUTFOV(MLRO)
RECOVY=RUTFRV(MLO)
GO TO 60
C URBAN (MODELS 3, 4, AND 5)
C OUTPUT AND RECOVERY RATES, BUT DO NOT EXCEED ARRAY MAXIMUMS
OK
50 OUTRAT=URTFOV(MLRO)
RECOVY=URTFRV(MLO)
C--RECOVERY MAY BE NOT LOWER THAN 1 VEHICLE/HR., GO TO 3,4, OR 5 MODEL.
OK
60 RECTPH=AMAX1(1.0,RECOVY-TIPH)
IF (MODEL-4) 80,90,110
C--MODEL 2
OK
70 AQ=XLSO*TIPH/ASO
PO1=0.5*(1.-EXP(-AQ))**2
PN1=PO1
DO1=(1.+EXP(2.*AQ))*(EXP(AQ)-AQ-1.)/(2.*TIPH*PO1*(EXP(2.*AQ)-EXP(A
1Q)+1.))
DN1=DO1
GO TO 120
C--MODEL 3
OK
80 IF (TIPH.LE.OUTRAT) GO TO 120
PO1=HPD*(TIPH-OUTRAT)/(2.*TIPH*D)
IF (PO1.GT.1.) PO1=1.
DO1=HPD*(TIPH-OUTRAT)*(RECOVY-OUTRAT)/(2.0*TIPH*PO1*RECTPH)
GO TO 120
C--MODEL 4
OK
90 IF (TIPH.LE.OUTRAT) GO TO 100
PO1=HPD*(TIPH-OUTRAT)/(2.*TIPH*D)
IF (PO1.GT.1.) PO1=1.
DO1=HPD*(TIPH-OUTRAT)*(RECOVY-OUTRAT)/(2.0*TIPH*PO1*RECTPH)
OK
100 OUTRAT=RUTFOV(NLRN)
IF (ITYPE.EQ.2) OUTRAT=URTFOV(NLRN)
IF (TIPH.LE.OUTRAT) GO TO 120
PN1=HPD*(TIPH-OUTRAT)/(2.*TIPH*D)
IF (PN1.GT.1.) PN1=1.
DN1=HPD*(TIPH-OUTRAT)*(RECOVY-OUTRAT)/(2.0*TIPH*PN1*RECTPH)


PAGE 4
GO TO 120
C--MODEL 5
OK
110 IF (TIPH.LE.OUTRAT) GO TO 120
PO1=HPD*(TIPH-OUTRAT)/(2.*TIPH*D)
IF (PO1.GT.1.) PO1=1.
DO1=HPD*(TIPH-OUTRAT)*(RECOVY-OUTRAT)/(2.0*TIPH*PO1*RECTPH)
OK
120 CONTINUE
IF (RURAL) CO2=DO1*CODR
IF (RURAL) CN2=DN1*CODR
IF (.NOT.RURAL) CO2=DO1*CODU
IF (.NOT.RURAL) CN2=DN1*CODU
C--NOW COLLECT ALL PERTINENT INFORMATION SO THAT THE USER COST
C FOR THE OVERLAY CAN BE COMPUTED.
TUCH=TIPH*(PO1*(CO1+CO2+CO3)+(1.-PO1)*(CO3+CO4)+PO2*CO5)+TIPH*(PN1.
1*(CN1+CN2+CN3)+(1.-PN1)*(CN3+CN4)+PN2*CN5)
C--USER RETURNED AS ZERO IF IN INITIALIZATION MODE.
USER=HPSV*TUCH
RETURN
END

APPENDIX C

SAMP6 USERS' GUIDE

CHAPTER 1

INTRODUCTION

The objective of the Systems Flexible Pavement Design Manual is to provide instructions for highway department personnel to design flexible pavements using the systems approach. This design system is built around the AASHO Road Test flexible pavement performance equation and uses the computer for making numerous calculations of different trial designs. The least costly of these designs are retained and printed out for consideration by the highway designer. The computer program which does these calculations is called SAMP6, SAMP being an acronym for Systems Analysis Model for Pavements and the 6 indicating that this is the sixth in the series of development.

The design of a pavement involves considering a number of different factors such as material costs, material properties, traffic, the effects of the environment, deterioration of the pavement riding quality due to traffic and non-traffic causes and the costs of different overlay strategies sometime in the future.

The SAMP6 computer program is written to reflect all of these variables and others to be shown later in this design manual. The SAMP6 system is broken down into a number of subsystems, some of which are listed below:

1. Structural subsystem
2. User cost subsystem

3. Environmental serviceability loss subsystem
4. Overlay strategy subsystem
5. Input and output subsystem
6. Maintenance costs subsystem
7. Cross-sectional area and initial cost subsystem
8. Stochastic variation subsystem.

Each of these subsystems is written as a module of the overall pavement system so that each can be taken out and replaced with some other similar system with a minimum of programming effort. A more detailed description of the SAMP6 pavement design system is given in the NCHRP Project 1-10A final report. Data is input to the computer program on a series of cards, each of which will be explained in detail in the remainder of the design manual.

GENERAL DESCRIPTION OF THE SAMP6 PROGRAM

The SAMP6 system is built around the general concept of the serviceability index. It is assumed in composing this program that the design engineer wishes to provide from available materials a pavement that can be maintained above a specified level of serviceability over a specified period of time within a specified degree of reliability at a minimum overall total cost. The computer program provides for selecting a complete pavement design strategy which calls for action both at present, during initial construction and in the future with overlays, reconstruction, or routine maintenance. For a given design analysis, both initial construction costs and future costs are computed for various design strategies. Future costs consist of future overlay costs, user costs during the overlay operation, maintenance costs, and present worth of the salvage value of

the materials at the end of the specified analysis period. In order to compare design strategies on an equitable basis, all future costs are discounted to the present using an input interest rate or time value of money. The computer program is so structured that it first computes the thicknesses of each of the combinations of materials chosen by the designer, then it begins to check each initial design for feasibility from the point of view of cost and thickness, then various overlay strategies are tried by the computer program. A summary flow chart of the SAMP6 computer program is shown in Figure 1.1. This figure illustrates how the program checks each initial design against its constraints to determine all feasible design strategies. If the funds available are inadequate or the maximum allowable thickness too small, then the initial design is not feasible and the program considers the next design. If these first two restrictions are met, the design life of the initial construction is calculated. If the initial design life does not meet the constraint of minimum time to the first overlay, the program discards this level of overlay thickness and proceeds to the next. If the constraint of the minimum time to first overlay is met, then the program checks to see if there are any overlay strategies which last the analysis period. These checks involve calculating the design life of each overlay thickness for all combinations of overlay strategies. Depending upon the range of thicknesses that the designer wishes to try, there can be a large number of possible overlay strategies for each initial design. A feasible design strategy is one for which both the initial construction and the overlay strategy meet all constraints placed upon them. Total cost is calculated for each of the feasible design strategies. The costs include initial construction cost, user cost during overlay, maintenance cost and costs of overlay materials.

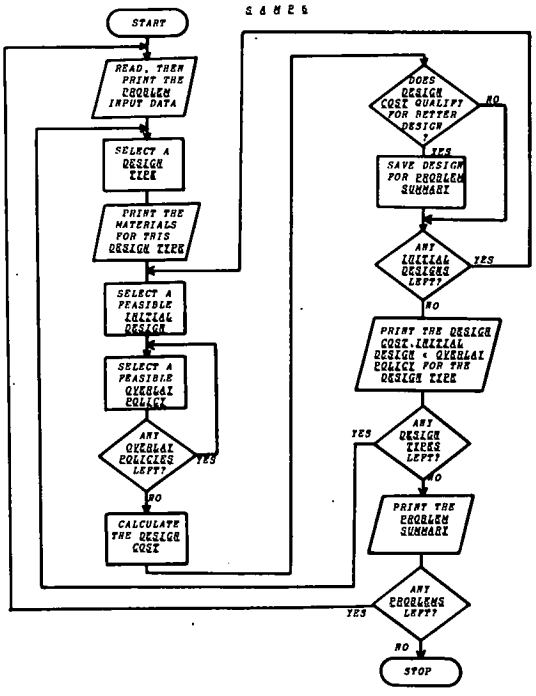


FIGURE 1.1. GENERAL FLOWCHART FOR SAMP6

The program then considers the next initial design and repeats this procedure until all possible design strategies are either found to be feasible or not. The feasible strategies are sorted by total cost and a set of design strategies are printed in order of increasing total cost. Out of the 30 design strategies arranged in ascending order according to total cost, the designer can usually find one which is most suitable in his experience for the kinds of construction and maintenance capabilities that he expects to prevail.

PAVEMENT DESIGN PROCESS

The design process using the SAMP6 Pavement Design System involves three steps. First, obtain the inputs for the SAMP6 program. Second, use the computer program to calculate different design strategies, and third, out of the feasible design strategies select the preferred pavement design. This last step is an essential part of the design process because often there are practical considerations that cannot be incorporated into the SAMP6 Program which nevertheless should influence the choice of the preferred design strategy. For example, the feasible design that has the lowest total cost may have large overlay thicknesses which might reduce the effectiveness of drainage and drop inlet capacities. Another design might be preferred because of this consideration.

CHAPTER 2

PROGRAM, RUN, AND
PROJECT IDENTIFICATION

The first two cards input into the SAMP6 Pavement Design System are for identification of the run to be made. Extensive use of the design system will result in large numbers of runs on different projects throughout the state. As an aid to filing and record keeping it has been found useful to include a fairly complete description of the project and its location on the first two data cards.

These data will provide the engineer with a way to classify each computer run in his use of the SAMP6 Pavement Design System. Input number 1.1 is 80 columns of verbal or numerical description of the project for which the computer is to be run and the specific run identification number. This same identification may be used for a number of different problems to be run on the same project only varying one or more of the input variables in his efforts to evaluate different design strategies on the same stretch of road. This card should never be completely blank.

Input number 2.1, called NPROB, is a four column number. This number can be used to identify the specific problem within a project that the engineer is attempting to run.

Input number 2.2 is 76 columns of verbal or numerical description of the project itself. These 76 columns may be used to identify some of the major inputs that are being varied with this run. Cards number 1 and 2 are shown in Figure 2.1.

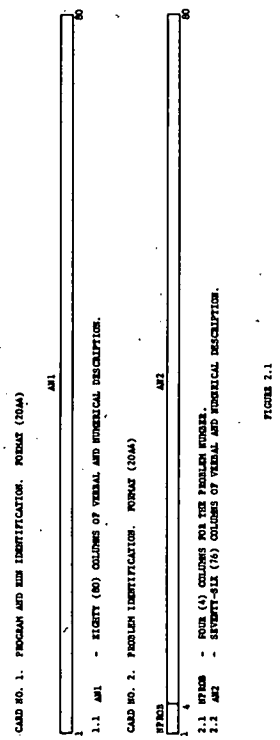


FIGURE 2.1

CHAPTER 3

PROGRAM CONTROL AND MISCELLANEOUS INPUT

The data input on this card controls the amount of output the program produces and certain other important time, costs, geometrical and production variables.

Input number 3.1 is the number of output pages (maximum of 3) for the summary table which will be printed out at the end of the problem run. There will be 10 designs summarized on each page.

Input number 3.2 is the number of lanes on a highway in both directions.

Input number 3.3 is the length of the analysis period in years.

Input number 3.4 is the width of each traffic lane in feet.

Input number 3.5 is the interest rate or the time value of money in percent per year.

Input number 3.6 is the maximum amount of overlay thickness of all overlays combined that will be allowed during the analysis period.

Input number 3.7 is the production rate in tons per hour at which the wearing surface material can be produced.

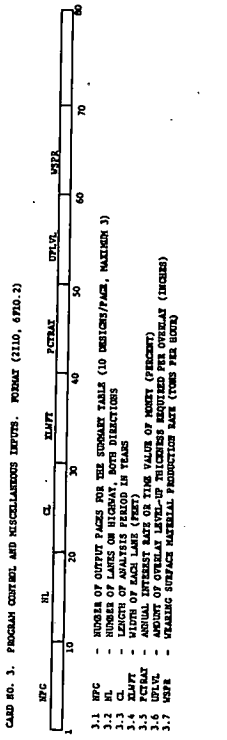


FIGURE 3.1

3.3 Length of Analysis Period

Selection of an analysis period should be based upon the expected period of time that the geometry of the pavement will remain adequate. Most pavement facilities will use a 20 year analysis period although some of the rural roads may best be designed for a 10 year analysis period. Other important urban arterial streets and expressways and other high volume facilities should be designed for an even longer analysis period. In some cases designers have chosen analysis periods of 30 to 40 years. Temporary connections, detours, and other short life expectancy pavements should use an analysis period equal to the expected life of the pavement.

3.4 Width of Each Lane

This input is the average width of each traffic lane (not including shoulders) in feet per lane.

3.5 Interest Rate

Interest rate is used in SAMP6 to discount future expenditures. By discounting these future expenses, the designer is planning realistically for the investment of only that money that should be spent now to provide the pavement services needed. The amount of the costs shown for overlays, maintenance, and salvage value is the amount of money that would have to be invested at a specified interest rate in order to have the needed monies available to perform these various operations at the appropriate time. Although this money is not literally being invested by a highway department,

this concept is necessary to have a valid comparison of design strategies. It could be considered that this money is being invested in other projects which have a return equal to or greater than the specified interest rate. It is recommended that a value of interest rate of about 7% be used in SAMP6 unless the state has guidelines or information that suggest that some other rate be used.

The SAMP6 program currently has no provision for considering inflation. If a state desires to consider inflation, a slight modification in the SAMP6 computer program will be required.

3.6 Amount of Overlay Level-Up Thickness Required Per Overlay

The program has the option of including the cost of a level-up of asphaltic concrete pavement in each overlay, although no structural value is attributed to the level-up and the pavement thickness is not considered to be increased. The level-up cost is calculated by using this input, level-up thickness, in inches, together with the overlay costs from Card No. 17. The level-up is assumed to be necessary to smooth up the unevenness that develops in a pavement, and it is assumed that the level-up also is applied to the shoulders if they are asphaltic (i.e., if variable 10.3, MASPHS, equals 1). This level-up thickness is not considered in testing for constraint of maximum total thickness of all overlays during the analysis period.

3.7 Wearing Surface Material Production Rate (Non-Compacted Tons Per Hour)

The production rate of the asphaltic concrete batch plant is usually the controlling factor in the speed with which a new wearing surface can be placed. This input is used to calculate how long it will take to place a wearing surface and, therefore, the number of cars that will be delayed. This input is divided by input no. 7.2, the asphaltic concrete compacted density, in tons per compacted cubic yard, to determine the wearing surface production rate in cubic yards per hour, which is used in determining the time traffic will be delayed while constructing the wearing surface.

CHAPTER 4

ENVIRONMENTAL AND SERVICEABILITY VARIABLES

The SAMP6 design system is built around the concept of the serviceability index which measures the performance of a pavement based upon its riding quality. The serviceability index of a new pavement usually begins at a level somewhere between 4.0 and 5.0 and then decreases with time as a result of traffic and nontraffic influences. When the serviceability index has dropped to a certain minimum level then some major maintenance effort must be applied to return the riding quality to an acceptable level. Provision is made in SAMP6 for the program user to input the expected serviceability index for both initial construction and overlays.

The user also may provide factors which are related mainly to the environment. First, there is the regional factor which multiplies the traffic loading on a pavement and indicates the relative severity of traffic loading to a pavement in a local region as compared to pavements at the AASHO Road Test in Ottawa, Illinois. The remaining three environmental variables are related to the general roughness that a pavement surface may develop due to a variety of causes, none of which is associated with traffic loading. There are vaious interpretations that can be given to the environmental deterioration model that uses these three variables. One is that roughness is due to expansive clay activity, and another is that the roughness is due to frost heave. Still another is that roughness is due to a softening of material properties with time due perhaps to the action of water or to a brittleness in the asphaltic layers. Another useful interpretation of the environmental deterioration model is that roughness develops in a

pavement's surface due to post construction compaction and settlement of foundation soils. In all cases this environmental deterioration of the pavement riding quality can be specified by three quantities, the first of which tells the proportion of a project on which such roughness is expected to develop. The second is a measure of the differential movement from peak to trough of any of the roughness patterns. The third indicates the rate at which such roughness develops after construction has been completed. The expansive clay serviceability loss model is presented in this user guide, for it is the one on which there is most experience. The concepts presented should be applicable to other forms of environmental deterioration of riding quality.

4.1 The Regional Factor

The regional factor should be equal to 1.0 in all cases where the climatic and foundation soil conditions are expected to be about the same as that of the AASHO Road Test in Ottawa, Illinois. If the climate is greatly different, and is expected to accelerate the effect of the traffic loading on the pavement then the regional factor should be greater than 1.0. If the experience of the designer is such that the climate is expected to be less severe then a regional factor lower than 1.0 is justified. The regional factor is used as a multiplier on the traffic loading within the program. Figure 4.1 shows the layout of Input Card No. 4.

4.2 Serviceability Index of Initial Structure

This input depends upon the materials used and the construction practices employed. Initial serviceability indices are somewhere between 4.0 and

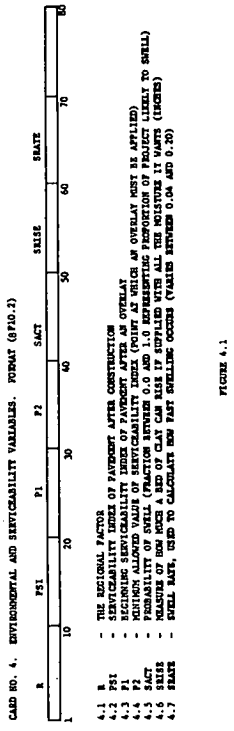


FIGURE 4.1

5.0, perhaps averaging about 4.2. Surface treatments may be near 3.8 and very smooth asphaltic concrete pavement may be as high as 4.8.

