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16. Abstract

The effects of using the full pavement cross-section and a quantity-discount on the cost of the construction materials in the Texas Flexible Pavement Design System (FPS) are evaluated in this study. Including the shoulders in the pavement cross-section and the discounted materials cost does change the selection of the optimal design strategy of new construction. A fairly general pavement cross-section model and four quantity-discount cost models have been integrated into the FPS computer program for use by the State Department of Highways and Public Transportation. In addition, a master pavement cross-section model (MPCS) has been devised and coded to calculate the area of any complicated pavement cross-section. The MPCS model provides the information to determine the minimum data requirement to precisely describe an in-service pavement cross-section for use in the pavement feedback data system.

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OPTIMAL FLEXIBLE PAVEMENT CROSS-SECTION DESIGN USING QUANTITY-DISCOUNT COST MODEL

by

Danny Y. Lu
Robert L. Lytton
Chester H. Michalak

Research Report Number 123-28

A System Analysis of Pavement Design and Research Implementation

Research Project 1-8-69-123

conducted for

State Department of Highways and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

Highway Design Division
State Department of Highways and Public Transportation

Texas Transportation Institute
Texas A&M University

Center for Highway Research
The University of Texas at Austin

June 1975

PREFACE

This report is one of a series issued under Research Study 1-8-69-123, "A Systems Analysis of Pavement Design and Research Implementation". This study is being conducted jointly by principal investigators and their staffs in three agencies -- The State Department of Highways and Public Transportation at Austin, The Center for Highway Research at Austin, and The Texas Transportation Institute at College Station, as a part of the cooperative research program with the Department of Transportation, Federal Highway Administration.

DISCLAIMER

ACKNOWLEDGMENT

Special appreciation is extended to Mr. James L. Brown of the State Department of Highways and Public Transportation for helpful discussions. The cooperation and assistance given by many individuals in the Texas Transportation Institute are sincerely appreciated. Mr. D. L. Schafer was particularly helpful throughout this research effort.

LIST OF REPORTS

Report No. 123-1, "A Systems Approach Applied to Pavement Design and Research", by W. Ronald Hudson, B. Frank McCullough, F. H. Scrivner, and James L. Brown, describes a long-range comprehensive research program to develop a pavement systems analysis and presents a working systems model for the design of flexible pavements.

Report No. 123-2, "A Recommended Texas Highway Department Pavement Design System Users Manual", by James L. Brown, Larry J. Buttler, and Hugo E. Orellana, is a manual of instructions to Texas Highway Department personnel for obtaining and processing data for flexible pavement design system.

Report No. 123-3, "Characterization of the Swelling Clay Parameter Used in the Pavement Design System" by Arthur W. Witt, III, and B. Frank McCullough, describes the results of a study of the swelling clay parameter used in pavement design system.

Report No. 123-4, "Developing A Pavement Feedback Data System", by R.C.G. Haas, describes the initial planning and development of a pavement feedback data system.

Report No. 123-5, "A Systems Analysis of Rigid Pavement Design", by Ramesh K. Kher, W. R. Hudson, and B. F. McCullough, describes the development of a working systems model for the design of rigid pavements.

Report No. 123-6, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections", by F. H. Scrivner, C. H. Michalak, and William M. Moore, describes a computer program which will serve as a subsystem of a future Flexible Pavement System founded on linear elastic theory.

Report No. 123-6A, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections, Part II", by Frank H. Scrivner, Chester H. Michalak, and William M. Moore, is a supplement to Report No. 123-6 and describes the effect of a change in the specified location of one of the deflection points.

Report No. 123-7, "Annual Report on Important 1970-71 Pavement Research Needs", by B. Frank McCullough, James L. Brown, W. Ronald Hudson, and F. H. Scrivner, describes a list of priority research items based on findings from use of the pavement design system.

Report No. 123-8, "A Sensitivity Analysis of Flexible Pavement System FPS2", by Ramesh K. Kher, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this system, the relative importance of the variables of the system and recommendations for efficient use of the computer program.

Report No. 123-9, "Skid Resistance Considerations in the Flexible Pavement Design System", by David C. Steitle and B. Frank McCullough, describes skid resistance consideration in the Flexible Pavement System based on the testing of aggregates in the laboratory to predict field performance and presents a nomograph for the field engineer to use to eliminate aggregates which would not provide adequate skid resistance performance, April 1972.

Report No. 123-10, "Flexible Pavement System - Second Generation, Incorporating Fatigue and Stochastic Concepts", by Surendra Prakash Jain, B. Frank McCullough, and W. Ronald Hudson, describes the development of new structural design models for the design of flexible pavement which will replace the empirical relationship used at present in flexible pavement systems to simulate the transformation between the input variables and performance of a pavement, January 1972.

Report No. 123-11, "Flexible Pavement System Computer Program Documentation", by Dale L. Schafer, provides documentation and an easily updated documentation system for the computer program FPS-9.

Report No. 123-12, "A Pavement Feedback Data System", by Oren G. Strom, W. Ronald Hudson, and James L. Brown, defines a data system to acquire, store, and analyze performance feedback data from in-service flexible pavements, May 1972.

Report No. 123-13, "Benefit Analysis for Pavement Design System", by W. Frank McFarland, present a method for relating motorist's cost to the pavement serviceability index and a discussion of several different methods of economic analysis, April 1972.

Report No. 123-14, "Prediction of Low-Temperature and Thermal-Fatigue Cracking in Flexible Pavements", by Mohamed Y. Shahin and B. Frank McCullough, describes a design system for predicting temperature cracking in asphalt concrete surfaces, August 1972.

Report No. 123-15, "FPS-11 Flexible Pavement System Computer Program Documentation", by Hugo E. Orellana, gives the documentation of the computer program FPS-11, October 1972.

Report No. 123-16, "Fatigue and Stress Analysis Concepts for Modifying the Rigid Pavement Design System", by Piti Yimprasert and B. Frank McCullough, describes the fatigue of concrete and stress analyses of rigid pavement, October 1972.

Report No. 123-17, "The Optimization of a Flexible Pavement System Using Linear Elasticity", by Danny Y. Lu, Chia Shun Shih and Frank H. Scrivner, describes the integration of the current Flexible Pavement System computer program and Shell Oil Company's program BISTRO, for elastic layered systems, with special emphasis on economy of computation and evaluation of structural feasibility of materials, March 1973.

Report No. 123-18, "Probabilistic Design Concepts Applied to Flexible Pavement System Design", by Michael I. Darter and W. Ronald Hudson, describes the development and implementation of the probabilistic design approach and its incorporation into the Texas flexible pavement design system for new construction and asphalt concrete overlay, May 1973.

Report No. 123-19, "The Use of Condition Surveys, Profile Studies, and Maintenance Studies in Relating Pavement Distress to Pavement Performance", by Robert P. Smith and B. Frank McCullough, introduces the area of relating pavement distress to pavement performance, presents work accomplished in this area and gives recommendations for future research, August 1973.

Report No. 123-20, "Implementation of a Complex Research Development of Flexible Pavement Design System into Texas Highway Department Design Operations", by Larry Buttler and Hugo Orellana, describes the step by step process used in incorporating the implementation research into the actual working operation.

Report No. 123-21, "Rigid Pavement Design System, Input Guide for Program RPS2 in Use by the Texas Highway Department", by R. Frank Carmichael and B. Frank McCullough, describes the input of variables necessary to use in the Texas rigid pavement design system program RPS2, January 1974.

Report No. 123-22, "An Integrated Pavement Design Processor", by Danny Y. Lu, Chia Shun Shih, Frank H. Scrivner and Robert L. Lytton, provides a comprehensive decision framework with a capacity to drive different pavement design programs at the user's command through interactive queries between the computer and the design engineer.

Report No. 123-23, "Stochastic Design Parameters and Lack-of-Fit of Performance Model in the Texas Flexible Pavement Design System", by Malvin Holsen and W. Ronald Hudson, describes a study of initial serviceability index of flexible pavements and a method for quantifying lack-of-fit of the performance equation.

Report No. 123-24, "The Effect of Varying the Modulus and Thickness of Asphaltic Concrete Surfacing Materials", by Danny Y. Lu and Frank H. Scrivner, investigates the effect on the principal stresses and strains in asphaltic concrete resulting from varying the thickness and modulus of that material when used as the surfacing of a typical flexible pavement.

Report No. 123-25, "Elastic Layer Theory as a Model of Displacements Measured Within Flexible Pavement Structures Loaded by the Dynaflect", by Frank H. Scrivner et al, describes the fitting of an empirical model to the study of 136 (TTI) data.

Report No. 123-26, "Modification and Implementation of the Rigid Pavement Design System", by Robert F. Carmichael and B. Frank McCullough, describes the new RPS-3 version of the rigid pavement design system in detail and complete with an input guide, documentation, and listing.

Report No. 123-28, "Optimal Flexible Pavement Cross-Section Design Using Quantity-Discount Cost Model", by Danny Y. Lu, Robert L. Lytton and Chester H. Michalak, describes the development of a fairly general pavement cross-section model and quantity-discount cost models and the integration of these models into the Flexible Pavement Design System.

ABSTRACT

The effects of using the full pavement cross-section and a quantity-discount on the cost of the construction materials in the Texas Flexible Pavement Design System (FPS) are evaluated in this study. Including the shoulders in the pavement cross-section and the discounted materials cost does change the selection of the optimal design strategy of new construction. However, the effects are insignificant in overlay construction. A fairly general pavement cross-section model and four quantity-discount cost models have been integrated into the FPS computer program for use by the State Department of Highways and Public Transportation. In addition, a master pavement cross-section model (MPCS) has been devised and coded to calculate the area of any complicated pavement cross-section. The MPCS model provides the information to determine the minimum data requirement to precisely describe an in-service pavement cross-section for use in the pavement feedback data system.

Key Words: Computer program, cross section, flexible pavements, optimal design strategy, quantity discount, systems analysis.

SUMMARY

Purpose

The principal purpose of this study is to develop a fairly general pavement cross-section model and several typical quantity-discount cost models, and integrate these models into the Texas Flexible Pavement Design System (FPS). Also included in this report is the development of a master pavement cross-section model which is capable of calculating cross-sectional areas for any cross-section.

Pavement Cross-Section Model

A fairly general pavement cross-section model has been developed. Input data for this model are: (1) widths of pavement, shoulders and road sides; (2) thicknesses of pavement layers, shoulder layers, fill material, overlay material and upgrade material and (3) side slopes. The model calculates the volumes of each of the pavement, shoulder, fill, overlay and upgrade materials layers per unit length along the pavement centerline direction. This model has 36 versatile features.

Quantity-Discount Cost Model

Construction material discounts are often offered for the purchase of larger quantities. Four discount models of unit construction material cost have been developed: constant cost, log-log relation of cost to layer thickness, log-arithmetic, and linear. Usage of the quantity-discount model can be divided into two stages. In the first stage, unit costs at maximum and minimum thickness are input to the model. These data are used to calculate two parameters representing the relation between cost and layer thickness. Once these two parameters have been calculated, a specific thickness can be used in the second stage to calculate the discounted unit cost at that thickness.

Modified FPS Cost Model

Cost models used in previous FPS programs have been extensively modified due to the inclusion of the full pavement cross-section model. Additions to calculations of the initial construction cost are shoulder costs and fill material costs. Costs of subbase extensions under shoulders are also included. Added to the overlay construction cost are costs of overlay extensions over the shoulders and the material costs of upgrading materials. Maintenance of the shoulder surface is included in the calculation of the routine maintenance cost. The rates of production of both overlay and upgrading materials are used to calculate the traffic delays during an overlay construction period during which excessive traffic delays result in higher user's cost. At the end of the analysis cycle, the salvage value of the pavement is estimated based on the residual worth of the pavement, shoulder, fill, overlay and upgrading materials.

Findings

Significant findings are: (1) the inclusion of shoulders, subbase extensions under shoulder and fill materials in the estimation of initial construction costs may alter the optimal design strategy that is selected; (2) the optimal design strategy selected for new construction may not be the same when costs are computed by the constant unit cost and by a quantity-discount unit material cost model; (3) neither overlay extensions over shoulders nor upgrading materials nor the use of the quantity-discount of unit cost models have any noticeable effects on the final selection of an optimal overlay design strategy and (4) the potential savings in construction cost from using the full-cross section and quantity-discount models in selecting pavement designs for new construction warrants its implementation in FPS.

Master Pavement Cross-Section Model

Separately from the FPS program, a master pavement cross-section model has been devised to calculate each specific area of any complicated pavement cross-section. Input data for this model are known slopes of lines, known coordinates of points, known thicknesses of layers and point numbers of bounded areas. This model is essentially a set of simultaneous linear algebraic equations. The model provides the minimum data requirement to precisely describe an in-service pavement cross-section for use in the pavement feedback data system.

Conclusions

The simple pavement cross-section model and the linear quantity-discount cost model, which have been integrated into the FPS computer program, are recommended for use by the State Department of Highways and Public Transportation. The master pavement cross-section model will assist the development of the pavement feedback data system in the description of the pavement cross-section, and should eventually be incorporated into FPS for determining the optimum strategy for reconstructed and widened pavements.

IMPLEMENTATION STATEMENT

This report presents evidence to show that consideration of the quantity of materials in the full pavement cross-section and the decrease of construction material costs with increasing quantities will affect the selection and total cost of the optimal design strategy in the State Department of Highways and Public Transportation's Flexible Pavement Design System (FPS). A new version of the FPS computer program, FPS-13-TTI, has been developed in this study and is recommended for immediate implementation. Changes in FPS-13-TTI as compared to FPS-11 are additions of a fairly general pavement cross-section model and four quantity-discount cost models.

In addition, a master pavement cross-section model (MPCS) has been developed in this study to calculate the area of any complicated cross-section whenever it becomes necessary to know the precise material requirements of the optimal design strategy resulting from the FPS-13-TTI. The MPCS program is ready for immediate implementation too. The MPCS model can also be utilized to determine the minimum data storage requirement of in-service pavement cross-sections for use in the pavement feedback data system.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

The Texas Flexible Pavement Design System (FPS) (1) is a comprehensive decision and analysis framework for the design and management of pavement construction and rehabilitation. The FPS provides from available materials the optimal design strategy of a pavement that can be maintained above a specific level of serviceability over a specified period of time, at the minimum overall cost. Cost variables considered in the FPS are: initial construction cost, routine maintenance cost, overlay construction cost, user's cost due to traffic delays during the overlay construction period and salvage value.

However, previous FPS versions did not include a full pavement cross-section for the estimation of construction costs. Shoulder costs were assumed proportional to pavement costs. In addition, the unit cost of construction materials was assumed independent of the material quantities used for construction. Specific objectives of this study are: (1) to develop a full pavement cross-section model and different quantity-discount cost models for use in FPS, (2) to integrate these models into the current FPS version (2), (3) using the new FPS version to solve typical design problems in order to evaluate the effects of the full pavement cross-section model and quantity-discount cost models in the determination of optimal design strategies and (4) to devise a master pavement cross-section model which can be utilized to describe any pavement type.

CHAPTER II

PAVEMENT CROSS-SECTION MODEL

A fairly general pavement cross-section model has been developed for FPS. The sketch in Figure 1 represents a pavement cross-section composed of n pavement layers above the subgrade level, two shoulder layers, and m overlays above the initial construction surface. Pavement and shoulder layers are numbered consecutively from the top downward; thus, pavement layers 1 and n+1 are respectively the pavement surface and foundation; shoulder layers 1 and 2 are respectively the shoulder surface and base. This cross-section model is limited to at most two shoulder layers. Thickness of pavement layer i is represented by D_i; thickness of shoulder surface and base are represented respectively by S_1 and S_2. A number, N, is defined as the number of top pavement layers equivalent to total shoulders in thickness, such that

$$S_1 + S_2 = \sum_{i=1}^{N} D_i$$

In Figure 1, N=2. The thickness of the fill material equals the thickness of the top N pavement layers, i.e., the sum of two shoulder layer thicknesses. The subgrade material is considered to be of infinite thickness. Overlays are numbered consecutively from the initial construction surface upward. The thickness of the i^{th} overlay (excluding level-up) and the i^{th} level-up are represented, respectively, by O_i and U_i.

The width of the riding surface is represented by W. The widths of the left and right shoulders are represented respectively by X_2 and X_3 and the cross-section widths outside of the left and right shoulders are represented respectively by X_1 and X_4. The widths of W_1 and W_2 are defined as follows:

$$W_1 = W + X_2 + X_3$$

$$W_2 = W_1 + X_1 + X_4$$

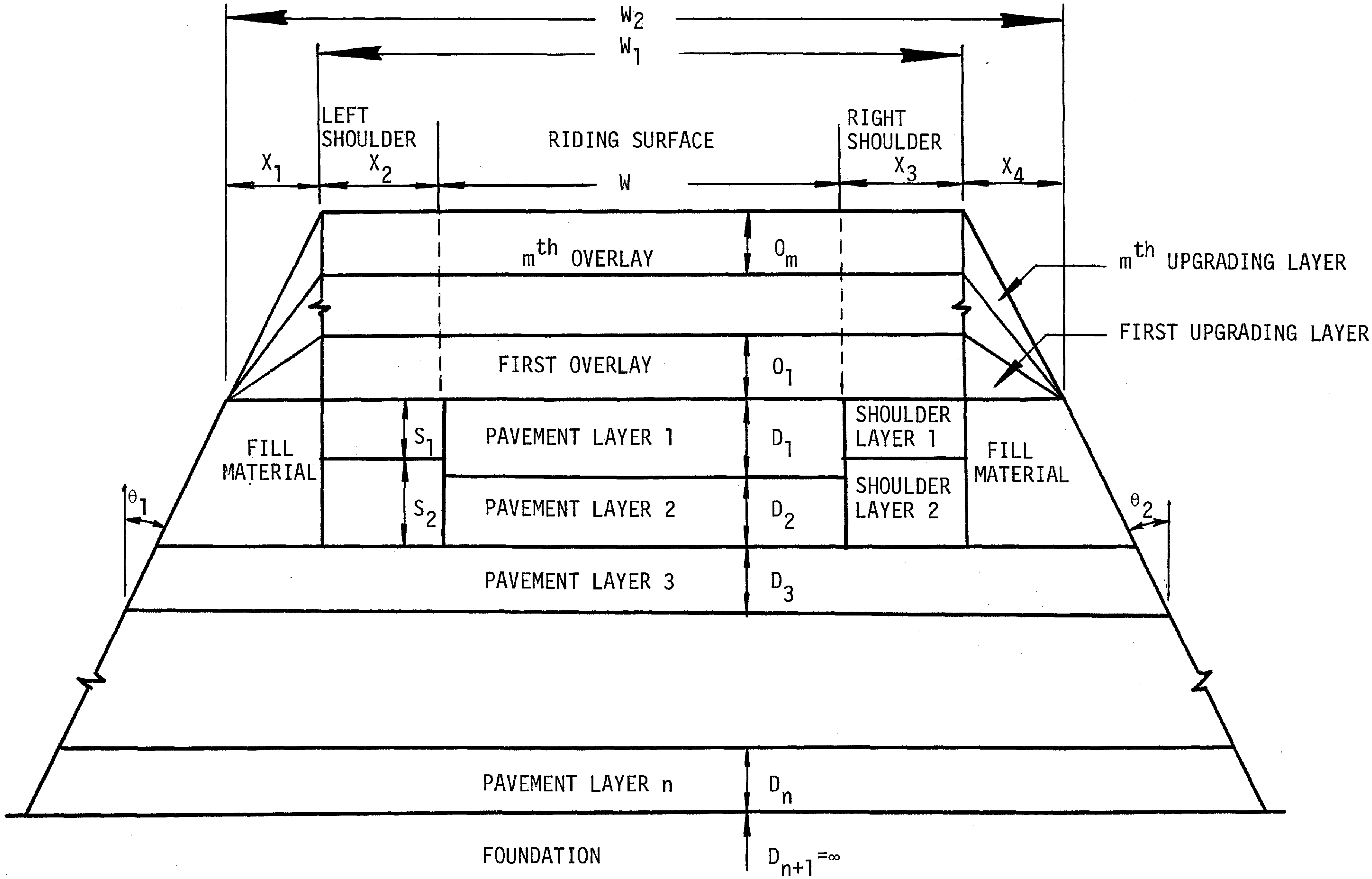


Figure 1. Pavement cross-section model

Side slopes are represented by k_1 and k_2, where $k_1 = \tan\theta_1$ and $k_2 = \tan\theta_2$. In construction practice, and in the input to the FPS-13-TTI program these slopes are designated by the ratio of run to rise (e.g., 3 to 1 slope).

The volumes of pavement and shoulder layers and fill materials per unit distance down the centerline are calculated by

$$V_{pi} = D_i W \qquad \text{if } 1 \le i \le N$$

$$= D_i[W_2 + (k_1 + k_2)(\sum_{j=1}^{i} D_j - \frac{D_i}{2})] \qquad \text{if } N < i \le n$$

$$V_{s1} = S_1(X_2 + X_3)$$

$$V_{s2} = (\sum_{i=1}^{N} D_i - S_1)(X_2 + X_3)$$

$$V_f = (\sum_{i=1}^{N} D_i)[(X_1 + X_4) + \frac{1}{2}(k_1 + k_2)\sum_{i=1}^{N} D_i]$$

in which

V_{pi} = volume of pavement layer i material,

V_{si} = volume of shoulder layer i material,

V_f = volume of fill material.

When this cross-section model is utilized in FPS, W, X_1, X_2, X_3, X_4, k_1, k_2, S_1, and N are input variables; while n, D_i(i = 1, 2, , n), and S_2 are decision variables. Some adjustments are required in using these equations in FPS. For example, when N>n, the input value of N is assigned the value of n. Also, when $S_1 > \sum_{i=1}^{N} D_i$, the input value of S_1 is replaced by the value of $\sum_{i=1}^{N} D_i$. In this case, $S_2 = 0$, i.e., there is only one shoulder layer.

