A PAVEMENT DESIGN AND MANAGEMENT SYSTEM FOR FOREST SERVICE ROADS - A WORKING MODEL

FINAL REPORT - PHASE II
FEBRUARY 1977

RESEARCH REPORT 43

CONDUCTED FOR
U. S. FOREST SERVICE
WASHINGTON, D.C. 20250

COUNCIL FOR ADVANCED TRANSPORTATION STUDIES

The University of Texas at Austin

A PAVEMENT DESIGN AND MANAGEMENT SYSTEM FOR FOREST SERVICE ROADS - A WORKING MODEL

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Research Report 43
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U. S. Forest Service Agreement No. 13-794

conducted for

Forest Service
U. S. Department of Agriculture

by the

Council for Advanced Transportation Studies

The University of Texas at Austin

Technical Report Documentation Page

1. Report No. Research Report 43

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
A Pavement Design and Management System for Forest Service Roads - A Working Model

5. Report Date February 1977

6. Performing Organization Code

7. Author(s) Freddy L. Roberts, B. Frank McCullough Hugh J. Williamson and William R. Wallin

8. Performing Organization Report No. Research Report 43

9. Performing Organization Name and Address
Division of Research in Transportation, Council for Advanced Transportation Studies, The University of Texas at Austin, Austin, Texas

10. Work Unit No. (TRAIS)

11. Contract or Grant No. FS-13-883

12. Sponsoring Agency Name and Address
FOREST SERVICE, USDA
ENGINEERING STAFF
P.O. BOX 2417
WASHINGTON, D.C. 20013

13. Type of Report and Period Covered Final

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This is the second phase of a three-phase effort to develop and implement a pavement design and management system for low-cost, low-volume roads, in particular, Forest Service roads. The specific object of this phase is to develop working pavement design and management models and other information needed for optimization and decision making.

Using the results of the Phase I conceptual study and a pre-existing program, an initial computerized working pavement design and management model was developed. During this phase, through continual coordination with various Forest Service engineers, this initial model was constantly modified to better consider the Forest conditions, design requirements and operating procedures.

The resulting model, LVR, which is now ready for implementation and trial usage by the Forest Service during Phase III of this project, will design pavement structures based on an equal-effectiveness criterion for bituminous surfaced, aggregate surfaced or surface treatment roads. Two roads are considered to have equal effectiveness if they provide the same quality of service for the same length of time. Bituminous surfaced pavements are designed using a single failure criterion which is based on the AASHTO method currently in use by the Forest Service. The failure criteria for

17. Key Words
(See next page)

18. Distribution Statement
No restriction on distribution.
Available from National Technical Information Service, Springlfield, VA 22161

19. Security Classif. (of this report) UNCLASSIFIED

20. Security Classif. (of this page) UNCLASSIFIED

21. No. of Pages 132

22. Price

aggregate surfaced pavements involves (1) the current Forest Service procedure, which is a combination of both the AASHTO method and a method developed by the U. S. Army Corps of Engineers for aggregate surfaced roads and airfields, and (2) a failure criterion due to excessive aggregate loss in the surface layer.

This report describes changes to previously developed pavement management work (3, 9) and the other models developed and employed in the current version of LVR. In addition, three example problems are included along with a complete discussion of the inputs required and solutions obtained from each. A copy of the current LVR User's Manual is also included.

This pavement management system has been planned, developed and made operational for the purpose of designing and managing the surfacing systems for low-volume roads typical of those constructed by the Forest Service. Recommendations for major areas of implementation and further research are also included. The program will be designed to ensure its compatibility with the Road Design System (RDS) currently used by the Forest Service.

KEY WORDS: Pavement management system, pavement design system, low-volume roads, Forest Service roads, unsurfaced roads, logging roads, bituminous surfaced roads, aggregate surfaced roads, surface treatment, stage construction

PREFACE

This is the final report for Phase II of a projected three-phase study being conducted for the Forest Service by the Council for Advanced Transportation Studies, The University of Texas at Austin. The purpose of the total project, FS-1, is to develop and implement a pavement design and management system for low-volume roads, in particular, Forest Service roads. The purpose of this report is to familiarize the Forest Service engineer with LVR, the initial computerized pavement design and management system developed in Phase II. The report contains a description of the various models currently employed in the system along with a copy of the user's manual.

The authors appreciate the helpful suggestions made by the project's Forest Service advisory committee. As a result of their comments, the final product of this study will be much more tailored to account for the particular design problems which the sponsors must consider in developing low-volume roads for National Forests. The committee includes representatives from various Regional Offices and the Washington, D. C., Office and consists of the following individuals: Loren Evans, Dave Franklin, Larry Hendrickson, Lou Heppl, Bob Hinshaw, Duane Logan, Jim Miller, Adrian Pelzner, Ted Stuart, Heyward Taylor, and Ron Williamson.

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CHAPTER 1. INTRODUCTION

BACKGROUND

In 1972, The University of Texas and the U. S. Forest Service initiated a cooperative study to develop a pavement management system that would be applicable to Forest Service roads. It was intended that the work proceed in three phases:

(1) Conduct a feasibility study, Phase I, to ascertain the practicality of developing such a system for the Forest Service.

(2) If Phase I was positive, conduct a second phase to develop a working system.

(3) Conduct a third phase to implement the system in the various Forest Service design offices.

The Phase I report, "A Pavement Design and Management System for Forest Service Roads - A Conceptual Study," (1) concluded that it was feasible to develop a system. The objective of the current report is to present the development of a working pavement management system for Forest Service roads. The report presents the principles of the working system and the development of several key mathematical models used in the system. The product is an operational computer program that has been put on line with USDA computer center at Ft. Collins, Colorado.