4.3 Beginning Serviceability Index of Pavement After an Overlay

The serviceability index expected after overlays usually is not greatly different from that of initial construction, but may be either higher or lower. Experience is the best guide on what to choose here; numbers between 4.0 and 4.5 often are selected.

4.4 Minimum Allowed Value of Serviceability Index

This input specifies the riding quality of a pavement at which a pavement is overlaid. The minimum acceptable level of the serviceability index may change with the purpose of the highway and the average travelling speed. Serviceability indices between 2.5 and 3.0 have been used in a number of states on high type interstate and US highway routes. Serviceability indices below 2.5 have been found to be acceptable on roads with posted speed limits of 45 MPH or less and a serviceability index of 2.0 has been found acceptable on those stretches of pavement where stop signs, signals, dips, and other impedances prevent drivers from operating their vehicles faster than about 20 MPH. Inputs 4.2, 4.3, and 4.4 are depicted graphically in Figure 4.2.

4.5 Probability of Surface Activity

In general, the probability of surface activity is a fraction between 0.0 and 1.0 representing the proportion of a project that is expected to experience environmentally caused roughness. In areas where non-traffic

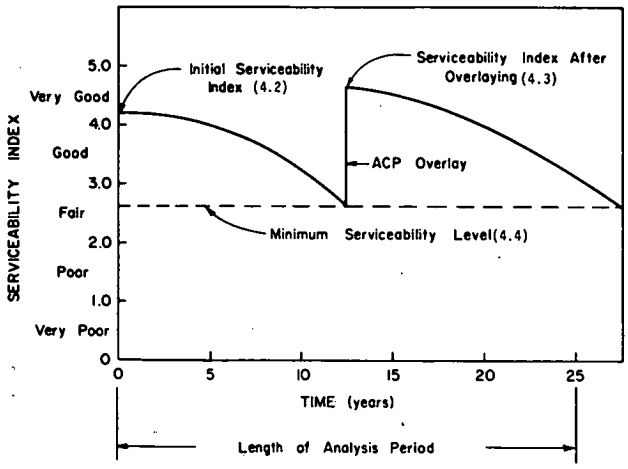


FIGURE 4.2 INPUTS 4.2, 4.3, AND 4.4

roughness is caused by expansive clay this probability of surface activity indicates that proportion of the project where swelling clay is present and local conditions such as drainage are conducive to swelling. These local conditions might be cuts, grade points, bridge approaches, grass root grade lines, and choppy fills which seem to be more of a problem in expansive clay areas than uniform fills. In areas where frost heave prevails, this probability of surface activity indicates those areas where the subgrade and base courses are susceptible to frost action. Local experience may be helpful in estimating the probability of surface activity if more definite guidelines are not available.

4.6 Potential Vertical Rise of the Surface

The potential vertical rise (PVR) is an estimate of how much the surface of a pavement can rise under the influence of different kinds of environmentally caused roughness. This PVR can be estimated in a particular locality from the total amount of differential heave. The designer or maintenance personnel might expect to observe, over a long period of time, extremely active expansive clays having a PVR in the order of 10 to 20 inches. Even larger heaves may be expected from frost action.

Once a highway has been built, the paving materials and supporting soils begin to adjust to the surrounding climate. After a highway has been in service for some time, a certain amount of the maximum vertical rise has taken place and the remaining portion of the maximum vertical rise is what should be used for the design of any improvements of that highway. How much maximum vertical rise has occurred will depend upon the age of the

road bed and the rate at which the adjustment to the climate has taken pace. The adjustment rate constant will be discussed in the next section.

Figure 4.3 provides a multiplier ratio to apply to the original maximum vertical rise if the adjustment rate constant and the age of existing pavement are known.

4.7 Surface Climatic Adjustment Rate Constant

The adjustment rate constant is used to calculate how fast the adjustment of the pavement materials and the supporting soils heave with time. Usual values of the adjustment rate constant lie between 0.04 and 0.20. It is larger when the adjustment rate proceeds at a much faster pace. In the case of expansive clay the adjustment rate constant is larger when the soil is cracked and open and when a large moisture supply is available to the poor drainage, high rainfall, underground seeps, or other sources of water. When drainage conditions are good or the soil is tight, the adjustment rate constant becomes smaller. The nomograph in Figure 4.4 gives an approximate method of selecting this input, based upon the judgement of the designer of local soil and moisture conditions.

Figure 4.5 shows the effects in the absence of traffic for three values of surface rise and two values of the adjustment rate constants on the performance curve. For the curves shown the probability of surface activity used is 1.0. The effect of other values of surface activity probability can be evaluated considering that this input is used solely as a multiplying modifier on the maximum surface rise in the program. For example, a surface activity probability of 0.10 and a maximum surface rise of 10 inches is exactly equal in the program to a surface activity probability of 1.0 and

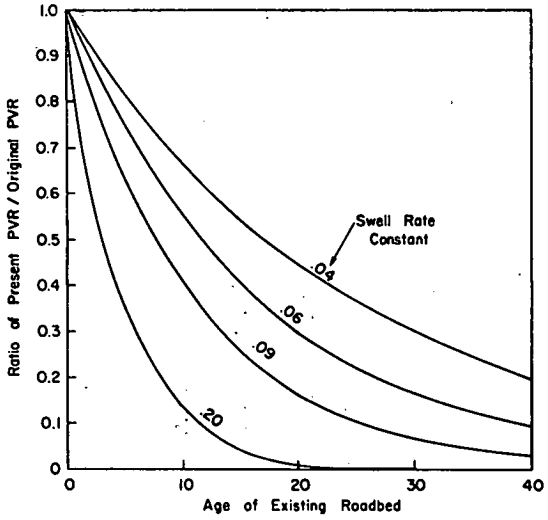
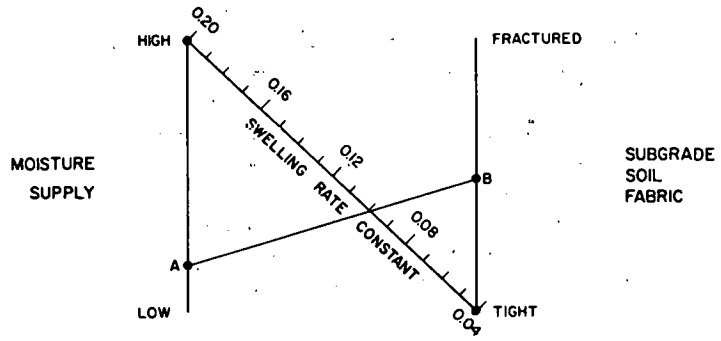


FIGURE 4.3 CHART FOR ESTIMATING REMAINING PVR FOR AN EXISTING ROAD



NOTES: a) LOW MOISTURE SUPPLY:

Low Rainfall
Good drainage

b) HIGH MOISTURE SUPPLY

High Rainfall
Poor drainage
Vicinity of culverts, bridge abutments, inlet leads

c) SOIL FABRIC CONDITIONS

Self explanatory

d) USE OF THE NOMOGRAPH

1) Select the appropriate moisture supply condition which may be somewhere between low and high (such as A).
2) Select the appropriate soil fabric (such as B).
3) Draw a straight line between the selected points (A to B).
4) Read SWRATE from the diagonal axis (read 0.10).

FIGURE 4.4 NOMOGRAPH FOR SELECTING INPUT 4.7

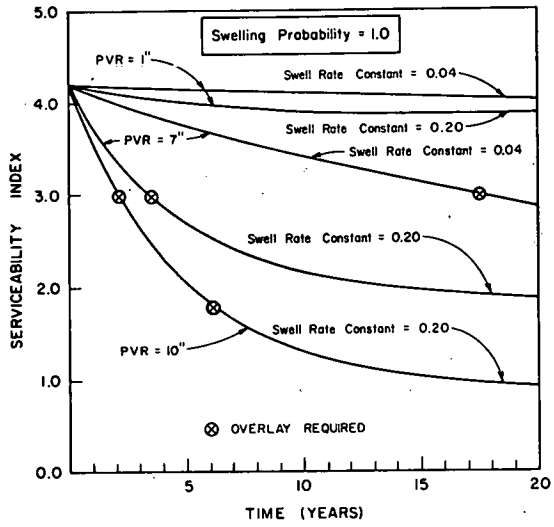


FIGURE 4.5 PERFORMANCE CURVES ILLUSTRATING SERVICEABILITY LOSS NOT CAUSED BY TRAFFIC

a maximum surface rise of 1 inch. Until the designer has had some experience in using this environmental deterioration model, it would be well for him to try a number of designs at different levels of surface activity and surface rise, so that he can evaluate the effect of each of these variables on the overall pavement design strategy. If the designer does not wish to consider environmentally caused roughness, inputs 4.5, 4.6, and 4.7 should be set at 0.0.

CHAPTER 5

TRAFFIC AND RELIABILITY VARIABLES

Two different kinds of input variables are considered in this chapter. Within the SAMP6 design system the traffic inputs are used twice, once to estimate the loading history on the pavement, and the other is in the calculation of the cost of delaying traffic during an overlay construction.

The reliability inputs have been found useful in a few states, because they allow the designer to say how accurately he knows the material properties and regional factor that he is using. These inputs also allow the designer to specify the degree of certainty that he wishes to have that his structural subsystem will last at least a minimum period of time.

5.1 and 5.2 One Direction ADT at Beginning and End of Analysis Period

Average daily traffic (ADT) is assumed to increase uniformly from the beginning to the end of the analysis period. These two inputs are used together to determine the distribution of equivalent 18-kip single axle loads with time and they are also used for calculating traffic delay costs during overlay construction. Traffic delay cost increases with an increase in ADT. For traffic volumes greater than about 1350 to 1400 vehicles per hour per lane left open during overlay construction, the computed cost of traffic delay is exceptionally high because the assumed lane capacity is exceeded. Such high traffic delay cost has the greatest influence on the selection of an optimum design when the high hourly traffic is predicted to occur early in the analysis period.

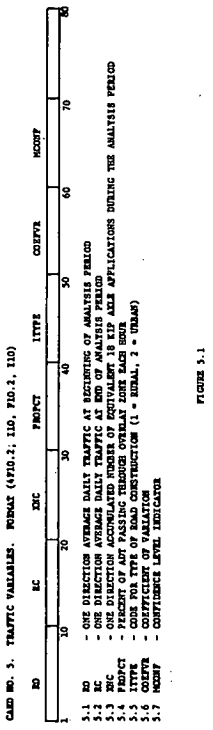


FIGURE 5.1

5.3 One Direction Accumulated 18-KIP Equivalent Single Axle Applications

This input is an estimate of the total number of 18-kip axle equivalents that are expected to be accumulated in the heaviest-traveled (i.e., design) lane during the entire analysis period. These load applications are assumed to accumulate in proportion to the rate of accumulation of total traffic. This is the same thing as assuming that the distribution of trucks and passenger vehicles in the traffic now does not change with time. This input actually is dependent on the structural number of the pavement yet to be calculated, but any reasonable assumption regarding the structural number should not appreciably affect the load estimate and thus should not unduly influence the program results.

5.4. Percent ADT Passing Through Overlay Zone Each Hour

If traffic were evenly distributed through the day, 4.17 percent would pass each hour. The percent ADT Passing through the overlay zone each hour is used in the traffic delay models to calculate user cost during overlay construction. Estimated percentages usually are about 6 percent for rural areas and about 5.5 percent for urban areas, but will vary according to the time interval of the day that overlay construction is expected to occur.

5.5 Code For Type of Road Construction

This code tells the type of area, urban or rural, in which the road being designed will be built, with "1" denoting rural and "2" denoting urban. This input is used to select the appropriate roadway capacity and user cost tables in the user cost subroutine within the program. This input

is also used internally in the program in calculating the cost per unit of maintenance effort when the N.C.H.R.P. maintenance model is used, i.e., when MNTMOD (Input 9.1) - 2.

5.6 Coefficient of Variation

In the SAMP6 Pavement Design System the designer is required to furnish various stiffness coefficients, soil support values, and regional factors, all of which have to be estimated on the basis of lab tests and field experience. Each designer has some idea within what accuracy he knows each of these numbers. A coefficient of variation tells within what percent of the average he estimates that about 70 percent of all values that he measures will fall. Standard percentages for the coefficient of variation may be estimated from materials data and will normally range around 10 to 15 percent, which would be input as .10 or .15.

5.7 Confidence Level Indicator

The confidence level indicator varies from 1 to 7 and allows the program user to choose how certain he wants to be that the pavement will last for at least the minimum period of time between overlays that he specified elsewhere in this program. A confidence level of 1 indicates that he is willing to accept a fairly high degree of risk and is willing to be only 50 percent certain that the pavement will not have to be overlaid in less than the minimum time. On the other hand, confidence level 7 indicates that the designer places great importance upon the requirement that the pavement should last at least the minimum period of time that he has specified.

A certain amount of design experience with the SAMP6 Pavement Design System will indicate to the designer at what level of confidence he usually likes to design pavements.

The following list indicates the chances the designer is taking that the structural design will be adequate to last the required time.

Confidence Level	Chances That the Design Produced Will Not Last the Minimum Required Time
1	1 in 2
2	3 in 10
3	1 in 10
4	1 in 20
5	1 in 100
6	1 in 200
7	1 in 1000

CHAPTER 6

CONSTRAINT VARIABLES

The constraint variables described in this chapter permit the designer to control the kind of performance that he wants the pavement to have and constrain the SAMP6 program to practical designs. The designer may specify the minimum time between initial construction and first overlay, the minimum allowed time between succeeding overlays, the maximum funds available for initial construction, the maximum allowable thickness of initial construction, the allowable thickness for all subsequent overlays combined and the overlay thickness increment which specifies the difference between overlay thicknesses that will be tried. In general, the program will try all possible designs within the constraints using the input design increments, therefore judicious use of the constraints provides more effective utilization of computer resources. The variables described in this chapter are on Input Card Number 6, as shown in Figure 6.1.

6.1 Minimum Allowed Time to First Overlay

This input specifies the minimum time the initial design must last. Choice of an appropriate value for use in the SAMP6 Flexible Pavement Design System depends essentially upon four considerations. First, if funds are limited for initial construction, it is possible to build a pavement of only limited initial life. In other cases, funds may be provided only for initial construction and no overlaying funds will be available during the analysis period; in such cases, the designer must specify that the minimum time to the first overlay is equal to the length of the

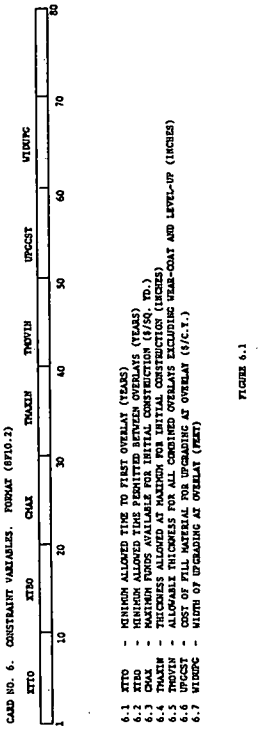


FIGURE 6.1

analysis period. The second consideration is that having to overlay a pavement too soon after construction can be unpopular with the travelling public and embarrassing to the design agency. For this reason the initial design should be specified to last a reasonable, minimum length of time. The third consideration is the rate of development of non-traffic roughness, such as in expansive clay or frost heave areas. In numerous cases it is not economically feasible to reduce or eliminate such heaving with initial construction and the expected time to the first overlay is usually very short. In such cases, neither those pavements which are initially very strong nor those which are fairly weak will show much advantage in reducing the expected roughness. It is recommended in such cases that the designer select a very short (1 to 3 years) expected time to first overlay. The fourth consideration is economics. On some highways it is more economical to maintain the required serviceability level by using frequent overlays rather than by investing in an expensive initial design.

It is recommended that, on the initial design attempt, a minimum time to the first overlay of five to ten years be used. If, because of limited available funds or extensive activity of expansive clay or frost action, this gives no solutions or results in unacceptable solutions, the minimum time to overlay can be changed and additional calculations made.

6.2 Minimum Allowed Time Between Overlays

This input has an effect similar to input number 6.1 in determining a flexible pavement design overlay strategy except that it is the minimum time

between succesive overlays instead of minimum time to the first overlay after initial construction. In most situations, this input should be about the same or less than input 6.1. For analysis periods substantially greater than twenty years, however, it is recommended that this input be only one-half to two-thirds as large as input 6.1, unless there are concrete reasons for having it otherwise. It should be recognized that this input interacts with 17.3, minimum thickness of each overlay, to produce practical overlay strategies.

6.3 Maximum Funds Available for Initial Construction Per Square Yard

When the designer can specify the funds that will be available for initial construction, this input will be a constraint and the SAMP6 program will consider only those designs that have initial costs less than the specified limit. When funds for initial construction are limited, this input should be such that it constrains designs to those limits except when the designer is interested in knowing what the optimum design would be if funds were not limited. When there are high traffic volume conditions, a high initial cost pavement may be a part of the least cost design strategy. If there are no specific fund limitations, input should be large enough that potentially interesting designs are not omitted because of this constraint. However, this input or the layer and pavement thickness constraints should be used to constrain designs and computer running time to reasonable limits.