For each overlay construction the volumes of overlay and upgrading materials per unit distance along the centerline can be determined by

$$V_{oi} = W_1(O_i + U_i)$$

$$V_{\mu i} = \frac{1}{2}(X_1 + X_4)(O_i + U_i)$$

$$V'_{oi} = W_1 O_i$$

$$V'_{\mu i} = \frac{1}{2}(X_1 + X_4)O_i$$

in which

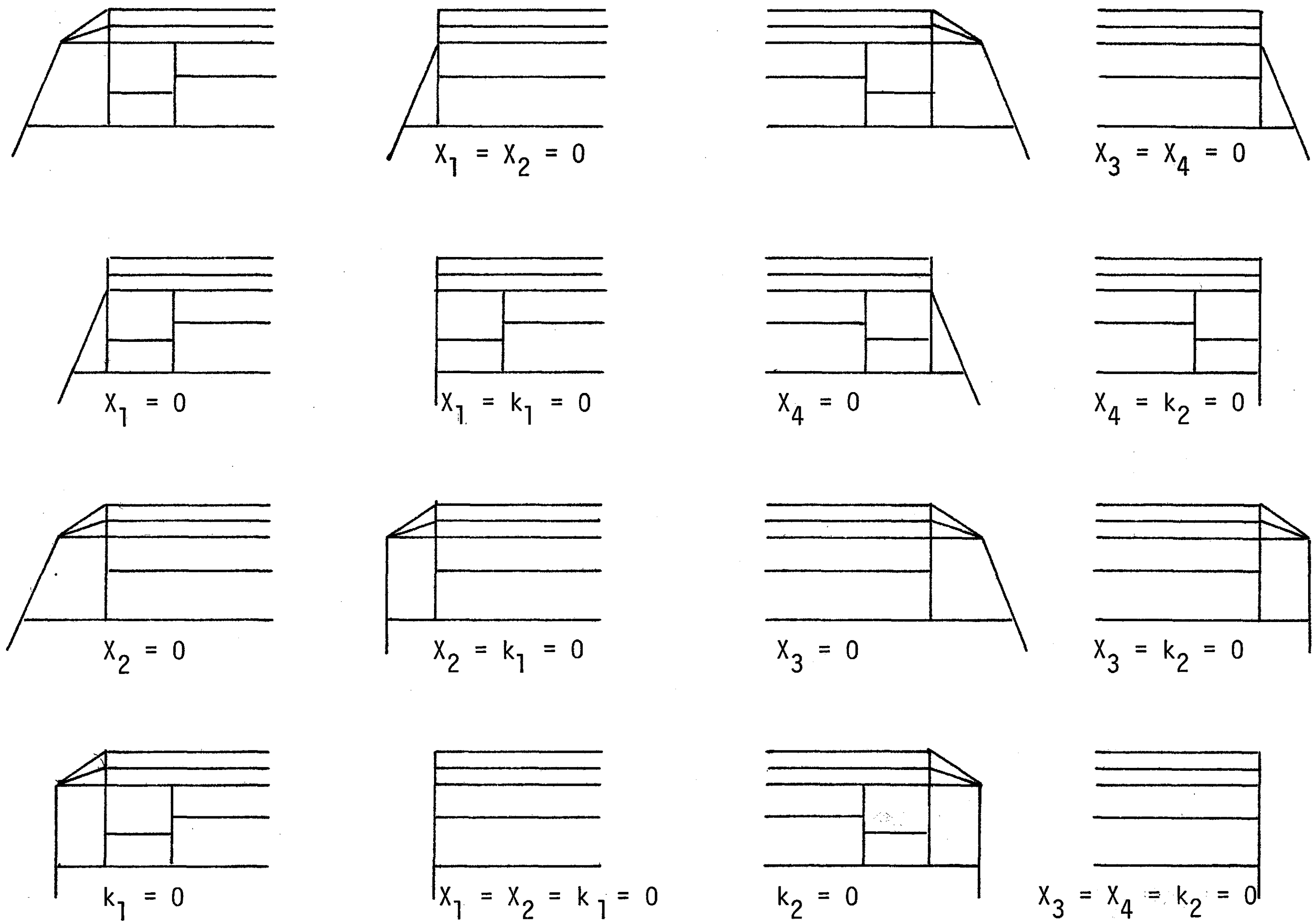
V_{oi} = required overlay material volume for the construction of the i^{th} overlay

$V_{\mu i}$ = required upgrading material volume for the i^{th} overlay

V'_{oi} = overlay material volume for the i^{th} overlay, excluding level-up

$V'_{\mu i}$ = upgrading material volume for the i^{th} overlay, excluding level-up

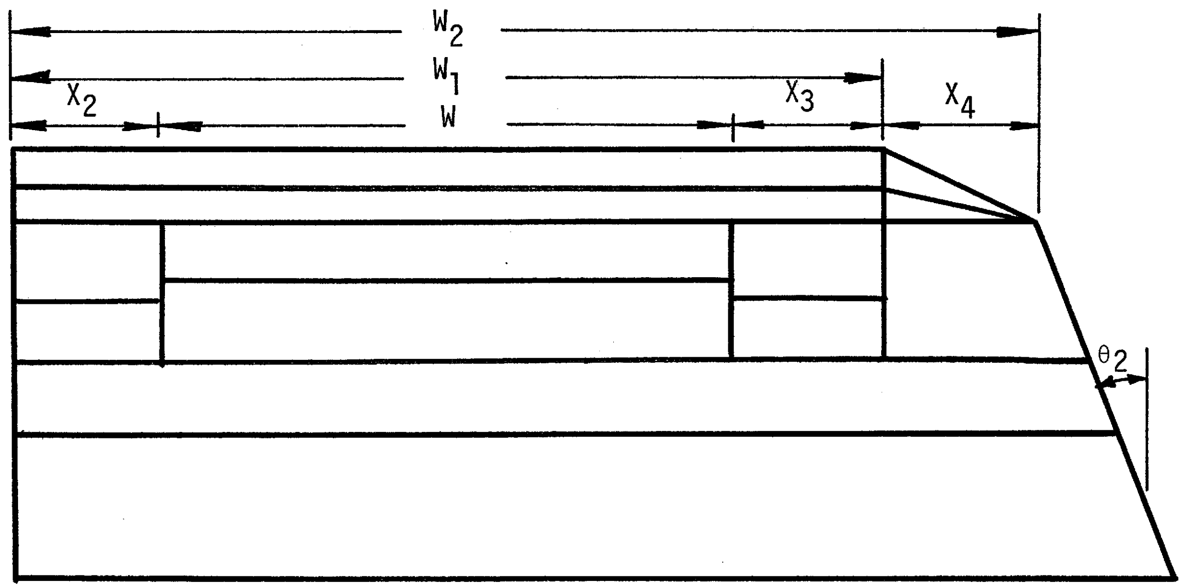
Versatile features of this cross-section model are illustrated in Figure 2. Any of the eight cross-section designs for the left side of the pavement as shown in Figure 2(a) can be combined with any of the eight right side cross-section designs as shown in Figure 2(b) to form a full cross-section. There are a total of 36 different combinations of the right- and left-side cross-sections rather than the 64 combinations because 28 out of the 64 possible combinations are essentially duplicates. Some example combinations are illustrated in Figure 3.



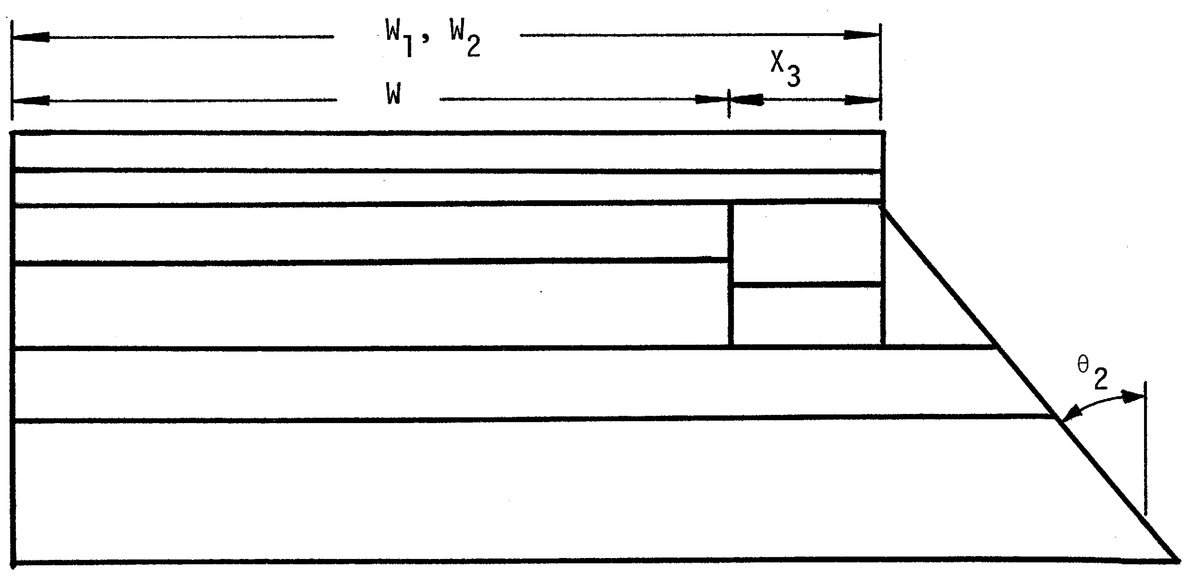
(a) Left side cross-section

(b) Right side cross-section

Figure 2. Versatility of the pavement cross-section



$X_1 = k_1 = 0$



$X_1 = X_2 = X_4 = k_1 = 0$

Figure 3. Typical pavement cross-sections

CHAPTER III

QUANTITY-DISCOUNT COST MODEL

In construction, it is usually the case that the unit cost of a material depends on the quantity procured. Often, discounts are offered for the purchase of larger quantities. A constant cost model and three quantity-discount models are investigated in this study to examine how quantity-discounts will affect the selection of an optimal design strategy by FPS.

Figure 4 shows four unit cost models. (a) is the constant cost model with no discount. (b), (c) and (d) are respectively the linear, log-normal and log-log discount models. Given the unit material costs, C_1 and C_2, corresponding to material quantities Q_2 and Q_1 where $C_1 \leq C_2$ and $Q_1 \leq Q_2$, then the unit cost, C, at a specific quantity, Q, is calculated by the following equations:

(a) No discount,

$$C = C_1 = C_2$$

(b) Linear discount,

$$C = C_1 + \left(\frac{C_2-C_1}{Q_2-Q_1}\right)(Q_2-Q)$$

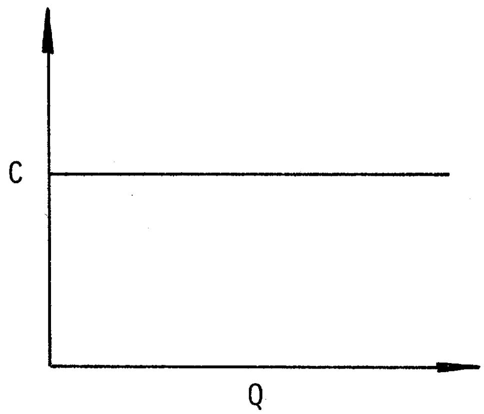
(c) Log-normal discount

$$C = C_1\left(\frac{C_2}{C_1}\right)^{\frac{Q_2-Q}{Q_2-Q_1}}$$

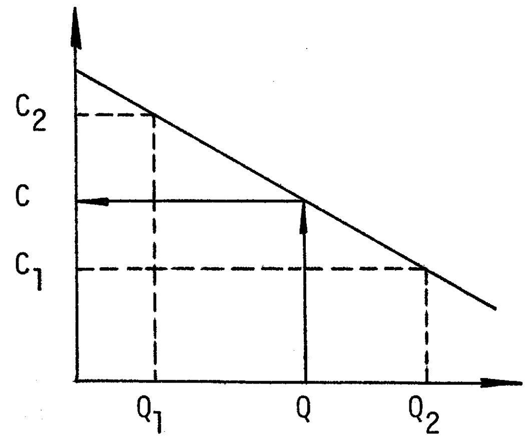
(d) Log-log discount,

$$C = C_1\left(\frac{Q_2}{Q}\right)^{\frac{\ln(C_2/C_1)}{\ln(Q_2/Q_1)}}$$

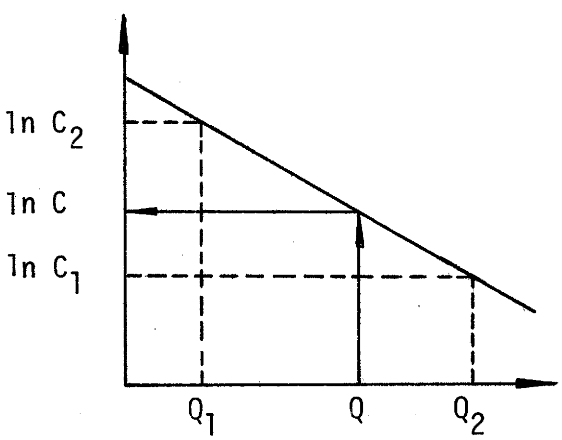
where C_1, Q_1, and $Q \neq 0$, and $Q_1 \neq Q_2$. For use in FPS, these equations are rewritten as follows:



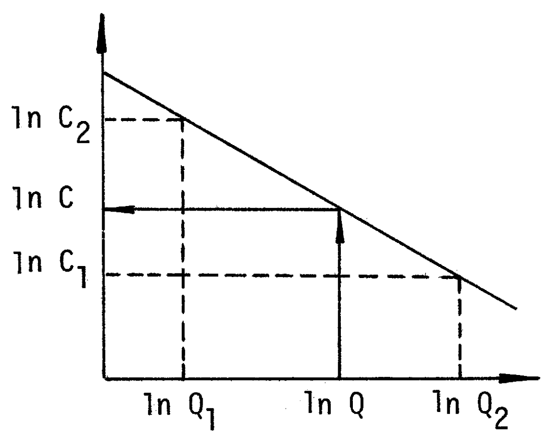
(a) constant cost, no discount



(b) linear discount



(c) log-normal discount



(d) log-log discount

Figure 4. Unit cost versus quantity procured

(a) No discount,

$$C = a_1, \text{ where } a_1 = \frac{1}{2}(C_1 + C_2)$$

(b) Linear discount

$$C = a_1 - a_2Q, \text{ where}$$

$$a_1 = C_1 + a_2Q_2, \text{ and}$$

$$a_2 = \frac{C_2 - C_1}{Q_2 - Q_1}$$

(c) Log-normal discount

$$C = a_1/a_2^{Q}, \text{ where}$$

$$a_1 = C_1a_2^{Q2}, \text{ and}$$

$$a_2 = \left(\frac{C_2}{C_1}\right)^{\frac{1}{Q_2-Q_1}}$$

(d) Log-log discount

$$C = a_1Q^{-a_2}, \text{ where}$$

$$a_1 = C_1Q_2^{a_2}, \text{ and}$$

$$a_2 = \frac{\ln(C_2/C_1)}{\ln(Q_2/Q_1)}$$

These equations are not valid if $C_1=0$, $C_2=0$, $Q_1=0$, $Q_2=0$, or $Q=0$. When $Q_1=Q_2$, these equations can be used by setting $a_2=0$ for linear and log-log discounts and $a_2=1$ for a log-normal discount. When $C_1=C_2$, no adjustment is required to use these equations. The following example will illustrate the use of these models. Let $Q_1=4$ units, $Q_2=10$ units, $C_1=\$5$/unit, and $C_2=\$6$/unit, then

$$
\begin{aligned}
c &= 5.50 && \text{no discount,} \\
&= 6.667 - 0.1667Q && \text{linear discount,} \\
&= 6.7755\ (0.9701)^{Q} && \text{log-normal discount,} \\
&= 7.9058Q^{-0.1990} && \text{log-log discount}
\end{aligned}
$$

This is shown in Figure 5. It is noted that the unit cost by the log-log model $\leq$ unit cost by log-normal model $\leq$ unit cost by linear model.

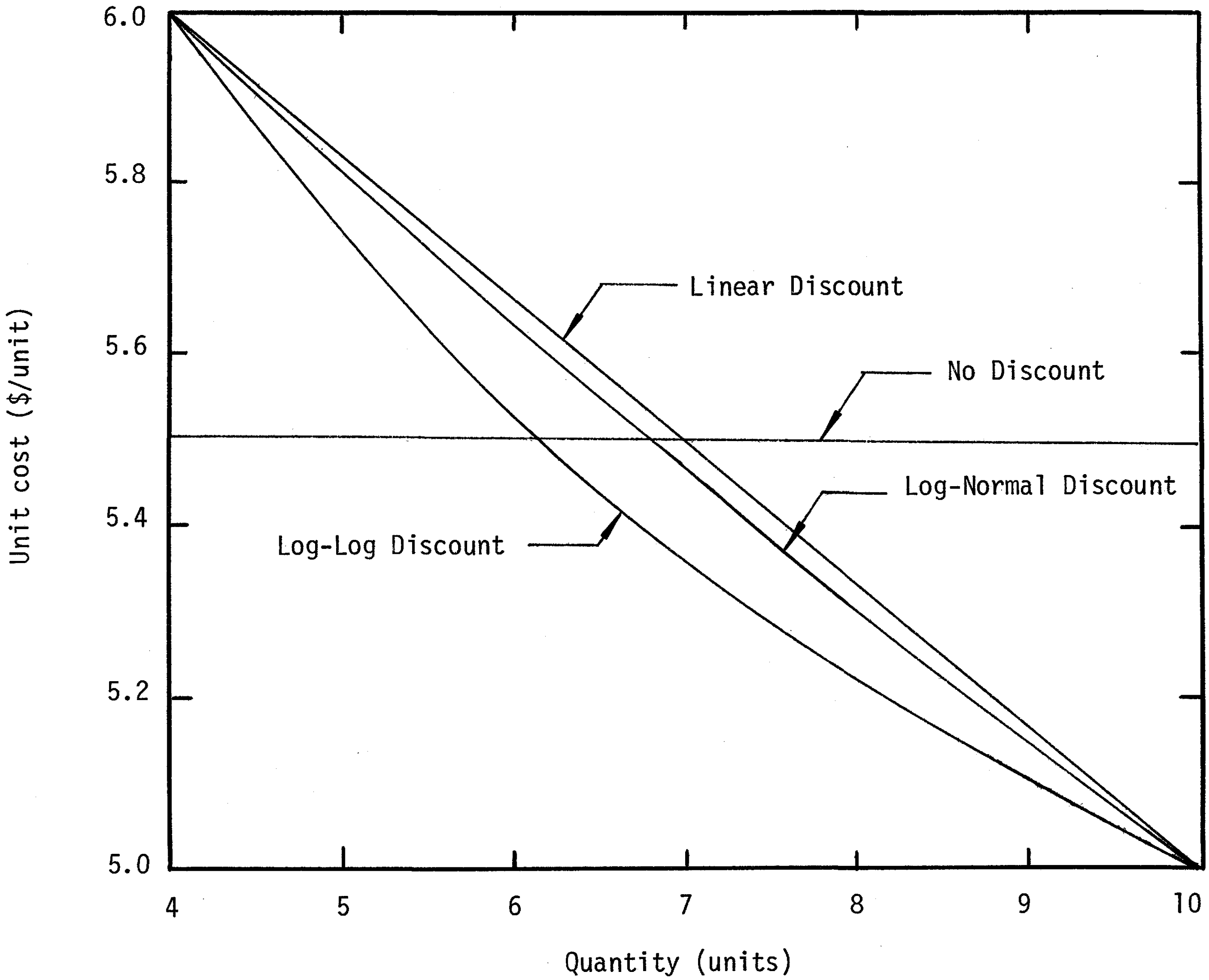


Figure 5. Various unit costs by quantity discounts

CHAPTER IV

ECONOMIC EVALUATION IN SYSTEMS ANALYSIS

Cost models used in previous FPS versions are extensively modified to include the full pavement cross-section model.

Initial Construction Cost

The initial pavement construction cost per unit area of riding surface, C_I, is the sum of: the cost of such materials in the pavement layers, shoulder layers and fill materials; that is,

$$C_I = \frac{1}{W}\left[\sum_{i=1}^{n} V_{pi}C_{pi} + \sum_{i=1}^{2} V_{si}C_{si} + V_f C_f\right]$$

where

C_{pi} = unit material cost of pavement layer i,

C_{si} = unit material cost of shoulder layer i,

C_f = unit material cost of fill material.

Overlay Construction Cost

The present worth of overlay construction cost per unit area of riding surface, C_v, includes the overlay and upgrading material costs; that is,

$$C_v = \frac{1}{W} \sum_{i=1}^{m} \left[\frac{V_{oi}C_o + V_{\mu i}C_\mu}{(1+r)^{t_i}} \right]$$

where

m = number of overlays placed during an analysis period,

C_o = unit cost of overlay material,

C_μ = unit cost of upgrade material,

r = annual interest rate,

t_i = time of the i^{th} overlay after initial construction, (t_0=0).

Routine Maintenance Cost

The cost of annual routine maintenance during each year after initial construction or after an overlay has been placed is assumed to increase at a uniform rate. The present worth of total routine maintenance cost per unit area of riding surface, C_M, is calculated by

$$C_M = \frac{W_1}{W} \left\{ \sum_{i=1}^{m} \frac{1}{(1+r)^{t_{i-1}}} \left[\sum_{j=1}^{t_i - t_{i-1}} \frac{C_1+(j-1)C_2}{(1+r)^{j-1}} \right] \right\}$$

where

C_1 = routine maintenance cost during the first year after initial or overlay construction,

C_2 = annual incremental increase in routine maintenance cost.

User's Cost Due to Traffic Delays

The total present worth of user's cost per unit area of riding surface due to traffic delays during the construction of an overlay C_D is calculated by

$$C_D = \frac{1}{W} \sum_{i=1}^{m} \frac{N_{vi}}{(1+r)^{t_i}} \left\{ \left(\frac{CD_o V_{oi}}{PR_o} + \frac{CD_\mu V_{\mu i}}{PR_\mu} \right) \right.$$

$$\left[P_{01}(C_{01}+C_{02}+C_{03}) + (1-P_{01})(C_{03}+C_{04}) + P_{02}C_{05} \right.$$

$$\left. \left. + P_{N1}(C_{N1}+C_{N2}+C_{N3}) + (1-P_{N1})(C_{N3}+C_{N4}) + P_{N2}C_{N5} \right] \right\}$$

where

N_{vi} = number of arriving vehicles per hour from each direction during the construction of the i^{th} overlay

CD_o = compacted density of overlay material,

CD_μ = compacted density of upgrade material,

PR_o = production rate of overlay material,

PR_{μ} = production rate of upgrade material,

P_{01} = proportion of traffic stopped because of congestion in overlay direction,

P_{N1} = proportion of traffic stopped because of congestion in non-overlay direction,

P_{02} = proportion of traffic stopped due to overlay personnel and equipment in overlay direction,

P_{N2} = proportion of traffic stopped due to overlay personnel and equipment in non-overlay direction,

C_{01} = excess costs of stopping from highway speeds in overlay direction,

C_{N1} = excess costs of stopping from highway speeds in non-overlay direction,

C_{02} = excess costs of vehicle idling time while stopped in overlay direction

C_{N2} = excess costs of vehicle idling time while stopped in non-overlay direction,

C_{03} = excess costs for reduced speed in overlay direction

C_{N3} = excess costs for reduced speed in non-overlay direction

C_{04} = excess costs of changing speed in overlay direction

C_{N4} = excess costs of changing speed in non-overlay direction

C_{05} = excess costs due to delays from overlay personnel and equipment in overlay direction

C_{N5} = excess costs due to delays from overlay personnel and equipment in non-overlay direction

Salvage Value

The present worth of total salvage value per unit area of riding surface, S_g, is calculated as follows:

$$S_g = \frac{1}{W}\left\{\sum_{i=1}^{n} V_{pi}C_{pi}P_{pi} + \sum_{i=1}^{2} V_{si}C_{si}P_{si} + V_f C_f P_f + \frac{\sum_{i=1}^{m} [V'_{oi}C_o P_o + V'_{\mu i}C_\mu P_\mu]}{(1+r)^T}\right\}$$

where

P_{pi} = salvage fraction of pavement layer i material,

P_{si} = salvage fraction of shoulder layer i material,

P_f = salvage fraction of fill material,

P_o = salvage fraction of overlay material,

P_μ = salvage fraction of subgrade material,

T = analysis period.

Total Cost

The total cost is the sum of initial construction cost, overlay construction cost, routine maintenance cost and user's cost due to traffic delays, from which the salvage value is deducted.

Total cost = $C_I + C_V + C_M + C_D - S_g$

CHAPTER V

EFFECTS OF FULL PAVEMENT CROSS-SECTION AND COST BY QUANTITY-DISCOUNTS

The pavement cross-section model and quantity-discount cost models developed in this study have been integrated into the Texas Flexible Pavement Design System. The effects of using these models on the selection of optimal design strategies are illustrated herein. This study is aimed at demonstrating the adaptability and practicality of the new developed models. Full-scale analysis of the sensitivity of these models is left for future research.