SYSTEMS APPROACH

The fundamental concepts of the Systems Approach were succinctly stated in the first report:

> "A system has been described as a procedure or scheme which behaves according to some prescribed manner in performing an operational process. Accordingly, systems engineering provides a means of organizing the various segments of the total problem into an understandable framework. When using a systematic approach to solve a problem, the entire system is seen as a whole and not as a collection of individual parts functioning by themselves."

PROJECT APPROACH

In developing a systems approach for pavement design, two techniques are available for making comparisons. One approach is to develop the alternative design strategies that will give equal performance. For example, a design analysis period is selected, then all the combinations of initial thickness, rehabilitation, and minor maintenance are developed that will permit the pavement to remain in service during the period. The alternative design strategies can then be ranked in order of increasing cost. A second approach is to develop all the design strategies that result in an equal cost even though the performance periods may be different. Early in the project, a decision was made to pursue the first approach since it more closely follows the Forest Service operations procedure than does the equal cost technique.

WORK PLAN

The work plan for the second phase was separated into three time periods. During the first period, the project staff selected mathematical models, such as thickness deterioration, traffic equivalences, etc. from available sources. The intent was to combine the procedures in the present USDA Forest Service Transportation Engineering Handbook into a computer algorithm. In several cases, results from recent Forest Service studies were also incorporated. These sources along with the past experience of The University of Texas project staff were used to finalize the algorithm. These development steps were coordinated closely with the Washington office of the Forest Service.

After an initial system was developed, it was presented to the project's Forest Service Advisory Committee in Ft. Collins, Colorado. This committee represented the operational staff from various Regional Offices and the Washington, D. C. office and consisted of the following individuals: Loren Evans, Dave Franklin, Larry Hendrickson, Lou Hepfl, Bob Hinshaw, Duane Logan, Jim Miller, Adrian Pelzner, Ted Stuart, Heyward Taylor, and Ron Williamson.

The models were presented to the committee and example problems were worked to familiarize them with the input and output format during a three day meeting. As a result of this review, a series of modifications and additions were suggested by the committee for inclusion into the computer algorithm.

During the remaining time period, the project staff incorporated the changes and additions agreed to at the meeting. Prior to preparation of the final report, Mr. Ron Williamson of Region 6 visited The University of Texas as a committtee representative to make a final review of the working system. The design system agreed to during these meetings is presented in this report.

SCOPE OF REPORT

Chapter 2 describes the models used and algorithm development. Chapter 3 presents a description and discussion of three example problems to demonstrate some of the capabilities of the program. Chapters 4 and 5 include a discussion of the implementation phase and presents recommendations and conclusions. The report does not contain a detailed documentation of the computer program but rather contains discussions of the models and the general rationale for how design decisions are made inside the program. A detailed documentation report for the program is included as a part of the implementation phase.

CHAPTER 2. DESCRIPTION OF THE PAVEMENT MANAGEMENT PROGRAM

INTRODUCTION

As is discussed in the preceding chapter, the basic purpose of the low-volume road management program, LVR, is to allow the user to identify the most economical road designs, taking into account both initial construction and subsequent costs related to road maintenance and vehicle operation. The actual costs which are included are listed below:

(1) initial construction costs
(2) seal cost costs for bituminous surfaced roads or grading costs for aggregate surfaced roads
    (a) materials, equipment, and labor costs
    (b) user-delay costs
(3) minor maintenance costs
(4) rehabilitation costs (overlays for bituminous surfaced roads or aggregate addition plus grading for aggregate surfaced roads)
    (a) materials, equipment, and labor costs
    (b) user-delay costs
(5) vehicle operating costs
(6) salvage value costs

The total cost for a candidate design is calculated on a net present value basis relative to the time of construction. This is to ensure that the costs incurred at various times throughout the road's design life will be combined in a meaningful way. The total cost for each candidate design is computed, and the designs are ordered on the basis of cost. Then the least-cost designs are printed in the order of increasing cost.

These candidate designs are enumerated within the program on the basis of inputs by the user; the inputs include the number of layers, the type of material for each layer, the maximum and minimum thickness for each layer, etc. All possible combinations of material arrangements are considered, with layer thicknesses varying between the input limits in small steps.

The calculation of the cost for a given candidate design requires various mathematical models for predicting the times when rehabilitations will be required, for representing the traffic volume and for the composition of traffic over time, etc. These models are discussed in the following sections of this chapter. Subsequently, the organization of the program, which is discussed briefly above, is presented in more detail.

CAPABILITIES OF THE PROGRAM

The pavement management system consists of a single computer program, identified as LVR, that can be used to design both bituminous surfaced and aggregate surfaced roads. However, since the program will only design for a single road surface type at a time, in order to compare an aggregate surfaced road with a bituminous surfaced road, it is necessary either (1) to make a run with an aggregate surface, modify the input data slightly and rerun the program, or (2) to stack both sets of input data and obtain separate outputs for bituminous surfaced and for aggregate surfaced designs in one run of the program.

A brief description of the capabilities of the program follows, however details of various options are described later.

BITUMINOUS SURFACED ROADS

The bituminous surfaced road design portion of the program uses the AASHTO structural design equation for flexible pavements (2, 3, 4). This equation, which is currently being used by the U. S. Forest Service (5), is based on the concept of the Present Serviceability Index (PSI) of a pavement.

Using the bituminous surfaced road model, the user can design and compare single and multi-layered pavement structures of either of the following two types:

Asphaltic Concrete Surfaced Roads (ACP)

To obtain an ACP design, the user must specify that ACP is the material for the top layer of the pavement structure. The program will then determine all feasible single and multi-layered designs based on the constraints input by the user. All rehabilitations consisting of regularly scheduled seal coats and ACP overlays applied when the serviceability index (PSI) reaches the minimally acceptable level specified by the user will be considered.

Bituminous Surface Treated Roads

The other type of bituminous surfaced road design available to the user, is essentially an aggregate surfaced road over which a thin bituminous surface treatment is applied during initial construction. Future rehabilitation may consist of either additional surface treatments or of ACP overlays depending on constraints input by the user.