6.4 Maximum Total Thickness of Initial Construction (Inches)

This input should be no greater than the sum of the maximum thicknesses of the thickest individual layers input as Item 18.8. If the designer is restricted to a fixed total thickness less than this amount for initial construction, this

input will act as a constraint that will result in a solution that may not be the least costly strategy. It also may prevent calculation of any feasible solutions if it is too binding. Therefore, even though this input can be used to control the number of calculations made by the SAMP6 Pavement Design System, care must be used in such cases so that the optimum design strategy will not be omitted from consideration.

6.5 Allowable Thickness for All Overlays (Inches)

This input is usually determined by the geometry of the cross-section or curbing, drainage, and clearance details. If the designer has specified level-up courses, their thickness will not be included in testing whether the maximum total thickness of all overlays has been exceeded. No structural value is attributed to the level-up.

6.6 Overlay Thickness Increment (Inches)

The SAMP6 program tries a variety of overlay thicknesses before it finds one which is optimal. This input specifies the difference in thickness between successive overlay thicknesses that are tried. For example, if the designer wishes to try overlay thicknesses of 1 inch, 1-1/2 inches, 2 inches, 2-1/2 inches, etc., his overlay thickness increment would be 1/2 inch. This number should be made as large as is practical since a small overlay thickness increment results in large numbers of trial computations to determine the optimum overlay strategy. The program will not use an increment less than 1/4 inch.

CHAPTER 7

TRAFFIC DELAY VARIABLES

This chapter is concerned with variables that affect the costs to motorists of having to slow down and detour or be diverted around an overlay operation. These traffic delay costs usually are not very large except in high traffic volume situations but are sometimes of sufficient size to justify the construction of very strong, low-maintenance pavements.

Two computer input cards must be filled out to complete the list of traffic delay inputs. These cards are shown in Figure 7.1.

7.1 Asphaltic Concrete Production Rate (Tons Per Hour).

This input is used to calculate the time it will take to place the overlay and the number of cars that will be delayed due to the overlaying operation. It affects the traffic delay cost.

7.2 Asphaltic Concrete Compacted Density (Tons Per Compacted Cubic Yard).

This input is used together with Input Number 7.1 to determine how long it will take to place an overlay and therefore the number of cars that will be delayed. It also affects the traffic delay cost.

7.3 and 7.4 Distance Traffic Is Slowed in the Overlay and Non-Overlay Directions (Miles).

These two inputs are used in calculating the time that vehicles are delayed in travelling around an overlay operation. (See Figures 7.2 through 7.6.)

CARD NO. 7. TRAFFIC DELAY VARIABLES. FORMAT (6F10.0, 2I10)

7.1	ACPR	- -	ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)
7.2	ACCD	- -	ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/COMPACTED C.Y.)
7.3	XLSO	- -	DISTANCE TRAFFIC IS SLOWED IN OVERLAY DIRECTION (MILES)
7.4	XLSN	- -	DISTANCE TRAFFIC IS SLOWED IN NON-OVERLAY DIRECTION (MILES)
7.5	HPD	- -	DETOUR DISTANCE AROUND OVERLAY ZONE (MILES)
7.6	NLSO	- -	NUMBER OF LANES IN RESTRICTED ZONE IN OVERLAY DIRECTION
7.7	NLSN	- -	NUMBER OF LANES IN RESTRICTED ZONE IN NON-OVERLAY DIRECTION
7.8	MLEN	- -	NUMBER OF LANES IN RESTRICTED ZONE IN NON-OVERLAY DIRECTION

CARD NO. 8. ADDITIONAL TRAFFIC DELAY VARIABLES. FORMAT (7F10.2, I10)

8.1	PFO2	- -	PERCENT VEHICLES STOPPED IN OVERLAY DIRECTION DUE TO OVERLAY CONSTRUCTION
8.2	PFN2	- -	PERCENT VEHICLES STOPPED IN NON-OVERLAY DIRECTION DUE TO OVERLAY CONSTRUCTION
8.3	DO2	- -	AVERAGE DELAY PER VEHICLE STOPPED IN OVERLAY DIRECTION DUE TO OVERLAY CONSTRUCTION (HOURS)
8.4	DN2	- -	AVERAGE DELAY PER VEHICLE STOPPED IN NON-OVERLAY DIRECTION DUE TO OVERLAY CONSTRUCTION (HOURS)
8.5	AAS	- -	AVERAGE APPROACH SPEED TO OVERLAY ZONE (ASSUMED SAME FOR BOTH DIRECTIONS, MPH)
8.6	ASO	- -	AVERAGE SPEED THROUGH OVERLAY ZONE, IN OVERLAY DIRECTION (MPH)
8.7	ASN	- -	AVERAGE SPEED THROUGH OVERLAY ZONE, IN NON-OVERLAY DIRECTION (MPH)
8.8	MODEL	- -	THE MODEL NUMBER OF THE TRAFFIC SITUATION (1, 2, 3, 4, OR 5)

FIGURE 7.1

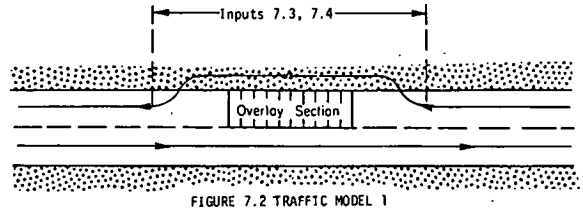


FIGURE 7.2 TRAFFIC MODEL 1

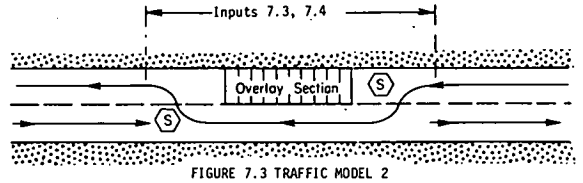


FIGURE 7.3 TRAFFIC MODEL 2

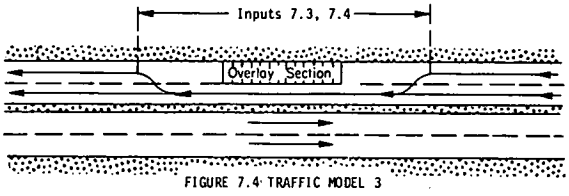


FIGURE 7.4 TRAFFIC MODEL 3

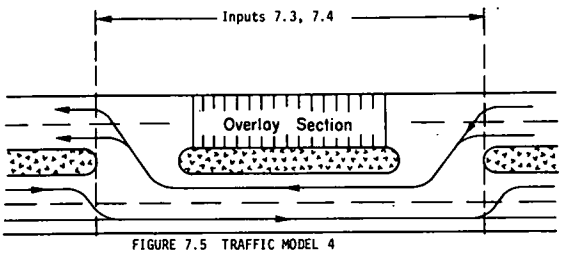


FIGURE 7.5 TRAFFIC MODEL 4

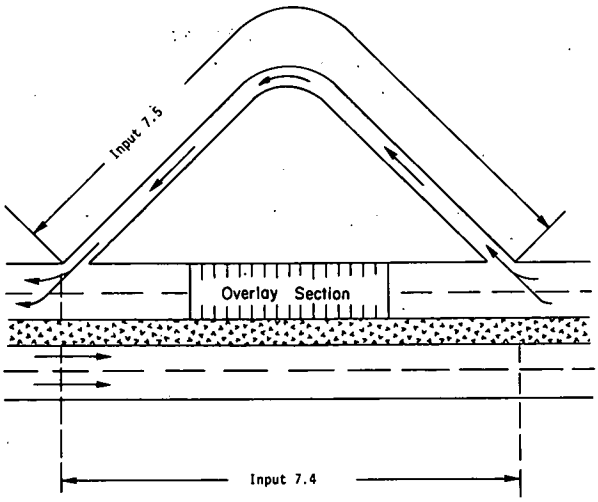


FIGURE 7.6 TRAFFIC MODEL 5

8.1 and 8.2 Percent Vehicles Stopped in Overlay and Non-Overlay Directions Due to Overlay Construction.

Input Numbers 8.1 and 8.2 are estimates of the percent of traffic that is expected to be stopped due to movement of overlay equipment and personnel in the overlay zone. This percent does not include vehicle stop due to congestion.

8.3 and 8.4 Average Delay Per Vehicle Stopped and the Overlay and Non-Overlay Directions Due to Overlay Construction.

Input Numbers 8.3 and 8.4 are self-explanatory. These delays are averages for vehicles stopped and do not include delay because of congestion.

8.5 Average Approach Speed to Overlay Zone (MPH).

This input is assumed to be the same for both directions. It is assumed that all vehicles approach the overlay area at the same speed called the approach speed and upon leaving this restricted zone the vehicles return to the approach speed. This input is used to compute the cost of delaying traffic during overlay operations. (See Figure 7.7.)

8.6 and 8.7 Average Speed Through the Overlay Zone in the Overlay and Non-Overlay Directions (MPH).

During overlay operations, vehicles must travel through the restricted zone at reduced speed called the through-speed-overlay-direction and through-speed-non-overlay direction. It is assumed in each of the traffic models that vehicles maintain these speeds throughout the restricted zone. (See Figure 7.7.)

7.5 Detour Distance Around Overlay Zone.

In some cases during overlay operations a special detour has to be built to handle traffic. At other times traffic is directed along an alternate route. Detour model five is used for these two cases. The length in miles of this detour is coded for this input. This input is not used and can be left blank unless detour model five is used.

7.6 Number of Hours Per Day of Overlay Construction (Hours Per Day).

The expected number of hours per day that overlay operations will take place is coded for this input. It is used in calculating the number of cars that will be delayed during an overlay operation, which in turn will affect the traffic delay costs.

7.7 and 7.8 Number of Lanes in the Restricted Zone in the Overlay and Non-Overlay Directions.

Input Number 7.7 is the total number of lanes left open to traffic travelling in the overlay direction. Input Number 7.8 is the number of lanes in the restricted zone left open to traffic travelling in the non-overlay direction. These two inputs depend upon the method of handling traffic around the overlay operation and the number of lanes on the highway. They should be chosen to be consistent with the traffic delay model being used to represent the detour or diversion of traffic around the overlay operation. The model number is Input Number 8.8.

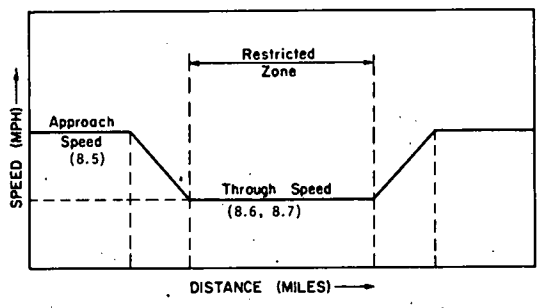


FIGURE 7.7 INPUTS 8.5, 8.6, AND 8.7

8.8 Detour Model Used During Overlaying.

The program provides for five different methods of handling traffic during overlay operations. (See Figures 7.2 and 7.6.) The first two methods of detouring traffic, Figures 7.2 and 7.3, offer two-lane roads with or without shoulders and the other three methods are for roads with four lanes or more. The designer must decide which detouring method he expects will be used when asphaltic concrete overlays are made upon the proposed project. The model number selected is coded for this input.

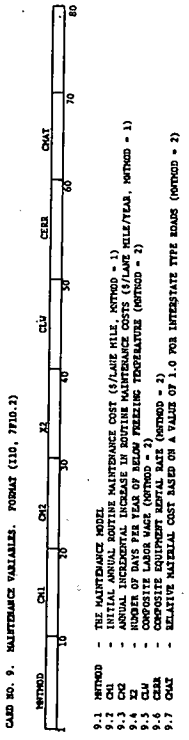


FIGURE 8.1

Chapter 8

MAINTENANCE VARIABLES

Routine maintenance costs are assumed to include all future pavement costs except overlay costs. In SAMP6, maintenance costs are assumed to be the same base level immediately after initial construction and after each overlay and are assumed to increase over time until the pavement is overlaid, at which time they return to the base rate.

Two maintenance cost models are available in SAMP6. Model 1 is a simple linear model relating maintenance costs to time after initial construction or overlay. Model 2 is based on NCHRP Report 42 and also assumes that maintenance cost is related to pavement age, but takes into consideration other variables.

9.1 Routine Maintenance Cost Model.

The value of this input should be either 1 or 2. Routine maintenance cost model 1 assumes a linear increase, over time, in routine maintenance costs and uses inputs 9.2 and 9.3. If 2 is input as the routine maintenance cost model, inputs 9.4 through 9.7 must be provided and are used in the routine maintenance cost model as reported in NCHRP Report 42.

9.2 First Year Cost of Routine Maintenance (Dollars Per Lane-Mile).

The annual rate of routine maintenance for the first year after initial or overlay construction should be coded for this input. As an example, the first year costs of routine maintenance in some states may vary between $25 and $50 per lane-mile. It is assumed in discounting these expenses to the present that they are paid at the beginning of the year in which they occur. (See Figure 8.2.)

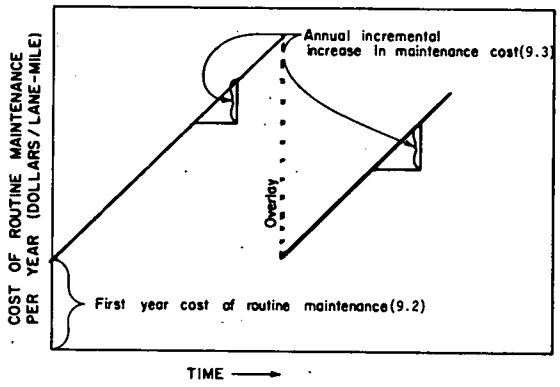


FIGURE 8.2 INPUTS 9.2 AND 9.3 TO BE USED WHEN INPUT 9.1 = 1

9.3 Annual Incremental Increase in Maintenance Cost (Dollars Per Lane-Mile).

The annual incremental increase in routine maintenance cost during each year after the initial or overlay construction is completed is assumed to increase at a uniform rate. As an example, the annual incremental increase in routine maintenance costs in some states varies between $10 and $30 per lane-mile.

9.4 Number of Days Per Year that Temperature Remains Below 32°F.

This input can be obtained from U.S. Weather Bureau data and is used in calculating the routine maintenance cost.

9.5 Composite Labor Wage (Dollars Per Hour).

This input is the average wage for a maintenance crew and is used in the NCHRP model for routine maintenance costs. (SEE NCHRP Report No. 42.)

9.6 Composite Equipment Rental Rate (Dollars Per Hour).

This input is an average of the rental rates of all equipment used in routine maintenance activity. (See NCHRP Report No. 42.)

9.7 Relative Material Cost Factor.

The cost of materials used in routine maintenance activities vary considerably depending mainly upon the location of the project within the state and the type of road, whether they be Interstate, U. S., State or Rural roads. The relative cost factor assumes a value of 1.0 for Interstate type roads. (See NCHRP Report No.42.)

CHAPTER 9

CROSS-SECTION, COST MODEL, AND SHOULDER VARIABLES

The optimum pavement design strategy depends upon the total cost of all materials used in the entire cross section of a pavement including those materials in the shoulders. Studies with the SAMP6 pavement design system have indicated that the cost of these materials in the shoulders can significantly affect the optimum design strategy. Cards Number 10 through 14 specify the cross-section geometry and the initial cost model. (See Figures 9.1, 9.2, and 9.3.) Several of the inputs for these cards are shown in Figure 9.4. If the traffic model (Input 8.8) is either Number 1 or Number 2, these inputs should apply to the entire roadway cross section; also, with two-lane roads, the "inside" and "outside" widths should be the same for similar variables. If the project under consideration has four or more traffic lanes (i.e., traffic model 3, 4, or 5), then these inputs should apply only to half of the total roadway cross-section, for one direction of travel.