Eight example problems concerned with new construction are compared. The input data of problem 1, the same problem as illustrated in reference (2), is shown in Table 1. The differences in the input data of the eight problems are listed in Table 2. The "0" cross-section model in Problems 1, 2, 3, and 4 is, in effect, the provision not to consider the materials outside of the pavement edge. Cross-section model "1" which is used in Problems 5, 6, 7, and 8 considers the full cross-section. Quantity-discount cost models 1, 2, 3 and 4 are, respectively, the constant, linear discount, log-normal discount and log-log discount cost models. When the full cross-section model is used, the maximum funds for initial construction should be increased to cover the cost of shoulder, subbase extension under shoulder and fill materials. In addition, the compacted density and production rate of upgrading material are needed to estimate the traffic delays during overlay construction periods. When a quantity-discount model is used, the material cost at both the minimum and maximum levels is needed. Since the maximum and minimum thickness of materials A, B and E are the same, the materials costs at each of the two levels is kept constant. In this study, the costs of materials C and D at the two levels are assumed to be a certain percent increase and decrease from the constant cost. For material C, the unit cost per cubic

TABLE 1

BASIC INPUT DATA OF A FLEXIBLE PAVEMENT DESIGN PROBLEM

BASIC DESIGN CRITERIA
****

LENGTH OF THE ANALYSIS PERIOD (YEARS)	20.0
MINIMUM TIME TO FIRST OVERLAY (YEARS)	6.0
MINIMUM TIME BETWEEN OVERLAYS (YEARS)	6.0
MINIMUM SERVICEABILITY INDEX P2	3.0
DESIGN CONFIDENCE LEVEL	E
INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)	7.0

PROGRAM CONTROLS AND CONSTRAINTS
****

NUMBER OF SUMMARY OUTPUT PAGES DESIRED (8 DESIGNS/PAGE)	1
MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)	8.00
MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)	36.0
ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)	6.0
PAVEMENT CROSS-SECTION MODEL USED	0
QUANTITY-DISCOUNT COST MODEL USED	1

TRAFFIC DATA
****

ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)	39330.
ADT AT END OF TWENTY YEARS (VEHICLES/DAY)	64752.
ONE-DIRECTION 20.-YEAR ACCUMULATED NO. OF EQUIVALENT 18-KSA	6894000.
AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)	50.0
AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION) (MPH)	20.0
AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)	50.0
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)	5.5
PERCENT TRUCKS IN ADT	8.0

ENVIRONMENT AND SUBGRADE
****

DISTRICT TEMPERATURE CONSTANT	31.0
SWELLING PROBABILITY	0.85
POTENTIAL VERTICAL RISE (INCHES)	5.00
SWELLING RATE CONSTANT	0.08
SUBGRADE STIFFNESS COEFFICIENT	0.26

TABLE 1. (CONTINUED)

CONSTRUCTION AND MAINTENANCE DATA

****

SERVICEABILITY INDEX OF THE INITIAL STRUCTURE	4.0
SERVICEABILITY INDEX P1 AFTER AN OVERLAY	3.9
MINIMUM OVERLAY THICKNESS (INCHES)	0.8
OVERLAY CONSTRUCTION TIME (HOURS/DAY)	7.0
ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)	1.26
ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)	75.0
WIDTH OF EACH LANE (FEET)	12.0
FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)	100.00
ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)	10.00

DETOUR DESIGN FOR OVERLAYS

****

TRAFFIC MODEL USED DURING OVERLAYING	3
TOTAL NUMBER OF LANES OF THE FACILITY	6
NUMBER OF OPEN LANES IN RESTRICTED ZONE (OVERLAY DIRECTION)	1
NUMBER OF OPEN LANES IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)	3
DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)	1.00
DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)	0.0
DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)	0.0

PAVING MATERIALS INFORMATION

****

LAYER	MATERIALS CODE	NAME	MIN. COST	MAX. COST	STR. COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	LT. WT. ACP	21.42	21.42	0.96	1.00	1.00	30.00
2	B	ACP	15.48	15.48	0.96	1.50	1.50	30.00
3	C	BLACK BASE	13.93	13.93	0.96	2.50	10.00	40.00
4	D	CRUSHED STONE	4.40	4.40	0.60	10.00	18.00	75.00
5	E	LIME TREATED SUB	2.40	2.40	0.40	6.00	6.00	90.00

OTHER MATERIALS INFORMATION

****

MATERIALS	COST AT 8 IN. THICK	COST AT 1 IN. THICK	SALVAGE PCT.
OVERLAY MATERIAL	21.42	21.42	30.00

TABLE 2

DIFFERENCES ON INPUT INFORMATION OF EIGHT EXAMPLE FLEXIBLE PAVEMENT DESIGN PROBLEMS

INPUT	PROBLEM NUMBER							
	1	2	3	4	5	6	7	8
Cross-section model used	0	0	0	0	1	1	1	1
Quantity-discount model used	1	2	3	4	1	2	3	4
Max funds for initial design ($/S.Y.)	8.00	8.00	8.00	8.00	12.00	12.00	12.00	12.00
Upgrade material compacted density (tons/C.Y.)	-	-	-	-	1.20	1.20	1.20	1.20
Upgrade material production rate (tons/hour)	-	-	-	-	100.	100.	100.	100.
Min. cost of material C ($/C.Y.)	13.93	11.14	11.14	11.14	13.93	11.14	11.14	11.14
Max. cost of material C ($/C.Y.)	13.93	16.72	16.72	16.72	13.93	16.72	16.72	16.72
Min. cost of material D ($/C.Y.)	4.40	3.96	3.96	3.96	4.40	3.96	3.96	3.96
Max. cost of material D ($/C.Y.)	4.40	4.84	4.84	4.84	4.40	4.84	4.84	4.84
Cost of shoulder surface material at 8" thick ($/C.Y.)	-	-	-	-	15.48	13.93	13.93	13.93
Cost of shoulder surface material at 1" thick ($/C.Y.)	-	-	-	-	15.48	17.03	17.03	17.03
Salvage percent of shoulder surface material (%)	-	-	-	-	30.00	30.00	30.00	30.00
Cost of shoulder base material at 8" thick ($/C.Y.)	-	-	-	-	13.93	12.54	12.54	12.54
Cost of shoulder base material at 1" thick ($/C.Y.)	-	-	-	-	13.93	15.32	15.32	15.32
Salvage percent of shoulder base material (%)	-	-	-	-	40.00	40.00	40.00	40.00

TABLE 2 (CONTINUED)

INPUT	PROBLEM NUMBER							
	1	2	3	4	5	6	7	8
Cost of fill material at 8" thick ($/C.Y.)	-	-	-	-	2.40	2.16	2.16	2.16
Cost of fill material at 1" thick ($/C.Y.)	-	-	-	-	2.40	2.64	2.64	2.64
Salvage percent of fill material (%)	-	-	-	-	90.00	90.00	90.00	90.00
Cost of overlay material at 8" thick ($/C.Y.)	21.42	19.28	19.28	19.28	21.42	19.28	19.28	19.28
Cost of overlay material at 1" thick ($/C.Y.)	21.42	23.56	23.56	23.56	21.42	23.56	23.56	23.56
Cost of upgrade material at 8" thick ($/C.Y.)	-	-	-	-	4.40	3.96	3.96	3.96
Cost of upgrade material at 1" thick ($/C.Y.)	-	-	-	-	4.40	4.84	4.84	4.84
Salvage percent of upgrade material (%)	-	-	-	-	75.00	75.00	75.00	75.00
Cross-section width outside of left shoulder (ft.)	-	-	-	-	6.00	6.00	6.00	6.00
Width of left shoulder (ft.)	-	-	-	-	10.00	10.00	10.00	10.00
Width of right shoulder (ft.)	-	-	-	-	10.00	10.00	10.00	10.00
Cross-section width outside of right shoulder (ft.)	-	-	-	-	6.00	6.00	6.00	6.00
Cross-section slope outside of left shoulder	-	-	-	-	8.00	8.00	8.00	8.00
Cross-section slope outside of right shoulder	-	-	-	-	8.00	8.00	8.00	8.00
Thickness of shoulder surface (in.)	-	-	-	-	2.00	2.00	2.00	2.00
Number of top pavement layers equivalent to total shoulder in thickness	-	-	-	-	3	3	3	3

yard is \$13.93 x (1.0 ± 20%) = (\$11.14, \$16.72); for material D, the material unit cost is \$4.40 x (1.0 ± 10%) = (\$3.96, \$4.84). It is also assumed that the constant costs and salvage percents of shoulders, fill, overlay and upgrading material are the same as the constant costs and salvage percents of materials B, C, E, A and D, respectively. Costs of the shoulder surface, shoulder base, fill, overlay and upgrading materials at the minimum and maximum levels are estimated by a 10 percent decrease and increase over the constant costs.

Optimal design strategies (program output) of the eight example problems are shown in Table 3. When the companion problems 1 and 5, 2 and 6, 3 and 7, and 4 and 8 are compared, it is obvious that the full pavement cross-section (model "1") has significant effects on the selection of the optimal design strategy. It is apparent from these results that the pavement, shoulder and fill materials should all be included in the economic evaluation of new flexible pavement construction.

When the "0" cross-section model is used (problems 1, 2, 3 and 4) the use of the quantity-discount models does not change the optimal design strategy. However, when the full cross-section model (model "1") is used, the optimal design strategy is changed from a five layer design (no discount in problem 5) to a four layer design (linear, log-normal and log-log discounts, respectively, in problems 6, 7 and 8). The thicknesses of pavement layers 3 (material C) and 4 (material D) are changed from 5.50 and 12.50 inches (no discount) to 8.50 and 10.00 inches (linear and log-normal discount) and 4.50 and 17.50 inches (log-log discount). A six inch thickness of material E is used in problem 5 to construct the pavement layer 5, but material E is not used in problems 6, 7 and 8. The thickness of the shoulder surface layer is a constant (input value), while the thickness of the shoulder base layer is determined by the following rules: the total thickness of the shoulder equals to the total thickness of the top three

TABLE 3

OPTIMAL DESIGN STRATEGY OF EIGHT EXAMPLE FLEXIBLE PAVEMENT DESIGN PROBLEMS

OUTPUT	PROBLEM NUMBER							
	1	2	3	4	5	6	7	8
Material arrangement	ABCDE	ABCDE	ABCDE	ABCDE	ABCDE	ABCD	ABCD	ABCD
Initial construction cost	5.21	5.33	5.29	5.16	10.19	9.99	9.96	9.51
Overlay construction cost	0.42	0.46	0.46	0.45	0.67	0.68	0.68	1.20
User cost	0.12	0.12	0.12	0.12	0.24	0.26	0.26	0.23
Routine maintenance cost	0.22	0.22	0.22	0.22	0.35	0.35	0.35	0.35
Salvage value	-0.76	-0.77	-0.77	-0.75	-1.58	-1.40	-1.39	-1.54
Total cost ($/sq.yd.)	5.22	5.36	5.33	5.20	9.86	9.88	9.86	9.74
Number of layers	5	5	5	5	5	4	4	4
Layer depth (inches)								
Pavement layer 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pavement layer 2	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Pavement layer 3	4.50	4.50	4.50	4.50	5.50	8.50	8.50	4.50
Pavement layer 4	15.00	15.00	15.00	15.00	12.50	10.00	10.00	17.50
Pavement layer 5	6.00	6.00	6.00	6.00	6.00	-	-	-
Shoulder layer 1	-	-	-	-	2.00	2.00	2.00	2.00
Shoulder layer 2	-	-	-	-	6.00	9.00	9.00	5.00
No. of performance periods	2	2	2	2	2	2	2	2
Performance time (year)								
Performance time 1	9.4	9.4	9.4	9.4	9.4	9.6	9.6	9.0
Performance time 2	20.1	20.1	20.1	20.1	20.3	20.8	20.8	20.9

TABLE 3 (CONTINUED)

OUTPUT	PROBLEM NUMBER							
	1	2	3	4	5	6	7	8
Overlay policy (inches) (including level-up)								
Overlay layer 1	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.3
Total number of feasible designs considered	79	79	79	79	49	61	63	62

(another input value) pavement layers. In Table 3, the thickness of the shoulder base is changed from 6 inches (no discount) to 9 inches (linear and log-normal discount) and 5 inches (log-log discount). It is thus concluded that quantity-discount is needed in the cost analysis of construction materials. The linear discount is suggested for use if a low discount rate is offered; and the log-log discount is recommended when higher discount rates prevail.

The effects of the new models are relatively insignificant on pavement service life and overlay construction. For instance, as shown in Table 3, the service lives for the initial construction in the eight problems are very close, ranging from 9.0 to 9.6 years. The same 1.3 inch overlay, except problem 8 using 2.3 inches overlay, is applied to the pavement at 9.0 to 9.6 years after initial construction. The service lives of the overlay construction of the eight problems are also very close, ranging from 10.7 to 11.9 years. The total lives range from 20.1 to 20.9 years.

In addition to the eight new construction problems, eight example ACP overlay construction problems are analyzed herein. The input data for problem 1A, the same ACP overlay problem as illustrated in reference (2), is shown in Table 4. The differences of the input data of the eight problems are summarized in Table 5. When the full cross-section (model "1") is used, the maximum funds allowed for the first overlay should be increased to cover the cost of overlay materials over shoulders and roadside upgrading materials. The constant unit costs and the unit costs at 1 and 8 inches of thickness of the overlay and upgrading materials used in problems 1A to 8A have the same values as used in problems 1 to 8.

Optimal design strategies of the eight ACP overlay design problems are shown in Table 6. Neither the full pavement cross-section nor the quantity-discount models affect the selection of the optimal overlay design strategy. One of the

TABLE 4

BASIC INPUT DATA OF AN ACP OVERLAY DESIGN PROBLEM

BASIC DESIGN CRITERIA	
********************	
LENGTH OF THE ANALYSIS PERIOD (YEARS)	20.0
MINIMUM TIME BETWEEN OVERLAYS (YEARS)	6.0
MINIMUM SERVICEABILITY INDEX P2	3.0
DESIGN CONFIDENCE LEVEL	D
INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)	7.0
PROGRAM CONTROLS AND CONSTRAINTS	
********************************	
NUMBER OF SUMMARY OUTPUT PAGES DESIRED (8 DESIGNS/PAGE)	1
MAX FUNDS AVAILABLE PER SQ.YD. FOR FIRST OVERLAY (DOLLARS)	5.00
ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)	10.0
PAVEMENT CROSS-SECTION MODEL USED	0
QUANTITY-DISCOUNT COST MODEL USED	1
TRAFFIC DATA	
************	
ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)	52000.
ADT AT END OF TWENTY YEARS (VEHICLES/DAY)	104000.
ONE-DIRECTION 20.-YEAR ACCUMULATED NO. OF EQUIVALENT 18-KSA	8272800.
AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)	50.0
AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION) (MPH)	20.0
AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)	50.0
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)	5.5
PERCENT TRUCKS IN ADT	8.0
ENVIRONMENT AND SUBGRADE	
************************	
DISTRICT TEMPERATURE CONSTANT	31.0
SWELLING PROBABILITY	0.85
POTENTIAL VERTICAL RISE (INCHES)	2.30
SWELLING RATE CONSTANT	0.08

TABLE 4 (CONTINUED)

CONSTRUCTION AND MAINTENANCE DATA
****

SERVICEABILITY INDEX P1 AFTER AN OVERLAY	3.9
MINIMUM OVERLAY THICKNESS (INCHES)	0.5
OVERLAY CONSTRUCTION TIME (HOURS/DAY)	7.0
ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)	2.00
ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)	120.0
WIDTH OF EACH LANE (FEET)	12.0
FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)	100.00
ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)	10.00

DETOUR DESIGN FOR OVERLAYS
****

TRAFFIC MODEL USED DURING OVERLAYING	3
TOTAL NUMBER OF LANES OF THE FACILITY	6
NUMBER OF OPEN LANES IN RESTRICTED ZONE (OVERLAY DIRECTION)	1
NUMBER OF OPEN LANES IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)	3
DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)	1.00
DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)	0.0
DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)	0.0

EXISTING PAVEMENT AND PROPOSED ACP
****

THE AVERAGE SCI OF THE EXISTING PAVEMENT	0.100
THE STANDARD DEVIATION OF SCI	0.035
THE COMPOSITE THICKNESS OF THE EXISTING PAVEMENT (INCHES)	28.0
IN-PLACE VALUE OF EXISTING PAVEMENT (DOLLARS/C.Y.)	5.21
SALVAGE VALUE OF EXISTING PAVT. AT END OF ANALYSIS PERIOD (PERCENT)	66.0
LEVEL-UP REQUIRED FOR THE FIRST OVERLAY (INCHES)	1.00

OTHER MATERIALS INFORMATION
****

MATERIALS	COST AT 8 IN. THICK	COST AT 1 IN. THICK	SALVAGE PCT.
OVERLAY MATERIAL	15.48	15.48	10.00

TABLE 5

DIFFERENCES ON INPUT INFORMATION OF EIGHT EXAMPLE ACP OVERLAY DESIGN PROBLEMS

INPUT	PROBLEM NUMBER							
	1A	2A	3A	4A	5A	6A	7A	8A
Cross-section model used	0	0	0	0	1	1	1	1
Quantity-discount model used	1	2	3	4	1	2	3	4
Max. funds for first overlay ($/C.Y.)	5.00	5.00	5.00	5.00	6.50	6.50	6.50	6.50
Upgrade material compacted density (tons/C.Y.)	-	-	-	-	1.50	1.50	1.50	1.50
Upgrade material production rate (tons/hour)	-	-	-	-	100.	100.	100.	100.
Cost of overlay material at 8" thick ($/C.Y.)	15.48	13.93	13.93	13.93	15.48	13.93	13.93	13.93
Cost of overlay material at 1" thick ($/C.Y.)	15.48	17.03	17.03	17.03	15.48	17.03	17.03	17.03
Cost of upgrade material at 8" thick ($/C.Y.)	-	-	-	-	4.40	3.96	3.96	3.96
Cost of upgrade material at 1" thick ($/C.Y.)	-	-	-	-	4.40	4.84	4.84	4.84
Salvage percent of upgrade material (%)	-	-	-	-	75.00	75.00	75.00	75.00
Cross-section width outside of left shoulder (ft.)	-	-	-	-	6.00	6.00	6.00	6.00
Width of left shoulder (ft.)	-	-	-	-	10.00	10.00	10.00	10.00
Width of right shoulder (ft.)	-	-	-	-	10.00	10.00	10.00	10.00
Cross-section width outside of right shoulder (ft.)	-	-	-	-	6.00	6.00	6.00	6.00

TABLE 6

OPTIMAL DESIGN STRATEGY OF EIGHT EXAMPLE ACP OVERLAY DESIGN PROBLEMS

OUTPUT	PROBLEM NUMBER							
	1A	2A	3A	4A	5A	6A	7A	8A
Initial overlay								
Construction cost	3.22	2.95	2.94	2.92	5.17	4.73	4.72	4.68
User cost	2.38	2.38	2.38	2.38	4.42	4.42	4.42	4.42
Future overlay(s)								
Construction cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
User cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Routine maintenance cost	0.28	0.28	0.28	0.28	0.43	0.43	0.43	0.43
Salvage value	-0.76	-0.76	-0.76	-0.76	-0.83	-0.82	-0.82	-0.82
Total cost ($/sq.yd.)	5.13	4.85	4.85	4.83	9.20	8.77	8.76	8.72
No. of performance periods	1	1	1	1	1	1	1	1
Performance time (year)								
Performance time 1	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9
1st level-up (inches)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Future level-up(s)(inches)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Overlay policy (inches) (including level-up)								
Overlay layer 1	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
Total number of feasible schemes considered	4	4	4	4	4	4	4	4

probable reasons for this is that there are only four feasible overlay schemes considered in the example problems. The overlay construction costs are relatively low in comparison with the new construction costs.

CHAPTER VI

MASTER PAVEMENT CROSS-SECTION MODEL

It is generally understood that although the FPS program considers the overall problem more completely than any analysis package in use today it utilizes some over-simplifications in order to do this (1). Thus, the best design strategies resulting from the program analysis must be carefully examined for structural and cost feasibility in order to determine the final selection of an optimal design strategy. The pavement cross-section model included in the present version of FPS is illustrated in Figure 1 and is a fairly good approximation of the in-service pavements in Texas. The approximation is needed in a large scale system (like FPS) in order to economize the cumbersome numerical computations. However, there is a need for a general cross-section model which is capable of describing any pavement cross-section. As a consequence, a master pavement cross-section model is developed herein and programmed separately from FPS, which allows the volumes of various construction materials used for any complicated cross-section design to be calculated precisely. This master model provides information on the minimum data requirements for cross-section information to be stored in the pavement feedback data system (3, 4) in order to sufficiently describe a full pavement cross section. This model meets the requirement of many state highway departments to accurately represent their cross-section geometry (4).

A pavement cross-section as shown in Figure 6 is used to illustrate the algorithm. Usually the master pavement cross-section model requires three sets of equations: slope equations, coordinate equations and thickness equations.

Slope Equations

The slope of the line connecting points i and j in Figure 6 is represented by S_{ij}, such that $S_{ij} = (Y_j-Y_i)/(X_j-X_i)$. Nine equations of this type can be

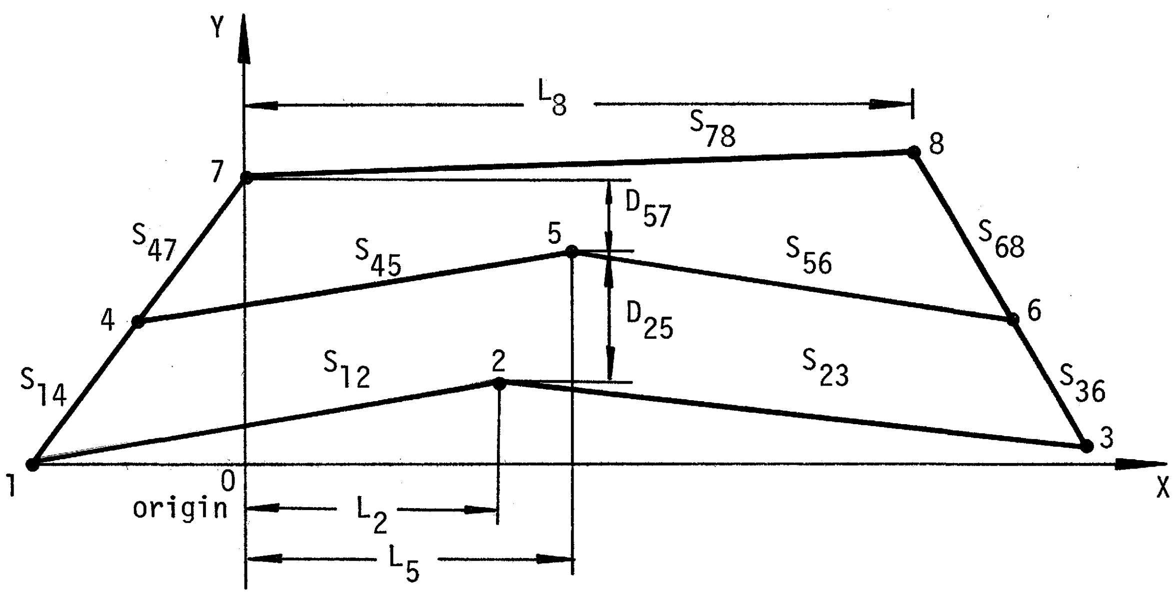


Figure 6. An example pavement cross-section

written for the nine slopes shown in Figure 6.

Coordinate Equations

Some coordinates are obvious, such as $Y_1 = X_7 = 0$. Also, given the horizontal length L_i, from the point i to the Y-axis, then $X_i = L_i$. In Figure 6, $X_2 = L_2$, $X_5 = L_5$ and $X_8 = L_8$.

Thickness Equations

Layer thickness, D_{ij}, represents the vertical distance between points i and j, where $Y_j > Y_i$, such that $Y_j - Y_i = D_{ij}$. Applied to the model in Figure 6, $Y_7 - Y_5 = D_{57}$ and $Y_5 - Y_2 = Y_{25}$.

The three sets of equations for the cross-section shown in Figure 6 can be better represented in matrix terms as shown in Figure 7. An efficient matrix inversion routine is required to solve the simultaneous linear algebraic equations for the coordinates of each point, especially when the number of points is large. It must be noted that 2M simultaneous equations are needed for an M-point cross-section. Necessary and sufficient conditions must be examined very carefully in applying this algorithm. Redundant equations will result in a singular matrix which cannot be inverted. In addition, a vertical line cannot be described by the slope equation since the slope of a vertical line is infinite (either positive or negative). An infinite number also results in a singular matrix. Instead of the slope equation, the coordinate or thickness equation can be used by setting equal the x-coordinates of points above and below each other.

Once the coordinates of each point in the cross-section are known, the area of each specific layer or material can be determined by the double meridian distance method (Appendix A). The area of the surface layer bounded by points 4,5,6,8 and 7 (denoted by A_{45687}) as shown in Figure 6 is

$$
\begin{bmatrix}
S_{12} & -1 & -S_{12} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & S_{23} & -1 & -S_{23} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
S_{14} & -1 & 0 & 0 & 0 & 0 & -S_{14} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & S_{45} & -1 & -S_{45} & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & S_{56} & -1 & -S_{56} & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & S_{36} & -1 & 0 & 0 & 0 & 0 & -S_{36} & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & S_{47} & -1 & 0 & 0 & 0 & 0 & -S_{47} & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & S_{78} & -1 & -S_{78} & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & S_{68} & -1 & 0 & 0 & -S_{68} & 1 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
X_1 \\ Y_1 \\ X_2 \\ Y_2 \\ X_3 \\ Y_3 \\ X_4 \\ Y_4 \\ X_5 \\ Y_5 \\ X_6 \\ Y_6 \\ X_7 \\ Y_7 \\ X_8 \\ Y_8
\end{bmatrix}
=
\begin{bmatrix}
0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ L_2 \\ L_5 \\ L_8 \\ D_{57} \\ D_{25}
\end{bmatrix}
$$

Figure 7. Matrix representing an example pavement cross-section

$$A_{45687} = \frac{1}{2} [X_4(Y_5-Y_7) + X_5(Y_6-Y_4) + X_6(Y_8-Y_5) + X_8(Y_7-Y_6) + X_7(Y_4- Y_8)]$$

The area of the second layer bounded by points 1, 2, 3, 6, 5 and 4 is

$$A_{123654} = \frac{1}{2} [X_1(Y_2- Y_4) + X_2(Y_3-Y_1) + X_3(Y_6- Y_2) + X_6(Y_5- Y_3) + X_5(Y_4-Y_6) + X_4(Y_1-Y_5)]$$

The master pavement cross-section model (MPCS) has been coded for high-speed data processing. Inputs are slopes, known coordinates, layer thicknesses and boundary points. The MPCS program calculates the coordinates of each point and areas of each layer (or material). Four rather complicated pavement cross-sections as shown in Figure 8 have been solved by the MPCS program to confirm the applicability of this model. The findings are satisfactory.

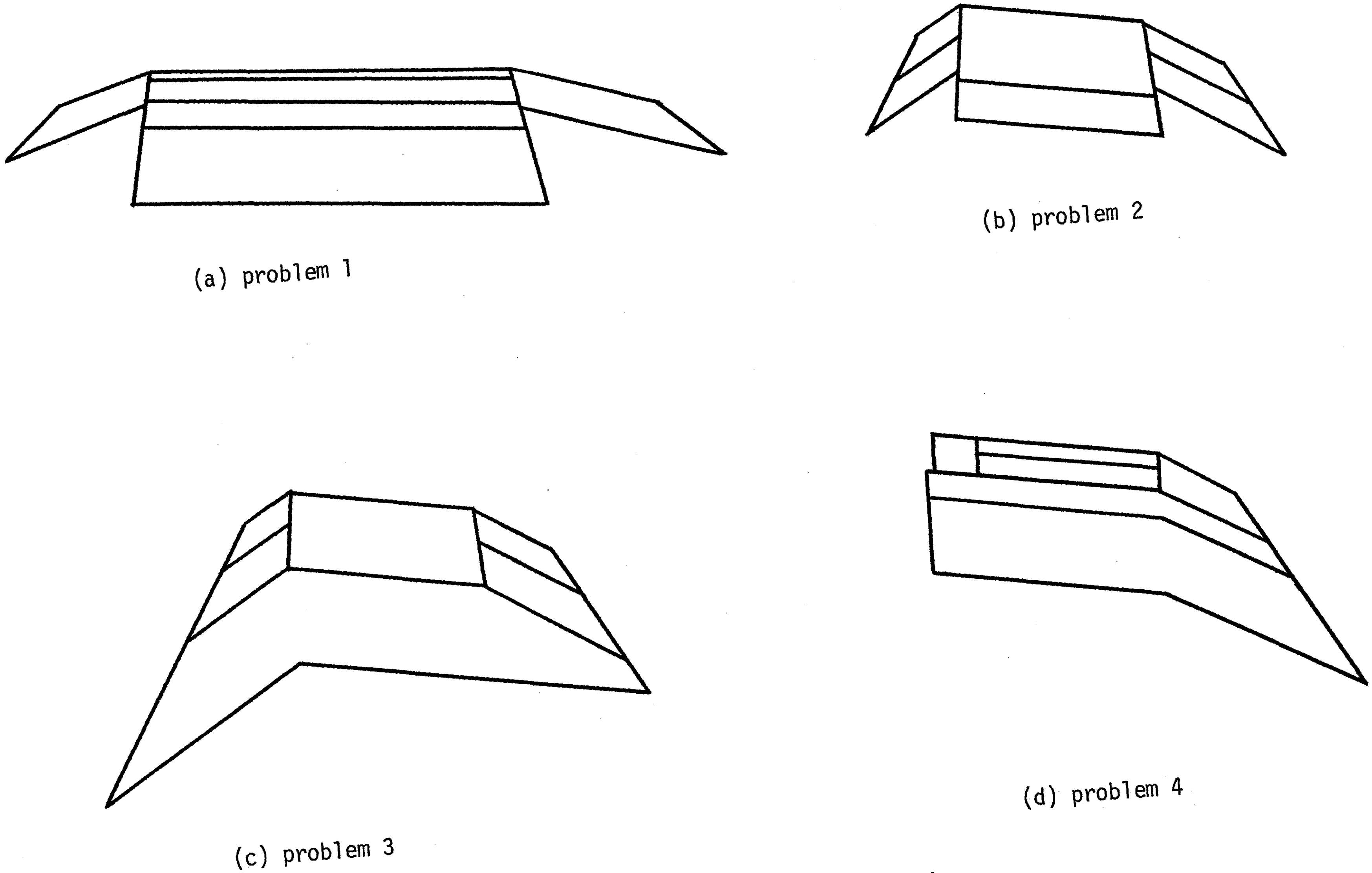


Figure 8. Four example pavement cross-sections

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The full pavement cross-section and the quantity-discount of unit material costs do affect the selection of the optimal design strategies of new construction. However, negligible effects are noted in the selection of the optimal overlay scheme.