Thin bituminous surface treatments, unlike ACP overlays, do not increase the structural number (SN) of the pavement structure significantly. However, a buildup of one or more inches of successive surface treatments will begin to have a considerable effect on the SN of the pavement structure to which they have been applied.

AGGREGATE SURFACED ROADS

Like the bituminous surfaced road design previously described, the aggregate surfaced design utilizes the current U. S. Forest Service method which is based on a combination of the AASHTO structural design equation for flexible pavements (2, 3, and 4), and the U. S. Army Corps of Engineers Thickness Design Charts (6). As described later in this chapter, this method has also been further modifed to account for aggregate loss in the top layer due to traffic movements.

Failure of a candidate structure is defined as any of three events representing the time at which (1) the PSI reaches the minimum acceptable level, or (2) a 2-inch wheel path rut develops, or (3) the reduced thickness of the top layer due to aggregate loss reaches a minimum acceptable value as specified by the user. The triple failure criteria is discussed later.

Using the aggregate surface design model, the user can design and compare single and multi-layered structures of either of two types of aggregate surfaced road. One case is the use of only aggregate surfacing during the design period; whereas the second case recognizes that a bituminous surface treatment may be placed during the analysis period.

Aggregate Surfaced Roads Without Bituminous Surfacing

Using this design, the initial structure consists of aggregate layers. All future rehabilitation will consist of regularly scheduled gradings and of aggregate additions applied when failure occurs as defined by one of three failure criterion.

Aggregate Surfaced Roads With Bituminous Surface Treatment

Using a combination of both the aggregate surfaced and the bituminous surfaced design methods, a pavement structure can be initially designed as an aggregate surfaced road that has, at some future time, one or more surface treatments applied. This combination can be accomplished by first producing an aggregate surfaced design with the design life equal to the time between initial construction and the first surface treatment application. The chosen initial structure is then input into the bituminous surface design model and run as a new design with a surface treatment where the design life is equal to the years remaining after the first surface treatment. This same procedure can also be used for stage construction in which an aggregate surfaced road is upgraded to a bituminous surfaced road by overlaying the aggregate structure with ACP at some time after initial construction.

FAILURE CRITERIA

The two types of low-volume, low-cost roads used by the Forest Service perform in vastly different ways. Because of this problem, separate sets of failure criteria are used by the program for bituminous and aggregate surfaced roads.

BITUMINOUS SURFACED ROADS FAILURE CRITERION

The performance of bituminous surfaced roads is based on the results of the AASHTO Road Test as presented in the 1972 Edition of the AASHTO Interim Guides for Design of Pavements (2) and in NCHRP Reports 128 (3) and 139 (4). In these reports, failure of a bituminous surfaced road is defined as the time at which the Present Serviceability Index of a pavement reaches the minimally acceptable value, P_t . This concept is demonstrated pictorially in Fig 2.1. Further explanations of the performance and structural models for bituminous surfaced roads are presented later.

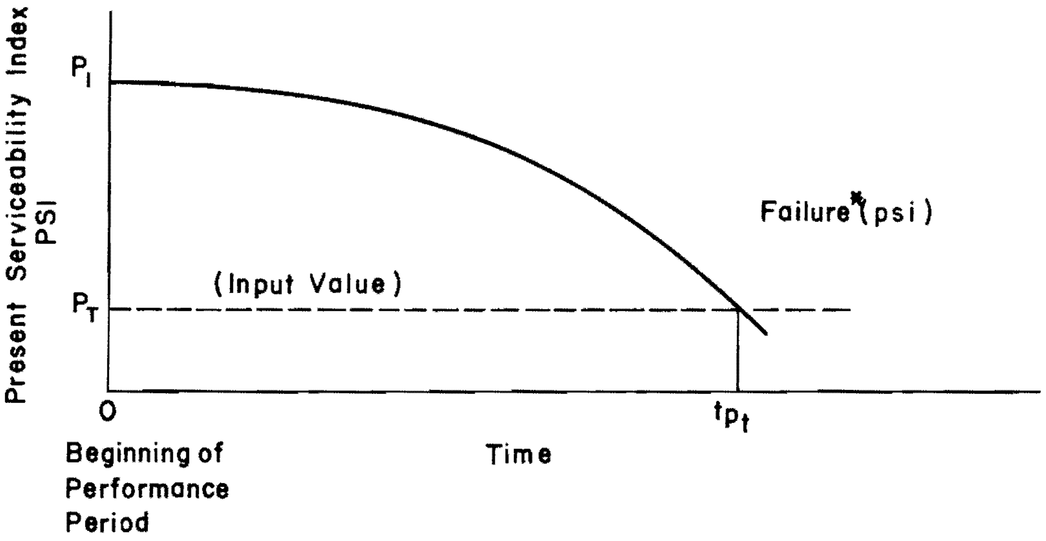
AGGREGATE SURFACED ROADS FAILURE CRITERIA

Unlike a bituminous surfaced road with its single failure criterion, the performance of an aggregate surfaced road is based on a triple failure criteria. The first component of the triple failure criteria is the PSI concept which is applied in the same manner for aggregate surfaced as for bituminous surfaced roads. The decision to use this as a component is based in part upon a small-scale study conducted at The University of Texas at Austin that involved the evaluation of PSR values and measurements of roughness with a roughness measuring device called the Mays Meter. Four highway sections were included in the study of which two were bituminous surfaced and two were aggregate surfaced. It was noted that the PSR ratings for the sections were ordered the same as were the objective roughness measurements. Thus, the implication of this small experiment is that PSR values for bituminous surfaced and aggregate surfaced roads have a common meaning regarding a road's quality and can validly be compared.

Additionally, the PSR concept is now successfully being used in management systems for flexible and rigid pavements, which differ with respect to distress mechanisms and rates of development of different types of distress. Thus, the fact that aggregate surfaced roads differ from bituminous surfaced roads in these same respects does not imply that PSR cannot be used as a common measure of the quality of a bituminous or aggregate surfaced road section at a given time.