10.1 Model Used to Calculate Cross-Sectional Areas

The SAMP6 program has two cross-section models, "0" and "1". The "0" cross-section model is, in effect, the provision for no cross section. If the "0" model is used, Input Cards 11 through 15 are omitted. Cross-Section Model No. 1 is the basic cross-section model with which the cross section inputs are used. Cross-Section Model No. 1 has provision for considering the amount that pavement and shoulder layers extend past the traffic lanes and shoulder. Also, with Model No. 1, the shoulders are overlaid

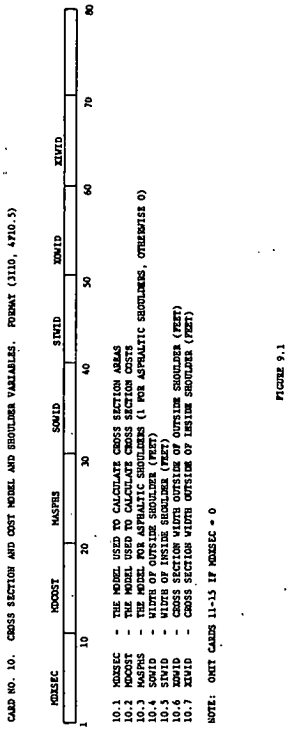


FIGURE 9.1

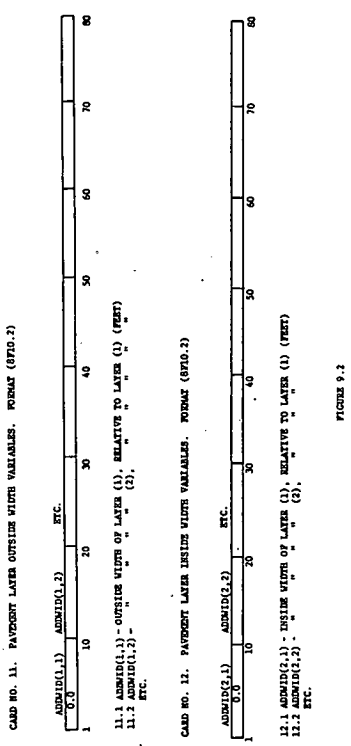


FIGURE 9.2

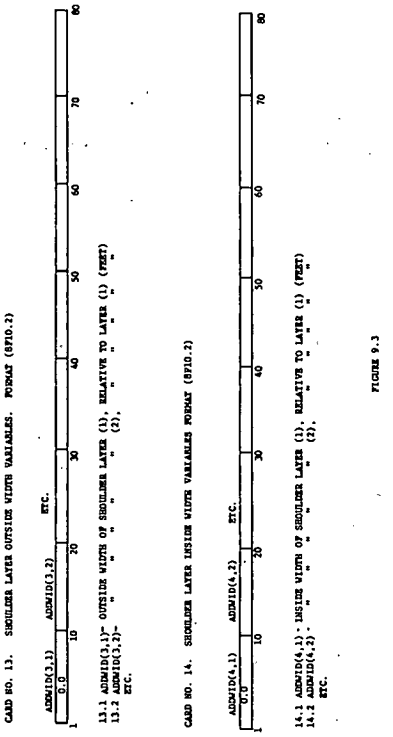
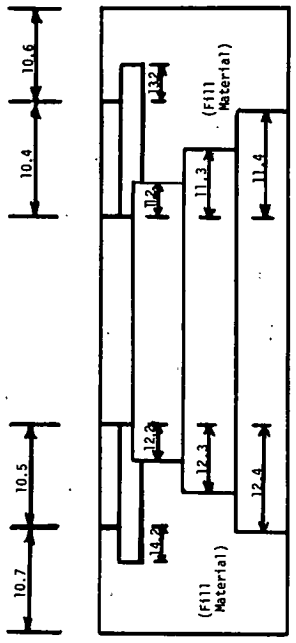


FIGURE 9.3



NOTES: (1) Inputs 11.1, 12.1, 13.1, and 14.1 are always 0.0.
(2) The fill material is omitted if the last card in Card Group No. 19 is blank.

FIGURE 9.4 SELECTED CROSS-SECTION INPUTS FROM INPUT CARDS 10, 11, 12, 13, and 14

and upgraded whenever the traffic lanes are overlaid. Consideration of the entire cross-section often leads to thicker initial designs since overlays are relatively more expensive when overlay of the shoulders is taken into consideration.

Another aspect of Model No. 1 is that the bitumen costs for the asphaltic layers are calculated separately using Input 15.3 together with inputs on Cards Number 16 through 19. With Cross-Section Model No. 0, the bitumen costs are assumed to be included in the basic material costs for each material on Cards Number 16 through 19. Also, with Model No. 0, no provision is made for explicitly calculating tack coat and prime coat costs.

10.2 Model Used to Calculate Cross-Section Costs

Input 10.2 is the model used to estimate the unit costs of materials used in the initial pavement design. This input is "0" for Model No. 0 and "1" for Model No. 1. Model No. 0 assumes that unit material costs per square yard are a simple linear function of pavement depth. Model No. 1 assumes that the logarithm of pavement material cost per square yard is a linear function of the log of material thickness. Either model uses constant unit costs for any material that has the same cost at the maximum and minimum material depths.

10.3 Model for Asphaltic Shoulders

Input 10.3 should be "1" if the pavement has asphaltic shoulders and should be "0" if the pavement does not have asphaltic shoulders. (Omit with Cross-Section Model No. 0)

10.4 Width of Outside Shoulder (Feet)

This width is the distance between the edge of the pavement and the outside edge of the outside shoulder. (Omit with Cross-Section Model No. 0.)

10.5 Width of Inside Shoulder (Feet)

This width is the distance between the inside edge of the pavement and the outside edge of the inside shoulder. This input should be equal to one-half the median if there is a paved median between inside edges of the pavement; and, all inputs on Cards 12 and 14 should also equal one-half the median width. (Omit with Cross-Section Model No. 0.)

10.6 Cross-Section Width Outside of Outside Shoulder (Feet)

This input is the distance between the outside edge of the shoulder and the end of the cross section being considered. (Omit with Cross-Section Model No. 0.)

10.7 Cross-Section Width Outside of Inside Shoulder (Feet)

This input is the distance between the inside edge of the shoulder and the inside edge of the cross section being considered. (Omit with Cross-Section Model No. 0.)

11.1, 11.2, 11.3 and 11.4 Outside Widths of Layers Relative to Pavement Layer 1

These inputs permit the designer to describe various widths of materials underlying the pavement. They are shown schematically in Figure 9.4. There are numerous practical reasons for carrying base course and subbase courses below the pavement out beyond the edge of the pavement and the construction practices of several state highway departments reflect this in their standard cross sections. Input 11.1 is the outside width of layer 1 relative to pavement layer 1 and is always zero by definition. This input is included as a reminder to the designer that layer 1 is the reference layer for the width of all subsequent layers beneath. Input 11.2 is the outside width of layer 2 relative to the outside edge of pavement layer 1. This is the distance by which layer 2 beneath the pavement is wider than the outside edge of the pavement. Input 11.3 is the outside width of layer 3 relative to pavement layer 1. This input is the distance by which layer 3 beneath the pavement is wider than the outside edge of the pavement. Input 11.4 is the outside width of layer 4 relative to pavement layer 1. This input is the distance by which layer 4 beneath the pavement is wider than the outside edge of the pavement. (See Figure 9.4.)

12.1, 12.2, 12.3 and 12.4 Inside Width of Layers Relative to Pavement Layer 1

Input 12.1 is the distance by which pavement layer 1 is wider than itself on the inside. Consequently this input is always set to zero. Input 12.2 is the inside width of layer 2 relative to pavement layer 1. This input is

the distance by which layer 2 beneath the pavement is wider than the inside edge of the pavement. Input 12.3 is the inside width of layer 3 relative to pavement layer 1. This input is the distance by which layer 3 beneath the pavement is wider than the inside edge of pavement layer 1. Input 12.4 is the inside width of layer 4 relative to pavement layer 1. This input is the distance by which layer 4 beneath the pavement is wider than the inside edge of pavement layer 1.

13.1, 13.2, 13.3 and 13.4 Additional Width of Outside Shoulder Relative to Shoulder 1

These inputs allow a variety of widths of shoulder materials to be placed. Input 13.1 is the additional width of the outside shoulder layer 1 relative to itself. Consequently, Input 13.1 will always be zero since it will never be wider than itself. Input 13.2 is the additional width of outside shoulder 2 relative to the topside edge of shoulder layer 1. Input 13.3 is the additional width of outside shoulder layer 3 relative to the outside edge of shoulder layer 1 and input 13.4 is the additional width of outside shoulder layer 4 relative to the outside edge of shoulder layer 1. These inputs are shown schematically in Figure 9.4.

14.1, 14.2, 14.3 and 14.4 Additional Width of Inside Shoulder Layers Relative to Shoulder Layer 1

Input 14.1 is always set to zero since it is the additional width of inside shoulder layer 1 relative to itself. Input 14.2 is the additional width of inside shoulder layer 2 relative to the outside edge of shoulder layer 1.

Input 14.3 is the additional width of the inside shoulder layer 3 relative to the outside edge of shoulder layer 1. Input 14.4 is the additional width of inside shoulder layer 4 relative to the outside edge of shoulder layer 1. These inputs are shown on Figure 9.4. They may be left blank if the cross section does not require them.

CHAPTER 10

TACK COAT, PRIME COAT, AND BITUMINOUS MATERIAL VARIABLES

This chapter deals with the costs and limiting dimensions on several of the bituminous material variables associated with construction and maintenance activities. These include tack coat and prime coat costs as well as the maximum depth of layers which will not require a tack coat. Figure 10.1 shows the layout of card No. 15 where these variables are input. This card must be omitted with Cross-Section Model No. 0.

15.1 Tack Coat Cost, (Dollars Per Gallon)

Input 15.1 is the cost per gallon of material used for tack coats. This input is useful in estimating a fairly accurate total cost of a project. It amounts to such a small portion of the total cost of a paving project that it usually will not alter the choice of which kind of pavement design is optimum. Its major use is in getting a fairly accurate cost estimate.

15.2 Prime Coat Cost, (Dollars Per Gallon)

Input 15.2 is the cost per gallon of material used for prime coats. Like Input 15.1 it will rarely affect the optimum design chosen and is used primarily in getting an accurate cost estimate.

15.3 Bitumen Cost, (Dollars Per Gallon)

Input 15.3 is the cost per gallon of bitumen, which is used in calculating the cost of bitumen for each asphaltic layer, when Cross-Section Model No. 1 is used.

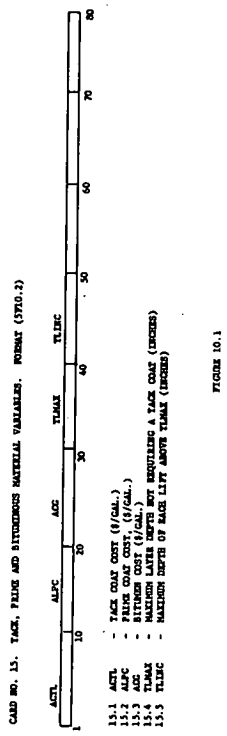


FIGURE 10.1

15.4 Maximum Layer Depth Not Requiring a Tack Coat (Inches)

This input is self-explanatory. The computer program will check to see whether the depth of each asphaltic layer is greater than this maximum, and if it is, a tack coat cost will be included in the total cost of that layer.

15.5 Maximum Depth of Each Lift Above Input 11.4 (Inches)

For thick asphaltic concrete thicker than Input 15.4, an additional tack coat is assumed to be applied for each increment of depth equal to Input 15.5.

CHAPTER 11

WEARING SURFACE VARIABLES

In most flexible pavements the asphaltic concrete used for the wearing surface differs in its gradation and in its strength coefficient from the asphaltic concrete or black base which may lie below it. Because of this, provision has been made in the SAMP6 computer program for considering separately the structural characteristics of this layer. Figure 11.1 shows how the wearing surface variables are input into the computer program. This card must be included, but will have no effect if the cost variables are zero or blank.

16.1 Wearing Surface Description

There is provided on this card sufficient space for a description of the kind of material placed in the wearing surface.

16.2 Wearing Surface Strength Coefficient

This input is the AASHO structural coefficient for the wearing surface layer. It will normally vary between about .38 and .50 and will depend upon its composition, its relative value in standard engineering tests, and its performance. If this layer has a high asphalt content and is subject to rutting, then it would be appropriate to lower the structural coefficient to reflect that fact.

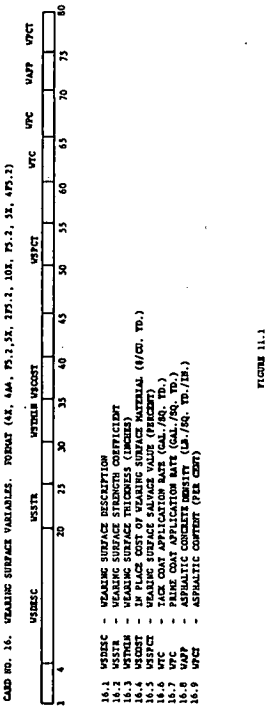


FIGURE 11.1

16.3 Wearing Surface Thickness (Inches)

Input no. 16.3 is the thickness in inches of the wearing surface, applicable to both initial construction and overlay.

16.4 In Place Cost of Wearing Surface Material (Dollars Per Cubic Yard)

Input 16.4 is the estimated cost of the wearing surface material in place in dollars per compacted cubic yard.

16.5 Wearing Surface Salvage Value (Percent)

Input 16.5 is the wearing surface salvage value expressed as a per cent of initial cost. Because wearing surfaces usually are expensive relative to the strength they add, this percentage usually will be less than that for the first pavement layer, but of similar magnitude. Input 16.5 is applicable only to calculating the salvage value of the wearing surface used in the initial construction. Input 17.8 is used for the wearing surface used with overlays.

16.6 Tack Coat Application Rate (Gallons Per Sq. Yd.)

Input no. 16.6 is the tack coat application rate. In SAMP6, it is assumed that one tack coat is used with the wearing surface and Inputs 16.6 and 15.1 are used to calculate its cost.

16.7 Prime Coat Application Rate (Gallons Per Sq. Yd.)

Input 16.7 is the prime coat application rate, assumed to be used with the wearing surface, and normally will be blank or 0.0.

16.8 Asphaltic Concrete Density (Pounds Per Sq. Yd. Per Inch)

Input 16.8 gives the density of the wearing surface material, which is used together with Inputs 16.9 and 15.3 to calculate the coat of bitumen in the wearing surface.

16.9 Asphaltic Content (Percent)

Input 16.9 is the asphaltic content by weight of the wearing surface material, expressed in percent.

CHAPTER 12

OVERLAY VARIABLES

When an overlay is applied, it is assumed in the SAMP6 computer program that it covers the full width of the pavement. If the original pavement shoulders are asphaltic, the overlay material and level-up are applied across the shoulder. If the original pavement has shoulders that are not asphaltic, the overlay material is used only on the traffic lanes and the shoulders are overlaid with the same material used in the top shoulder layer in the original pavement.

If the program user wants to use a level-up but does not wish to use an overlay material as provided for on Card No. 17, then he must nevertheless provide an overlay card with Inputs 17.4, 17.5, 17.6, 17.7, and 17.9. For this situation, Input 17.4 must be 0.0; Input 17.6 should be some thickness such as 2.0; both Inputs 17.5 and 17.7 must be the cost per cubic yard that the user wishes to use as the cost per cubic yard for level-up; and Input 17.9 must be some number larger than Input 17.6. These inputs must be coded this way to provide a cost for the level-up material, since the program uses the overlay material costs to calculate level-up cost.

Card No. 17 makes provision for including all of the material and cost variables for the overlays that are expected to be placed. (See Figure 12.1 for the layout of Card No. 17.) If the program user wishes to use only a wearing surface for overlays and does not use a level-up, this card must nevertheless be included even though it will be totally blank.

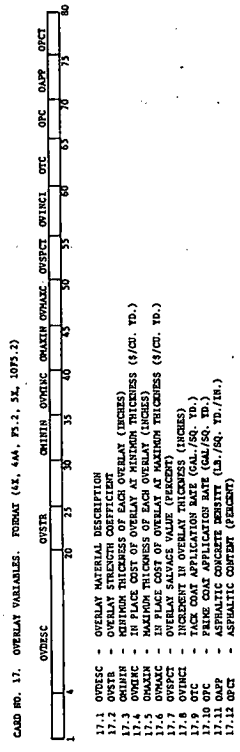


FIGURE 12.1

17.1 Overlay Material Description

Input 17.1 provides space for describing the overlay material that will be used.

17.2 Overlay Structural Coefficient

Input 17.2 is the AASHO structural coefficient for the overlay material. It may or may not be the same as the structural coefficient of the top pavement layer (Input 18.4 on the first card in Card Group 18). The overlay structural coefficient usually will be between .30 and .50, the precise number depending upon the material used, its engineering test properties, and its expected behavior in service.

17.3 Minimum Thickness of Each Overlay (Inches)

Input 17.3 is the minimum thickness that will be considered on each individual overlay. This input and the following three are used to calculate the variable costs of overlay materials as the quantities of materials used are changed. Generally speaking, as a greater volume of overlay material is placed, the unit cost goes down.

17.4 In-Place Cost of Overlay at Minimum Thickness (Dollars Per Cubic Yard)

Input 17.4 is the cost per cubic yard of the overlay material at the thickness used for Input 17.3. Input 17.4 should be estimated separately from, and usually will be greater than, Input 17.6. If Cross-Section Model 1 is used, Input 17.4 does not include bitumen cost which is calculated separately using other inputs.

17.5 Maximum Thickness of Each Overlay (Inches)

Input 17.5 is the maximum thickness that will be considered on each individual overlay and is the maximum thickness that the designer believes is practical to use on an individual overlay. At this thickness, the in-place cost of the overlay material is expected to be at its minimum.

17.6 In-Place Cost of Overlay at Maximum Thickness (Dollars Per Cubic Yard)

Input 17.6 is the unit cost of the overlay material at its maximum thickness and is expected to be less, or at least no greater than, Input 17.4. If Cross-Section Model 1 is used, Input 17.6 does not include bitumen cost which is calculated separately using other inputs.

17.7 Overlay Salvage Value (Percent)

Input 17.7 is the salvage value of overlays expressed as a percentage of their cost. The salvage value of the overlay material will depend upon its anticipated future use at the end of the analysis period. If the right-of-way is fairly well established and the alignment and geometry of the pavement appear to be adequate for years beyond the analysis period, it may be that the present pavement will simply be overlaid and be used as a base material for some future pavement. In this case it would be appropriate to consider the overlay material to be salvageable as a base course and discounted accordingly. On the other hand, if the alignment and geometry of the pavement are inadequate and it is expected that some reconstruction may occur in the future requiring that the present pavement be torn up, the overlay materials should have little salvage value or even a negative salvage value if the cost of removing and disposing of the material is expected to cost more than it would be worth in its best use at that time.

17.8 Increment in Overlay Thickness (Inches)

A variety of overlay thicknesses may be tried in determining the optimum overlay strategy. The increment in overlay thickness is read into the computer program at this place to specify the different overlay thicknesses that will be tried. The minimum overlay thickness is Input 17.3, and the maximum is Input 17.5, and the overlay increment, Input 17.8, determines how many overlay thicknesses will be tried between those two inputs.