The full pavement cross-section model (Figure 1) has been integrated into the Texas Flexible Pavement Design System (FPS-13-TTI) in this study. The same model can be modified for use in the rigid pavement design system, RPS-3 (5), and the linear-elasticity-based flexible pavement design system, FPS-BISTRO (6). The model uses less input data than the cross-section model utilized in the systems analysis model for pavements, SAMP6 (4), and is suggested for use in SAMP6 as an alternative.

The quantity-discount models developed in this study have also been integrated into the FPS-13-TTI and are recommended for use in RPS-3, FPS-BISTRO and SAMP6. The constant cost model is used when no quantity discount is applicable. The linear, log-normal and log-log cost models are used, respectively, for low, intermediate and high discount rates.

The master pavement cross-section model, developed in this study, and programmed separately from FPS-13-TTI, is recommended to calculate accurately the quantities of each construction material required in the optimal designs resulting from analyses using the pavement design systems such as FPS-13-TTI, FPS-BISTRO, RPS-3 and SAMP6. This accurate material requirement can be used to estimate the construction cost more precisely than the simplified estimations used in the large-scale optimization systems. In addition, parameters used in the master pavement cross-section model identify the minimum cross-section data requirement for the pavement data feedback system (3, 4) to describe a full pavement cross-section.

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APPENDIX A

DOUBLE MERIDIAN DISTANCE METHOD

The double meridian distance method calculates the area of any geometric shape, given the coordinates of each point on a two-dimensional plane. Consecutive numbers are assigned to n points on the plane in a counter-clockwise order. The area, A, is calculated by the following equation:

$$A = \frac{1}{2}\left[X_1(Y_2-Y_n) + \sum_{i=2}^{n-1} X_i(Y_{i+1}-Y_{i-1}) + X_n(Y_1-Y_{n-1})\right]$$

where (X_i,Y_i) are coordinates of point i, i=1, 2,..., n.

APPENDIX B

DOCUMENTATION OF FLEXIBLE PAVEMENT DESIGN SYSTEM, FPS-13-TTI

Page

INTRODUCTION

The FPS-13-TTI computer program is one of a series of Flexible Pavement Design Systems (FPS) developed under Research Study 1-8-69-123, "A Systems Analysis of Pavement Design and Research Implementation". This study is being conducted jointly in three agencies - The State Department of Highways and Public Transportation at Austin, The Texas Transportation Institute at College Station, and the Center for Highway Research at Austin, as a part of the cooperative research program with the Department of Transportation, Federal Highway Administration.

The FPS is a decision and analysis framework for the design and management of pavement construction and rehabilitation. This system is based on the following general premise: it is the aim of the design engineer to provide from available materials a pavement that can be maintained above a specified level of serviceability over a specified period of time and at the minimum overall cost.

The original FPS was developed under Research Study 2-8-62-32, "Extension of AASHO Road Test Results", conducted by Texas Transportation Institute during 1962-68. Since then, different refinements and modifications have been added to the initial version to incorporate the results of later research and to meet the needs of the FPS users. FPS-1 and FPS-2 were the original and first revision, respectively, of the FPS computer program, each of which utilized pavement deflection equations for predicting pavement performance. Following these, a numbering convention was adopted to be used for later revisions of FPS. The pavement deflection method series of programs were to use odd numbers for later revisions (3, 5, 7,...). The programs basically similar but using the AASHO based equation for predicting pavement performance were to use even numbers (4, 6, 8,...). Each program as it evolved would use a further suffix while in the development, debugging, evaluation, and testing stages (FPS-5-TTI, FPS-6-CFHR, and FPS-11-THD as examples) until approved for publication by the cooperating agencies, at which time the suffix would be dropped.

The FPS-13-TTI is a major updating of FPS-11. Changes in FPS-13-TTI as compared to FPS-11 are additions of a full pavement cross-section model and four quantity-discount cost models. This documentation is a supplement to the FPS-11 documentation. A complete FPS-13 documentation will not be published until new additions in FPS-13-TTI are approved for use by the State Department of Highways and Public Transportation.

PROGRAM IDENTIFICATION

Title: Flexible Pavement System (FPS-13-TTI)

Language: FORTRAN IV and IBM 360 Assembly Language

Machine: IBM 360/65

Programmer: Danny Y. Lu

Availability: Department of Pavement Design, Texas Transportation Institute
Texas A&M University, College Station, Texas 77843
Phone (713) 845-3735

Date: April 1975

Source Deck: about 2,500 cards

Storage: 228 k bytes

Timing:
(1) Compilation time - 1.77 minutes (FORTRAN G compiler)
(2) Execution time - highly dependent on the input data and the constraints set by the user. It will normally take 0.15 to 0.40 minutes per new construction design problem, and 0.05 to 0.15 minutes per ACP overlay design problem.

Printout:
(1) Program list - about 2,500 lines
(2) Program output - highly dependent on the number of summary output pages desired (Ns) and the number of design types (Nd). It will normally print Ns+Nd+3 pages for each new construction design problem and Ns+3 pages for each ACP overlay design problem.

Documentation: Lu, D.Y., Lytton, R.L. and Michalak, C.H., "Optimal Flexible Pavement Cross-Section Design Using Quantity-Discount Cost Model", Research Report 123-28, Texas Transportation Institute, 1975.

PROGRAM DESCRIPTION

The FPS-13-TTI computer program is composed of a MAIN program and twenty-one subroutines. Additions, as compared to FPS-11, are subroutines INCOST, OLCOST, SVCOST, COSTMD and UNITCT.

Subroutines INPUT, OVLAY2, OVRLAY and SOLVE2 of FPS-11 have been extensively revised for use in FPS-13-TTI. Minor modifications have been added to MAIN, HEADING, OUTPUT, PWRM, SUMMARY and USER. Subroutines CALC, CHECK, CHECK2, STORE, SUMMARY, TIME and CORE have no changes at all. A new COMMON statement, named FPSTTI, is used in the MAIN program and ten subroutines: INPUT, OUTPUT, OVRLAY, PWRM, SOLVE2, SUMMARY, USER, INCOST, OLCOST, and SVCOST.

A cross-reference table, as shown in the following page, is designed to aid the programmer or analyst to alter one portion of the program without causing unknown or disastrous effects on other portions of the program. Each called subroutine is listed down the left side of the table with a cross sign, X, under the column for the routine from which it was called.

Usage of the new subroutines and variables passed as arguments of these subroutines and the common statement, FPSTTI, are documented herein.

Subroutine INCOST (CT, SVG)

Subroutine INCOST calculates initial construction cost and salvage value of the initial construction at the end of the analysis period, in which

CT = initial construction cost in dollars per square yard, and

SVG = salvage value of the initial construction in dollars per square yard at end of analysis period.

Subroutine OLCOST (DEXT, ITIME, OCCT)

Subroutine OLCOST calculates the present worth of overlay construction cost. This cost represents one specific overlay construction only, not the total

CROSS-REFERENCE OF MAIN PROGRAM AND SUBROUTINES

Called Program Name	Calling Program Name																					
	MAIN	CALC	CHECK	CHECK2	HEADNG	INPUT	OUTPUT	OVLAY2	OVRLAY	PWRM	SOLVE2	STORE	SUMARY	SUMMY	TIME	USER	INCOST	OLCOST	SVCOST	COSTMD	UNITCT	CORE
CALC	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
CHECK	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHECK 2	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HEADNG	-	-	-	-	-	X	X	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-
INPUT	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OUTPUT	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OVLAY 2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OVRLAY	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PWRM	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
SOLVE 2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
STORE	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SUMARY	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SUMMY	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TIME	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
USER	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
INCOST	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
OLCOST	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
SVCOST	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
COSTMD	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UNITCT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-
CORE	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

number of overlay constructions during an analysis period. Arguments of the subroutine are

DEXT = overlay thickness (in yards) excluding level up,

ITIME = time, rounded to the nearest integer year, from initial construction (new construction mode) or the first overlay construction (ACP overlay mode) to the present overlay construction, and

OCCT = present worth of overlay construction cost in dollars per square yard.

<u>Subroutine SVCOST (I, DEXT, SOCCT)</u>

Subroutine SVCOST calculates salvage value of total overlays constructed during an analysis period, in which

I = number of performance periods over an analysis period.

DEXT = an array of overlay thicknesses (in yards), excluding level up, for each overlay constructed during the analysis period, and

SVCOST = salvage value of overall overlay construction cost in dollars per square yard at end of analysis period.

<u>Subroutine COSTMD (MDQD, C1, C2, Q1, Q2, A1, A2)</u>

Given material costs at minimum and maximum layer thicknesses, subroutine COSTMD determines the parameters of the quantity-discount cost model for use in subroutine UNITCT, in which

MDQD = quantity-discount cost model number used,

C1 = material cost in dollars per cubic yard in place at a specified upper thickness of a pavement layer as described below.

C2 = material cost in dollars per cubic yard in place at a specified lower thickness of a pavement layer as described below.

Q1 = specified lower thickness of a pavement layer in inches for which unit cost C2 applies. For materials other than those in pavement layers this number will be assumed to be 1 inch or (1/36) yards thick.

Q2 = specified upper thickness of a pavement layer in inches for which unit cost C1 applies. For materials other than those in pavement layers, this number will be assumed to be 8 inches or (8/36) yards thick.

A1 = first parameter of quantity-discount cost model, and

A2 = second parameter of quantity-discount cost model.

Subroutine UNITCT (MDQD, A1, A2, Q, C)

Subroutine UNITCT calculates unit material cost at a specific quantity, in which

MDQD = quantity-discount cost model number used,

A1 = first parameter of quantity-discount cost model determined in subroutine COSTMD,

A2 = second parameter of quantity-discount cost model determined in subroutine COSTMD,

Q = a specific layer thickness (in yards) used to determine the unit cost, and

C = unit material cost in dollars per cubic yard at a given thickness, Q.

COMMON/FPSTTI/

Variables included in common statement FPSTTI are defined as follows:

MDCS = pavement cross-section model number used,

MDQD = quantity-discount cost model number used,

NSHDR = number of top pavement layers equivalent in thickness to the total shoulder thickness,

UGCD = upgrade material compacted density in tons per cubic yard,

UGPR = upgrade material production rate in tons per hour.

CSC = an array of in-place costs in dollars per cubic yard of the following materials if 1 inch thick of that material is designed: (1) shoulder surface material, (2) shoulder base material (3) fill material, (4) overlay material, and (5) upgrade material.

CSC1 = an array of in-place costs in dollars per cubic yard of the following materials if 8 inches thick of that material is designed: (1) shoulder surface material, (2) shoulder base material, (3) fill material, (4) overlay material, and (5) upgrade material.

CSS = an array of slavage percents of the following materials: (1) shoulder surface material, (2) shoulder base material, (3) fill material, (4) overlay material, and (5) upgrade material,

ACOST1 = an array of the first parameters of the quantity-discount cost model for each of the paving materials, calculated in subroutine COSTMD,

ACOST2 = an array of the second parameters of the quantity-discount cost model for each of the paving materials, calculated in subroutine COSTMD,

BCOST1 = an array of the first parameters of the quantity-discount cost model for each of the paving materials, selected from array ACOST1 in MAIN program for use by subroutine UNITCT,

BCOST2 = an array of the second parameters of the quantity-discount cost model for each of the paving materials selected from array ACOST2 in MAIN program for use by subroutine UNITCT,

CCOST1 = an array of the first parameters of the quantity-discount cost model for shoulder surface (element 1) shoulder base (element 2) fill material (element 3), overlay material (element 4) and upgrade material (element 5), calculated in subroutine COSTMD for use by subroutine UNITCT.

CCOST2 = an array of the second parameters of the quantity-discount cost model for shoulder surface (element 1), shoulder base (element 2), fill material (element 3), overlay material (element 4) and upgrade material (element 5), calculated in subroutine COSTMD for use by subroutine UNITCT,

AD1 = thickness of shoulder surface layer in yards,

AW = an array of pavement cross-section dimensions: (1) cross-section width outisde of left shoulder in feet, (2) width of left shoulder in feet, (3) width of right shoulder in feet, (4) cross-section width outside of right shoulder in feet, (5) side slope outside of left shoulder, and (6) side slope outside of right shoulder.

S12 = sum of cross-section slopes outside of left and right shoulders,

X14 = sum of cross-section widths in yards outside of left and right shoulders,

X23 = sum of left and right shoulder widths in yards,

AL = width of total traffic lanes in yards,

SL = width of total traffic lanes and shoulders in yards,

XL = total cross-section width in yards, including width of traffic lanes, shoulder lanes and places outside of shoulders considered in the problem, and

Z2Z = an array of salvage values for each of a maximum of 1,000 feasible initial designs, determined in subroutine SOLVE2 for use by subroutine OVRLAY.

DATA1 = an array of the minimum in-place costs of paving materials in dollars per cubic yard

DATA2 = an array of the maximum in-place costs of paving materials in dollars per cubic yard.

In COMMON/FPSTTI/, variables CSC, CSC1, CSS, CCOST1, CCOST2, and AW are dimensioned as follows:

CSC (5)	CCOST1 (5)
CSC1 (5)	CCOST2 (5)
CSS (5)	AW (6)

Dimensions of the following variables should be checked when planning changes to the FPS program to prevent potential illegal subscript values and storing numbers outside their assigned arrays:

ACOST1 (NM+1)	DATA1 (NM+1)
ACOST2 (NM+1)	DATA2 (NM+1)
BCOST1 (LAYER)	Z2Z (NUMBER)
BCOST2 (LAYER)	

Dimensions are defined as follows:

NM = maximum number of paving materials, excluding subgrade,

LAYER = maximum number of layers in a design, excluding subgrade,

NUMBER = maximum number of feasible initial designs.

In FPS-13-TTI, NM = 10, LAYER = 6 and NUMBER = 1000.

INPUT GUIDE

The FPS-13-TTI computer program can solve one or more problems in one run. Input data is one or more sets of data cards, one set for each problem. Each data card is numbered in sequence from 1 through 13; this number is the card type identifier. A problem is described by a set of cards consisting of one card of each type with the exception of card type 2 which could be coded up to seven times and card type 10 of which there can be a maximum of ten, one for each paving material considered in the problem.

Program users have the option of running an ACP overlay or a new construction problem. Also, there are two alternatives to describe the pavement cross-section: one using a full pavement cross-section model which includes traffic lanes and shoulders; the other using a cross-section model with traffic lanes only. Data card types required for each of these alternatives are listed below.

New const. w/o full cross-section - Card types 1-8, 10-11, 13

New const. w/ full cross-section - Card types 1-8, 10-13

ACP overlay w/o full cross-section - Card types 1-9, 11, 13

ACP overlay w/ full construction - Card types 1-9, 11-13.

Additional data card types, as compared to FPS-11, are information of shoulder surface, shoulder base, fill, overlay and upgrade materials (card type 11), as well as dimensions of the full pavement cross-section (card type 12). An "End of Problem" card (Card type 13) is placed at end of each problem set to terminate the data input of each problem.

The description of overlay material which was coded in card types 9 and 10 in FPS-11 has been replaced by a new card type 11 in FPS-13-TTI. Program users can utilize different overlay materials other than the pavement surface material used in the initial construction. In addition, the constant material cost used in card type 10 of FPS-11 has been replaced by two costs at minimum and maximum thickness levels for use in the quantity-discount model. If the quantity-discount cost model is not used, the constant material cost should be coded in the columns for the minimum cost level. In this case, the columns for the maximum cost level can be left blank or given any numerical value.

The FPS-13-TTI makes use of a subroutine "CORE", which is written in IBM 360 Assembly Language. Subroutine "CORE" allows the use of FORTRAN formatted I/O statements (READ and WRITE) in conjunction with core buffers. Subroutine "CORE" is used to read under format control from an area in core which contains character codes (A4 format) of a card image. Subroutine "CORE" can thus be used to convert A to F or I format. Following the CALL "CORE" statement in subroutine "INPUT" is a standard FORTRAN READ statement which specifies the format to be used and the variables to receive the data.

The first two columns on all input cards have the card type code number. The card(s) of any card type used in a problem which are identical to the card(s) of the same card type used in the immediately preceding problem can be deleted to minimize coding effort and program execution time.

Input variable number, description, format in FORTRAN, and column number(s) applied to each specific data card are summarized in the input guide tables to be presented in subsequent pages. An asterisk sign, *, before a variable number indicates that this variable is a new input to FPS-13-TTI. The use of each variable in different problem types is also presented in the input guide tables. Eight problem types can be solved by FPS-13-TTI. They are:

Problem Type	Design Option	Full Cross-Section	Quantity-Discount
1	New Const.	No	No
2	New Const.	No	Yes
3	New Const.	Yes	No
4	New Const.	Yes	Yes
5	Overlay	No	No
6	Overlay	No	Yes
7	Overlay	Yes	No
8	Overlay	Yes	Yes

A cross sign, x, in the input guide table under a specific problem type column, means the input variable is required for that problem type; while a dash sign, -, indicates otherwise.

CARD TYPE 1: PROJECT IDENTIFICATION

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
1.0	"01"	I2	1-2	X	X	X	X	X	X	X	X
1.1	Problem number	A3	3-5	X	X	X	X	X	X	X	X
1.2	District number	A2	6-7	X	X	X	X	X	X	X	X
1.3	County name	3A4, A2	8-21	X	X	X	X	X	X	X	X
1.4	Control number	A4	22-25	X	X	X	X	X	X	X	X
1.5	Section number	A2	26-27	X	X	X	X	X	X	X	X
1.6	Highway name	2A4, A2	28-37	X	X	X	X	X	X	X	X
1.7	Date the problem was coded	2A4	38-45	X	X	X	X	X	X	X	X
1.8	IPE number	A4	46-49	X	X	X	X	X	X	X	X

CARD TYPE 2: PROJECT COMMENTS

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
2.0	"02"	I2	1-2	X	X	X	X	X	X	X	X
2.1	Project Comments	19A4, A2	3-80	X	X	X	X	X	X	X	X

CARD TYPE 3: BASIC DESIGN CRITERIA

Variable Number	Variable	Format	Columns	Problem Type							
				1	2	3	4	5	6	7	8
3.0	"03"	I2	1-2	X	X	X	X	X	X	X	X
3.1	Length of analysis period (years)	F5.2	3-7	X	X	X	X	X	X	X	X
3.2	Minimum time to first overlay (years)	F5.2	8-12	X	X	X	X	-	-	-	-
3.3	Minimum time between overlays (years)	F5.2	13-17	X	X	X	X	X	X	X	X
3.4	Minimum serviceability index	F5.2	18-22	X	X	X	X	X	X	X	X
3.5	Reliability level (A=50%, B=80%, C=95%) D=99%, E=99.9%, F=99.99%, G=99.999%)	A1	23	X	X	X	X	X	X	X	X
3.6	Interest rate (%)	F5.2	24-28	X	X	X	X	X	X	X	X

CARD TYPE 4: PROGRAM CONTROLS AND CONSTRAINTS

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
4.0	"04"	I2	1-2	X	X	X	X	X	X	X	X
4.1	Problem Type (1=new pavt. const., 2=ACP overlay)	I2	3-4	X	X	X	X	X	X	X	X
4.2	Number of summary output pages 8 designs/page, 3 pages max.)	I2	5-6	X	X	X	X	X	X	X	X
4.3	Maximum funds for initial construction ($/sq. yd)	F5.2	7-11	X	X	X	X	X	X	X	X
4.4	Maximum total thickness of initial construction (in.)	F5.2	12-16	X	X	X	X	-	-	-	-
4.5	Maximum total thickness of all overlays (in.)	F5.2	17-21	X	X	X	X	X	X	X	X
*4.6	Cross-section model used (0=w/o shoulder 1=with shoulder)	I2	22-23	X	X	X	X	X	X	X	X
*4.7	Cost model used (1=no discount, 2= linear discount, 3=log-normal discount, 4=log-log discount)	I2	24-25	X	X	X	X	X	X	X	X

CARD TYPE 5: TRAFFIC DATA

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
5.0	"05"	I2	1-2	X	X	X	X	X	X	X	X
5.1	Initial average daily traffic (veh./day)	F10.2	3-12	X	X	X	X	X	X	X	X
5.2	Average daily traffic at end of 20 years (veh./day)	F10.2	13-22	X	X	X	X	X	X	X	X
5.3	One-direction cumulative 18 KSA in 20 years	F10.2	23-32	X	X	X	X	X	X	X	X
5.4	Average approach speed to the overlay area (mph)	F5.2	33-37	X	X	X	X	X	X	X	X
5.5	Average speed through overlay area in overlay direction (mph)	F5.2	38-42	X	X	X	X	X	X	X	X
5.6	Average speed through overlay area in non-overlay direction (mph)	F5.2	43-47	X	X	X	X	X	X	X	X
5.7	Percent of ADT through overlay area during each hour	F5.2	48-52	X	X	X	X	X	X	X	X
5.8	Percent of trucks in ADT	F5.2	53-57	X	X	X	X	X	X	X	X

CARD TYPE 6: ENVIRONMENT AND SUBGRADE

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
6.0	"06"	I2	1-2	X	X	X	X	X	X	X	X
6.1	District temperature constant	F5.2	3-7	X	X	X	X	X	X	X	X
6.2	Probability of swelling	F5.2	8-12	X	X	X	X	X	X	X	X
6.3	Potential vertical rise due to swelling clay (in.)	F5.2	13-17	X	X	X	X	X	X	X	X
6.4	Swelling rate	F5.2	18-22	X	X	X	X	X	X	X	X
6.5	Subgrade stiffness coefficient	F5.2	23-27	X	X	X	X	-	-	-	-

CARD TYPE 7: CONSTRUCTION AND MAINTENANCE DATA

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
7.0	"07"	I2	1-2	X	X	X	X	X	X	X	X
7.1	Initial serviceability index	F5.2	3-7	X	X	X	X	-	-	-	-
7.2	Serviceability index after an overlay	F5.2	8-12	X	X	X	X	X	X	X	X
7.3	Minimum overlay thickness (inches)	F5.2	13-17	X	X	X	X	X	X	X	X
7.4	Overlay construction time (hours/day)	F5.2	18-22	X	X	X	X	X	X	X	X
7.5	Asphalt concrete compacted density (tons/cu. yd.)	F5.2	23-27	X	X	X	X	X	X	X	X
7.6	Asphalt concrete production rate (tons/hour)	F5.2	28-32	X	X	X	X	X	X	X	X
7.7	Width of each lane (feet)	F5.2	33-37	X	X	X	X	X	X	X	X
7.8	Annual maintenance cost for the first year after construction or an overlay ($/lane-mile)	F6.2	38-43	X	X	X	X	X	X	X	X
7.9	Annual incremental increase in maintenance cost ($/lane-mile)	F6.2	44-49	X	X	X	X	X	X	X	X
*7.10	Upgrade material compacted density (tons/cu. yd.)	F5.2	50-54	-	-	X	X	-	-	X	X
*7.11	Upgrade material production rate (tons/hour)	F5.2	55-59	-	-	X	X	-	-	X	X

CARD TYPE 8: DETOUR DESIGN FOR OVERLAYS

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
8.0	"08"	I2	1-2	X	X	X	X	X	X	X	X
8.1	Detour model used during overlay period	I2	3-4	X	X	X	X	X	X	X	X
8.2	Number of lanes	I2	5-6	X	X	X	X	X	X	X	X
8.3	Number of lanes open in overlay direction	I2	7-8	X	X	X	X	X	X	X	X
8.4	Number of lanes open in non-overlay direction	I2	9-10	X	X	X	X	X	X	X	X
8.5	Distance traffic is slowed in overlay direction (miles)	F5.2	11-15	X	X	X	X	X	X	X	X
8.6	Distance traffic is slowed in non-overlay direction (miles)	F5.2	16-20	X	X	X	X	X	X	X	X
8.7	Detour distance around the overlay zone (miles)	F5.2	21-25	X	X	X	X	X	X	X	X