The second component of the triple failure criteria is related to rutting. Failure in this case is defined as the time at which a 2-inch rut develops in the wheelpath. This criterion was developed and reported (6) by the U. S. Army Corps of Engineers and is discussed later.

The third and final component of the triple failure criteria is based on failure due to excessive aggregate loss, which results when the thickness of the top layer is reduced to a user specified minimally acceptable level. The amount of aggregate loss as a function of time is either predicted by the Lund (3) aggregate loss model or specified directly; the choice is based on user preference. The aggregate loss models are discussed later in more detail.



*Time of failure is defined as the time (t_{P_t}) at which the present servicability index reaches the minimally acceptable value (P_T) as input by the user.

Fig 2.1. Failure criterion for a bituminous surfaced road.

The resulting failure time is then the minimum of the following:

(1) The rutting model as used by the U. S. Forest Service involves computing the failure time due to rutting as the maximum of either

    (a) the failure time predicted by way of the rutting model briefly discussed above or

    (b) the failure time predicted by the AASHTO performance model.

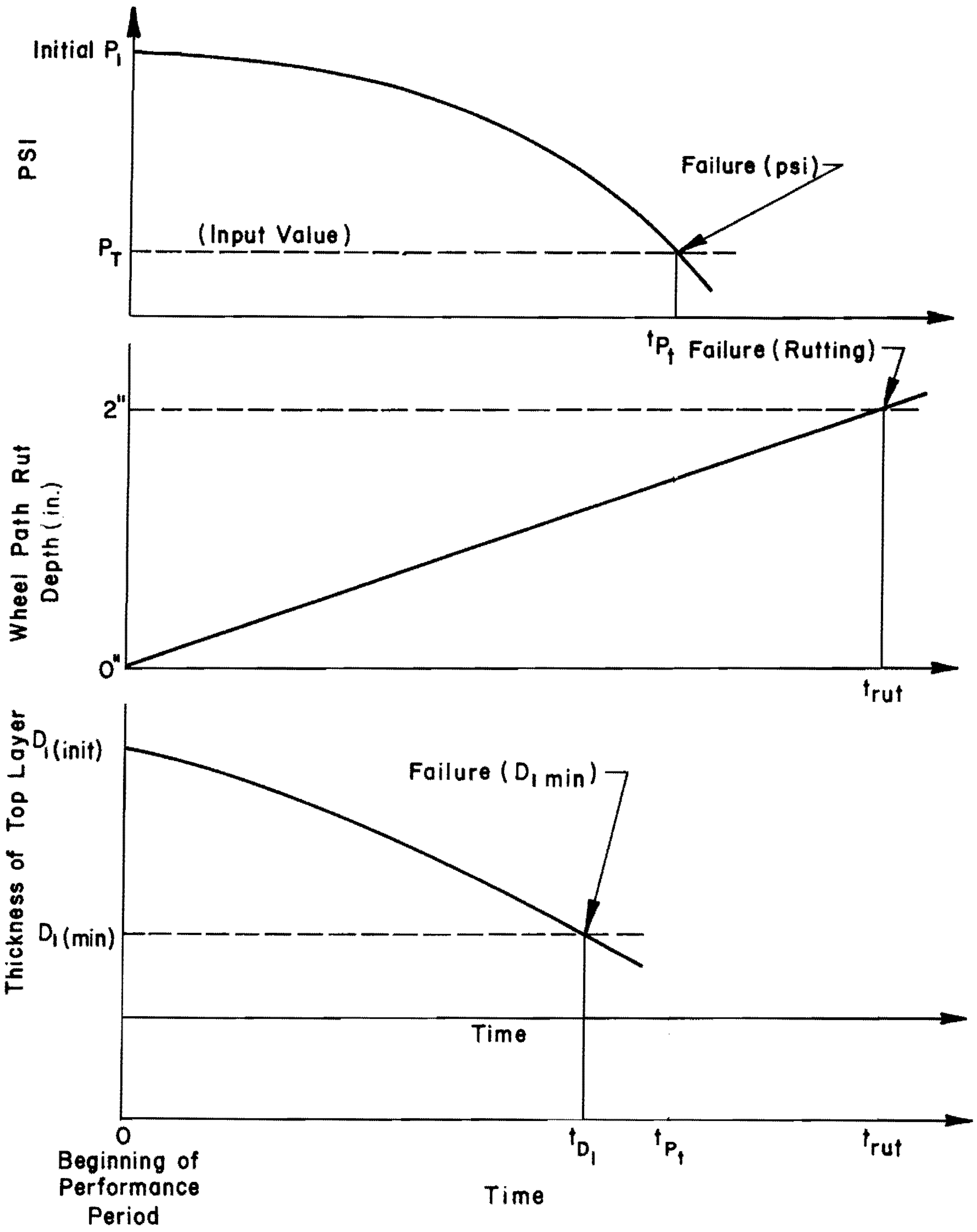
(2) The time at which excessive aggregate loss has occurred.

The rutting model, like the AASHTO performance model, was originally intended to be used to compute the design thickness needed to carry a certain number of 18-kip equivalent single axle loads under given circumstances. Given the thicknesses of the layers, the layer coefficients, and other necessary information, however, both models can be used to compute the number of 18-kip equivalent single axle loads which will have been accumulated when failure occurs. The number of these loads, then, can be converted to failure time by using the non-linear traffic model, which is discussed later. An illustrative application of the triple criteria is shown in Fig 2.2.