17.9 Tack Coat Application Rate (Gallons Per Sq. Yd.)

Input 17.9 is the tack coat application rate used to tack the overlay to an existing surface layer. This input together with Inputs 15.1, 15.4 and 15.5 is used to calculate overlay tack cost coats. If Cross-Section Model No. 0 is used, Inputs 17.9 through 17.12 should be left blank since they will be ignored.

17.10 Prime Coat Application Rate (Gallons Per Sq. Yd.)

This input is the application rate of prime coats in applying an overlay, and normally should be 0.0.

17.11 Asphaltic Concrete Density (Pounds Per Sq. Yd. Per Inch)

Input 17.11 specifies the density of the overlay material, which is used together with Inputs 17.12 and 15.3 to calculate the cost of bitumen in the overlay and level-up.

17.12 Asphaltic Content (Percent)

Input 17.12 specifies the asphalt content by weight of the overlay material, expressed in percent.

CHAPTER 13

PAVEMENT MATERIAL VARIABLES

This chapter describes Card Group No. 18. Each card is used to describe a different material that is used in the different pavement designs generated in the program. The last card in this group is the subgrade material card. Included on each card except the subgrade card is a layer where the material is used, a code letter identifying the material, the name of the material, the structural coefficient, the equivalent soil support value (which is optional), minimum and maximum thicknesses, minimum and maximum costs, a salvage value, a layer increment, and various asphalt variables. Figure 13.1 shows how each of these inputs are to be entered on the cards of Card Group No. 18. As noted on that figure, some of the inputs may be left blank, but others are required for the computer program to run. If Cross-Section Model No. 0 is used, Inputs 18.12 through 18.15 are ignored and can be left blank on all cards.

18.1 Layer Number Where Material Is Used

Each material card except the subgrade card must have a layer designation number which indicates the layer in which the material will be used. The layer numbering is done in sequence from top to bottom. For top-layer materials, this number is 1; for base materials it is 2; etc.; for the subgrade, this space must be blank. This numbering scheme allows alternative materials to be used in each layer of different design. For example, the program user may want to consider two or more base materials. The surface material would be designated by the number 1, and each of the base materials would be designated by the number 2. The program is written so that all combinations

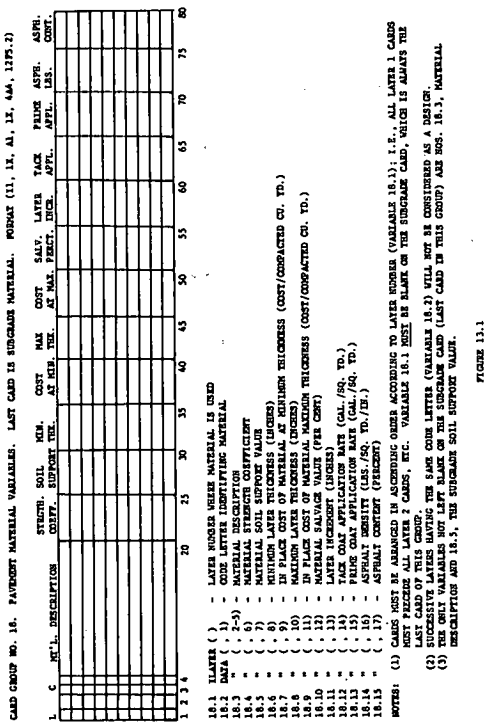


FIGURE 13.1

of materials are analyzed with the stipulation that no two materials with the same designation number are used in the same design and no higher-numbered layer is used above a lower-numbered layer. In addition to the layer designation each material must have an alphabetic code. This code is Input No. 18.2 which is described below. Also, an example is given below of the way that the layer number and material code are used.

18.2 Code Letter Identifying Material (User Specified)

Input 18.2 is a code letter for the material on the card with which it appears. A unique letter code should be assigned to each material so that it can be identified in the output summary table and to prevent successive layers of the same material. The example given below shows the way in which the layer numbers and material codes are used in forming the design combinations that will be tried by the computer program.

Example:

	Layer	Code	Design Combinations				
Surfacing	1	A	1A	1A	1A	1A	1A
Base	2	B	Subg	2B	2B	2C	2C
Base	2	C		Subg	3D	Subg	3D
Subbase	3	D			Subg		Subg
Subgrade	(unnumbered)						

Design(s) using the top layer(s) over only the subbase and subgrade can be obtained by having an additional material card similar to the subbase card (i.e., same name and same code) but with the layer number designated as 2. Having the additional subbase card designated as Layer = 2 allows it to be run as a design with all layers designated as Layer = 1, but having a

material Code = D prohibits it from being run with the third layer (which actually is the same material). The additional design would be 1A, 2D, Subg.

18.3 Name of Material

Input 18.3 provides space to identify the material in words as well as with a letter code, Input 18.2.

18.4 Material Structural Coefficient

AASHO structural coefficients are used to describe the structural properties of each material. The structural coefficients found at the AASHO road test were as follows: for the surface course, 0.44; for the base course, 0.14; and for the subbase course, 0.11. Values have been estimated for materials other than those used at the AASHO road test by comparing their engineering test properties with those of materials used at the AASHO road test. For a compilation of the AASHO structural coefficients of other materials, see NCHRP reports on projects 1-11 and 1-10A.

18.5 Soil Support Value

This soil support value may be provided for each of the materials or it may be provided only for the subgrade depending upon what options the designer wished to have checked out. There is an option in the computer program explained in NCHRP Report 1-10A that checks to see which of the interfaces between materials is most critical. In order to do this, the materials above the interface must have an AASHO structural coefficient, and the materials below the interface must have a soil support value. Empirical

equations relating AASHO structural coefficients to soil support value have been derived and are presented in NCHRP Report 1-10A.

If the designer is confident that the materials he is specifying in each of the layers will perform well in service, there is no need for this test to be applied, and Input 18.5 can be left blank on all material cards except the last, which applies to the subgrade and always must be provided. The soil support value for the subgrade at the AASHO road test has been assumed to be 3.0. The soil support value for a very stiff subgrade corresponding with a very good base course has been assumed to be about 10.0. Typical soil support values are given in NCHRP Report 1-10A.

18.6 Minimum Layer Thickness (Inches)

Input 18.6 and the following three inputs are used to specify layer thicknesses and to determine variable unit costs. Unit material costs are assumed to decrease with increases in layer thicknesses. The minimum thickness, input 18.6, and the maximum thickness, 18.8 and the layer increment, 18.11 should be chosen wisely to reduce the number of thicknesses that are tried by the computer program. The greater the number of thicknesses that are tried, the larger is the number of alternatives considered and the computer running time. It is recommended that minimum and maximum thicknesses that are practical to construct be chosen. It is especially important to restrict layers with low structural coefficients to ranges of thickness that are practical.

18.7 In Place Cost of Material at Minimum Thickness (Cost Per Compacted Cubic Yard

Input 18.7 is the cost of the material described on this card at the minimum thickness. It is generally expected that this cost will be higher than

Input 18.9, although for some materials the cost per compacted cubic yard does not seem to vary much with the material thickness.

18.8 Maximum Layer Thickness (Inches)

Input 18.8 specifies the maximum layer thicknesses of each layer which the designer wishes the computer program to consider.

18.9 In-Place Cost of Material at Maximum Thickness (Cost Per Compacted Cubic Yard)

Input 18.9 is the unit cost of material at the maximum thickness. It usually is expected that the unit cost at this thickness will be lower than the unit cost at the minimum thickness.

18.10 Material Salvage Value (Percent)

Input 18.10 is the material salvage value expressed as a percent of its initial cost. The salvage value percentage for a layer depends upon its expected use at the end of the analysis period. Selection of a percentage for the asphaltic layers should be on a basis similar to that discussed for Input 17.7. Other layers probably should have higher percentages than the asphaltic layers since they might be expected to deteriorate less with time and be more easily salvaged. All layers should have higher percentages the higher the design standards of the roadway and the longer the expected life relative to the analysis period that is used.

18.11 Layer Increment (Inches)

There are a variety of layer thicknesses which will be tried by the computer program for each material that is specified. This number should be relatively

large in order to reduce computation time. For surface layers the increment may be 1/2 inch. For base layers it may be one inch or two inches. For subbase layers it may be two or four inches and so on. If Input 18.11 is blank the increment of Layer No. 1 will be assumed to be 1/4 inch and successive layer increments will be multiples of the Layer No. 1 increment depending on the relative cost of the materials.

18.12 Tack Coat Application Rate (Gallons Per Sq. Yd.)

Input 18.12 gives the tack coat application rate used for this material. It should be left blank for materials not using tack coats. Input 18.12 is used together with Inputs 15.1, 15.4, and 15.5 to calculate the total cost of tack coats applied to a given layer. (Inputs 18.12 through 18.15 are ignored if Cross-Section Model No. 0 is used.)

18.13 Prime Coat Application Rate (Gallons Per Sq. Yd.)

Input 18.13 is the prime coat application rate used with this material. It should be left blank for materials not using prime coats. Input 18.13 is used together with Input 15.2, prime coat cost in dollars per gallon, in arriving at a total prime coat cost for a given pavement.

18.14 Asphalt Concrete Density (Pounds Per Sq. Yd. Per Inch)

Input 18.14 is the in-place density of the asphalt concrete as placed. If the material being described on this card is not asphalt concrete, then this input should be left blank.

18.15 Asphalt Content (Percent)

This input gives the asphalt content of the material being described. It should be left blank if the material has no asphalt in it.

CHAPTER 14

SHOULDER LAYER MATERIAL VARIABLES

It has been found that the materials used in shoulders, their unit costs, their slopes, and the way they are built can affect the choice of an optimum strategy. For this reason the SAMP6 computer program makes provision for including the cost of shoulder materials in the complete pavement cross-section using Cross-Section Model No. 1. The input format for the input variables is shown in Figure 14.1 Each card of Card Group No. 19 describes a different material. Included in the description of this material is the thickness, cost and salvage value of the material, the tack and prime coat application rates, asphaltic concrete density and asphaltic content, and other variables. This card group is similar to Card Group No. 18 with the following exceptions. Layer numbers and code letters are not provided for the shoulder layers; instead, each shoulder material is used in the order in which it is read into the program and there are no options available for varying these materials in the SAMP6 program. (Another version of the program that changes shoulder materials as pavement materials are changed is available.) Only one thickness is specified for each layer and, with one exception, this layer thickness is used if the sum of the shoulder layer depths down to the bottom of that layer do not exceed the sum of the same number of pavement layers, in which case the shoulder depth is set equal to a depth that equalizes the shoulder depth and the pavement depth. The one exception to this is the first shoulder layer when it is not asphaltic; if the first shoulder layer is not asphaltic, then it is permitted to be thicker than the first pavement layer, if there is a second

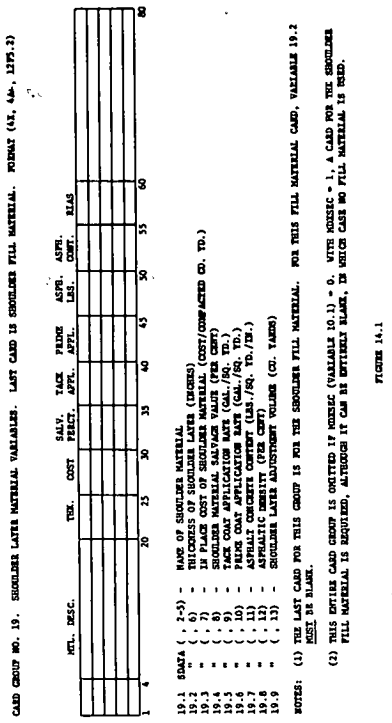


FIGURE 14.1

pavement layer; however, the first and second shoulder layers are not allowed to be thicker than the first and second pavement layers even in this case.

Strength coefficients and soil support values are not provided for shoulder layers. Also only one thickness and one cost is provided; this thickness is, in effect, the maximum thickness the shoulder layer is allowed to take. No layer increment is used on shoulder layers; the shoulder layers are incremented along with corresponding pavement layers up to the point where the shoulder layers reach their maximum or constrained thicknesses.

The last card in Card Group No. 19 is the fill material card. It specifies the material that is used to "fill out" all cross section areas not "filled out" by pavement and shoulder layers. That is, the entire cross-section is basically a rectangular box; the rectangle's depth is equal to the sum of the pavement layer thicknesses, for a particular design, plus the thickness of the wearing surface. The rectangle's width is the sum of the lane widths, the shoulder widths, and the widths outside the shoulder. The rectangles length, measured along the centerline of the pavement is taken as one yard. The fill material is equal to this total volume less the volume of the pavement and shoulder layers. Since the volume of fill material is calculated in this way, it has no input for layer thickness. The only inputs provided on the last, fill material card are Inputs 19.1, 19.3, and 19.4; the entire card is blank if no fill material is used.

Each shoulder layer volume and the fill material volume can be reduced by any specified number of cubic yards through use of an adjustment volume, the last input on each card in this group.

This entire card group is omitted if Cross-Section Model No. 0 is used.

19.1 Name of Shoulder Material

Input 19.1 provides space to describe the shoulder material in words.

19.2 Thickness of Shoulder Layer (Inches)

The thickness of each shoulder material is specified by Input 19.2.

19.3 In-Place Cost of Shoulder Material at Thickness (Cost Per Compacted Cubic Yd.)

Input 19.3 is the cost of the shoulder material per compacted cubic yard.

19.4 Shoulder Material Salvage Value (Percent)

The salvage values for the shoulder materials should be similar to that for the pavement materials and depends primarily upon their expected use at the end of the analysis period. If it is expected that the pavement will simply be overlaid or broadened, then the shoulder material may be regarded as a base course and estimated accordingly. However, if reconstruction is anticipated at the end of the analysis period or sometime thereafter requiring a relocation of the road or the removal of the shoulders along with the pavement, then the shoulder material may have a small or negative salvage value reflecting the cost that it would take to dig up the material and transport it elsewhere.

19.5 Tack Coat Application Rate (Gallons Per Sq. Yd.)

Input 19.5 gives the tack coat application rate for this material, and should be left blank if the material is not asphaltic.

19.6 Prime Coat Application Rate (Gallons Per Sq. Yd.)

Input 19.6 is the prime coat application rate for this material. It may not be applicable, in which case it is left blank. This input combined with input 15.2 prime coat cost per gallon, is used to calculate the prime coat cost for this layer.

19.7 Asphalt Concrete Density (Pounds Per Sq. Yd. Per Inch)

This is the density of the asphalt concrete that is used. If this material is not asphaltic concrete, then this input is left blank.

19.8 Asphaltic Content (Percent)

This is the asphaltic content by weight of the material described on this card. If there is no asphalt in the material, then it is left blank.

19.9 Shoulder Layer Adjustment Volume (Cubic Yds.)

Because of the slopes of the pavement and embankment cross-section in a roadway, it is not always possible to describe the total area of any one shoulder layer as a rectangular area. A certain area in cubic yards must be subtracted from the total area of the shoulder material in order to arrive at an accurate estimate of the total area of material used. The shoulder layer adjustment volume is the total area that must be subtracted in order to get a good estimate. It is multiplied by one yard length in order to get the total cubic yards per yard of length of pavement that must be subtracted in order to get an accurate estimate of cubic yards per center-line yard. For two-lane pavements this is the volume subtracted from both shoulders. For four-or-more lanes, undivided roads, it is the volume subtracted from one shoulder and half of the median. For roads that

are divided, this volume is the amount subtracted from both the inside and outside shoulders in one direction of travel.

NOTE: Input data for SAMP6 is composed of one or more sets of cards, one set for each problem. After the last problem there should be one or more blank cards.

Although 19 card formats may appear complex, all cards which do not have alphanumeric description fields may be prepared by only noting the first letter of the variable names to punch the data in the ten column fields. The "REAL" variables (beginning with letters A-H, O-Z) are punched anywhere in the field with the decimal punched. "INTEGER" variables (first letter I, J. K, L, M or N) must be right-justified in the field with no decimal.

SUMMARY OF BEST OVERALL DESIGNS

The third part of the output is presented in the form of a table that shows the best overall designs, of which there may be up to 30, in order of increasing total cost. These designs are presented as an aid to the pavement designer. Using this output together with judgment, he should be able to choose a design to use for the pavement under consideration. (See Figure 15.3.)

CHAPTER 15

PROGRAM OUTPUT

The output of the SAMP6 computer program is provided in three parts, as follows:

1. A summary of the input data,
2. A summary of the best design strategy for each material combination, and
3. A summary of the best design strategies in order of increasing total cost per square yard of traffic lane.

Figures 15.1, 15.2, and 15.3 show example output.

SUMMARY OF INPUT DATA

All input data are summarized in the first part of the output. The inputs are listed in the same order and units used in the input card formats. Figure 15.1 shows an example listing.

SUMMARY OF BEST DESIGN STRATEGY FOR EACH SET OF MATERIALS

The second part of the output presents a summary of the best design strategies for each set of materials. The design with least total cost is determined and printed for each set of materials. These designs are presented so that the program user will know the optimum thickness, overlay policy, costs, and other characteristics of the least costly design for a set of materials. Many of these designs may not appear in the overall summary table, but the program user, nevertheless, can compare them with the optimum overall designs to determine why some particular sets of materials do not appear in the optimum overall ranking. (See Figure 15.2.)

news

TRANSPORTATION
RESEARCH BOARD

TRANSPORTATION PROGRESS THROUGH RESEARCH

2101 Constitution Avenue • Washington, D.C. 20418

For further information call:

(202) 389-6741

For immediate release

COMPUTER PROGRAM HELPS TO DESIGN AND MANAGE ASPHALT PAVEMENTS

"Flexible Pavement Design and Management -- Systems Approach Implementation," NATIONAL COOPERATIVE HIGHWAY RESEAFCH PROGRAM REPORT 160, 53 Pages, $4.00. (ISBN 0-309-02339-4)

An operational computer program that provides a basis for selecting flexible pavement design and management strategies with the lowest predicted total cost over a prescribed period is described in NCHRP REPORT 160, "Flexible Pavement Design and Management -- Systems Approach Implementation," recently published by the Transportation Research Board, which administers the National Cooperative Highway Research Program (NCHRP). The computer program, designated SAMP6, considers such cost elements as initial construction, routine maintenance, periodic rehabilitation, interest on investment, salvage value, and roadway user cost. The program uses the AASHTO Interim Guides as its structural subsystem and the predicted decrease in serviceability with time and traffic as developed at the AASHO Road Test. The program has been pilot tested in three states and found to be workable where suitable computer facilities and personnel are available.