CARD TYPE 9: EXISTING PAVEMENT AND PROPOSED ACP

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
9.0	"09"	I2	1-2	-	-	-	-	X	X	X	X
9.1	SCI of the existing pavement	F5.3	3-7	-	-	-	-	X	X	X	X
9.2	Standard deviation of SCI	F5.3	8-12	-	-	-	-	X	X	X	X
9.3	Composite thickness of existing pavement (in.)	F5.2	13-17	-	-	-	-	X	X	X	X
9.4	In-place value of existing pavement ($ / cu. yd.)	F5.2	29-33	-	-	-	-	X	X	X	X
9.5	Salvage percent of existing pavement (%)	F6.2	34-39	-	-	-	-	X	X	X	X
9.6	Level-up required for the first overlay (in.)	F5.2	40-44	-	-	-	-	X	X	X	X

CARD TYPE 10: PAVING MATERIAL INFORMATION

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
10.0	"10"	I2	1-2	X	X	X	X	-	-	-	-
10.1	Layer designation number	I1	4	X	X	X	X	-	-	-	-
10.2	Letter code of material	A1	8	X	X	X	X	-	-	-	-
10.3	Name of material	6A3	12-29	X	X	X	X	-	-	-	-
10.4	Stiffness coefficient	F8.2	36-43	X	X	X	X	-	-	-	-
10.5	Minimum allowed thickness (in.)	F8.2	44-51	X	X	X	X	-	-	-	-
10.6	Maximum allowed thickness (in.)	F8.2	52-59	X	X	X	X	-	-	-	-
10.7	Salvage percent (%)	F8.2	60-67	X	X	X	X	-	-	-	-
*10.8	Minimum in-place cost ($/cu.yd.)	F6.2	68-73	X	X	X	X	-	-	-	-
*10.9	Maximum in-place cost ($/cu.yd.)	F6.2	74-79	-	X	-	X	-	-	-	-
10.10	Check	I1	80	X	X	X	X	-	-	-	-

CARD TYPE 11: OTHER MATERIAL INFORMATION

Variable Number	Variable	Format	Columns	Problem Type 1	2	3	4	5	6	7	8
*11.0	"11"	I2	1-2	X	X	X	X	X	X	X	X
*11.1	Cost of Shoulder surface material at 8 in. thick ($/cu. yd)	F5.2	6-10	-	-	X	X	-	-	-	-
*11.2	Cost of shoulder surface material at 1 in. thick ($/cu. yd)	F5.2	11-15	-	-	-	X	-	-	-	-
*11.3	Salvage percent of shoulder surface material (%)	F5.2	16-20	-	-	X	X	-	-	-	-
*11.4	Cost of shoulder base material at 8 in. thick ($/cu. yd.)	F5.2	21-25	-	-	X	X	-	-	-	-
*11.5	Cost of shoulder base materail at 1 in. thick ($/cu. yd.)	F5.2	26-30	-	-	-	X	-	-	-	-
*11.6	Salvage percent of shoulder base material (%)	F5.2	31-35	-	-	X	X	-	-	-	-
*11.7	Cost of fill material at 8 in. thick ($/cu. yd)	F5.2	36-40	-	-	X	X	-	-	-	-
*11.8	Cost of fill material at 1 in. thick ($/cu. yd.)	F5.2	41-45	-	-	-	X	-	-	-	-
*11.9	Salvage percent of fill material (%)	F5.2	46-50	-	-	X	X	-	-	-	-
*11.10	Cost of overlay material at 8 in. thick ($/cu. yd.)	F5.2	51-55	X	X	X	X	X	X	X	X
*11.11	Cost of overlay material at 1 in. thick ($/cu. yd.)	F5.2	56-60	-	X	-	X	-	X	-	X
*11.12	Salvage percent of overlay material (%)	F5.2	61-65	X	X	X	X	X	X	X	X
*11.13	Cost of upgrade material at 8 in. thick ($/cu. yd.)	F5.2	66-70	-	-	X	X	-	-	X	X
*11.14	Cost of upgrade material at 1 in. thick ($/cu. yd.)	F5.2	71-75	-	-	-	X	-	-	-	X
*11.15	Salvage percent of upgrade material (%)	F5.2	76-80	-	-	X	X	-	-	X	X

CARD TYPE 12: CROSS-SECTION DATA

Variable Number	Variable	Format	Columns	Problem Type 1 2 3 4 5 6 7 8
*12.0	"12"	I2	1-2	- - X X - - X X
*12.1	Cross-section width outside of left shoulder (ft.)	F6.2	6-11	- - X X - - X X
*12.2	Width of left shoulder (ft.)	F6.2	12-17	- - X X - - X X
*12.3	Width of right shoulder (ft.)	F6.2	18-23	- - X X - - X X
*12.4	Cross-section width outside of right shoulder (ft.)	F6.2	24-29	- - X X - - X X
*12.5	Cross-section slope outside of left shoulder	F6.2	30-35	- - X X - - - -
*12.6	Cross-section slope outside of right shoulder	F6.2	36-41	- - X X - - - -
*12.7	Thickness of shoulder surface (in.)	F6.2	42-47	- - X X - - - -
*12.8	Number of top pavement layers equivalent to total shoulder in thickness	I2	48-49	- - X X - - - -

CARD TYPE 13: END OF PROBLEM

Variable Number	Variable	Format	Columns	Problem Type 1 2 3 4 5 6 7 8
*13.0	"13"	I2	1-2	X X X X X X X X

OUTPUT FORMAT

The output of the FPS-13-TTI computer program can be divided into three portions. In the first portion, the first two pages (or three if the full pavement cross-section is used) are the listing of the input parameters as shown on pp. B-27 to B-29 and B-34 to B-36. Of these input data, paving material information is used only for the new construction design option. The ACP overlay design option requires input of existing pavement and proposed ACP overlay materials data. The second portion of the output is shown on pp. B-30 to B-32 and is the resulting optimal design strategy for each design type, i.e., each different combination of paving materials. If the ACP overlay design option is utilized, this portion is deleted. In the third portion of the output, shown on p. 33 and p. 37, up to twenty-four feasible design strategies are tabulated on a summary table in the order of increasing total cost. The total number of feasible designs considered is printed at the end of the program output.

Presented on the following pages is the program output from example problems 6 (nine pages) and 6A (four pages) as will be described in the next section, "Example Problems". Problem 6 illustrates the new construction design option, while problem 6A utilizes the ACP overlay design option. FPS-13-TTI output formats of any problem type are basically similar to those presented either in problem 6 or in problem 6A.

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	1

****

COMMENTS ABOUT THIS PROBLEM

****

BASIC DESIGN CRITERIA
****

LENGTH OF THE ANALYSIS PERIOD (YEARS)	20.0
MINIMUM TIME TO FIRST OVERLAY (YEARS)	6.0
MINIMUM TIME BETWEEN OVERLAYS (YEARS)	6.0
MINIMUM SERVICEABILITY INDEX P2	3.0
DESIGN CONFIDENCE LEVEL	E
INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)	7.0

PROGRAM CONTROLS AND CONSTRAINTS
****

NUMBER OF SUMMARY OUTPUT PAGES DESIRED (8 DESIGNS/PAGE)	1
MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)	12.00
MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)	36.0
ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)	6.0
PAVEMENT CROSS-SECTION MODEL USED	1
QUANTITY-DISCOUNT COST MODEL USED	2

TRAFFIC DATA
****

ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)	39330.
ADT AT END OF TWENTY YEARS (VEHICLES/DAY)	64752.
ONE-DIRECTION 20.-YEAR ACCUMULATED NO. OF EQUIVALENT 18-KSA	6894000.
AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)	50.0
AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION) (MPH)	20.0
AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)	50.0
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)	5.5
PERCENT TRUCKS IN ADT	8.0

ENVIRONMENT AND SUBGRADE
****

DISTRICT TEMPERATURE CONSTANT	31.0
SWELLING PROBABILITY	0.85
POTENTIAL VERTICAL RISE (INCHES)	5.00
SWELLING RATE CONSTANT	0.08
SUBGRADE STIFFNESS COEFFICIENT	0.26

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	2

INPUT DATA CONTINUED

CONSTRUCTION AND MAINTENANCE DATA
****

SERVICEABILITY INDEX OF THE INITIAL STRUCTURE	4.0
SERVICEABILITY INDEX P1 AFTER AN OVERLAY	3.9
MINIMUM OVERLAY THICKNESS (INCHES)	0.8
OVERLAY CONSTRUCTION TIME (HOURS/DAY)	7.0
ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)	1.26
ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)	75.0
WIDTH OF EACH LANE (FEET)	12.0
FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)	100.00
ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)	10.00
UPGRADE MATERIAL COMPACTED DENSITY (TONS/C.Y.)	1.20
UPGRADE MATERIAL PRODUCTION RATE (TONS/HOUR)	100.00

DETOUR DESIGN FOR OVERLAYS
****

TRAFFIC MODEL USED DURING OVERLAYING	3
TOTAL NUMBER OF LANES OF THE FACILITY	6
NUMBER OF OPEN LANES IN RESTRICTED ZONE (OVERLAY DIRECTION)	1
NUMBER OF OPEN LANES IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)	3
DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)	1.00
DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)	0.0
DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)	0.0

PAVING MATERIALS INFORMATION
****

LAYER	MATERIALS CODE	NAME	MIN. COST	MAX. COST	STR. COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	LT. WT. ACP	21.42	21.42	0.96	1.00	1.00	30.00
2	B	ACP	15.48	15.48	0.96	1.50	1.50	30.00
3	C	BLACK BASE	11.14	16.72	0.96	2.50	10.00	40.00
4	D	CRUSHED STONE	3.96	4.84	0.60	10.00	18.00	75.00
5	E	LIME TREATED SUBG	2.40	2.40	0.40	6.00	6.00	90.00

OTHER MATERIALS INFORMATION
****

MATERIALS	COST AT 8 IN. THICK	COST AT 1 IN. THICK	SALVAGE PCT.
SHOULDER SURFACE	13.93	17.03	30.00
SHOULDER BASE	12.54	15.32	40.00
FILL MATERIAL	2.16	2.64	90.00
OVERLAY MATERIAL	19.28	23.56	30.00
UPGRADE MATERIAL	3.96	4.84	75.00

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	3

INPUT DATA CONTINUED

CROSS SECTION DATA
****

CROSS SECTION WIDTH OUTSIDE OF LEFT SHOULDER (FEET)	6.00
WIDTH OF LEFT SHOULDER (FEET)	10.00
WIDTH OF RIGHT SHOULDER (FEET)	10.00
CROSS SECTION WIDTH OUTSIDE OF RIGHT SHOULDER (FEET)	6.00
CROSS SECTION SLOPE OUTSIDE OF LEFT SHOULDER	8.00
CROSS SECTION SLOPE OUTSIDE OF RIGHT SHOULDER	8.00
THICKNESS OF SHOULDER SURFACE (IN.)	2.00
NO. OF TOP PAVEMENT LAYERS EQUIVALENT TO TOTAL SHOULDER IN THICKNESS	3

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	4

FOR THE 1 LAYER DESIGN WITH THE FOLLOWING MATERIALS--

LAYER	CODE	MATERIALS NAME	MIN. COST	MAX. COST	STR. COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	LT. WT. ACP	21.42	21.42	0.96	1.00	1.00	30.00
		SUBGRADE			0.26			

THE CONSTRUCTION RESTRICTIONS ARE TOO BINDING TO OBTAIN A STRUCTURE THAT WILL MEET THE MINIMUM TIME TO THE FIRST OVERLAY RESTRICTION.

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	5

FOR THE 2 LAYER DESIGN WITH THE FOLLOWING MATERIALS--

LAYER	CODE	MATERIALS NAME	MIN. COST	MAX. COST	STR. COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	LT. WT. ACP	21.42	21.42	0.96	1.00	1.00	30.00
2	B	ACP	15.48	15.48	0.96	1.50	1.50	30.00
		SUBGRADE			0.26			

THE CONSTRUCTION RESTRICTIONS ARE TOO BINDING TO OBTAIN A STRUCTURE THAT WILL MEET THE MINIMUM TIME TO THE FIRST OVERLAY RESTRICTION.

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	6

FOR THE 3 LAYER DESIGN WITH THE FOLLOWING MATERIALS--

LAYER	CODE	MATERIALS NAME	MIN. COST	MAX. COST	STR. COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	LT. WT. ACP	21.42	21.42	0.96	1.00	1.00	30.00
2	B	ACP	15.48	15.48	0.96	1.50	1.50	30.00
3	C	BLACK BASE	11.14	16.72	0.96	2.50	10.00	40.00
		SUBGRADE			0.26			

THE CONSTRUCTION RESTRICTIONS ARE TOO BINDING TO OBTAIN A STRUCTURE THAT WILL MEET THE MINIMUM TIME TO THE FIRST OVERLAY RESTRICTION.

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	7

FOR THE 4 LAYER DESIGN WITH THE FOLLOWING MATERIALS--

LAYER	MATERIALS CODE	NAME	MIN. COST	MAX. COST	STR. COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	LT. WT. ACP	21.42	21.42	0.96	1.00	1.00	30.00
2	B	ACP	15.48	15.48	0.96	1.50	1.50	30.00
3	C	BLACK BASE	11.14	16.72	0.96	2.50	10.00	40.00
4	D	CRUSHED STONE	3.96	4.84	0.60	10.00	18.00	75.00
		SUBGRADE			0.26			

4 THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--
FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE

LT. WT. ACP	1.00	INCHES
ACP	1.50	INCHES
BLACK BASE	8.50	INCHES
CRUSHED STONE	10.00	INCHES

THE LIFE OF THE INITIAL STRUCTURE = 9.58 YEARS
THE OVERLAY SCHEDULE IS
1.30 (INCH(ES) (INCLUDING 0.5 INCH LEVEL-UP) AFTER 9.58 YEARS.

TOTAL LIFE = 20.76YEARS

SERVICEABILITY LOSS DUE TO SWELLING CLAY IN EACH PERFORMANCE PERIOD IS
(1) 0.762
(2) 0.391

THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE

INITIAL CONSTRUCTION COST	9.989
TOTAL ROUTINE MAINTENANCE COST	0.349
TOTAL OVERLAY CONSTRUCTION COST	0.682
TOTAL USER COST DURING OVERLAY CONSTRUCTION	0.261
SALVAGE VALUE	-1.397
TOTAL OVERALL COST	9.885

NUMBER OF FEASIBLE DESIGNS EXAMINED FOR THIS SET -- 35

AT THE OPTIMAL SOLUTION,THE FOLLOWING
BOUNDARY RESTRICTIONS ARE ACTIVE--
1. THE MINIMUM DEPTH OF LAYER 1
2. THE MAXIMUM DEPTH OF LAYER 1
3. THE MINIMUM DEPTH OF LAYER 2
4. THE MAXIMUM DEPTH OF LAYER 2
5. THE MINIMUM DEPTH OF LAYER 4

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	8

FOR THE 5 LAYER DESIGN WITH THE FOLLOWING MATERIALS--

LAYER	MATERIALS CODE	NAME	MIN. COST	MAX. COST	STR. COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	LT. WT. ACP	21.42	21.42	0.96	1.00	1.00	30.00
2	B	ACP	15.48	15.48	0.96	1.50	1.50	30.00
3	C	BLACK BASE	11.14	16.72	0.96	2.50	10.00	40.00
4	D	CRUSHED STONE	3.96	4.84	0.60	10.00	18.00	75.00
5	E	LIME TREATED SUBG	2.40	2.40	0.40	6.00	6.00	90.00
		SUBGRADE			0.26			

5 THE OPTIMAL DESIGN FOR THE MATERIALS UNDER CONSIDERATION--

FOR INITIAL CONSTRUCTION THE DEPTHS SHOULD BE

LT. WT. ACP 1.00 INCHES
ACP 1.50 INCHES
BLACK BASE 4.50 INCHES
CRUSHED STONE 15.00 INCHES
LIME TREATED SUBG 6.00 INCHES

THE LIFE OF THE INITIAL STRUCTURE = 9.39 YEARS

THE OVERLAY SCHEDULE IS

1.30 (INCH(ES) (INCLUDING 0.5 INCH LEVEL-UP) AFTER 9.39 YEARS.

TOTAL LIFE = 20.11YEARS

SERVICEABILITY LOSS DUE TO SWELLING CLAY IN EACH PERFORMANCE PERIOD IS

(1) 0.752
(2) 0.387

THE TOTAL COSTS PER SQ. YD. FOR THESE CONSIDERATIONS ARE

INITIAL CONSTRUCTION COST	10.378
TOTAL ROUTINE MAINTENANCE COST	0.347
TOTAL OVERLAY CONSTRUCTION COST	0.730
TOTAL USER COST DURING OVERLAY CONSTRUCTION	0.217
SALVAGE VALUE	-1.657
TOTAL OVERALL COST	10.015

NUMBER OF FEASIBLE DESIGNS EXAMINED FOR THIS SET -- 26

AT THE OPTIMAL SOLUTION,THE FOLLOWING BOUNDARY RESTRICTIONS ARE ACTIVE--

1. THE MINIMUM DEPTH OF LAYER 1
2. THE MAXIMUM DEPTH OF LAYER 1
3. THE MINIMUM DEPTH OF LAYER 2
4. THE MAXIMUM DEPTH OF LAYER 2
5. THE MINIMUM DEPTH OF LAYER 5
6. THE MAXIMUM DEPTH OF LAYER 5

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	9

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCD	ABCD	ABCDE	ABCDE	ABCD	ABCD	ABCD	ABCD
INIT. CONST. COST	9.99	9.74	10.38	10.37	9.78	9.83	10.25	9.19
OVERLAY CONST. COST	0.68	1.26	0.73	0.73	1.26	1.26	0.68	1.88
USER COST	0.26	0.23	0.22	0.24	0.23	0.23	0.35	0.34
ROUTINE MAINT. COST	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
SALVAGE VALUE	-1.40	-1.57	-1.66	-1.61	-1.50	-1.54	-1.47	-1.58
TOTAL COST	9.88	10.00	10.02	10.07	10.12	10.12	10.16	10.17
NUMBER OF LAYERS	4	4	5	5	4	4	4	4
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	8.50	4.50	4.50	5.50	6.50	5.50	7.50	3.50
D(4)	10.00	17.50	15.00	12.50	12.50	15.00	12.50	18.00
D(5)			6.00	6.00				
S(1)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
S(2)	9.00	5.00	5.00	6.00	7.00	6.00	8.00	4.00
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)								
T(1)	9.6	9.0	9.4	9.4	8.9	9.1	9.9	7.9
T(2)	20.8	20.9	20.1	20.3	20.3	21.0	22.0	20.2
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	1.3	2.3	1.3	1.3	2.3	2.3	1.3	3.3
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.76	0.73	0.75	0.76	0.72	0.73	0.78	0.67
SC(2)	0.39	0.42	0.39	0.39	0.42	0.42	0.40	0.47

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 61

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	1

****

COMMENTS ABOUT THIS PROBLEM

****

BASIC DESIGN CRITERIA
****

LENGTH OF THE ANALYSIS PERIOD (YEARS)	20.0
MINIMUM TIME BETWEEN OVERLAYS (YEARS)	6.0
MINIMUM SERVICEABILITY INDEX P2	3.0
DESIGN CONFIDENCE LEVEL	D
INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)	7.0

PROGRAM CONTROLS AND CONSTRAINTS
****

NUMBER OF SUMMARY OUTPUT PAGES DESIRED (8 DESIGNS/PAGE)	1
MAX FUNDS AVAILABLE PER SQ.YD. FOR FIRST OVERLAY (DOLLARS)	6.50
ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)	10.0
PAVEMENT CROSS-SECTION MODEL USED	1
QUANTITY-DISCOUNT COST MODEL USED	2

TRAFFIC DATA
****

ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)	52000.
ADT AT END OF TWENTY YEARS (VEHICLES/DAY)	104000.
ONE-DIRECTION 20.-YEAR ACCUMULATED NO. OF EQUIVALENT 18-KSA	8272800.
AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)	50.0
AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION) (MPH)	20.0
AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)	50.0
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)	5.5
PERCENT TRUCKS IN ADT	8.0

ENVIRONMENT AND SUBGRADE
****

DISTRICT TEMPERATURE CONSTANT	31.0
SWELLING PROBABILITY	0.85
POTENTIAL VERTICAL RISE (INCHES)	2.30
SWELLING RATE CONSTANT	0.08

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	2

INPUT DATA CONTINUED

CONSTRUCTION AND MAINTENANCE DATA
****

SERVICEABILITY INDEX P1 AFTER AN OVERLAY	3.9
MINIMUM OVERLAY THICKNESS (INCHES)	0.5
OVERLAY CONSTRUCTION TIME (HOURS/DAY)	7.0
ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)	2.00
ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)	120.0
WIDTH OF EACH LANE (FEET)	12.0
FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)	100.00
ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)	10.00
UPGRADE MATERIAL COMPACTED DENSITY (TONS/C.Y.)	1.50
UPGRADE MATERIAL PRODUCTION RATE (TONS/HOUR)	100.00

DETOUR DESIGN FOR OVERLAYS
****

TRAFFIC MODEL USED DURING OVERLAYING	3
TOTAL NUMBER OF LANES OF THE FACILITY	6
NUMBER OF OPEN LANES IN RESTRICTED ZONE (OVERLAY DIRECTION)	1
NUMBER OF OPEN LANES IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)	3
DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)	1.00
DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)	0.0
DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)	0.0

EXISTING PAVEMENT AND PROPOSED ACP
****

THE AVERAGE SCI OF THE EXISTING PAVEMENT	0.100
THE STANDARD DEVIATION OF SCI	0.035
THE COMPOSITE THICKNESS OF THE EXISTING PAVEMENT (INCHES)	28.0
IN-PLACE VALUE OF EXISTING PAVEMENT (DOLLARS/C.Y.)	5.21
SALVAGE VALUE OF EXISTING PAVT. AT END OF ANALYSIS PERIOD (PERCENT)	66.0
LEVEL-UP REQUIRED FOR THE FIRST OVERLAY (INCHES)	1.00

OTHER MATERIALS INFORMATION
****

MATERIALS	COST AT 8 IN. THICK	COST AT 1 IN. THICK	SALVAGE PCT.
OVERLAY MATERIAL	13.93	17.03	10.00
UPGRADE MATERIAL	3.96	4.84	75.00

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	3

INPUT DATA CONTINUED

CROSS SECTION DATA
****

CROSS SECTION WIDTH OUTSIDE OF LEFT SHOULDER (FEET)	6.00
WIDTH OF LEFT SHOULDER (FEET)	10.00
WIDTH OF RIGHT SHOULDER (FEET)	10.00
CROSS SECTION WIDTH OUTSIDE OF RIGHT SHOULDER (FEET)	6.00

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6A	14	TRAVIS	3136	1	LP 1 MOPÀC	02/17/75	238	4

AVERAGE SCI = 0.100 CONFIDENCE LEVEL = D

SUMMARY OF THE BEST OVERLAY SCHEMES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4
**				
INITIAL OVERLAY				
CONSTRUCTION COST	4.73	3.68	3.10	3.10
USER COST	4.42	3.24	2.65	2.65
FUTURE OVERLAY(S)				
CONSTRUCTION COST	0.0	0.34	1.26	0.70
USER COST	0.0	11.43	22.27	26.24
ROUTINE MAINT. COST	0.43	0.36	0.35	0.32
SALVAGE VALUE	-0.82	-0.80	-0.82	-0.79
**				
**				
TOTAL COST	8.77	18.26	28.81	32.23
**				
**				
NO.OF PERF.PERIODS	1	2	2	3
**				
PERF. TIME (YEARS)				
T(1)	22.9	12.2	8.2	8.2
T(2)		24.5	21.7	16.1
T(3)				23.2
**				
1ST LEVEL-UP(INCHES)	1.0	1.0	1.0	1.0
FUTURE LEVEL-UP(S)	0.5	0.5	0.5	0.5
**				
OVERLAY POLICY(INCH)				
(INCLUDING LEVEL-UP)				
O(1)	7.5	5.5	4.5	4.5
O(2)		1.0	3.0	1.0
O(3)				1.0
**				
SWELLING CLAY LOSS				
(SERVICEABILITY)				
SC(1)	0.55	0.41	0.32	0.32
SC(2)		0.16	0.22	0.16
SC(3)				0.08
**				

THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS 4

EXAMPLE PROBLEMS

In order to illustrate the use of FPS-13-TTI, sixteen example problems were coded herein for one computer run. The sixteen problems cover all combinations of two design options (IPTYPE = 1 or 2), two cross-section options (MDCS = 0 or 1) and four quantity-discount cost options (MDQD = 1, 2, 3 or 4). They are:

Problem	IPTYPE	MDCS	MDQD
1	1	0	1
2	1	0	2
3	1	0	3
4	1	0	4
5	1	1	1
6	1	1	2
7	1	1	3
8	1	1	4

Problem	IPTYPE	MDCS	MDQD
1A	2	0	1
2A	2	0	2
3A	2	0	3
4A	2	0	4
5A	2	1	1
6A	2	1	2
7A	2	1	3
8A	2	1	4

IPTYPE, MDCS and MDQD are defined as follows:

IPTYPE = 1 for new construction design option,
2 for ACP overlay design option;

MDCS = 0 for pavement cross section without shoulders,
1 for full pavement cross section; and

MDQD = 1 for constant cost model,
2 for linear discount cost model,
3 for log-normal discount cost model,
4 for log-log discount cost model.