MODELS

In the following sections, the component models of the low-volume-road management system are discussed. Included are models for performance, non-linear traffic history, structural properties, user-delay costs, aggregate loss, rutting, routine maintenance, and vehicle operating cost. Of these, the performance, structural, and user-delay models were taken directly from a previously existing pavement management system (4, 9). The other component models were either modified significantly if from this source, obtained from another source, or developed specifically for the Forest Service system. The changes in component modeling from those in the existing pavement management system were made in order to represent accurately the factors which affect the design and construction of low-volume roads for the Forest Service. Many of these changes were based on discussions with Forest Service representatives.

In the sections below, the analysis which is implemented in the component models is discussed, and references are given in cases where a model was taken or modified from an existing source. These discussions should provide the reader with a basic understanding of the rationale and the analytical approach



P_T ~ minimally acceptable level of PSI
D_1(init) ~ Initial thickness of top layer
D_1(min) ~ minimum allowable thickness of top layer
t_{P_t} ~ Time at which psi equals P_t
t_{rut} ~ Time at which a 2" rut develops in the wheelpath
t_{D_1} ~ Time at which thickness of top layer equal $D_{1\,min}$

Fig 2.2. Failure criteria for an aggregate surfaced road.

used in each of the component models. A highly detailed discussion of the subroutines, including extensive flow charts, however, is not included. It is not the purpose of this report to provide the necessary program documentation so that a reader could easily modify the program, although the user's guide presented in the appendix presents a complete guide for use of the present program. The detailed program documentation would, at this stage, be premature, since certain modifications and additions to the program, in accordance with discussions with the study sponsors, are now underway. Detailed flowcharting and other technical documentation will be prepared in the next phase of the project. In some areas, where the modeling work has been finalized, the documentation process has already begun.

PERFORMANCE MODEL

The performance model is used to determine when a bituminous surfaced road is expected to fail and it is also one of three models used to determine when an aggregate surfaced road is expected to fail. The performance model predicts the time when the serviceability index of a road reaches the minimally acceptable value. The decrease of serviceability in time is assumed to be due to:

(1) Traffic-related deterioration, which is a function of:
    (a) traffic composition and volume,
    (b) quality of support of existing soil,
    (c) regional characteristics, and
    (d) thickness of each layer and type of materials used.
(2) Non-traffic related deterioration.

The exact functional form of the performance equation is given in Reference 4 as follows:

$$SN = \frac{1.051\ (W_t R)^{0.1068}}{10^{0.03973(SS-3)}\ (g-g')^{0.1068/\beta_{18}}} - 1 \qquad (1)$$

where

SN = structural number,

W_t = total equivalent 18-kip single axle loads accumulated during the performance period in question at the time when failure occurs,

SS = soil support of the subgrade,

R = regional factor,

$$\beta_{18} = \frac{0.4 + 0.081(19)^{3.23}}{(SN + 1)^{5.19}} = \cancel{\frac{1094}{(SN + 1)^{5.19}}}$$

$$g = \frac{P_1 - P_2}{P_1 - 1.5}$$

P_1 = serviceability index at the beginning of the performance period in question,

P_2 = minimally acceptable serviceability index,

$$g' = \frac{M^2 + 2M\sqrt{5-P_1}}{P_1 - 1.5}$$

$$M = (\sqrt{5 - P_2'} - \sqrt{5 - P_1})\ (1 - e^{-b_1 t})$$

b_1 = factor related to non-traffic deterioration rate at the beginning of the performance period,

P_2' terminal serviceability index which would be reached in infinite time in the absence of traffic, and

t = time of failure, that is, the length of the performance period.

The functional forms of the expressions for β_{18} , g , g' , and M reflect simply the combinations of the basic parameters which were necessary to fit the data from which the performance equation was derived.

Given that the traffic history is defined by input, the accumulated traffic, W_t , can clearly be thought of as a function of time. Equation 1 can be solved, then, for the length of the performance period; an iterative solution is required due to the non-linear nature of the equation.

It is also possible to determine a failure time, F_k , for the first k layers, where the layers are numbered from the top, by considering the (k+1) layer as the "subgrade." In this calculation, the structural number to be used is the value for the first k layers, and the soil support value is that specified for the (k+1) layer. Calculations can be performed to determine which part of the road structure has the shortest life. The actual failure time is the minimum lf all such failure times, F_k , where k varies from one to the total number of layers. The non-traffic related term is included only when k equals the total number of layers (b = 0 otherwise), and SS is the value for the actual existing subgrade in this case. This procedure is discussed briefly in Reference 3.

NON-LINEAR TRAFFIC MODEL

In pavement management systems for public roads, it is often considered reasonable to assume that the traffic volume increases linearly during the design life (4). For the Forest Service roads, this assumption is not usually valid since there may be heavy traffic during periods of logging sales and light traffic at other times. This is illustrated by Fig 2.3, which could represent the logging-truck traffic history for a road which supported intensive logging operations during the first three years and the twelfth through the fifteenth years of its life.