- more -

NCHRP-B/25/76/2
84+; 86+; 87+; 88+; 89+
8A+; 8B+; 8D+; 8F+

Management benefits of using SAMP6 include the ability to quantify decisions. An example of this is the choice between light pavement with several overlays and thick heavy pavements with virtually zero rehabilitation. Decisions can also be updated; several runs of the program at various stages of design construction and service will allow the user to judge the effects of fluctuating prices and interest rates, scarcity of materials, and revised maintenance and rehabilitation policy.

Several long-range physical and economic factors not normally considered in pavement design are included in the analysis. They include users' costs due to traffic delay around rehabilitation work, investment costs to the highway agency, and salvage values of materials in place at the end of an analysis period.

Predicted total costs, as determined by the computer program, are most sensitive to changes in the following variables:

- Traffic delay costs when congestion occurs.
- Serviceability loss because of environmental factors, e.g., swelling clay, frost heave, various forms of cracking.
- Soil support offered by the subgrade.
- Material properties and unit costs of the surface and the base courses.
- Degree of reliability the designer requires of the performance of the pavement.

Some of the variables found to be less important were the serviceability index at the time of overlay, the total 18-kip equivalent single-axle loads applied to the pavement, interest rates, and the length of the analysis period.

Researchers at Texas A & M University, who carried out the research under contract to NCHRP, strongly recommend further research in the areas of the most sensitive variables, along with further development of the structural and environmental subsystems of SAMP6. In the interim, this report will be of particular interest to administrators who must make policy decisions concerning use of the systems approach to pavement design and management; to pavement designers who will be involved in its implementation; and to materials, soils, maintenance, and traffic engineers who provide the input information for its operation.

NCHRP REPORT 160 is available for $4.00 a copy from the Transportation Research Board, Publications Department 805, 2101 Constitution Avenue, N. W., Washington, D. C. 20418. (Payment in advance is required on orders of $7.50 or less.)

The NCHRP was created in June 1962 as a means to accelerate research into particularly acute problems affecting highway transportation on a nationwide scale. It is sponsored by the American Association of State Highway and Transportation Officials in cooperation with the U.S. Department of Transportation's Federal Highway Administration.

The Transportation Research Board evolved from the Highway Research Board, which was organized in 1920. It is a cooperative organization of professionals from government, the academic world, and industry. The Board's purpose is to advance knowledge of the nature and performance of transportation systems and their interaction with society through the stimulation of research and the dissemination of information resulting from research.

The Board operates within the Commission on Sociotechnical Systems of the National Research Council, which serves both the National Academy of Sciences and the National Academy of Engineering.

###############

INPUT DATA

PROGRAM CONTROL AND MISCELLANEOUS VARIABLES	
NPG-THE NUMBER OF OUTPUT PAGES FOR THE SUMMARY TABLE(10 DESIGNS/PAGE).	3
NL-THE NUMBER OF LANES ON THE HIGHWAY (BOTH DIRECTIONS).	4
CL-THE LENGTH OF THE ANALYSIS PERIOD(YEARS).	20.
XLWFT-THE WIDTH OF EACH LANE (FEET).	12.
PCTRAT-THE INTEREST RATE OR TIME VALUE OF MONEY(PERCENT).	5.00
UPLVL-THE LEVEL-UP THICKNESS REQUIRED PER OVERLAY(INCHES).	0.5
WSPR-WEARING SURFACE PRODUCTION RATE(TONS/HOUR).	75.0
ENVIRONMENTAL AND SERVICEABILITY VARIABLES	
R-REGIONAL FACTOR.	1.5
PSI-THE SERVICEABILITY INDEX OF THE INITIAL STRUCTURE.	4.2
P1-THE SERVICEABILITY INDEX OF AN OVERLAY.	4.5
P2-THE MINIMUM ALLOWED VALUE OF THE SERVICEABILITY INDEX, AT WHICH AN OVERLAY WILL BE APPLIED.	2.0
SACT-PROPORTION OF THE PROJECT'S LENGTH LIKELY TO SWELL	0.0
SRISE-VERTICAL DISTANCE THE SURFACE OF A CLAY LAYER CAN RISE(INCHES)	0.0
SRATE-CALCULATES HOW FAST SWELLING OCCURS	0.0
LOAD AND TRAFFIC VARIABLES	
RO-THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE START OF THE ANALYSIS PERIOD.	5635.
RC-THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE END OF ANALYSIS PERIOD.	8635.
XNC-THE ONE-DIRECTION ACCUMULATED NUMBER OF EQUIVALENT 18-KIP AXLES DURING THE ANALYSIS PERIOD.	6700000.
PROPCT-THE PERCENT OF ADT WHICH WILL PASS THROUGH THE OVERLAY ZONE DURING EACH HOUR WHILE OVERLAYING IS TAKING PLACE.	5.5
ITYPE-THE TYPE OF ROAD UNDER CONSTRUCTION(1-RURAL,2-URBAN)..	2
COEFVR-COEFFICIENT OF VARIATION.	0.0
MCONF-CONFIDENCE LEVEL INDICATOR.	3
CONSTRAINT VARIABLES	
XTTO-THE MINIMUM ALLOWED TIME TO THE FIRST OVERLAY.	2.0
XTBO-THE MINIMUM ALLOWED TIME BETWEEN OVERLAYS.	10.0
CMAX-THE MAXIMUM FUNDS AVAILABLE FOR INITIAL CONSTRUCTION.	10.00
TMAXIN-THE MAXIMUM ALLOWABLE TOTAL THICKNESS OF INITIAL CONSTRUCTION(INCHES).	32.00
TMOVIN-THE ACCUMULATED THICKNESS MAXIMUM OF ALL OVERLAYS (INCHES), (EXCLUDING WEAR-COAT AND LEVEL-UP).	10.00
UPGCST-COST/CU. YD. TO UPGRADE AFTER AN OVERLAY.	0.0
WIDUPG-WIDTH OF PAVEMENT & SHOULDERS TO BE UPGRADED(FEET).	0.0
TRAFFIC DELAY VARIABLES ASSOCIATED WITH OVERLAY AND ROAD GEOMETRICS	
ACPR-ASPHALTIC CONCRETE PRODUCTION RATE(TONS/HOUR).	75.0
ACCD-ASPHALTIC CONCRETE COMPACTED DENSITY(TONS/COMPACTED CY)	1.80
XLSO-THE DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE OVERLAY DIRECTION.	0.50
XLSN-THE DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE NON-OVERLAY DIRECTION.	0.50
XLSD-THE DISTANCE AROUND THE OVERLAY ZONE(MILES).	0.0
HPD-THE NUMBER OF HOURS/DAY OVERLAY CONSTRUCTION TAKES PLACE.	8.0
NLRO-THE NUMBER OF LANES IN THE RESTRICTED ZONE IN THE OVERLAY DIRECTION.	1
NLRN-THE NUMBER OF LANES IN THE RESTRICTED ZONE IN THE NON-OVERLAY DIRECTION.	2

TRAFFIC DELAY VARIABLES ASSOCIATED WITH TRAFFIC SPEEDS AND DELAYS	
THE PERCENT OF VEHICLES STOPPED DUE TO MOVEMENT OF PERSONNEL OR EQUIPMENT.	
PPO2-IN THE OVERLAY DIRECTION.	5.00
PPN2-IN THE NON-OVERLAY DIRECTION.	0.0
THE AVERAGE DELAY PER VEHICLE STOPPED DUE TO MOVEMENT OF PERSONNEL & EQUIP.	
DO2 -IN THE OVERLAY DIRECTION(HOURS).	0.150
DN2 -IN THE NON-OVERLAY DIRECTION(HOURS).	0.0
AAS-THE AVERAGE APPROACH SPEED TO THE OVERLAY AREA.	60.
THE AVERAGE SPEED THROUGH THE OVERLAY AREA	
ASO-IN THE OVERLAY DIRECTION(MPH).	45.
ASN-IN THE NON-OVERLAY DIRECTION(MPH).	60.
MODEL-THE TRAFFIC HANDLING MODEL USED.	3
MAINTENANCE VARIABLES	
MNTMOD-THE MAINTENANCE MODEL(EXPLICIT=1,NCHRP=2).	2
CM1-INITIAL ANNUAL ROUTINE COST($/LANE MILE, MNTMOD=1).	0.0
CM2-ANNUAL INCREMENTAL INCREASE IN COSTS($/LANE MILE/YR, MNTMOD=1).	0.0
X2-DAYS THE TEMPERATURE REMAINS BELOW 32F.(DAYS/YEAR, MNTMOD=2).	10.
CLW-THE COMPOSITE LABOR WAGE($/HR).	2.05
CERP-THE COMPOSITE EQUIPMENT RENTAL RATE.	2.50
CMAT-THE RELATIVE MATERIAL COST(1.00 IS AVERAGE).	1.00

FIGURE 15.1 SAMPLE INPUT DATA

CROSS SECTION MODEL, COST AND SHOULDER VARIABLES

MDXSEC-THE CROSS SECTION MODEL USED.	1
MDCOST-THE COST MODEL USED.	1
MASPHS-ASPHALTIC SHOULDER MODEL (0 IF NOT ASPHALTIC SHOULDERS).	1
SOWID-WIDTH OF OUTSIDE SHOULDER, IN FEET	10.00
SIWID-WIDTH OF INSIDE SHOULDER, IN FEET	4.00
XOWID-CROSS SECTION WIDTH OUTSIDE OF OUTSIDE SHOULDER(FEET)	0.0
XIWID-CROSS SECTION WIDTH OUTSIDE OF INSIDE SHOULDER(FEET)	0.0

ADDITIONAL WIDTH(FEET) OF LAYERS RELATIVE TO LAYER ONE.

LAYER NO.	PAVEMENT-LAYERS OUTSIDE	PAVEMENT-LAYERS INSIDE	SHOULDER-LAYERS OUTSIDE	SHOULDER-LAYERS INSIDE
1	0.0	0.0	0.0	0.0
2	2.00	2.00	0.25	0.25
3	10.25	4.25		
4	10.25	4.25		

TACK, PRIME, AND BITUMINOUS VARIABLES

ACTL-TACK COAT COST($/GAL).	0.0
ALPC-PRIME COAT COST($/GAL).	0.0
ACG-BITUMINOUS MATERIAL COST($/GAL).	0.0
TLMAX-MAXIMUM LAYER DEPTH FOR NO TACK COATS, INCHES	4.00
TLINC-MAXIMUM DEPTH OF EACH LIFT ABOVE TLMAX, INCHES	3.00

THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE

LAYER NO.	-PAVEMENT MATERIALS- CODE	DESCRIPTION	STRENGTH COEFF.	SOIL SUPPORT	----MINIMUM---- DEPTH	$/CU.YD.	----MAXIMUM---- DEPTH	$/CU.YD.	SALVAGE VALUE	INCREMENT
-	-	NO SEP. W.S.	0.0	------	0.0	0.0	------	------	0.0	------
-	-	AC,TYPE 3	0.44	------	1.00	18.00	5.00	18.00	30.00	1.00
1	A	ASPH.CONC.TYPE 3	0.44	0.0	1.50	18.00	1.50	18.00	30.00	0.50
2	3	ASPH.CONC.TYPE 3	0.40	10.00	2.00	18.00	8.00	18.00	30.00	1.00
3	S	LIME STAB.SOIL	0.11	7.80	4.00	5.00	10.00	5.00	50.00	2.00
3	L	LIME STAB. S-C-G	0.11	7.80	4.00	7.00	10.00	7.00	50.00	2.00
3	C	CEM.STAB.S-C-G	0.15	10.00	4.00	8.00	10.00	8.00	50.00	2.00
4	M	SELECT MATERIAL	0.04	0.50	4.00	2.00	10.00	2.00	50.00	2.00
-	-	SUBGRADE	------	3.10	------	------	------	------	------	

LAYER NO.	-PAVEMENT MATERIALS- CODE	DESCRIPTION	---APPLICATION RATES---- TACK COAT	PRIME COAT	ASPHALT (LB/IN)	ASPHALT CONTENT (PCT)
-		NO SEP. W.S.	0.0	0.0	0.0	0.0
-		AC,TYPE 3	0.0	0.0	0.0	0.0
1	A	ASPH.CONC.TYPE 3	0.0	0.0	0.0	0.0
2	3	ASPH.CONC.TYPE 3	0.0	0.0	0.0	0.0
3	S	LIME STAB.SOIL	0.0	0.0	0.0	0.0
3	L	LIME STAB. S-C-G	0.0	0.0	0.0	0.0
3	C	CEM.STAB.S-C-G	0.0	0.0	0.0	0.0
4	M	SELECT MATERIAL	0.0	0.0	0.0	0.0

LAYER NO.	-SHOULDER MATERIALS- DESCRIPTION	DEPTH	$/CU.YD.	SALVAGE VALUE	---APPLICATION RATES---- TACK COAT	PRIME COAT	ASPHALT (LB/IN)	ASPHALT CONTENT (PCT)	ADJUST. VOLUME
1	- AC-WC-SH-MIX	1.50	18.00	30.00	0.0	0.0	0.0	0.0	0.0
2	- SELECT MATERIAL	8.00	2.00	50.00	0.0	0.0	0.0	0.0	0.0
-	- NO FILL USED	------	0.0	0.0	------	------	------	------	0.0

FIGURE 15.1 (CONTINUED) SAMPLE INPUT DATA

```
SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A          ' PAGE  4
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

DESIGN TYPE   1, A 1 LAYER DESIGN
MATERIAL ARRANGEMENT A

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER -----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750

THE FOLLOWING CONSTRAINTS PREVENTED A DESIGN WITH
 THIS SET OF MATERIALS (THIS DESIGN TYPE).


   THE CONSTRUCTION RESTRICTIONS ARE TOO BINDING TO OBTAIN A STRUCTURE
   THAT WILL MEET THE MINIMUM TIME TO THE FIRST OVERLAY RESTRICTION.

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A
 INITIAL DESIGNS
        1 WITHIN COST AND THICKNESS CONSTRAINTS
        0 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
        0 CONSIDERED
        0 FEASIBLE
        0 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
        0 FEASIBLE
```

```
SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A          ' PAGE  5
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

DESIGN TYPE   2, A 2 LAYER DESIGN
MATERIAL ARRANGEMENT A3

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER -----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750
 2      3  ASPH.CONC.TYPE 3     1.000   4.000

  2   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
      FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
             A    ASPH.CONC.TYPE 3    1.50 INCHES
             3  * ASPH.CONC.TYPE 3    8.00 INCHES
      THE LIFE OF THE INITIAL STRUCTURE =   3.3 YEARS     STRUCTURAL NUMBER  3.86
      THE OVERLAY SCHEDULE IS
           3.00INCH(ES) (EXCLUSIVE OF LEVEL-UP AND WEAR-COURSE) AFTER   3.3 YEARS.
      THE TOTAL LIFE =   25.2 YEARS.

      THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
            INITIAL CONSTRUCTION COST          6.049
            TOTAL ROUTINE MAINTENANCE COST     0.934
            TOTAL OVERLAY CONSTRUCTION COST    2.358
            TOTAL USER COST DURING
                      OVERLAY CONSTRUCTION     0.075
            SALVAGE VALUE                     -1.012
            TOTAL OVERALL COST                 8.403

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A3
 INITIAL DESIGNS
        7 WITHIN COST AND THICKNESS CONSTRAINTS
        1 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
        3 CONSIDERED
        1 FEASIBLE
        1 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
        1 FEASIBLE
```