INPUT DATA

PROBLEM NO. 1-8 and 1A-8A

EXAMPLE INPUT DATA FOR FPS-13-TTI

COLUMN NUMBER

```
CARD            1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
NUMBER ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

    1  01 1 14     TRAVIS   313601LP 1 MOPAC02/17/75 238
    2  02
    3  03 20    6    6   3.0 E 7.0
    4  04 1 1 8.00 36.0  6.0 0 1
    5  05   39330.    64752.  6894000.  50   20   50   5.5   8
    6  06 31   0.85 5.0  0.08 0.26
    7  07 4.0  3.9  0.8   7   1.26 75   12  100.00 10.00
    8  08 3 6 1 3 1.0  0.   0.
    9  10 1   A    LT. WT. ACP                0.96    1.00    1.00    30   21.42      1
   10  10 2   B    ACP                        0.96    1.50    1.50    30   15.48      1
   11  10 3   C    BLACK BASE                 0.96    2.50   10.00    40   13.93      1
   12  10 4   D    CRUSHED STONE              0.60   10.00   18.00    75    4.40      1
   13  10 5   E    LIME TREATED SUB           0.40    6.00    6.00    90    2.40      0
   14  11                                                21.42     30.
   15  13
   16  01 2 14     TRAVIS   313601LP 1 MOPAC02/17/75 238
   17  04 1 1 8.00 36.0  6.0 0 2
   18  10 1   A    LT. WT. ACP                0.96    1.00    1.00    30   21.42 21.421
   19  10 2   B    ACP                        0.96    1.50    1.50    30   15.48 15.481
   20  10 3   C    BLACK BASE                 0.96    2.50   10.00    40   11.14 16.721
   21  10 4   D    CRUSHED STONE              0.60   10.00   18.00    75    3.96  4.841
   22  10 5   E    LIME TREATED SUBG          0.40    6.00    6.00    90    2.40  2.400
   23  11                                                19.2823.5630.
   24  13
   25  01 3 14     TRAVIS   313601LP 1 MOPAC02/17/75 238
   26  04 1 1 8.00 36.0  6.0 0 3
   27  13
   28  01 4 14     TRAVIS   313601LP 1 MOPAC02/17/75 238
   29  04 1 1 8.00 36.0  6.0 0 4
   30  13
   31  01 5 14     TRAVIS   313601LP 1 MOPAC02/17/75 238
   32  04 1 112.00 36.0  6.0 1 1

                1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
       ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
```

EXAMPLE INPUT DATA FOR FPS-13-TTI (CONTINUED)

COLUMN NUMBER

```
CARD            1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
NUMBER ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

  33   07 4.0  3.9  0.8   7   1.26 75   12  100.00 10.00 1.20  100.
  34   10 1   A    LT. WT. ACP                0.96    1.00    1.00    30   21.42      1
  35   10 2   B    ACP                        0.96    1.50    1.50    30   15.48      1
  36   10 3   C    BLACK BASE                 0.96    2.50   10.00    40   13.93      1
  37   10 4   D    CRUSHED STONE              0.60   10.00   18.00    75    4.40      1
  38   10 5   E    LIME TREATED SUB           0.40    6.00    6.00    90    2.40      0
  39   11   15.48     30.  13.93     40.  2.40      90.  21.42     30.  4.40      75.
  40   12   6.    10.   10.   6.    8.    8.    2.     3
  41   13
  42   01 6 14    TRAVIS    313601LP 1 MOPAC02/17/75 238
  43   04 1 112.00 36.0  6.0 1 2
  44   10 1   A    LT. WT. ACP                0.96    1.00    1.00    30   21.42 21.421
  45   10 2   B    ACP                        0.96    1.50    1.50    30   15.48 15.481
  46   10 3   C    BLACK BASE                 0.96    2.50   10.00    40   11.14 16.721
  47   10 4   D    CRUSHED STONE              0.60   10.00   18.00    75    3.96  4.841
  48   10 5   E    LIME TREATED SUBG          0.40    6.00    6.00    90    2.40  2.400
  49   11   13.9317.0330.  12.5415.3240.  2.16 2.64 90.  19.2823.5630.  3.96 4.84 75.
  50   13
  51   01 7 14    TRAVIS    313601LP 1 MOPAC02/17/75 238
  52   04 1 112.00 36.0  6.0 1 3
  53   13
  54   01 8 14    TRAVIS    313601LP 1 MOPAC02/17/75 238
  55   04 1 112.00 36.0  6.0 1 4
  56   13
  57   01 1A14TRAVIS        3136 1LP 1 MOPAC02/17/75 238
  58   02
  59   03 20         6   3.0 D 7.0
  60   04 2 1 5.00   .  10.0 0 1
  61   05   52000.   104000.  8272800.  50   20   50   5.5   8
  62   06 31   0.85 2.3  0.08  .
  63   07 .    3.9  0.5   7   2.00120   12  100.00 10.00
  64   08 3 6 1 3 1.0 0.0  0.0

                1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
       ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
```

EXAMPLE INPUT DATA FOR FPS-13-TTI (CONTINUED)

COLUMN NUMBER

```
CARD             1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
NUMBER  ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

   65   090.1000.03528.0             5.21  66   1.0
   66   11                                                08.48     10.
   67   13
   68   01 2A14TRAVIS        3136 1LP 1 MOPAC02/17/75 238
   69   04 2 1 5.00   .  10.0 0 2
   70   11                                                13.9317.0310.
   71   13
   72   01 3A14TRAVIS        3136 1LP 1 MOPAC02/17/75 238
   73   04 2 1 5.00   .  10.0 0 3
   74   13
   75   01 4A14TRAVIS        3136 1LP 1 MOPAC02/17/75 238
   76   04 2 1 5.00   .  10.0 0 4
   77   13
   78   01 5A14TRAVIS        3136 1LP 1 MOPAC02/17/75 238
   79   04 2 1 6.50   .  10.0 1 1
   80   07  .   3.9  0.5   7   2.00120   12  100.00 10.001.50 100.
   81   11                                                15.48     10.  4.40      75.
   82   12   6.    10.   10.   6.
   83   13
   84   01 6A14TRAVIS        3136 1LP 1 MOPAC02/17/75 238
   85   04 2 1 6.50   .  10.0 1 2
   86   11                                                13.9317.0310.  3.96 4.84 75.
   87   13
   88   01 7A14TRAVIS        3136 1LP 1 MOPAC02/17/75 238
   89   04 2 1 6.50   .  10.0 1 3
   90   13
   91   01 8A14TRAVIS        3136 1LP 1 MOPAC02/17/75 238
   92   04 2 1 6.50   .  10.0 1 4
   93   13


                 1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
        ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
```

OUTPUT DATA

SUMMARY TABLES OF EIGHT EXAMPLE FLEXIBLE PAVEMENT DESIGN PROBLEMS

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
1	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	8

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCDE	ABCDE	ABCDE	ABCD	ABCD	ABCDE	ABCD	ABCDE
INIT. CONST. COST	5.21	5.30	5.13	5.12	5.20	4.52	4.79	4.83
OVERLAY CONST. COST	0.42	0.42	0.74	0.74	0.74	0.80	1.14	1.14
USER COST	0.12	0.13	0.13	0.13	0.13	0.72	0.19	0.19
ROUTINE MAINT. COST	0.22	0.22	0.22	0.22	0.22	0.20	0.22	0.22
SALVAGE VALUE	-0.76	-0.74	-0.83	-0.77	-0.75	-0.70	-0.79	-0.81
TOTAL COST	5.22	5.33	5.40	5.44	5.54	5.54	5.56	5.57
NUMBER OF LAYERS	5	5	5	4	4	5	4	5
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	4.50	5.50	3.50	4.50	5.50	3.50	3.50	3.50
D(4)	15.00	12.50	17.50	17.50	15.00	12.50	18.00	15.00
D(5)	6.00	6.00	6.00			6.00		6.00
NO.OF PERF.PERIODS	2	2	2	2	2	3	2	2
PERF. TIME (YEARS)								
T(1)	9.4	9.4	9.1	9.0	9.1	6.9	7.9	8.1
T(2)	20.1	20.3	21.0	20.9	21.0	13.2	20.2	20.6
T(3)						20.1		
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	1.3	1.3	2.3	2.3	2.3	1.3	3.3	3.3
O(2)						1.3		
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.75	0.76	0.73	0.73	0.73	0.61	0.67	0.68
SC(2)	0.39	0.39	0.42	0.42	0.42	0.32	0.47	0.47
SC(3)						0.21		

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 79

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
2	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	8

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCDE	ABCDE	ABCD	ABCDE	ABCD	ABCD	ABCD	ABCD
INIT. CONST. COST	5.33	5.14	5.10	5.44	5.41	5.48	4.77	5.24
OVERLAY CONST. COST	0.46	0.79	0.79	0.46	0.43	0.43	1.18	0.79
USER COST	0.12	0.13	0.13	0.13	0.24	0.15	0.19	0.13
ROUTINE MAINT. COST	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
SALVAGE VALUE	-0.77	-0.82	-0.76	-0.77	-0.74	-0.70	-0.77	-0.76
TOTAL COST	5.36	5.47	5.48	5.49	5.55	5.58	5.59	5.62
NUMBER OF LAYERS	5	5	4	5	4	4	4	4
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	4.50	3.50	4.50	5.50	5.50	8.50	3.50	5.50
D(4)	15.00	17.50	17.50	12.50	17.50	10.00	18.00	15.00
D(5)	6.00	6.00		6.00				
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)								
T(1)	9.4	9.1	9.0	9.4	10.1	9.6	7.9	9.1
T(2)	20.1	21.0	20.9	20.3	22.9	20.8	20.2	21.0
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	1.3	2.3	2.3	1.3	1.3	1.3	3.3	2.3
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.75	0.73	0.73	0.76	0.79	0.76	0.67	0.73
SC(2)	0.39	0.42	0.42	0.39	0.41	0.39	0.47	0.42

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 79

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
3	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	8

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCDE	ABCDE	ABCD	ABCDE	ABCD	ABCD	ABCD	ABCD
INIT. CONST. COST	5.29	5.39	5.06	5.13	5.36	5.44	5.19	4.76
OVERLAY CONST. COST	0.46	0.46	0.79	0.79	0.43	0.43	0.79	1.18
USER COST	0.12	0.13	0.13	0.13	0.24	0.15	0.13	0.19
ROUTINE MAINT. COST	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
SALVAGE VALUE	-0.77	-0.76	-0.76	-0.81	-0.74	-0.69	-0.75	-0.77
TOTAL COST	5.33	5.44	5.45	5.45	5.51	5.54	5.58	5.58
NUMBER OF LAYERS	5	5	4	5	4	4	4	4
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	4.50	5.50	4.50	3.50	5.50	8.50	5.50	3.50
D(4)	15.00	12.50	17.50	17.50	17.50	10.00	15.00	18.00
D(5)	6.00	6.00		6.00				
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)								
T(1)	9.4	9.4	9.0	9.1	10.1	9.6	9.1	7.9
T(2)	20.1	20.3	20.9	21.0	22.9	20.8	21.0	20.2
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	1.3	1.3	2.3	2.3	1.3	1.3	2.3	3.3
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.75	0.76	0.73	0.73	0.79	0.76	0.73	0.67
SC(2)	0.39	0.39	0.42	0.42	0.41	0.39	0.42	0.47

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 79

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
4	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	8

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCDE	ABCDE	ABCD	ABCDE	ABCD	ABCD	ABCD	ABCD
INIT. CONST. COST	5.16	5.22	4.94	5.06	5.21	5.02	5.28	5.34
OVERLAY CONST. COST	0.45	0.45	0.76	0.76	0.42	0.76	0.42	0.42
USER COST	0.12	0.13	0.13	0.13	0.24	0.13	0.23	0.15
ROUTINE MAINT. COST	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
SALVAGE VALUE	-0.75	-0.74	-0.74	-0.80	-0.72	-0.73	-0.71	-0.68
TOTAL COST	5.20	5.29	5.31	5.36	5.37	5.40	5.44	5.45
NUMBER OF LAYERS	5	5	4	5	4	4	4	4
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	4.50	5.50	4.50	3.50	5.50	5.50	6.50	8.50
D(4)	15.00	12.50	17.50	17.50	17.50	15.00	15.00	10.00
D(5)	6.00	6.00		6.00				
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)								
T(1)	9.4	9.4	9.0	9.1	10.1	9.1	10.1	9.6
T(2)	20.1	20.3	20.9	21.0	22.9	21.0	22.7	20.8
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	1.3	1.3	2.3	2.3	1.3	2.3	1.3	1.3
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.75	0.76	0.73	0.73	0.79	0.73	0.79	0.76
SC(2)	0.39	0.39	0.42	0.42	0.41	0.42	0.40	0.39

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 79

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
5	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	9

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCDE	ABCDE	ABCD	ABCD	ABCD	ABCDE	ABCD	ABCDE
INIT. CONST. COST	10.19	10.32	9.79	9.91	10.04	8.76	10.37	9.36
OVERLAY CONST. COST	0.67	0.67	1.18	1.18	1.18	1.28	0.63	1.82
USER COST	0.24	0.22	0.23	0.23	0.23	1.28	0.26	0.34
ROUTINE MAINT. COST	0.35	0.35	0.35	0.35	0.35	0.32	0.35	0.35
SALVAGE VALUE	-1.58	-1.66	-1.48	-1.56	-1.64	-1.47	-1.41	-1.57
TOTAL COST	9.86	9.90	10.06	10.11	10.16	10.17	10.19	10.29
NUMBER OF LAYERS	5	5	4	4	4	5	4	5
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	5.50	4.50	6.50	5.50	4.50	3.50	8.50	5.50
D(4)	12.50	15.00	12.50	15.00	17.50	12.50	10.00	10.00
D(5)	6.00	6.00				6.00		6.00
S(1)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
S(2)	6.00	5.00	7.00	6.00	5.00	4.00	9.00	6.00
NO.OF PERF.PERIODS	2	2	2	2	2	3	2	2
PERF. TIME (YEARS)								
T(1)	9.4	9.4	8.9	9.1	9.0	6.9	9.6	8.1
T(2)	20.3	20.1	20.3	21.0	20.9	13.2	20.8	20.8
T(3)						20.1		
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	1.3	1.3	2.3	2.3	2.3	1.3	1.3	3.3
O(2)						1.3		
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.76	0.75	0.72	0.73	0.73	0.61	0.76	0.68
SC(2)	0.39	0.39	0.42	0.42	0.42	0.32	0.39	0.47
SC(3)						0.21		

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 49

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	9

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCD	ABCD	ABCDE	ABCDE	ABCD	ABCD	ABCD	ABCD
INIT. CONST. COST	9.99	9.74	10.38	10.37	9.78	9.83	10.25	9.19
OVERLAY CONST. COST	0.68	1.26	0.73	0.73	1.26	1.26	0.68	1.88
USER COST	0.26	0.23	0.22	0.24	0.23	0.23	0.35	0.34
ROUTINE MAINT. COST	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
SALVAGE VALUE	-1.40	-1.57	-1.66	-1.61	-1.50	-1.54	-1.47	-1.58
TOTAL COST	9.88	10.00	10.02	10.07	10.12	10.12	10.16	10.17
NUMBER OF LAYERS	4	4	5	5	4	4	4	4
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	8.50	4.50	4.50	5.50	6.50	5.50	7.50	3.50
D(4)	10.00	17.50	15.00	12.50	12.50	15.00	12.50	18.00
D(5)			6.00	6.00				
S(1)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
S(2)	9.00	5.00	5.00	6.00	7.00	6.00	8.00	4.00
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)								
T(1)	9.6	9.0	9.4	9.4	8.9	9.1	9.9	7.9
T(2)	20.8	20.9	20.1	20.3	20.3	21.0	22.0	20.2
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	1.3	2.3	1.3	1.3	2.3	2.3	1.3	3.3
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.76	0.73	0.75	0.76	0.72	0.73	0.78	0.67
SC(2)	0.39	0.42	0.39	0.39	0.42	0.42	0.40	0.47

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 61

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
7	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	9

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCD	ABCD	ABCDE	ABCDE	ABCD	ABCD	ABCD	ABCD
INIT. CONST. COST	9.96	9.70	10.32	10.30	9.71	9.76	10.18	9.17
OVERLAY CONST. COST	0.68	1.25	0.73	0.73	1.25	1.25	0.68	1.87
USER COST	0.26	0.23	0.22	0.24	0.23	0.23	0.35	0.34
ROUTINE MAINT. COST	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
SALVAGE VALUE	-1.39	-1.56	-1.65	-1.60	-1.49	-1.53	-1.47	-1.58
TOTAL COST	9.86	9.96	9.97	10.01	10.05	10.06	10.10	10.14
NUMBER OF LAYERS	4	4	5	5	4	4	4	4
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	8.50	4.50	4.50	5.50	6.50	5.50	7.50	3.50
D(4)	10.00	17.50	15.00	12.50	12.50	15.00	12.50	18.00
D(5)			6.00	6.00				
S(1)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
S(2)	9.00	5.00	5.00	6.00	7.00	6.00	8.00	4.00
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)								
T(1)	9.6	9.0	9.4	9.4	8.9	9.1	9.9	7.9
T(2)	20.8	20.9	20.1	20.3	20.3	21.0	22.0	20.2
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	1.3	2.3	1.3	1.3	2.3	2.3	1.3	3.3
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.76	0.73	0.75	0.76	0.72	0.73	0.78	0.67
SC(2)	0.39	0.42	0.39	0.39	0.42	0.42	0.40	0.47

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 63

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
FLEXIBLE PAVEMENT DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
8	14	TRAVIS	3136	01	LP 1 MOPAC	02/17/75	238	9

SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4	5	6	7	8
MATERIAL ARRANGEMENT	ABCD	ABCDE	ABCDE	ABCD	ABCD	ABCD	ABCD	ABCD
INIT. CONST. COST	9.51	10.09	10.05	9.89	9.51	9.47	9.99	9.04
OVERLAY CONST. COST	1.20	0.72	0.72	0.67	1.20	1.20	0.67	1.78
USER COST	0.23	0.22	0.24	0.26	0.23	0.23	0.35	0.34
ROUTINE MAINT. COST	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
SALVAGE VALUE	-1.54	-1.62	-1.57	-1.39	-1.50	-1.45	-1.44	-1.56
TOTAL COST	9.74	9.75	9.78	9.78	9.79	9.80	9.92	9.95
NUMBER OF LAYERS	4	5	5	4	4	4	4	4
LAYER DEPTH (INCHES)								
D(1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
D(2)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
D(3)	4.50	4.50	5.50	8.50	5.50	6.50	7.50	3.50
D(4)	17.50	15.00	12.50	10.00	15.00	12.50	12.50	18.00
D(5)		6.00	6.00					
S(1)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
S(2)	5.00	5.00	6.00	9.00	6.00	7.00	8.00	4.00
NO.OF PERF.PERIODS	2	2	2	2	2	2	2	2
PERF. TIME (YEARS)								
T(1)	9.0	9.4	9.4	9.6	9.1	8.9	9.9	7.9
T(2)	20.9	20.1	20.3	20.8	21.0	20.3	22.0	20.2
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)								
O(1)	2.3	1.3	1.3	1.3	2.3	2.3	1.3	3.3
SWELLING CLAY LOSS (SERVICEABILITY)								
SC(1)	0.73	0.75	0.76	0.76	0.73	0.72	0.78	0.67
SC(2)	0.42	0.39	0.39	0.39	0.42	0.42	0.40	0.47

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 62

OUTPUT DATA

SUMMARY TABLES OF EIGHT EXAMPLE
ACP OVERLAY DESIGN PROBLEMS

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
1A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	3

AVERAGE SCI = 0.100 CONFIDENCE LEVEL = D

SUMMARY OF THE BEST OVERLAY SCHEMES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4
INITIAL OVERLAY				
CONSTRUCTION COST	3.22	2.36	1.93	1.93
USER COST	2.38	1.75	1.43	1.43
FUTURE OVERLAY(S)				
CONSTRUCTION COST	0.0	0.19	0.75	0.40
USER COST	0.0	6.16	12.00	14.14
ROUTINE MAINT. COST	0.28	0.23	0.22	0.21
SALVAGE VALUE	-0.76	-0.75	-0.76	-0.74
TOTAL COST	5.13	9.95	15.58	17.37
NO.OF PERF.PERIODS	1	2	2	3
PERF. TIME (YEARS)				
T(1)	22.9	12.2	8.2	8.2
T(2)		24.5	21.7	16.1
T(3)				23.2
1ST LEVEL-UP(INCHES)	1.0	1.0	1.0	1.0
FUTURE LEVEL-UP(S)	0.5	0.5	0.5	0.5
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)				
O(1)	7.5	5.5	4.5	4.5
O(2)		1.0	3.0	1.0
O(3)				1.0
SWELLING CLAY LOSS (SERVICEABILITY)				
SC(1)	0.55	0.41	0.32	0.32
SC(2)		0.16	0.22	0.16
SC(3)				0.08

THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS 4

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
2A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	3

AVERAGE SCI = 0.100 CONFIDENCE LEVEL = D

SUMMARY OF THE BEST OVERLAY SCHEMES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4
INITIAL OVERLAY				
CONSTRUCTION COST	2.95	2.30	1.93	1.93
USER COST	2.38	1.75	1.43	1.43
FUTURE OVERLAY(S)				
CONSTRUCTION COST	0.0	0.21	0.78	0.44
USER COST	0.0	6.16	12.00	14.14
ROUTINE MAINT. COST	0.28	0.23	0.22	0.21
SALVAGE VALUE	-0.76	-0.75	-0.76	-0.74
TOTAL COST	4.85	9.90	15.61	17.41
NO.OF PERF.PERIODS	1	2	2	3
PERF. TIME (YEARS)				
T(1)	22.9	12.2	8.2	8.2
T(2)		24.5	21.7	16.1
T(3)				23.2
1ST LEVEL-UP(INCHES)	1.0	1.0	1.0	1.0
FUTURE LEVEL-UP(S)	0.5	0.5	0.5	0.5
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)				
O(1)	7.5	5.5	4.5	4.5
O(2)		1.0	3.0	1.0
O(3)				1.0
SWELLING CLAY LOSS (SERVICEABILITY)				
SC(1)	0.55	0.41	0.32	0.32
SC(2)		0.16	0.22	0.16
SC(3)				0.08

THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS 4

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
3A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	3

AVERAGE SCI = 0.100 CONFIDENCE LEVEL = D

SUMMARY OF THE BEST OVERLAY SCHEMES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4
INITIAL OVERLAY				
CONSTRUCTION COST	2.94	2.29	1.93	1.93
USER COST	2.38	1.75	1.43	1.43
FUTURE OVERLAY(S)				
CONSTRUCTION COST	0.0	0.21	0.78	0.44
USER COST	0.0	6.16	12.00	14.14
ROUTINE MAINT. COST	0.28	0.23	0.22	0.21
SALVAGE VALUE	-0.76	-0.75	-0.76	-0.74
TOTAL COST	4.85	9.89	15.60	17.40
NO.OF PERF.PERIODS	1	2	2	3
PERF. TIME (YEARS)				
T(1)	22.9	12.2	8.2	8.2
T(2)		24.5	21.7	16.1
T(3)				23.2
1ST LEVEL-UP(INCHES)	1.0	1.0	1.0	1.0
FUTURE LEVEL-UP(S)	0.5	0.5	0.5	0.5
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)				
O(1)	7.5	5.5	4.5	4.5
O(2)		1.0	3.0	1.0
O(3)				1.0
SWELLING CLAY LOSS (SERVICEABILITY)				
SC(1)	0.55	0.41	0.32	0.32
SC(2)		0.16	0.22	0.16
SC(3)				0.08

THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS 4

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
4A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	3

AVERAGE SCI = 0.100 CONFIDENCE LEVEL = D

SUMMARY OF THE BEST OVERLAY SCHEMES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4
INITIAL OVERLAY				
CONSTRUCTION COST	2.92	2.21	1.84	1.84
USER COST	2.38	1.75	1.43	1.43
FUTURE OVERLAY(S)				
CONSTRUCTION COST	0.0	0.21	0.74	0.44
USER COST	0.0	6.16	12.00	14.14
ROUTINE MAINT. COST	0.28	0.23	0.22	0.21
SALVAGE VALUE	-0.76	-0.74	-0.76	-0.74
TOTAL COST	4.83	9.81	15.48	17.32
NO.OF PERF.PERIODS	1	2	2	3
PERF. TIME (YEARS)				
T(1)	22.9	12.2	8.2	8.2
T(2)		24.5	21.7	16.1
T(3)				23.2
1ST LEVEL-UP(INCHES)	1.0	1.0	1.0	1.0
FUTURE LEVEL-UP(S)	0.5	0.5	0.5	0.5
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)				
O(1)	7.5	5.5	4.5	4.5
O(2)		1.0	3.0	1.0
O(3)				1.0
SWELLING CLAY LOSS (SERVICEABILITY)				
SC(1)	0.55	0.41	0.32	0.32
SC(2)		0.16	0.22	0.16
SC(3)				0.08

THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS 4

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
5A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	4