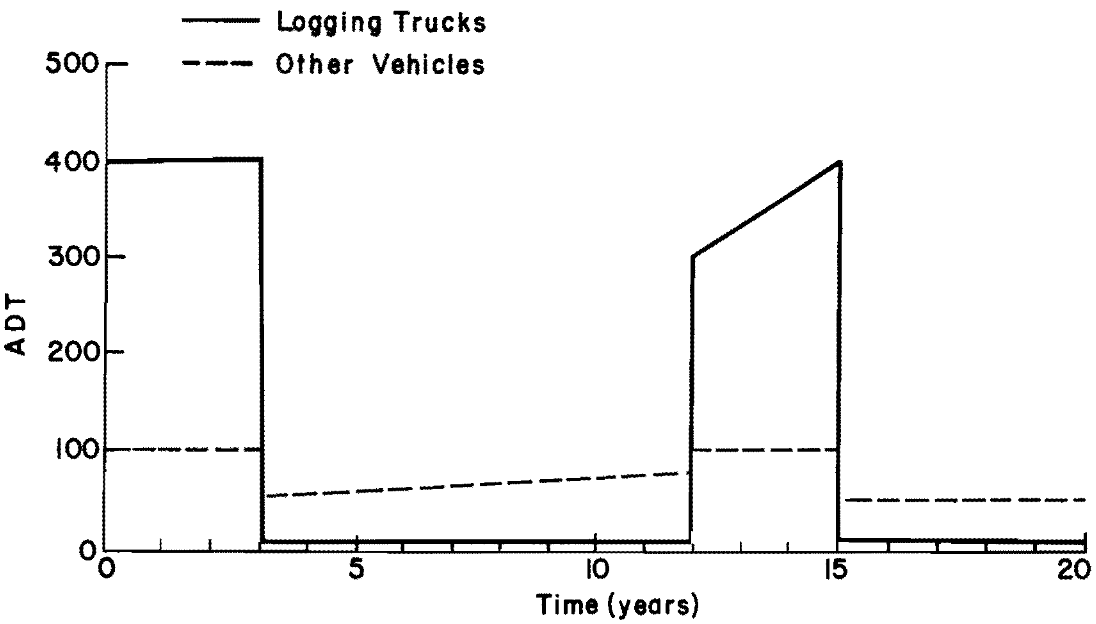
The actual traffic input to the program requires:

(1) ADT (average daily traffic) at particular times for logging trucks,
(2) ADT at particular times for other vehicles,
(3) cumulative 18-kip equivalent single axle loads at particular times for (1), and
(4) cumulative 18-kip equivalent single axle loads at particular times for (2).

Both ADT and 18-kip equivalent single axle loads are necessary inputs, since ADT is needed for computing both vehicle/user delay costs and vehicle operating/user time costs, and 18-kip equivalent single axle loads are needed for performance model calculations.

STRUCTURAL MODELS

Surfaces used on forest service roads can be classified into two categories, bituminous and aggregate. Factors such as environmental variables and the types and frequency of maintenance activities are usually different for the two types of surfaces. Thus, although the same basic structural model is used for both categories of roads, certain inputs are different. The



Traffic History

	ADT	
Year	Logging Trucks	Other Vehicles
0.0	400	100
3.0	400	100
3.1	10	50
12.0	10	75
12.1	300	100
15.0	400	100
15.1	10	50
20.0	10	50

Fig 2.3. Example traffic history illustrating the capability of the program to handle variable traffic variations during the analysis period.

minimally acceptable performance level, for example, is generally lower for aggregate surfaced than for bituminous surfaced roads.

It should be mentioned for completeness, that the Forest Service has many miles of unsurfaced roads. These roads, however, are not included in this study.

The AASHTO Structural Model

This model is based on the results of the extensive AASHTO Road Test conducted in Ottawa, Illinois in the late 1950's and early 1960's. The design method introduces a road-user definition of pavement failure rather than one based strictly on structural failure concepts (e.g. cracking and deformation). The road-user failure criterion depends upon the ability of the roadway to serve the public safely and smoothly. This AASHTO structural model can be used to design both bituminous and aggregate surfaced roads. However, additional experimental work to validate and possibly modify the structural model for application to aggregate surfaced roads would be beneficial.

In evaluating alternative structural designs under a simulated real world environment, this model incorporates three basic kinds of physical models:

(1) The traffic model

$$W_{T_{18}} = N_T \sum_{i=1}^{n} P_i e_i \tag{2}$$

where

N_T = total number of axles in mixed traffic
P_i = proportion of axles in the i^{th} load group
e_i = equivalence factors for i^{th} group
$W_{T_{18}}$ = total number of 18-kip equivalent single axle load applications.

(2) The structural capacity model

$$SN = \sum_{i=1}^{n} a_i D_i \tag{3}$$

where

a_i = i^{th} layer coefficient
D_i = i^{th} layer thickness in inches
SN = structural number.

The sum of the products of the layer thicknesses and the layer coefficients of the material for each layer is the SN value, which is indicative of the relative ability of the pavement to function as a structural unit.

(3) The AASHTO Performance Model

$$SN = \frac{1.051(W_{t_{18}} R)^{0.1068}}{10^{0.0397(SS-3)}(g-g')^{0.1068/\beta_{18}}} - 1 \qquad (4)$$

This equation is discussed in a previous section. It combines the traffic model and structural capacity model to predict the behavior of the pavement, at any time, in terms of its serviceability.

When there is no deterioration due to non-traffic related factors, i.e. $b_1 = 0$ in the g' term (See Eq. 1), Equation 4 can be rearranged to solve for $W_{t_{18}}$, resulting in the following expression:

$$W_{t_{18}} = \frac{0.62766}{R} \; g^{1/\beta_{18}} \left[(SN + 1) \; 10^{0.03973(SS-3.0)}\right]^{9.3633} \qquad (5)$$

This equation is being used in the LVR program to solve for the number of 18-kip single axle load applications, that have been accumulated when the serviceability index of the road reaches the minimally acceptable level. This is the failure criterion for bituminous surfaced roads; for aggregate surfaced roads, it is one of the triple criteria as discussed in a previous section.

Because of the exponent of 9.3633 in the previous equation, small errors in either of the multiplicative factors within brackets produce much larger errors in $W_{t_{18}}$. Suppose, then, that Q is defined as follows:

$$Q = 10^{0.03973(SS-3)} \tag{6}$$

then the relationship between (positive) errors in Q and resulting errors in W_t are illustrated by the following table:

Error in Q (percent)	Range of Errors in SS required to produce Error in Q	Error in $W_{t_{18}}$ (percent)
1	0.06 - 0.10	9.7
2	0.12 - 0.20	20.7
3	0.18 - 0.30	31.9
4	0.24 - 0.40	44.4
5	0.30 - 0.50	57.9
6	0.36 - 0.60	72.6

In order to give the reader an indication of the error required in SS to produce the error in Q , a range of errors in SS is included in the table. The low value of the range of error in SS corresponds to a SS value of 9 while the high value corresponds to a SS value of 3. Because of the large error generated in $W_{t_{18}}$ for relatively small errors in SS , the user should minimize any errors present in both the SS and SN values. The user could minimize the errors in SS by providing for adequate laboratory soil testing and using correlation charts that have been developed for local materials, if available. In minimizing the errors in SN the user should develop input data for the number of 18-kip SAL and regional factor using the most up to date procedures. In addition, he should try to develop experience or conduct or apply recent research results in selecting appropriate layer coefficients for local materials. Of the variables mentioned above, the soil support value and layer coefficients are probably obtained with the least reliability. These variables should have the highest priority for allocation of available funds for design.