FIGURE 15.2 SUMMARY OF BEST DESIGN STRATEGY

```
SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A          ' PAGE  6
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

DESIGN TYPE   3, A 3 LAYER DESIGN
MATERIAL ARRANGEMENT A3S

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER ----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750
 2      3  ASPH.CONC.TYPE 3     1.000   4.000
 3      S  LIME STAB.SOIL       0.556   1.389

  3   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
      FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
            A    ASPH.CONC.TYPE 3    1.50 INCHES
            3  * ASPH.CONC.TYPE 3    8.00 INCHES
            S    LIME STAB.SOIL      6.00 INCHES
      THE LIFE OF THE INITIAL STRUCTURE =   9.4 YEARS     STRUCTURAL NUMBER  4.52
      THE OVERLAY SCHEDULE IS
          1.00INCH(ES) (EXCLUSIVE OF LEVEL-UP AND WEAR-COURSE) AFTER   9.4 YEARS.
      THE TOTAL LIFE =   24.4 YEARS.

      THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
            INITIAL CONSTRUCTION COST          7.385
            TOTAL ROUTINE MAINTENANCE COST     0.450
            TOTAL OVERLAY CONSTRUCTION COST    0.752
            TOTAL USER COST DURING
                      OVERLAY CONSTRUCTION     0.027
            SALVAGE VALUE                     -1.085
            TOTAL OVERALL COST                 7.529

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A3S
 INITIAL DESIGNS
       28 WITHIN COST AND THICKNESS CONSTRAINTS
       10 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
       22 CONSIDERED
        9 FEASIBLE
        9 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
        9 FEASIBLE

SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A          ' PAGE  7
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

DESIGN TYPE   4, A 4 LAYER DESIGN
MATERIAL ARRANGEMENT A3SM

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER -----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750
 2      3  ASPH.CONC.TYPE 3     1.000   4.000
 3      S  LIME STAB.SOIL       0.556   1.389
 4      M  SELECT MATERIAL      0.222   0.556

  4   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
      FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
            A    ASPH.CONC.TYPE 3    1.50 INCHES
            3  * ASPH.CONC.TYPE 3    8.00 INCHES
            S    LIME STAB.SOIL      4.00 INCHES
            M    SELECT MATERIAL     6.00 INCHES
      THE LIFE OF THE INITIAL STRUCTURE =   9.6 YEARS     STRUCTURAL NUMBER  4.54
      THE OVERLAY SCHEDULE IS
          1.00INCH(ES) (EXCLUSIVE OF LEVEL-UP AND WEAR-COURSE) AFTER   9.6 YEARS.
      THE TOTAL LIFE =   25.0 YEARS.

      THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
            INITIAL CONSTRUCTION COST          7.475
            TOTAL ROUTINE MAINTENANCE COST     0.452
            TOTAL OVERLAY CONSTRUCTION COST    0.742
            TOTAL USER COST DURING
                      OVERLAY CONSTRUCTION     0.027
            SALVAGE VALUE                     -1.102
            TOTAL OVERALL COST                 7.594

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A3SM
 INITIAL DESIGNS
      112 WITHIN COST AND THICKNESS CONSTRAINTS
       52 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
      113 CONSIDERED
       42 FEASIBLE
       46 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
       46 FEASIBLE
```

FIGURE 15.2 (CONTINUED) SUMMARY OF BEST DESIGN STRATEGY

```
SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A          ' PAGE  8
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

DESIGN TYPE   5, A 3 LAYER DESIGN
MATERIAL ARRANGEMENT A3L

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER -----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750
 2      3  ASPH.CONC.TYPE 3     1.000   4.000
 3      L  LIME STAB. S-C-G     0.778   1.944

  5   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
      FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
            A    ASPH.CONC.TYPE 3    1.50 INCHES
            3  * ASPH.CONC.TYPE 3    8.00 INCHES
            L    LIME STAB. S-C-G    6.00 INCHES
      THE LIFE OF THE INITIAL STRUCTURE =   9.4 YEARS     STRUCTURAL NUMBER  4.52
      THE OVERLAY SCHEDULE IS
            1.00INCH(ES) (EXCLUSIVE OF LEVEL-UP AND WEAR-COURSE) AFTER   9.4 YEARS.
      THE TOTAL LIFE =   24.4 YEARS.

      THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
            INITIAL CONSTRUCTION COST          7.920
            TOTAL ROUTINE MAINTENANCE COST     0.450
            TOTAL OVERLAY CONSTRUCTION COST    0.752
            TOTAL USER COST DURING
                  OVERLAY CONSTRUCTION         0.027
            SALVAGE VALUE                     -1.186
            TOTAL OVERALL COST                 7.963

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A3L
 INITIAL DESIGNS
      28 WITHIN COST AND THICKNESS CONSTRAINTS
      10 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
      22 CONSIDERED
       9 FEASIBLE
       9 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
       9 FEASIBLE

SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A          ' PAGE  9
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

DESIGN TYPE   6, A 4 LAYER DESIGN
MATERIAL ARRANGEMENT A3LM

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER -----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750
 2      3  ASPH.CONC.TYPE 3     1.000   4.000
 3      L  LIME STAB. S-C-G     0.778   1.944
 4      M  SELECT MATERIAL      0.222   0.556

  6   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
      FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
            A    ASPH.CONC.TYPE 3    1.50 INCHES
            3  * ASPH.CONC.TYPE 3    8.00 INCHES
            L    LIME STAB. S-C-G    4.00 INCHES
            M  * SELECT MATERIAL     6.00 INCHES
      THE LIFE OF THE INITIAL STRUCTURE =   9.6 YEARS     STRUCTURAL NUMBER  4.54
      THE OVERLAY SCHEDULE IS
            1.00INCH(ES) (EXCLUSIVE OF LEVEL-UP AND WEAR-COURSE) AFTER   9.6 YEARS.
      THE TOTAL LIFE =   25.0 YEARS.

      THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
            INITIAL CONSTRUCTION COST          7.831
            TOTAL ROUTINE MAINTENANCE COST     0.452
            TOTAL OVERLAY CONSTRUCTION COST    0.742
            TOTAL USER COST DURING
                  OVERLAY CONSTRUCTION         0.027
            SALVAGE VALUE                     -1.169
            TOTAL OVERALL COST                 7.883

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A3LM
 INITIAL DESIGNS
     111 WITHIN COST AND THICKNESS CONSTRAINTS
      51 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
     113 CONSIDERED
      42 FEASIBLE
      45 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
      45 FEASIBLE
```

FIGURE 15.2 (CONTINUED) SUMMARY OF BEST DESIGN STRATEGY

```
SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A          ' PAGE 10
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

DESIGN TYPE   7, A 3 LAYER DESIGN
MATERIAL ARRANGEMENT A3C

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER -----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750
 2      3  ASPH.CONC.TYPE 3     1.000   4.000
 3      C  CEM.STAB.S-C-G       0.889   2.222

  7   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
      FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
            A    ASPH.CONC.TYPE 3    1.50 INCHES
            3  * ASPH.CONC.TYPE 3    8.00 INCHES
            C    CEM.STAB.S-C-G      4.00 INCHES
      THE LIFE OF THE INITIAL STRUCTURE =   8.6 YEARS     STRUCTURAL NUMBER  4.46
      THE OVERLAY SCHEDULE IS
            2.00INCH(ES) (EXCLUSIVE OF LEVEL-UP AND WEAR-COURSE) AFTER   8.6 YEARS.
      THE TOTAL LIFE =   31.4 YEARS.

      THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
            INITIAL CONSTRUCTION COST          7.475
            TOTAL ROUTINE MAINTENANCE COST     0.453
            TOTAL OVERLAY CONSTRUCTION COST    1.302
            TOTAL USER COST DURING
                  OVERLAY CONSTRUCTION         0.047
            SALVAGE VALUE                     -1.191
            TOTAL OVERALL COST                 8.085

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A3C
 INITIAL DESIGNS
       28 WITHIN COST AND THICKNESS CONSTRAINTS
       13 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
       29 CONSIDERED
       10 FEASIBLE
       11 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
       11 FEASIBLE

SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A          ' PAGE 11
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

DESIGN TYPE   8, A 4 LAYER DESIGN
MATERIAL ARRANGEMENT A3CM

     EXCLUDING TACK, PRIME, BITUMEN, AND THE SHOULDERS,
    THE MATERIAL LAYER COSTS/(SQ.YD.) ARE . . .

LAYER -----MATERIALS-------   -DOLLARS-PER-SQUARE-YARD-
NO.    CODE  DESCRIPTION      MINIMUM MAXIMUM INCREMENT

 1      A  ASPH.CONC.TYPE 3     0.750   0.750
 2      3  ASPH.CONC.TYPE 3     1.000   4.000
 3      C  CEM.STAB.S-C-G       0.889   2.222
 4      M  SELECT MATERIAL      0.222   0.556

  8   THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
      FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE
            A    ASPH.CONC.TYPE 3    1.50 INCHES
            3  * ASPH.CONC.TYPE 3    8.00 INCHES
            C    CEM.STAB.S-C-G      4.00 INCHES
            M    SELECT MATERIAL     4.00 INCHES
      THE LIFE OF THE INITIAL STRUCTURE =  10.8 YEARS     STRUCTURAL NUMBER  4.62
      THE OVERLAY SCHEDULE IS
            1.00INCH(ES) (EXCLUSIVE OF LEVEL-UP AND WEAR-COURSE) AFTER  10.8 YEARS.
      THE TOTAL LIFE =   27.5 YEARS.

      THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE
            INITIAL CONSTRUCTION COST          7.831
            TOTAL ROUTINE MAINTENANCE COST     0.484
            TOTAL OVERLAY CONSTRUCTION COST    0.701
            TOTAL USER COST DURING
                  OVERLAY CONSTRUCTION         0.026
            SALVAGE VALUE                     -1.169
            TOTAL OVERALL COST                 7.874

SAMP6 PROGRAM ACTIVITY REPORT, DESIGN TYPE A3CM
 INITIAL DESIGNS
      109 WITHIN COST AND THICKNESS CONSTRAINTS
       60 FEASIBLE TO FIRST OVERLAY
 OVERLAYS
      124 CONSIDERED
       43 FEASIBLE
       52 FEASIBLE OVERLAY POLICIES
 COMPLETE DESIGNS
       52 FEASIBLE
```

FIGURE 15.2 (CONTINUED) SUMMARY OF BEST DESIGN STRATEGY

SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A ' PAGE 12
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

PROBLEM SUMMARY OF THE BETTER FEASIBLE DESIGNS
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8	9	10
MATERIAL ARRANGEMENT	A3S	A3SM	A3S	A3SM	A3SM	A3SM	A3SM	A3S	A3CM	A3LM
INIT. CONST. COST	7.385	7.475	7.669	7.669	7.653	7.758	7.742	6.940	7.831	7.831
OVERLAY CONST. COST	0.752	0.742	0.732	0.752	0.701	0.721	0.670	1.423	0.701	0.742
USER COST	0.027	0.027	0.027	0.027	0.026	0.027	0.026	0.049	0.026	0.027
ROUTINE MAINT. COST	0.450	0.452	0.457	0.450	0.484	0.464	0.534	0.526	0.484	0.452
SALVAGE VALUE	-1.085	-1.102	-1.182	-1.182	-1.135	-1.199	-1.152	-1.090	-1.169	-1.169
TOTAL COST	7.529	7.594	7.703	7.715	7.729	7.771	7.819	7.847	7.874	7.883
NUMBER OF LAYERS	3	4	3	4	4	4	4	3	4	4
LAYER DEPTH (INCHES)										
D(1)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(2)	8.00*	8.00*	7.00*	7.00*	8.00*	7.00*	8.00*	8.00*	8.00*	8.00*
D(3)	6.00	4.00	10.00	6.00	4.00	8.00	6.00	4.00	4.00	4.00
D(4)		6.00		10.00	8.00	6.00	4.00		4.00	6.00
STRUCTURAL NUMBER	4.52	4.54	4.56	4.52	4.62	4.58	4.68	4.30	4.62	4.54
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)										
T(1)	9.4	9.6	9.9	9.4	10.8	10.2	11.7	6.8	10.8	9.6
T(2)	24.4	25.0	25.6	24.4	27.5	26.2	28.2	27.5	27.5	25.0
OVERLAY POLICY(INCH) EXCLUSIVE OF LEVEL-UP & WEAR-COURSE)										
O(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	1.00	1.00

SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A ' PAGE 13
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

PROBLEM SUMMARY OF THE BETTER FEASIBLE DESIGNS
IN ORDER OF INCREASING TOTAL COST

	11	12	13	14	15	16	17	18	19	20
MATERIAL ARRANGEMENT	A3SM	A3SM	A3SM	A3CM	A3S	A3SM	A3S	A3L	A3SM	A3S
INIT. CONST. COST	7.953	7.831	7.936	7.936	7.831	7.296	6.778	7.920	6.689	7.223
OVERLAY CONST. COST	0.732	0.659	0.680	0.752	0.638	1.302	1.544	0.752	1.580	1.394
USER COST	0.027	0.025	0.026	0.027	0.025	0.047	0.051	0.027	0.052	0.048
ROUTINE MAINT. COST	0.457	0.556	0.515	0.450	0.608	0.453	0.677	0.450	0.735	0.501
SALVAGE VALUE	-1.280	-1.169	-1.233	-1.233	-1.169	-1.157	-1.104	-1.186	-1.087	-1.188
TOTAL COST	7.889	7.903	7.925	7.932	7.933	7.940	7.946	7.963	7.968	7.979
NUMBER OF LAYERS	4	4	4	4	3	4	3	3	4	3
LAYER DEPTH (INCHES)										
D(1)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(2)	6.00*	8.00*	7.00*	7.00*	8.00*	8.00*	7.00*	8.00*	7.00*	7.00*
D(3)	10.00	4.00	8.00	6.00	8.00	4.00	6.00	6.00	4.00	8.00
D(4)	10.00	10.00	8.00	4.00		4.00*			4.00*	
STRUCTURAL NUMBER	4.56	4.70	4.66	4.52	4.74	4.46	4.12	4.52	4.06	4.34
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)										
T(1)	9.9	12.1	11.4	9.4	12.7	8.6	5.1	9.4	4.6	7.2
T(2)	25.6	27.9	28.6	24.4	27.3	31.4	22.1	24.4	20.5	28.8
OVERLAY POLICY(INCH) EXCLUSIVE OF LEVEL-UP & WEAR-COURSE)										
O(1)	1.00	1.00	1.00	1.00	1.00	2.00	2.00	1.00	2.00	2.00

FIGURE 15.3 SUMMARY OF BEST OVERALL DESIGNS

SAMP6 RUN='PUBLICATION EXAMPLE, SYSTEMS APPROACH TO PAVEMENT DESIGN NCHRP 1-10A ' PAGE 14
PROB=TEST='CONSTANT COST/CU.YD NO SEPARATE WEARING SURFACE

PROBLEM SUMMARY OF THE BETTER FEASIBLE DESIGNS
IN ORDER OF INCREASING TOTAL COST

	21	22	23	24	25	26	27	28	29	30
MATERIAL ARRANGEMENT	A3SM	A3SM	A3SM	A3LM	A3SM	A3SM	A3SM	A3SM	A3CM	A3CM
INIT. CONST. COST	6.867	7.134	7.045	8.009	7.312	7.920	8.025	7.223	8.009	8.115
OVERLAY CONST. COST	1.531	1.437	1.479	0.701	1.379	0.627	0.648	1.423	0.659	0.711
USER COST	0.051	0.049	0.050	0.026	0.048	0.025	0.025	0.049	0.025	0.026
ROUTINE MAINT. COST	0.658	0.540	0.587	0.484	0.489	0.639	0.581	0.526	0.556	0.473
SALVAGE VALUE	-1.121	-1.171	-1.154	-1.202	-1.204	-1.186	-1.249	-1.188	-1.202	-1.266
TOTAL COST	7.986	7.990	8.006	8.019	8.025	8.026	8.030	8.033	8.047	8.059
NUMBER OF LAYERS	4	4	4	4	4	4	4	4	4	4
LAYER DEPTH (INCHES)										
D(1)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(2)	7.00*	7.00*	7.00*	8.00*	7.00*	8.00*	7.00*	7.00*	8.00*	7.00*
D(3)	4.00	6.00	4.00	4.00	6.00	6.00	10.00	4.00	4.00	6.00
D(4)	6.00*	4.00*	8.00*	8.00	6.00*	6.00	4.00	10.00*	6.00	6.00
STRUCTURAL NUMBER	4.14	4.28	4.22	4.62	4.36	4.76	4.72	4.30	4.70	4.60
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)										
T(1)	5.3	6.6	6.0	10.8	7.4	13.1	12.4	6.8	12.1	10.5
T(2)	22.6	26.8	25.0	27.5	29.5	26.9	27.6	27.5	27.9	26.9
OVERLAY POLICY(INCH) EXCLUSIVE OF LEVEL-UP & WEAR-COURSE)										
O(1)	2.00	2.00	2.00	1.00	2.00	1.00	1.00	2.00	1.00	1.00

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 173

FIGURE 15.3 (CONTINUED) SUMMARY OF BEST OVERALL DESIGNS

APPENDIX G

PAVEMENT FEEDBACK DATA SYSTEMS

INTRODUCTION

As is apparent from the ratings and benefit-cost ratios presented in Appendix F,* the cooperating states consider their current data systems to be inadequate for purposes of developing inputs for SAMP6, and they estimate that they would benefit considerably from developing better data systems. The purpose of this appendix is to give a short, general discussion of pavement feedback data systems and to indicate how the pilot states may proceed to develop such systems.

SAMP6 AND PAVEMENT MANAGEMENT

The SAMP6 computer program for designing flexible pavements is only a small part of an overall pavement management system. Even though, with modifications, it can be used to design overlays and to evaluate reconstruction strategies, it is only a building block for approaching pavement management. Thus, such a computer program can be regarded as an end in itself or it can be regarded as one step toward developing a comprehensive pavement management system.

Researchers have outlined how a pavement management system might be developed. Figure G-1, developed by Haas (21)* shows the principal elements of pavement management and the role of performance evaluation in a pavement management system. Using the SAMP6 computer program simply as a design tool without data feedback evaluation, a design

*Refers to main report (NCHRP Report 160).