AVERAGE SCI = 0.100 CONFIDENCE LEVEL = D

SUMMARY OF THE BEST OVERLAY SCHEMES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4
INITIAL OVERLAY				
CONSTRUCTION COST	5.17	3.79	3.10	3.10
USER COST	4.42	3.24	2.65	2.65
FUTURE OVERLAY(S)				
CONSTRUCTION COST	0.0	0.31	1.20	0.63
USER COST	0.0	11.43	22.27	26.24
ROUTINE MAINT. COST	0.43	0.36	0.35	0.32
SALVAGE VALUE	-0.83	-0.80	-0.82	-0.79
TOTAL COST	9.20	18.33	28.76	32.17
NO.OF PERF.PERIODS	1	2	2	3
PERF. TIME (YEARS)				
T(1)	22.9	12.2	8.2	8.2
T(2)		24.5	21.7	16.1
T(3)				23.2
1ST LEVEL-UP(INCHES)	1.0	1.0	1.0	1.0
FUTURE LEVEL-UP(S)	0.5	0.5	0.5	0.5
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)				
O(1)	7.5	5.5	4.5	4.5
O(2)		1.0	3.0	1.0
O(3)				1.0
SWELLING CLAY LOSS (SERVICEABILITY)				
SC(1)	0.55	0.41	0.32	0.32
SC(2)		0.16	0.22	0.16
SC(3)				0.08

THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS 4

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
6A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	4

AVERAGE SCI = 0.100 CONFIDENCE LEVEL = D

SUMMARY OF THE BEST OVERLAY SCHEMES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4
INITIAL OVERLAY				
CONSTRUCTION COST	4.73	3.68	3.10	3.10
USER COST	4.42	3.24	2.65	2.65
FUTURE OVERLAY(S)				
CONSTRUCTION COST	0.0	0.34	1.26	0.70
USER COST	0.0	11.43	22.27	26.24
ROUTINE MAINT. COST	0.43	0.36	0.35	0.32
SALVAGE VALUE	-0.82	-0.80	-0.82	-0.79
TOTAL COST	8.77	18.26	28.81	32.23
NO.OF PERF.PERIODS	1	2	2	3
PERF. TIME (YEARS)				
T(1)	22.9	12.2	8.2	8.2
T(2)		24.5	21.7	16.1
T(3)				23.2
1ST LEVEL-UP(INCHES)	1.0	1.0	1.0	1.0
FUTURE LEVEL-UP(S)	0.5	0.5	0.5	0.5
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)				
O(1)	7.5	5.5	4.5	4.5
O(2)		1.0	3.0	1.0
O(3)				1.0
SWELLING CLAY LOSS (SERVICEABILITY)				
SC(1)	0.55	0.41	0.32	0.32
SC(2)		0.16	0.22	0.16
SC(3)				0.08

THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS 4

TEXAS HIGHWAY DEPARTMENT
FPS-13-TTI
ACP OVERLAY DESIGN

PROB	DIST.	COUNTY	CONT.	SECT.	HIGHWAY	DATE	IPE	PAGE
7A	14	TRAVIS	3136	1	LP 1 MOPAC	02/17/75	238	4

AVERAGE SCI = 0.100 CONFIDENCE LEVEL = D

SUMMARY OF THE BEST OVERLAY SCHEMES
IN ORDER OF INCREASING TOTAL COST

	1	2	3	4
INITIAL OVERLAY				
CONSTRUCTION COST	4.72	3.67	3.09	3.09
USER COST	4.42	3.24	2.65	2.65
FUTURE OVERLAY(S)				
CONSTRUCTION COST	0.0	0.34	1.25	0.70
USER COST	0.0	11.43	22.27	26.24
ROUTINE MAINT. COST	0.43	0.36	0.35	0.32
SALVAGE VALUE	-0.82	-0.80	-0.82	-0.79
TOTAL COST	8.76	18.24	28.79	32.21
NO.OF PERF.PERIODS	1	2	2	3
PERF. TIME (YEARS)				
T(1)	22.9	12.2	8.2	8.2
T(2)		24.5	21.7	16.1
T(3)				23.2
1ST LEVEL-UP(INCHES)	1.0	1.0	1.0	1.0
FUTURE LEVEL-UP(S)	0.5	0.5	0.5	0.5
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)				
O(1)	7.5	5.5	4.5	4.5
O(2)		1.0	3.0	1.0
O(3)				1.0
SWELLING CLAY LOSS (SERVICEABILITY)				
SC(1)	0.55	0.41	0.32	0.32
SC(2)		0.16	0.22	0.16
SC(3)				0.08

THE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSIDERED WAS 4

APPENDIX C

DOCUMENTATION OF MASTER PAVEMENT CROSS-SECTION MODEL, MPCS

Page

INTRODUCTION

The Master Pavement Cross Section Model (MPCS) is developed under Research Study 1-8-69-123, "A Systems Analysis of Pavement Design and Research Implementation". This study is being conducted jointly in three agencies - The State Department of Highways and Public Transportation at Austin, The Texas Transportation Institute at College Station, and The Center for Highway Research at Austin, as a part of the cooperative research program with the Department of Transportation, Federal Highway Administration.

The MPCS computer program calculates the area of each layer (or material) in any complex cross-section design. The algorithm requires the solution of a set of simultaneous linear algebraic equations to calculate the coordinates of each point which defines the cross-section. Also, a double meridian distance method is utilized in this program to calculate the cross-sectional area bounded by user-specified points in the two-dimensional plane.

PROGRAM IDENTIFICATION

Title:	Master Pavement Cross Section Model (MPCS)
Language:	FORTRAN IV
Machine:	IBM 360/65
Programmer:	Chester H. Michalak
Availability:	Department of Pavement Design
	Texas Transportation Institute
	Texas A&M University
	College Station, Texas 77843
	Phone (713) 845-3735
Date:	April 1975
Source Deck:	about 300 cards
Storage:	100 k bytes
Timing:	(1) Compilation time - 0.22 minutes (FORTRAN G compiler)
	(2) Execution time - ranging from 0.25 to 0.45 minutes
Printout:	(1) Program list - about 300 lines
	(2) Program output - 3 pages per problem

PROGRAM DESCRIPTION

The Master Pavement Cross Section (MPCS) program was written to find the end area of a pavement cross section using the double meridian distance method for computing the area. The computer code is IBM FORTRAN IV, with the "END = " option of the READ statement as the only non-standard FORTRAN statement used. The program consists of a main program and one subroutine, SUBROUTINE MATINV, which can be any routine that will solve a set of simultaneous linear equations.

The MPCS computer program was written to give pavement design engineers a convenient and simple method for finding the end areas of pavement cross sections for accurate cost analysis of the pavement designs from the Flexible Pavement System computer program. The program input also identifies the minimum number of cross section variables that should be specified in a pavement feedback data system, since the input data contains the minimum amount of information required to completely describe any conceivable pavement cross section.

If there are N points of intersection of lines that delineate the cross section, exactly 2N dimensions or slopes will have to be known in order to completely specify the cross-sectional geometry.

There will always be certain values that are known (slopes, lane widths, layer thicknesses). By choosing the origin of a co-ordinate system to define the pavement cross section in a two dimensional x-y plane, it is possible to write a slope equation, a horizontal distance equation, and a thickness equation to define every straight line or point that bounds the pavement cross section. If the number of unknown values (slopes, thicknesses, distances) equals the number of equations that define the bounded area, it is possible to solve these equations to find the co-ordinates of all the unknown points that define the area.

The known values (slopes, distances, thicknesses) are stored in a two-dimentional array as coefficients of simultaneous linear equations. The array is a (2N+1) x (2N+1) matrix, called the G matrix where N is the total number of points that define the pavement cross section. The $(2N+1)^{th}$ column stores the constants, i.e., the distances and thicknesses. The $(2N+1)^{th}$ row is used for coding convenience and does not have any specific usage. The simultaneous equations are solved by any convenient method (in this case SUBROUTINE MATINV) and the solutions of the equations are stored in a vector as the x, y co-ordinates that define the bounded area of the pavement cross section. The double meridian distance equation is then used to calculate the area of each layer in the pavement cross section from the x, y co-ordinates. Certain input and output data is printed and the program code is repeated for as many pavement cross sections as there is data provided for. A more detailed explanation of the MPCS computer code follows.

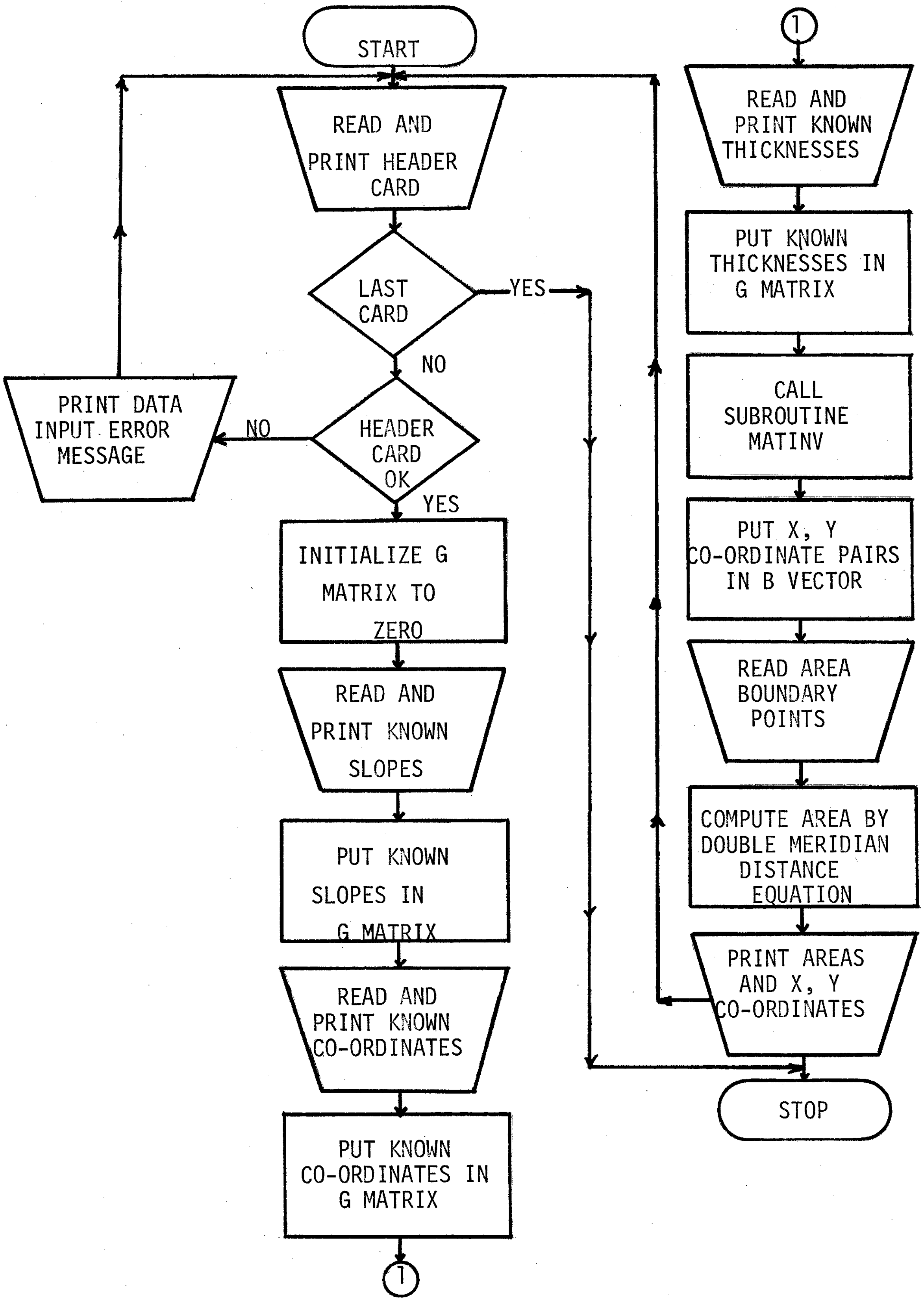
The known values of slope, co-ordinates, and thicknesses are punched on computer cards according to the formats specified. A header card containing the problem number, the total number of x, y co-ordinates, the number of known slopes, known co-ordinates, known thicknesses, and the number of bounded areas is the first input card. As a check on the inputs on the header card, a test is made to determine if the number of knowns is sufficient to determine the unknown co-ordinates before the program continues. If the input data fails the test, the program normally prints an error message for incorrect data input. Since MPCS is recursive, the G (for geometry) matrix is set to zero for each new cross section problem.

The known slopes are input next and stored in the G matrix as described previously in the main text. The known co-ordinates are then input and stored in the G matrix. The known thicknesses are read in and stored in the G matrix and at this point the G matrix contains all the known values as coefficients of simultaneous linear equations. Subroutine MATINV is then called to solve the equations by inverting the G matrix. The solution values are then stored in the B vector as the x, y co-ordinates that define the bounded areas.

The numbers of the co-ordinate points that define each individual material area of the total area are read in and the appropriate x, y values are selected from the B vector to calculate the individual area by the double meridian distance equation. The co-ordinates of the points defining each area and the area in square feet is printed for each bounded area and the program code returns to begin work on the next problem or terminates normally.

Subroutine MATINV can be any routine the user desires to use to solve a set of simultaneous linear equations, so it will not be described here. It may be necessary to make minor revisions to the computer code for any specific routine selected.

FLOWCHART


START
READ AND PRINT HEADER CARD
LAST CARD
YES
NO
HEADER CARD OK
NO
PRINT DATA INPUT ERROR MESSAGE
YES
INITIALIZE G MATRIX TO ZERO
READ AND PRINT KNOWN SLOPES
PUT KNOWN SLOPES IN G MATRIX
READ AND PRINT KNOWN CO-ORDINATES
PUT KNOWN CO-ORDINATES IN G MATRIX
1
1
READ AND PRINT KNOWN THICKNESSES
PUT KNOWN THICKNESSES IN G MATRIX
CALL SUBROUTINE MATINV
PUT X, Y CO-ORDINATE PAIRS IN B VECTOR
READ AREA BOUNDARY POINTS
COMPUTE AREA BY DOUBLE MERIDIAN DISTANCE EQUATION
PRINT AREAS AND X, Y CO-ORDINATES
STOP

PROGRAM LISTING

```
C
C
C     MASTER PAVEMENT CROSS SECTION (MPCS)                        04-28-75
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION G(41,41), B(41), IP(14), AREA(20)
C
      DATA X /'X'/
C
    1 CONTINUE
C
      WRITE(6,250)
  250 FORMAT( '1' )
C
C     READ HEADER CARD WITH NO. OF PONTS, ETC.
C
      READ(5,100,END=50) NPROB, NPTS, NSLOPE, NCOORD, NTHICK, NMTLS
  100 FORMAT( 6I5 )
C
      WRITE(6,200) NPROB, NPTS, NSLOPE, NCOORD, NTHICK, NMTLS
  200 FORMAT(4(/),T10,'PROBLEM',I6,' ..',3(/),T10,'INPUT TABLE 1. BASIC
     2PARAMETERS'//T10,'NUMBER OF POINTS',T41,I5/T10,'NUMBER OF KNOWN SL
     3OPES',T41,I5/T10,'NUMBER OF KNOWN COORDINATES',T41,I5/T10,'NUMBER
     4OF KNOWN THICKNESSES',T41,I5/T10,'NUMBER OF BOUNDED AREAS',T41,I5)
C
C     CHECK FOR ALL DATA SPECIFIED
C
      NSUM = NSLOPE + NCOORD + NTHICK
      IF( 2*NPTS .NE. NSUM ) GO TO 25
C
C     ZERO OUT THE G MATRIX AND B VECTOR
      NSUM = NSUM + 1
      DO 3 I = 1, NSUM
      DO 3 J = 1, NSUM
      G(I,J) = 0.0
    3 CONTINUE
C
      WRITE(6,202)
  202 FORMAT(2(/),T10,'INPUT TABLE 2. KNOWN SLOPES'//T10,'START POINT
     2END POINT     SLOPE'/)
C     READ IN POINTS AND SLOPES
C
      DO 5 I = 1, NSLOPE
C
      READ(5,101) IP1, IP2, SLOPE
  101 FORMAT( 2I3, T11, G15.5 )
C
C
      J = 2*IP1 - 1
      K = 2*IP2 - 1
C
      G(I,J) = SLOPE
      G(I,J+1) = -1.0
      G(I,K) = -SLOPE
      G(I,K+1) = 1.0
      G(I,NSUM) = 0.0
      WRITE(6,203) IP1, IP2, SLOPE
  203 FORMAT(3X,2I13,F13.4)
C
    5 CONTINUE
C
      L = NSLOPE
C
      WRITE(6,204)
  204 FORMAT(2(/),T10,'INPUT TABLE 3. KNOWN COORDINATES'//T11,'ID',4X,'P
     2OINT',4X,'VALUE (FEET)'/)
C
C     READ IN VALUES FOR THE KNOWN POINTS
C
      DO 7 I = 1, NCOORD
C
      READ(5,102) PT, IP1, VALUE
  102 FORMAT( 1X, A1, I3, T11, G15.5 )
C
      K = L + I
      J = 2*IP1
      IF( PT .EQ. X ) J = 2*IP1 - 1
      G(K,J) = 1.0
      G(K,NSUM) = VALUE
C
      WRITE(6,205) PT, IP1, VALUE
  205 FORMAT(T12,A1,I8,F15.4)
C
    7 CONTINUE
C
      L = K
C
      IF( NTHICK .EQ. 0 ) GO TO 11
C     READ IN KNOWN LAYER THICKNESSES
C
      WRITE(6,206) NPROB
  206 FORMAT('1',5(/),T10,'PROBLEM',I6,' ..',3(/),
     1                 T10,'INPUT TABLE 4. KNOWN THICKNESSES'//T10,'HIGH
     2POINT    LOW POINT    THICKNESS (FEET)'/)
C
```

```
      DO 10 I = 1, NTHICK
C
      READ(5,101) IP1, IP2, DIST
C
      K = L + I
      J = 2*IP1
      M = 2*IP2
C
      G(K,J) = 1.0
      G(K,M) = -1.0
      G(K,NSUM) = DIST
C
      WRITE(6,301) IP1, IP2, DIST
  301 FORMAT(4X,2I12,F18.4)
C
   10 CONTINUE
C
   11 CONTINUE
C
      KK = K
C
C
C     PUT G MATRIX IN A VECTOR FOR MATINV ROUTINE
C
C
C     INVERT THE G MATRIX
C
C
      CALL MATINV ( G, K, 0.1D-37, DET )
C
      IF( DET .EQ. 0.0D0 ) WRITE(6,207)
  207 FORMAT(/T10, 'SINGULAR MATRIX -- ANSWERS ARE MEANINGLESS' )
C
C
      DO 12 J = 1, NSUM
      B(J) = G(J,NSUM)
   12 CONTINUE
C
C     READ IN THE BOUNDARY POINTS COUNTER-CLOCKWISE FOR EACH LAYER
C
C
      WRITE(6,211)
  211 FORMAT(2(/),T10,'INPUT TABLE 5. BOUNDARY POINTS'//T10,'AREA NO.',
     24X,'BOUNDARY POINTS'/)
C
      DO 15 I = 1, NMTLS
C
      READ(5,103) J, ( IP(L), L = 1, J )
  103 FORMAT( I2, T11, 14I5 )
      WRITE(6,302) I,(IP(N),N=1,J)
  302 FORMAT(13X,I2,5X,14I3)
C
C     J IS THE NO. OF POINTS DEFINING THE LAYER
C
      DMD = 0.0
C
      JP = J + 1
      IP(J+1) = IP(1)
      IP(J+2) = IP(2)
C
C     CALCULATE THE DOUBLE MERIDIAN DISTANCE AROUND THE LAYER
C
      DO 13 N = 2, JP
      M = 2*IP(N) - 1
      N1 = 2*IP(N+1)
      N2 = 2*IP(N-1)
      DMD = DMD + B(M) * (B(N1) - B(N2) )
C
   13 CONTINUE
C
C
C
      AREA(I) = 0.5 * DMD
C
   15 CONTINUE
C
C     PRINT OUT THE AREAS OF THE LAYERS
C
      WRITE(6,303) NPROB
  303 FORMAT('1',5(/),T10,'PROBLEM',I6,' ..',3(/),
     1                    T10,'OUTPUT TABLE 1. AREA'          //T10,'AREA N
     2O.   AREA (SQ. FEET)'/)
      DO 304 I=1,NMTLS
  304 WRITE(6,212) I, AREA(I)
  212 FORMAT(13X,I2,F17.4)
C
C     PRINT THE X AND Y COORDINATES OF THE POINTS
C
      WRITE(6,209)
  209 FORMAT(2(/),T10,'OUTPUT TABLE 2. COORDINATES'//T19,'X COORD.',5X,
     2'Y COORD.'/T10,'POINT',5X,'(FEET)',7X,'(FEET)'/)
C
      DO 20 I = 1, NPTS
      L = 2*I
      WRITE(6,210) I, B(L-1), B(L)
  210 FORMAT(10X,I3,F13.4,F13.4)
```

```
   20 CONTINUE
C
C
      GO TO 1
C
   25 CONTINUE
C
C     PRINT THE ERROR MESSAGE FOR NOT ENOUGH DATA SPECIFIED
C
      WRITE(6,201)
  201 FORMAT( / T10,    'ERROR -- NOT ENOUGH DATA SPECIFIED'   )
      NSUM=NSUM+NMTLS
      READ(5,300) (DUM,I=1,NSUM)
  300 FORMAT(A1)
      GO TO 1
C
C
   50 CONTINUE
      STOP
      END
```

```
      SUBROUTINE MATINV ( A, N, EPS, DET  )
C
C    SUBROUTINE DIMEON IS A DOUBLE PRECISION MATRIX INVERSION ROUTINE
C     THAT SEEKS MAXIMUM PIVIOT ELEMENTS AND INVERTS IN PLACE
C    A = ARRAY CONTAINING MATRIX OF COEFFICIENTS TO BE INVERTED
C    N = ORDER OF A
C    EPS = MINIMUM ALLOWABLE VALUE OF MAXIMUM PIVIOT BEFORE MATRIX IS
C     TERMED SINGULAR
C    DET = VALUE OF DETERMINANT OF THE MATRIX
C
      IMPLICIT  REAL  *  8  ( A-H,O-Z )
           INTEGER*2  IPIV, ICJ
      DIMENSION Y(40), ICJ(40), IPIV(2,40), A(41,41)
      M  =  N   +  1
             IF(N .EQ. 1)  GO TO 1
              NX = N + 1
      DET=1.0
             ASSIGN 205 TO IZERO
                DO 1000  K=1,N
      KM1=K-1
           IF(KM1 .GT. 0)  ASSIGN 95 TO IZERO
      BIGA=0.0
      DO 101 I=1,N
      DO 101 J=1,N
           GO TO IZERO, (95,205)
   95 DO 102 II=1,KM1
      IF(I.EQ.IPIV(1,II).OR.J.EQ.IPIV(2,II)) GO TO 101
  102 CONTINUE
  205   CONTINUE
      IF(DABS(A(I,J)).LT.BIGA) GO TO 101
      BIGA=DABS(A(I,J))
      IPIV(1,K)=I
      IPIV(2,K)=J
  101 CONTINUE
      IF(BIGA.GE.EPS) GO TO 201
      DET = 0.0
      GO TO 200
  201 IR=IPIV(1,K)
      JC=IPIV(2,K)
      BIGA=A(IR,JC)
      DET=DET*BIGA
      DO 103 LL=1,M
  103 A(IR,LL)=A(IR,LL)/BIGA
      A(IR,JC)=1.0/BIGA
      DO 100 LLL=1,N
      AJCK=A(LLL,JC)
      IF(LLL.EQ.IR) GO TO 100
      A(LLL,JC)=-AJCK/BIGA
      DO 104 L4=1,M
      IF(L4.EQ.JC) GO TO 104
      A(LLL,L4)=A(LLL,L4) -AJCK*A(IR,L4)
  104 CONTINUE
  100 CONTINUE
 1000    CONTINUE
      DO 105 I=1,N
      IR=IPIV(1,I)
      ICJ(IR)=JC
  105 CONTINUE
      ICT=0
      NM1=N-1
      DO 106 I=1,NM1
      IP1=I+1
      DO 106 J=IP1,N
      IF(ICJ(J).GE.ICJ(I)) GO TO 106
      ITEMP=ICJ(J)
      ICJ(J)=ICJ(I)
      ICJ(I)=ITEMP
      ICT=ICT+1
  106 CONTINUE
      IF((ICT/2)*2.NE.ICT.AND.N.NE.1) DET=-DET
      DO 107 J=1,M
      DO 108 I=1,N
      JC=IPIV(2,I)
      IR=IPIV(1,I)
  108 Y(JC)=A(IR,J)
      DO 107 K=1,N
  107 A(K,J)=Y(K)
      DO 110 I=1,N
      DO 111 J=1,N
      IR =IPIV(1,J)
      JC=IPIV(2,J)
  111 Y(IR)=A(I,JC)
      DO 110 K=1,N
  110 A(I,K)=Y(K)
  200 RETURN
    1    DET = A(1,1)
             A(1,2)  =  A(1,2)  /  A(1,1)
             A(1,1) = 1.0D0 / A(1,1)
             RETURN
      END
```

NAME DICTIONARY

AREA	square foot quantity of each bounded area
B	vector of co-ordinates of the x and y points that define the pavement cross section, in feet
DET	determinant of the G (coefficient) matrix, used to check for a solution to the matrix inversion
DIST	thickness, in feet, between two points
DMD	double meridian distance of each bounded cross sectional area in square feet
DUM	number of cards skipped if there is an error in data input
G	matrix of the coefficients of the slope, distance, and thickness equations
IP	vector of the points that define each bounded cross sectional area
IP1	starting co-ordinate of each slope (either x or y)
IP2	ending co-ordinate of each slope (either x or y)
J	subscript denoting the column number in the G matrix of the coefficients for the slope, distance and thickness equations
JP	number of points defining a bounded area plus one used in calculating the double meridian distance of a cross sectional area
K	subscript denoting the raw number in the G matrix of the coefficients for the slope, distance and thickness equations
L	pointer to the starting locations of the slope, distance and thickness coefficients in the G matrix
M	subscript denoting the column position of the coefficient in the G matrix of the low point co-ordinate of the thickness equation
N1	subscript of y(i-1) in the double meridian distance calculation equation
N2	subscript of y(i+1) in the double meridian distance calculation equation
NCOORD	number of known co-ordinates
NMTLS	number of bounded areas

NPROB	problem identification number
NPTS	total number of co-ordinates defining the cross sectional area
NSUM	sum of number of co-ordinates, number of slopes, and number of thicknesses, to verify data input
NSLOPE	number of known slopes
NTHICK	number of known thicknesses
PT	denotes x or y co-ordinate of each point
SLOPE	a known slope between two points of a bounded area
VALUE	distance in feet of an x or y co-ordinate from the origin
X	test value to check if a known co-ordinate is an x or y co-ordinate

CRITICAL DIMENSION STATEMENTS

The following variables with FORTRAN DIMENSION statements should be checked when planning changes to the MPCS program to prevent potential illegal subscript values and storing numbers outside their assigned arrays. If dimensions of the arrays are defined as:

M = maximum number of points in the cross-section,

N = maximum number of bounded areas,

K = maximum number of points defining a specific area.