Modified U. S. Army Corps of Engineers Structural Model

The Forest Service considers aggregate surfaced roads to have failed when the rutting of the subgrade reaches a maximum allowable limit. The rutting model currently used by the Forest Service is based on test data collected for aggregate surfaced airfields by the U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi (6).

Tests were conducted on three aggregate surfaced test sections. The strength of the clay subgrades varied in CBR value from 2 to 4. The strength of the aggregate materials over the subgrade ranges in CBR value from 9 to 17. The thickness of these aggregate materials varied from 6 inches to 24 inches. The vehicles used to traffic these test sections had wheel loads ranging from 15,000 pounds to 80,000 pounds, and tire inflation pressures ranging from 80 psi to 165 psi. CBR, water content, deflection, and deformation data were recorded throughout testing. From these data, a thickness design equation was developed to design thicknesses for aggregate surfaced airfields and roads. The equation relating thickness requirements to load repetitions, loading condition, and soil strength was reported (6) as:

$$t = f\sqrt{\frac{P}{8.1\ \mathrm{CBR}} - \frac{A}{\pi}} \tag{7}$$

where

t = design thickness, in inches

P = single or equivalent single wheel load, in pounds

A = tire contact area, square inches, which equals wheel load (P) divided by tire contact pressure

f = factor used to account for traffic repetitions; if thickness t were required to support a load P, then the thickness ft would be required to sustain the load P applied repetitively:

$f = K_1 \log c + K_2$.

K_1 and K_2 = constants which depend upon the rut depth criterion chosen.

c = number of coverages which will be applied before failure occurs (one coverage occurs when each point of the pavement within the design traffic width receives one load application).

CBR = strength of subgrade soil as determined from the California Bearing Ratio Test.

For a given test section, the thickness over the subgrade, single wheel load, tire pressure, and CBR of the subgrade are all known variables. The only unknown in Eq 1 is the f-factor which can be determined by substituting all other known variables into the equation and solving for f . The number of coverages which produces the predetermined failure rut depth can be obtained from the test data. When ruts exceeded 3 inches, as measured from the 10 foot straightedge, or when overall subsidence was in excess of 4 inches, the road was judged as failed by the Corps of Engineers. After computing the f-factor for each set of the test section data, the computed values of f were plotted versus failure coverages. The method of least squares was used to determine the best equation relating f and coverages as described below (6):

$$f = 0.176 \log c + 0.120 \qquad (8)$$

The Forest Service, using the data collected from this study, and the procedure as described above, but using a 2-inch rather than a 3-inch rut depth as a failure criterion, derived an equation for the f-factor as described below:

$$f = 0.216 \log c + 0.1705 \qquad (9)$$

Substituting Equation 9 into Equation 7 for f , Equation 7 can be rewritten as:

$$t = (0.216 \log c + 0.1705) \sqrt{\frac{P}{8.1\ \text{CBR}} - \frac{A}{\pi}} \qquad (10)$$

This is the equation on which the design chart in Fig 3, Chapter 50 of the Forest Service Design Handbook, is based. To establish that chart, the following assumptions were made:

(1) Number of coverages equals the number of 18-kip equivalent single axle load applications

$c = W_{t_{18}}$

(2) Wheel load (P) is equal to 9000 pounds

$P = 9{,}000$ pounds

(3) Tire contact pressure is equal to 80 psi, and

$$A = \frac{\text{wheel load}}{\text{tire contact pressure}}$$

$$= \frac{9000}{80} = 112.5 \text{ square inches.}$$

Using the above assumptions, Equation 10 becomes:

$$t = (0.216 \log W_{t_{18}} + 0.1705)\sqrt{\frac{1111.1}{CBR} - 35.81} \qquad (11)$$

The user should remember two important facts in using this model. First, to reiterate point (1) above, a one to one equivalence between the number of coverages of the test traffic and the number of 18-kip single axle load applications has been assumed appropriate. Second, the design charts represent an extrapolation of the design equation well beyond the test data range from which it was derived; the failure coverages in the Corps of Engineers report range from a few coverages up to less than a thousand, while the number of 18-kip applications for a typical Forest Service roadway will range from several thousand up to perhaps a million or more 18-kip equivalent single axle load applications during the design period.

RUTTING PREDICTION MODEL

Rutting or permanent deformation of an aggregate surfaced road is an important failure criterion. When ruts exceed 2-inches in depth, the road is considered to have failed. The rutting model calculates the total number of 18-kip equivalent single axle loads that can then be converted to the time at which failure occurs for the road. Solving Equation 11 for the number of 18-kip equivalent single axle laods results in the equation below called the rutting model:

$$\text{Log } W_{t_{18}} = \frac{t}{0.216 \sqrt{\frac{1111.1}{\text{CBR}} - 35.81}} - 0.789 \qquad (12)$$

where

$W_{t_{18}}$ = total number of 18 kip single axle load applications required to produce 2-inch rut depth.

t = the thickness of the surface material over the subgrade (inches) having a layer coefficient of 0.14.

If the layer coefficient of the material is not equal to 0.14 or there are several types of material above the subgrade, the "thickness" variable t can be described by the following equation:

$$t = \sum_{i=1}^{n} \frac{a_i D_i}{0.14} \qquad (13)$$

where

D_i = the thickness in inches of the i^{th} layer,

a_i = the layer coefficient of the i^{th} layer, and

n = number of layers of material above subgrade.