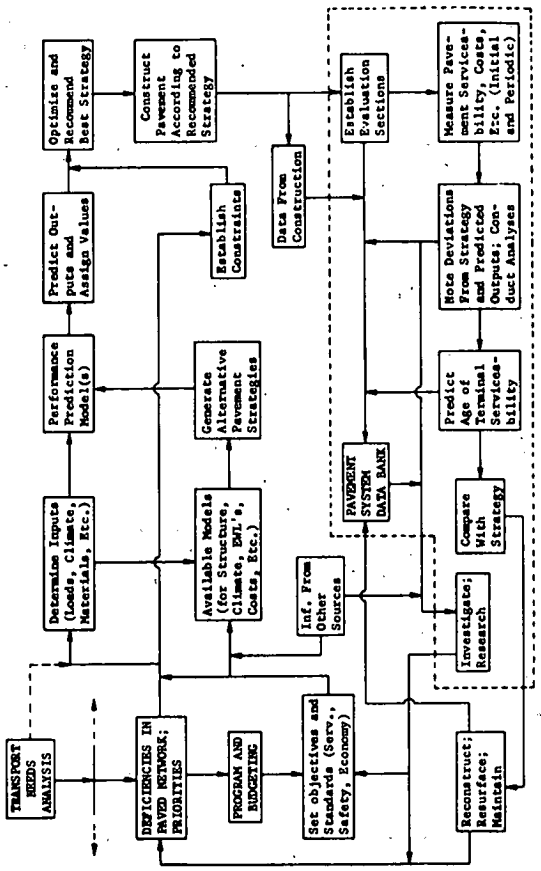


FIG. G-1 THE ROLE OF PERFORMANCE EVALUATION IN A GENERALIZED PAVEMENT MANAGEMENT SYSTEM. AFTER HAAS (21).

engineer would be concerned only with the five blocks in the upper-right side of Figure G-1. That is, he would develop inputs and then run the SAMP6 program which would predict output and performance for different designs and would also optimize and recommend the best strategies. The pavement then would be constructed according to the program recommendation. If, however, he wanted to determine how well the as-built pavement matched the SAMP6 optimum design and how well the pavement's actual performance matched the predicted performance, he would have to develop a pavement data system for collecting, storing, and analyzing information on design, construction, and performance, as outlined in the lower part of Figure G-1. Other information and decision rules regarding alternative types of activities, standards, and programming would have to be developed if the goal was to develop a comprehensive pavement management system. Thus, to develop an overall pavement management system, a state can develop an overall performance evaluation scheme. The major phases of such a scheme, outlined in Figure G-2, have been listed by Haas (21) as follows:

(1) preliminary planning, including an inventory of present practices and data collection resources (manpower and equipment), a review of other systems in use, a statement of goals and objectives as they relate to both the collection of performance data and to the user, a statement of constraints, and a preliminary estimate of costs in relation to a feasible schedule for the scheme;

(2) identification and classification of all factors (climatic, materials, load, construction, maintenance, etc.), and their interactions, that affect pavement performance or are measures of the performance achieved, and/or the

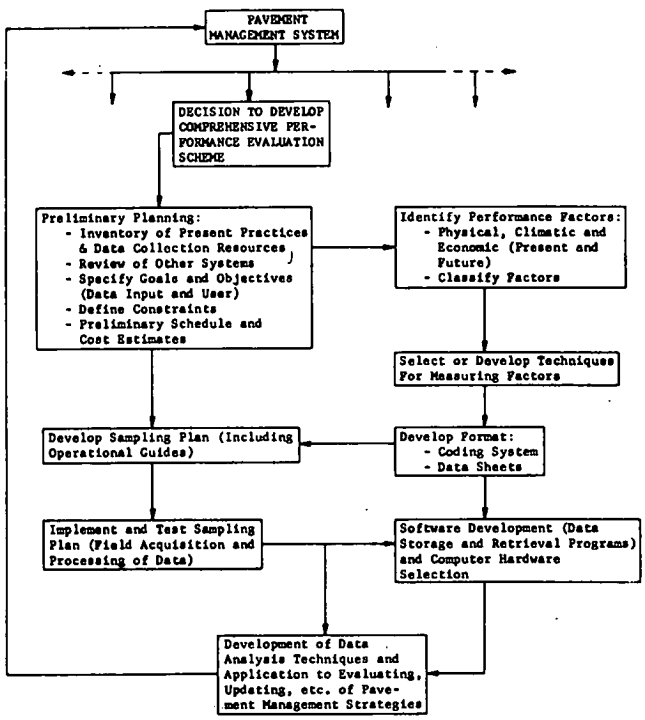


FIG. G-2 MAJOR PHASES IN DEVELOPING AND APPLYING A PAVEMENT PERFORMANCE EVALUATION SCHEME. AFTER HAAS (21).

pavement strategy adopted, which includes an initial selection of key factors (subject to future additions or deletions) based on:

(a) how many factors can be practically incorporated within the constraints of available resources, and

(b) what variables are recognized as most important by current technology;

(3) selection or development of techniques and/or units for quantitatively measuring the performance factors which, for the most part, would likely be those currently in use for measuring deflection, identifying costs, determining material properties, measuring serviceability, and so on;

(4) development of a format for the various factors, including coding sheets, etc., the design of which may be in accordance with the classification of factors, to reflect, for example, separate data files on serviceability, materials, costs, etc., and must also be in accordance with various software considerations, as shown in the Figure G-2.

(5) development of a sampling plan for acquiring data on the various evaluation segments (the assumption is made that it is not possible to obtain data on the whole network; consequently, representative evaluation segments will have to be established) which would include operational

guides or manuals for actually obtaining measurements and recording them;

(6) implementation of the sampling plan which would likely require initial testing of the plan, on a trial basis;

(7) design and implementation of the data bank itself, including primarily software development for data storage and retrieval (assuming that computer hardware requirements pose no special problems); and

(8) development of analysis techniques on stored data for:

(a) checking and updating management (including design) models,

(b) establishing sensitivity of performance factors,

(c) evaluating the effects of maintenance, and

(d) predicting terminal serviceability (or updating predictions) for programming or budgeting purposes.

PILOT STATES' DEVELOPMENT OF PAVEMENT FEEDBACK DATA SYSTEMS

As was explained in Appendix F, all three of the cooperating states believe they would benefit considerably from development of a pavement feedback data system. Also, it should perhaps be mentioned that the Texas Highway Department also has decided it would be beneficial to develop such a system and has proceeded with developing and pilot testing such a system.

Both Florida and Louisiana have developed maintenance management systems which are fully operative. These systems cover not only

pavement maintenance, but also structures, right-of-way, etc. Florida's system also has been developed to include the collection of pavement condition and ratings. Thus, Florida's maintenance management system already covers one of the most important facets of a pavement data system. Lacking in both of these systems, however, is a way of relating pavement maintenance, overlaying, and performance to the existing structure of the pavement. Also, information on traffic, loads, and environmental conditions are not collected in a way that they can easily be cross-referenced with other parts of their data system. Kansas has computerized detailed information on pavement structure, reconstruction, and overlays, and was the only one of the three states that had fully computerized such records.

Louisiana currently is evaluating different generalized data management systems and probably will purchase one of these some time in 1973 or 1974. Since it would be quite expensive to computerize all of their pavement records, Louisiana probably should begin their pavement feedback data system on a limited basis, using any pavements designed with the SAMP6 program together with their test sections for which they have complete data. This limited system would serve as a means of further evaluating and modifying SAMP6 and also for developing better SAMP6 inputs.

If Florida decides to develop a comprehensive pavement feedback data system for SAMP6, they probably should begin with a complete evaluation of their existing pavement records (e.g., following

Figure G-2) and also make a complete evaluation of existing generalized data management system (GDMS) software such as that outlined in Appendix H.

Since Kansas plans to use the SAMP6 program only as a research tool, at least in the immediate future, it would be premature to suggest that they proceed with developing a pavement feedback storage system for use with SAMP6. This is not meant to suggest, however, that it would not be possible for them to proceed with developing a pavement data system for pavement management. In fact, since much of their existing pavement data already is computerized and easily accessible, it appears that the cost to them of developing a system would be less than in the other states.

APPENDIX H

COMPUTER SOFTWARE FOR PAVEMENT FEEDBACK DATA SYSTEMS

PAVEMENT FEEDBACK DATA SYSTEM SOFTWARE

Researchers in Texas (22)* evaluated 21 different general data management systems (GDMS) for use in a pavement feedback data system. All but five were eliminated because of "...incompatability with IBM hardware or the resident operating system, or because the package was no longer being maintained." The five systems given a detailed study (attached at end of section) were:

(1) DM-1,

(2) COGENT III,

(3) MARK IV,

(4) GIS, and

(5) NIPS.

The MARK IV/260 file handling system marketed by Informatics was chosen by the Texas Highway Department, mainly to be used for handling personnel, equipment and accounting records but will be used with their PFDS. Although the THD did not evaluate the MARK IV system solely for use only with a PFDS, the cost, which exceeded $40,000, was considered justified for their overall data handling needs. One important feature considered essential for PFDS and handling of other data files was the MARK IV's "Indexed Coordinated Files," a feature that permits random (instead of sequential) access to the data base.

It should perhaps be mentioned that initial study of the five previously mentioned systems first led to the conclusion that none of the systems met

*Refers to main report (NCHRP Report 160).

all specifications for their PFDS and "a tentative conclusion was made that a best all-around answer would be to write the software package patterned after a system prepared by the Montana Highway Department."

Another feature of MARK IV found to be advantageous to PFDS in Texas is the "Extended File Processing" feature that permits simultaneous processing of nine files as compared to the basic MARK IV/260 without this feature. The conclusions of the Texas evaluation of MARK IV are that it possesses several characteristics that make its use in PFDS very promising (22).

(1) Data files are referred to by name,

(2) File record structure may be changed with little effort to insert or delete data fields. This is a powerful asset in any research endeavor.

(3) The coding forms are preprinted by the vendor and vastly simplify the use of the system.

(4) The files created by MARK IV are fully compatible with the existing (THD) operating system (OS) and are readily available for accessing by custom-written analysis routines.

If a state decides to develop a PFDS that does not have a generalized data management system, it is suggested that they carefully study the available systems since this probably would save time and money in implementing a PFDS. Many improvements have been made in generalized data management systems in the recent past. Therefore, the attached specifications and comparisons are only meant to be illustrative and are not intended as a recommendation for or against any data management system.

PFDS SPECIFICATIONS AND MACRO COMPARISON OF GDMS
(after Strom, et al., ref. 22)

Specifications for PFDS \ GDMS	DM-1	COGENT III	MARK IV	GIS	NIPS	PFDS Using ISAM + PL/1 + JCL + Utilities
MANDATORY						✓
IBM 360/50 ↓	360/50	360/40	360/30	360/40	360/40	
Operating System OS IBM	OS	OS	OS, DOS	OS	OS	✓
Cost	Auerbach Corp.	Computer Sciences Corp.	$33,000 + Informatics	IBM $400/mo.	National Defense	Free Package + Programming
Index Sequential Organization	✓	✓	✓	✓	✓	✓
Hierarchical File with Multi-level Arrangement	✓	✓	✓	✓	✓	✓
Update (add, delete, and modify)	✓	✓	✓	✓	✓	ISAM
Vendor Supplied IOCS	✓	✓	✓	✓	✓	✓
Scientific Library Subroutine Links	✓	✓	✓	✓	X	IBM Scientific Routines
DASD	✓	✓	✓	✓	✓	3336 2314

PFDS SPECIFICATIONS AND MACRO COMPARISON OF GDMS (Continued)

Specifications for PFDS \ GDMS	DM-1	COGENT III	MARK IV	GIS	NIPS	PFDS Using ISAM + PL/1 + JCL + Utilities
Procedural Language DO	#	X	✓	✓	X	Function of Command Processor of PFDS
GO TO	#	NM	X	✓	X	Function of Command Processor of PFDS
IF	#	NM	NF	✓	X	Function of Command Processor of PFDS
Mode of Computation: Floating Point	#	✓	✓	X	X	Feature of PL/1
Decimal	#	✓	✓	✓	X	Feature of PL/1
Integer	#	✓	✓	X	✓	Feature of PL/1
Operators: = ± x / EXP	#	✓	✓	✓	NM	Feature of PL/1
$\sqrt{}$ $\log_e$ Trigonometric Functions	#	#	#	X	#	Feature of PL/1
Logical and Boolean	✓	✓	✓	✓	✓	Feature of PL/1
Arithmetic Expression (number of operations per statement)	#	1	1	X	#	64
Built-in Engineering Analysis	X	X	X	X	X	Within Capability of PL/1

(Continued)

PFDS SPECIFICATIONS AND MACRO COMPARISON OF GDMS (Continued)

Specifications for PFDS \ GDMS	DM-1	COGENT III	MARK IV	GIS	NIPS	PFDS Using ISAM + PL/1 + JCL + Utilities
Levels of Nesting	∞		9	4	8	64
Temporary Hold File	✓	✓	✓	✓	NM	SYSOUT (JCL)
Update Multiple Files in One Pass	#	✓	NF	NM	X	#
Flexible Data Elements (overriding data attributes)	#	✓	X	✓	✓	Dynamic Declaration of Data Structure in Program
Data Name Directed Update	#	✓	X	X	✓	PL/1
List Directed Update	#	✓	✓	✓	✓	PL/1
Interruption and Recovery						"ON" Options of PL/1
Input Edit (error check):						
1. Maximum or Minimum Values	#	✓	✓	NM	✓	As Programmed
2. Range of Values	#	✓	✓	✓	✓	As Programmed
3. Specific Characters	#	✓	✓	✓	✓	As Programmed
4. Sequency or Identify	#	✓	✓	✓	✓	As Programmed
5. Cross Comparison	#	✓	✓	NM	✓	As Programmed

H-7

(Continued)

PFDS SPECIFICATIONS AND MACRO COMPARISON OF GDMS (Continued)

Specifications for PFDS \ GDMS	DM-1	COGENT III	MARK IV	GIS	NIPS	PFDS Using ISAM + PL/1 + JCL + Utilities
Documentation (detailed system)	NF	NF	Proprietary	✓	Not Generally Available	#
File Reorganization to Improve Efficiency	#	#	#	#	#	Read File Sequentially Onto New Storage Area Before Releasing Old Storage Area
Ease of Language Interface	Function of Chosen Language	COBOL	Difficult	Difficult	Difficult	PL/1
Missing Input Data Elements Permitted	✓	NF	X	X	NM	Feature of PL/1
Security:						
1. File	✓	✓	X	✓	✓	JCL
2. Entry, Group, Etc.	✓	✓	X	X	X	JCL
DESIRABLE						
Data Element Physical Size:						
1. Variable Length	254B		X	X	NM	255B
2. Fixed Length						
a. Numeric	254B		4B	31DD	4B	31DD
b. Alphanumeric	254B		255B	255B	255B	255B
3. Variable Name Length (max.)	#	29	7	NA		31

H-5

(Continued)

PFDS SPECIFICATIONS AND MACRO COMPARISON OF GDMS (Continued)

Specifications for PFDS \ GDMS	DM-1	COGENT III	MARK IV	GIS	NIPS	PFDS Using ISAM + PL/1 + JCL + Utilities
Decode and Encode	NF	✓	#	✓	✓	As Programmed
Subordinate File Creation from Source File	#	✓	✓	X	X	Derived from Source File from Programming
Physical Format of the Input Data to Generate a File:						
1. Must be Specific	#	NF	X	X	X	Not Necessary
2. May be Several	#	NF	✓	✓	✓	Optional
3. May be Any	#	NF	NM	✓	X	As Programmed
Pagination	#	✓	✓	✓	✓	As Programmed
Size, Title, Line, Positioning, etc.	#	✓	✓	✓	✓	As Programmed
Statistical Functions	#	NF	X	X	✓	IBM Routines
Picture Specification (input/output)	#	✓	✓	X		PL/1
Backup Capability	#					Utilities
Dynamic Storage in Programming						AUTOMATIC, CONTROLLED, BASED, ALLOCATE, and FREE

H-8

(Continued)

PFDS SPECIFICATIONS AND MACRO COMPARISON OF GDMS (Continued)

Specifications for PFDS \ GDMS	DM-1	COGENT III	MARK IV	GIS	NIPS	PFDS Using ISAM + PL/1 + JCL + Utilities
Documentation (detailed system)	NF	NF	Proprietary	✓	Not Generally Available	#
File Reorganization to Improve Efficiency	#	#	#	#	#	Read File Sequentially Onto New Storage Area Before Releasing Old Storage Area
Ease of Language Interface	Function of Chosen Language	COBOL	Difficult	Difficult	Difficult	PL/1
Missing Input Data Elements Permitted	✓	NF	X	X	NM	Feature of PL/1
Security:						
1. File	✓	✓	X	✓	✓	JCL
2. Entry, Group, Etc.	✓	✓	X	X	X	JCL
DESIRABLE						
Data Element Physical Size:						
1. Variable Length	254B		X	X	NM	255B
2. Fixed Length						
a. Numeric	254B		4B	31DD	4B	31DD
b. Alphanumeric	254B		255B	255B	255B	255B
3. Variable Name Length (max.)	#	29	7	NA		31

H-6

(Continued)

PFDS SPECIFICATIONS AND MACRO COMPARISON OF GDMS (Continued)

Specifications for PFDS \ GDMS	DM-1	COGENT III	MARK IV	GIS	NIPS	PFDS Using ISAM + PL/1 + JCL + Utilities
OPTIONAL						
Online Configuration	#	NF	X	✓	✓	THD Facility
Multiple Console/ Terminals	#	NF	X	✓	✓	THD Facility
Interactive Mode (tutorial)	#	NF	X	X	X	As Programmed
Erase	#	NF	X	QTAM	X	Optional
User Priorities	#	NF	X	QTAM	X	JCL
Background Processing	#	NF	X	QTAM	X	OS
System Tallies (keeping track)	#	NF	✓	✓	✓	OS
Sorting Capability	#	✓	✓	✓	✓	Utilities

Legend

✓ Yes, compatible

X No

Need to implement

NM Need modification

NF Not firm