The following arrays in the MAIN program should be dimensioned as:

G(2M + 1, 2M + 1)

B(2M + 1)

IP(K)

AREA(N)

The following arrays in subroutine MATINV should be dimensioned as:

Y(2M)

ICJ(2M)

IPIV(2, 2M)

A(2M + 1, 2M + 1)

In the current setup of the MPCS, M = 20, N = 20, K = 14.

INPUT GUIDE

The MPCS computer program can solve one or more problems in one run. Input data is one or more sets of data cards, one set for each problem. Each set consists of five card types as shown in the input guide tables.

Card type 1 includes basic parameters such as problem number, number of points (NPTS), number of known slopes (NSLOPE), number of known coordinates (NCOORD), number of known thicknesses (NTHICK), and number of bounded areas (NMTLS). The following restrictions must be noted: NPTS $\leq$ 20, NMTLS $\leq$ 20 and 2 x NPTS = NSLOPE + NCOORD + NTHICK.

The second card type indicates the known side slope of a cross-section and must be coded NSLOPE times. The start point number and end point number can be reversed without causing any difference in program output. The input slope is the tangent of the angle above the horizontal. For example, a 2 to 1 slope would be input as a 0.5 on Card 2, Variable 3. A slope pointing up toward the right is positive and one pointing down toward the right is negative. The sign of the slope should be input as part of Variable 2.3.

NCOORD cards of the third card type are required. The coordinate, either along the x-axis or along the y-axis, of a point in the x-y plane is coded on this card. Actually, the axes can be placed in any convenient location so that most coordinates can be determined easily.

Card type 4, which describes a known layer thickness within the cross-section, must be coded NTHICK times. If the high and low point numbers are reversed in their columns, the layer thickness must use a negative value.

Card type 5 is coded NMTLS times. Included in the card type are number of boundary points and the point numbers which define a specific area of the cross section.

CARD TYPE 1: BASIC PARAMETER

Variable Number	Variable	Format	Column
1.1	Problem number	I5	1-5
1.2	Number of points (Maximum 20)	I5	6-10
1.3	Number of known slopes	I5	11-15
1.4	Number of known coordinates	I5	16-20
1.5	Number of known thicknesses	I5	21-25
1.6	Number of bounded areas (Maximum 20)	I5	26-30

CARD TYPE 2: KNOWN SLOPE

Variable Number	Variable	Format	Column
2.1	Start point number	I3	1-3
2.2	End point number	I3	4-6
2.3	Slope	G15.5	11-25

CARD TYPE 3: KNOWN COORDINATE

Variable Number	Variable	Format	Column
3.1	X or Y axis	A1	2
3.2	Point number	I3	3-5
3.3	Value (feet)	G15.5	11-25

CARD TYPE 4: KNOWN THICKNESS

Variable Number	Variable	Format	Column
4.1	High point number	I3	1-3
4.2	Low point number	I3	4-6
4.3	Thickness (feet)	G15.5	11-25

CARD TYPE 5: BOUNDARY POINTS

Variable Number	Variable	Format	Column
5.1	Number of boundary points (Max. 14)	I2	1-2
5.2	First boundary point	I5	11-15
5.3	Second boundary point	I5	16-20
.			
.			
.			
5.15	Fourteenth boundary point	I5	76-80

OUTPUT FORMAT

Printout of the MPCS computer program is composed of five input tables and two output tables:

Input table 1 - Basic parameters.

Input table 2 - Known slopes.

Input table 3 - Known coordinates.

Input table 4 - Known thicknesses.

Input table 5 - Boundary points.

Output table 1 - Calculated area.

Output table 2 - Coordinates.

The printouts are self-explanatory.

EXAMPLE PROBLEMS

The coordinates and cross-sectional areas of the four pavement cross-sections shown in Figure 8 are determined by computer program MPCS. Input data and program printouts are documented herein to illustrate the utilization of the MPCS.

INPUT DATA

PROBLEM NO. 1-4

(See Figure 8)

EXAMPLE INPUT DATA FOR MPCS

COLUMN NUMBER

```
CARD            1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
NUMBER ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

     1     1   16   21    5    6    6
     2   1  2    -0.0156
     3   3  4    -0.0156
     4   5  6    -0.0156
     5   7  8    -0.0156
     6   9 10    -0.0156
     7   1  3     1.0000
     8   3  5     1.0000
     9   5  7     1.0000
    10   7  9     1.0000
    11  12  9     1.0000
    12   2  4    -1.0000
    13   4  6    -1.0000
    14   6  8    -1.0000
    15   8 10    -1.0000
    16  14 10    -1.0000
    17   9 13     0.0625
    18  11 12     0.0625
    19  10 16    -0.0625
    20  15 14    -0.0625
    21  11 13     0.1667
    22  15 16    -0.1667
    23  Y  1      0.
    24  X 13     -6.
    25  X  9      0.
    26  X 10     24.
    27  X 16     34.
    28   9  7     0.0625
    29   9 12     0.4167
    30  10 14     0.4167
    31   7  5     0.3333
    32   5  3     0.3333

                1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
       ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
```

EXAMPLE INPUT DATA FOR MPCS (CONTINUED)

COLUMN NUMBER

```
CARD              1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
NUMBER   ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

  33       3  1     1.0000
  34      4            7    8   10    9
  35      4            5    6    8    7
  36      4            3    4    6    5
  37      4            1    2    4    3
  38      4           11   12    9   13
  39      4           14   15   16   10
  40         2   16   21    5    6    6
  41       1  2    -0.0156
  42       3  4    -0.0156
  43       5  6    -0.0156
  44       1  3     1.0000
  45       3  5     1.0000
  46       8 10     1.0000
  47      10  5     1.0000
  48       2  4    -1.0000
  49       4  6    -1.0000
  50      12 14    -1.0000
  51      14  6    -1.0000
  52      11  5     0.0625
  53       9 10     0.0625
  54       7  8     0.0625
  55       6 16    -0.0625
  56      14 15    -0.0625
  57      12 13    -0.0625
  58       7  9     0.1667
  59       9 11     0.1667
  60      13 15    -0.1667
  61      15 16    -0.1667
  62      Y  1      0.
  63      X 11     -6.
  64      X  5      0.

                  1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
         ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
```

EXAMPLE INPUT DATA FOR MPCS (CONTINUED)

COLUMN NUMBER

```
  CARD          1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
NUMBER ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

  65    X  6     24.
  66    X 16     34.
  67      5  3     1.0000
  68      5 10     0.4167
  69      6 14     0.4167
  70      3  1    0.5000
  71     10  8    0.5000
  72     14 12    0.5000
  73     4            3    4    6    5
  74     4            1    2    4    3
  75     4            9   10    5   11
  76     4            7    8   10    9
  77     4           14   15   16    6
  78     4           12   13   15   14
  79        3   15   20    5    5    6
  80      1  2     0.0625
  81     11  4     0.0625
  82      9 10     0.0625
  83      8  6     0.0625
  84      7 12    -0.0625
  85     14 13    -0.0625
  86      5 15    -0.0625
  87      1 11     0.1667
  88     11  9     0.1667
  89      9  8     0.1667
  90     12 13    -0.1667
  91     13 15    -0.1667
  92     15  3    -0.1667
  93      6  7    -0.0156
  94      4  5    -0.0156
  95      2  3    -0.0156
  96      4 10     1.0000

                1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
       ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
```

EXAMPLE INPUT DATA FOR MPCS (CONTINUED)

COLUMN NUMBER

```
CARD            1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
NUMBER ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

    97  10  6     1.0000
    98   7 14    -1.0000
    99  14  5    -1.0000
   100  Y  1      0.
   101  X  6      0.
   102  X  8     -6.
   103  X  7     24.
   104  X 12     34.
   105   6 10     0.4167
   106   7 14     0.4167
   107   6  4     1.0000
   108  11  1     2.0000
   109   4  2     1.1667
   110  4            4    5    7    6
   111  7            1    2    3   15    5    4   11
   112  4            9   10    6    8
   113  4           11    4   10    9
   114  4           14   13   12    7
   115  4            5   15   13   14
   116     4   17   15   15    4    6
   117   1  2    -0.0156
   118   2  3    -0.0542
   119   4  5    -0.0156
   120   5  6    -0.0542
   121   3  6    -0.167
   122   7  8    -0.0156
   123   8  9    -0.0156
   124   9 10    -0.0156
   125  10 11    -0.0542
   126   6 11    -0.167
   127  14 15    -0.0156
   128  12 13    -0.0156

                1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
       ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
```

EXAMPLE INPUT DATA FOR MPCS (CONTINUED)

COLUMN NUMBER

```
CARD            1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
NUMBER ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

129     15 16    -0.0156
130     16 17    -0.0625
131     11 17    -0.167
132     X  1     0.
133     X  4     0.
134     X  7     0.
135     X  8       1.
136     X 14       1.
137     X  9       7.
138     X 12       7.
139     X 15       7.
140     X  2      31.
141     X  5      31.
142     X 10       31.
143     X 13       31.
144     X 16       31.
145     X 17       41.
146     Y  3     0.
147       4  1       1.
148       7  4      0.3333
149     12  9      0.3333
150     14  8      0.5
151     5             8    9   12   15   14
152     4            12   13   16   15
153     4             9   10   13   12
154     5            10   11   17   16   13
155     8             4    5    6   11   10    9    8    7
156     6             1    2    3    6    5    4
```


```
                1    1    2    2    3    3    4    4    5    5    6    6    7    7    8
       ....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
```

OUTPUT DATA

FOR CROSS SECTIONS IN FIGURE 8

PROBLEM 1 ..

INPUT TABLE 1. BASIC PARAMETERS

NUMBER OF POINTS	16
NUMBER OF KNOWN SLOPES	21
NUMBER OF KNOWN COORDINATES	5
NUMBER OF KNOWN THICKNESSES	6
NUMBER OF BOUNDED AREAS	6

INPUT TABLE 2. KNOWN SLOPES

START POINT	END POINT	SLOPE
1	2	-0.0156
3	4	-0.0156
5	6	-0.0156
7	8	-0.0156
9	10	-0.0156
1	3	1.0000
3	5	1.0000
5	7	1.0000
7	9	1.0000
12	9	1.0000
2	4	-1.0000
4	6	-1.0000
6	8	-1.0000
8	10	-1.0000
14	10	-1.0000
9	13	0.0625
11	12	0.0625
10	16	-0.0625
15	14	-0.0625
11	13	0.1667
15	16	-0.1667

INPUT TABLE 3. KNOWN COORDINATES

ID	POINT	VALUE (FEET)
Y	1	0.0
X	13	-6.0000
X	9	0.0
X	10	24.0000
X	16	34.0000

PROBLEM 1 ..

INPUT TABLE 4. KNOWN THICKNESSES

HIGH POINT	LOW POINT	THICKNESS (FEET)
9	7	0.0625
9	12	0.4167
10	14	0.4167
7	5	0.3333
5	3	0.3333
3	1	1.0000

INPUT TABLE 5. BOUNDARY POINTS

AREA NO.	BOUNDARY POINTS			
1	7	8	10	9
2	5	6	8	7
3	3	4	6	5
4	1	2	4	3
5	11	12	9	13
6	14	15	16	10

PROBLEM 1 ..

OUTPUT TABLE 1. AREA

AREA NO.	AREA (SQ. FEET)
1	1.5274
2	8.2816
3	8.5108
4	26.9105
5	2.9948
6	4.5575

OUTPUT TABLE 2. COORDINATES

POINT	X COORD. (FEET)	Y COORD. (FEET)
1	-1.7291	0.0
2	25.7839	-0.4292
3	-0.7291	1.0000
4	24.7522	0.6025
5	-0.3958	1.3333
6	24.4083	0.9464
7	-0.0625	1.6666
8	24.0645	1.2902
9	0.0	1.7291
10	24.0000	1.3547
11	-9.7491	0.7291
12	-0.4167	1.3124
13	-6.0000	1.3541
14	24.4167	0.9380
15	37.7491	0.1047
16	34.0000	0.7297

PROBLEM 2 ..

INPUT TABLE 1. BASIC PARAMETERS

NUMBER OF POINTS	16
NUMBER OF KNOWN SLOPES	21
NUMBER OF KNOWN COORDINATES	5
NUMBER OF KNOWN THICKNESSES	6
NUMBER OF BOUNDED AREAS	6

INPUT TABLE 2. KNOWN SLOPES

START POINT	END POINT	SLOPE
1	2	-0.0156
3	4	-0.0156
5	6	-0.0156
1	3	1.0000
3	5	1.0000
8	10	1.0000
10	5	1.0000
2	4	-1.0000
4	6	-1.0000
12	14	-1.0000
14	6	-1.0000
11	5	0.0625
9	10	0.0625
7	8	0.0625
6	16	-0.0625
14	15	-0.0625
12	13	-0.0625
7	9	0.1667
9	11	0.1667
13	15	-0.1667
15	16	-0.1667

INPUT TABLE 3. KNOWN COORDINATES

ID	POINT	VALUE (FEET)
Y	1	0.0
X	11	-6.0000
X	5	0.0
X	6	24.0000
X	16	34.0000

PROBLEM 2 ..

INPUT TABLE 4. KNOWN THICKNESSES

HIGH POINT	LOW POINT	THICKNESS (FEET)
5	3	1.0000
5	10	0.4167
6	14	0.4167
3	1	0.5000
10	8	0.5000
14	12	0.5000

INPUT TABLE 5. BOUNDARY POINTS

AREA NO.	BOUNDARY POINTS
1	3 4 6 5
2	1 2 4 3
3	9 10 5 11
4	7 8 10 9
5	14 15 16 6
6	12 13 15 14

PROBLEM 2 ..

OUTPUT TABLE 1. AREA

AREA NO.	AREA (SQ. FEET)
1	25.4061
2	13.4768
3	2.9948
4	5.3117
5	4.5575
6	7.1867

OUTPUT TABLE 2. COORDINATES

POINT	X COORD. (FEET)	Y COORD. (FEET)
1	-1.5000	0.0
2	25.5475	-0.4219
3	-1.0000	0.5000
4	25.0317	0.0939
5	0.0	1.5000
6	24.0000	1.1256
7	-14.2477	-0.2499
8	-0.9167	0.5833
9	-9.7491	0.5000
10	-0.4167	1.0833
11	-6.0000	1.1250
12	24.9167	0.2089
13	42.2477	-0.8743
14	24.4167	0.7089
15	37.7491	-0.1244
16	34.0000	0.5006

PROBLEM 3 ..

INPUT TABLE 1. BASIC PARAMETERS

NUMBER OF POINTS	15
NUMBER OF KNOWN SLOPES	20
NUMBER OF KNOWN COORDINATES	5
NUMBER OF KNOWN THICKNESSES	5
NUMBER OF BOUNDED AREAS	6

INPUT TABLE 2. KNOWN SLOPES

START POINT	END POINT	SLOPE
1	2	0.0625
11	4	0.0625
9	10	0.0625
8	6	0.0625
7	12	-0.0625
14	13	-0.0625
5	15	-0.0625
1	11	0.1667
11	9	0.1667
9	8	0.1667
12	13	-0.1667
13	15	-0.1667
15	3	-0.1667
6	7	-0.0156
4	5	-0.0156
2	3	-0.0156
4	10	1.0000
10	6	1.0000
7	14	-1.0000
14	5	-1.0000

INPUT TABLE 3. KNOWN COORDINATES

ID	POINT	VALUE (FEET)
Y	1	0.0
X	6	0.0
X	8	-6.0000
X	7	24.0000
X	12	34.0000

PROBLEM 3 ..

INPUT TABLE 4. KNOWN THICKNESSES

HIGH POINT	LOW POINT	THICKNESS (FEET)
6	10	0.4167
7	14	0.4167
6	4	1.0000
11	1	2.0000
4	2	1.1667

INPUT TABLE 5. BOUNDARY POINTS

AREA NO.	BOUNDARY POINTS
1	4 5 7 6
2	1 2 3 15 5 4 11
3	9 10 6 8
4	11 4 10 9
5	14 13 12 7
6	5 15 13 14

PROBLEM 3 ..

OUTPUT TABLE 1. AREA

AREA NO.	AREA (SQ. FEET)
1	25.4061
2	68.2766
3	2.9948
4	6.3788
5	4.5575
6	9.1047

OUTPUT TABLE 2. COORDINATES

POINT	X COORD. (FEET)	Y COORD. (FEET)
1	-26.9947	0.0
2	0.3352	1.7081
3	45.2010	1.0082
4	-1.0000	2.8748
5	25.0317	2.4687
6	0.0	3.8748
7	24.0000	3.5004
8	-6.0000	3.4998
9	-9.7491	2.8748
10	-0.4167	3.4581
11	-14.9971	2.0000
12	34.0000	2.8754
13	37.7491	2.2504
14	24.4167	3.0837
15	43.2823	1.3281

PROBLEM 4 ..

INPUT TABLE 1. BASIC PARAMETERS

NUMBER OF POINTS	17
NUMBER OF KNOWN SLOPES	15
NUMBER OF KNOWN COORDINATES	15
NUMBER OF KNOWN THICKNESSES	4
NUMBER OF BOUNDED AREAS	6

INPUT TABLE 2. KNOWN SLOPES

START POINT	END POINT	SLOPE
1	2	-0.0156
2	3	-0.0542
4	5	-0.0156
5	6	-0.0542
3	6	-0.1670
7	8	-0.0156
8	9	-0.0156
9	10	-0.0156
10	11	-0.0542
6	11	-0.1670
14	15	-0.0156
12	13	-0.0156
15	16	-0.0156
16	17	-0.0625
11	17	-0.1670

INPUT TABLE 3. KNOWN COORDINATES

ID	POINT	VALUE (FEET)
X	1	0.0
X	4	0.0
X	7	0.0
X	8	1.0000
X	14	1.0000
X	9	7.0000
X	12	7.0000
X	15	7.0000
X	2	31.0000
X	5	31.0000
X	10	31.0000
X	13	31.0000
X	16	31.0000
X	17	41.0000
Y	3	0.0

PROBLEM 4 ..

INPUT TABLE 4. KNOWN THICKNESSES

HIGH POINT	LOW POINT	THICKNESS (FEET)
4	1	1.0000
7	4	0.3333
12	9	0.3333
14	8	0.5000

INPUT TABLE 5..BOUNDARY POINTS

AREA NO.	BOUNDARY POINTS
1	8 9 12 15 14
2	12 13 16 15
3	9 10 13 12
4	10 11 17 16 13
5	4 5 6 11 10 9 8 7
6	1 2 3 6 5 4

PROBLEM 4 ..

OUTPUT TABLE 1. AREA

AREA NO.	AREA (SQ. FEET)
1	3.0000
2	4.0008
3	7.9992
4	5.3558
5	15.3899
6	52.0842

OUTPUT TABLE 2. COORDINATES

POINT	X COORD. (FEET)	Y COORD. (FEET)
1	0.0	1.8666
2	31.0000	1.3830
3	56.5168	0.0
4	0.0	2.8666
5	31.0000	2.3830
6	47.6515	1.4805
7	0.0	3.1999
8	1.0000	3.1843
9	7.0000	3.0907
10	31.0000	2.7163
11	44.6968	1.9739
12	7.0000	3.4240
13	31.0000	3.0496
14	1.0000	3.6843
15	7.0000	3.5907
16	31.0000	3.2163
17	41.0000	2.5913

RUNNING Guide

	Fronts		Backs		Fronts		Backs		Fronts		Backs
1.				25.				49.			
2.				26.				50.			
3.				27.				51.			
4.				28.				52.			
5.				29.				53.			
6.				30.				54.			
7.				31.				55.			
8.				32.				56.			
9.				33.				57.			
10.				34.				58.			
11.				35.				59.			
12.				36.				60.			
13.				37.				61.			
14.				38.				62.			
15.				39.				63.			
16.				40.				64.			
17.				41.				65.			
18.				42.				66.			
19.				43.				67.			
20.				44.				68.			
21.				45.				69.			
22.				46.				70.			
23.				47.				71.			
24.				48.				72.			

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Running and Gathering Guide for Research Report 123-28

1. Form
2. blank

3. Title
4. ii - Preface, Disclaimer, Acknowledgments

5. iii - List of Reports
6. iv - List of Reports, cont.

7. v - List of Reports, cont.
8. vi - Abstract

9. vii - Summary
10. viii - Summary, cont.

11. ix - Summary, cont.
12. x - Implementation Statement

13. xi - Table of Contents
14. xii - Table of Contents, cont.

15. xiii - List of Figures
16. xiv - List of Tables

17. 1 - Introduction, Chapter I
18. 2 - Chapter II

19. 3 - Figure 1
20. 4

21. 5
22. 6 - Figure 2

23. 7 - Figure 3
24. 8 - Chapter III

25. 9 - Figure 4
26. 10

27. 11
28. 12 - Figure 5

29. 13 - Chapter IV
30. 14

31. 15
32. 16

33. 17 - Chapter V
34. 18 - Table 1

35. 19 - Table 1, cont.
36. 20 - Table 2

37. 21 - Table 2, cont.
38. 22

39. 23 - Table 3
40. 24 - Table 3, cont.

41. 25
42. 26 - Table 4

43. 27 - Table 4, cont.
44. 28 - Table 5

45. 29 - Table 6
46. 30

47. 31 - Chapter VI
48. 32 - Figure 6

49. 33
50. 34 - Figure 7

51. 35
52. 36 - Figure 8

53. 37 - Chapter VII
54. 38 - References

55. A-1 - Appendix A
56. blank

57. B-1 - Appendix B
58. B-2 - Introduction

59. B-3
60. B-4 - Program Identification

61. B-5 - Program Description
62. B-6 - Cross Section

63. B-7
64. B-8

65. B-9
66. B-10

67. B-11
68. B-12 - Input Guide

69. B-13
70. B-14

71. B-15 - Card type 1
72. B-16 - Card type 3

73. B-17 - Card type 4
74. B-18 - Card type 5

75. B-19 - Card type 6
76. B-20 - Card type 7

77. B-21 - Card type 8
78. B-22 - Card type 9

79. B-23 - Card type 10
80. B-24 - Card type 11

81. B-25 - Card type 12
82. B-26 - Output foremat

83. B-27
84. B-28

85. B-29
86. B-30

87. B-31
88. B-32

89. B-33
90. B-34

91. B-35
92. B-36

93. B-37
94. B-38

95. B-39 - Input Data
96. B-40

97. B-41
98. B-42

99. B-43 - Output Data
100. B-44

101. B-45
102. B-46

103. B-47
104. B-48

105. B-49
106. B-50

107. B-51
108. blank

109. B-52 - Output Data
110. B-53

111. B-54
112. B-55

113. B-56
114. B-57

115. B-58
116. B-59

117. B-60
118. blank

119. C-1 - Appendix C
120. C-2 - Introduction

121. C-3 - Program Identification
122. C-4 - Program Description

123. C-5
124. C-6

125. C-7 - Flowchart
126. blank

127. C-8 - Program Listing
128. C-9

129. C-10
130. C-11

131. C-12
132. C-13 - Name Dictionary

133. C-14 - Name Dictionary, cont.
134. C-15

135. C-16 - Input Guide
136. C-17 - Card Type 1 and 2

137. C-18 - Card Type 3, 4, and 5
138. C-19 - Output Format

139. C-20
140. blank

141. C-21 - Input Data
142. C-22

143. C-23
144. C-24

145. C-25
146. C-26

147. C-27 - Output Data
148. C-28

149. C-29
150. C-30

151. C-31
152. blank