For a road section with three layers of material as shown below, Equation 13 becomes:

$$t = \frac{a_1 D_1}{0.14} + \frac{a_2 D_2}{0.14} + \frac{a_3 D_3}{0.14}$$

For a given subgrade CBR value and a given combination of thicknesses of materials above the subgrade, equation (12) can be solved to predict the cumulative number of 18-kip equivalent single axle load applications at the time of failure. The failure time is the time at which this number of 18-kip equivalent single axle loads will have been accumulated and is calculated from the 18-kip equivalent single axle load versus time data input by the user.

AGGREGATE SURFACE LOSS MODELS

One component of the failure criteria for aggregate surfaced roads is loss of surfacing material due to the action of traffic. In order to accurately predict total cost of these roads, estimates of aggregate loss must be included to reflect added material cost and reduced thicknesses in the structural section. Two techniques for including aggregate loss are described in the following sections.

Loss Prediction Models

Two aggregate loss prediction models were available from the technical literature and both were considered for adoption in this project. One of the models was developed by the Transport and Road Research Laboratory of England based on a study conducted in Kenya (7). In the Kenya model, the aggregate loss is a function of traffic volume, annual rainfall, percentage gradient of the road, and the property of the road surfacing materials. A second aggregate loss prediction model was reported by John Lund (8) for the Forest Service. These two models were used to calculate the aggregate loss for a set of data representing low, moderate, and high values for the terms in each model. The results were presented to the project Advisory Committee at a meeting at Fort Collins, Colorado. The Lund Aggregate Loss Model was chosen by the committee because it was more applicable to Forest Service roadway conditions then the Kenya model. Traffic in the Kenya study was primarily light vehicles, whereas Forest service roads carry a wide range of loads including heavy logging trucks. Presently, this Lund Aggregate Loss Model is included in LVR to estimate the loss of surfacing aggregate under traffic operation.

The Lund study was conducted on aggregate surfaced roads located in the southcentral portion of Oregon on the Eastern side of the Cascades in a generally dry region of the state. Eight aggregate surfaced roads (3 cinder, 2 pit run gravel and 3 crushed basalt) were selected and 23 test sections, 75 feet long were marked off to represent a variety of geometric situations. Cross sections were taken at 25-foot intervals along the road and at 1-foot intervals across the road. Settlement plates were installed in each section at the subgrade level. Laboratory tests were performed on the surfacing material including: gradation, Atterburg limits, sand equivalent, degradation, maximum dry density and optimum moisture content (AASHO T-99), Los Angeles abrasion, specific gravity, and sulfate soundness on both coarse and fine aggregates. Traffic counters were placed near the sections and classification studies were conducted.

Several models were developed using regression analysis techniques. The following model was proposed as the best model for consideration:

$$GL = 0.162 + 0.0188\ (LT) + 0.0382\ (F/C) - 0.00110\ (TTU) - 0.00213\ (P3/4) \qquad (14)$$

where

GL = Aggregate loss, corrected for settlement, in feet
LT = Number of loaded log trucks in thousands
F/C = Fill or cut section (fill = 1.0, side cast = 1.5, cut = 2.0)
TTU = Total 2 way traffic units in thousands
P3/4 = Percent of road surfacing sample smaller than 3/4 inches in diameter

where the correlation coefficient (R) is 0.8882.

This model was designed to reflect not only the loss due to traffic, but also all other effects such as rainfall, wind action, and properties of the surfacing material. If the test sections were representative of the full range of both environmental and logging conditions, then the equation could be universally applied. However, this is not the case and the results were not considered to be universally acceptable because of a number of questionable items; therefore, further study was instituted to resolve these questions.

At present a more recent study of aggregate loss by John Lund is nearing completion. When this report is obtained, appropriate modifications to the aggregate loss model will be made to make it more widely applicable. If a user does not wish to use the aggregate loss prediction model, the next section describes how aggregate loss can be input directly into the program.

Direct Input Model

The user has the option of specifying the aggregate loss by direct input rather than by using the Lund aggregate loss model. To accomplish this, the values of the following two quantities must be specified for each time interval:

(1) the number of thousands of board-feet of lumber hauled and

(2) the aggregate loss rate in inches of thickness per thousand board feet of timber hauled.

The appropriate time intervals are the same intervals as those used in the non-linear traffic model, which was discussed earlier.

A constant aggregate loss rate in inches per year may also be input to account for additional loss due to erosion that may not be predicted adequately by the Lund model or the direct input described above. This loss due to erosion will of necessity be selected based on local experience. If the thickness loss due to erosion is negligible, the constant aggregate loss rate is set equal to zero.

ROUTINE MAINTENANCE COST MODEL

The routine maintenance cost covers such things as repairing small failed areas, application of dust palliatives and other items which are not covered under

(1) seal coat or overlay costs for bituminous surfaced roads or

(2) grading or aggregate addition costs for aggregate surfaced roads.

The level of routine maintenance is allowed to vary in a piecewise-linear manner exactly as is ADT as discussed in a preceding section. Thus, it is possible to set the cost at a higher level during periods of heavy traffic, than during periods of light traffic.

A provision is also made for decreasing the cost rate after a major rehabilitation. Suppose, for example, that the annual routine maintenance cost per lane mile is specified as $100 after ten years and $200 after twenty years. Then the cost rate versus time is as shown in Fig 2.4. If an overlay were performed at the beginning of the fifteenth year, it is reasonable to expect that the subsequent routine maintenance costs would be decreased. Thus, after the overlay, the LVR program automatically changes the cost rate to $100, the value at the beginning of the time period, and the cost rate begins to increase linearly exactly as before the overlay. The second routine maintenance history is shown in Fig 2.5.

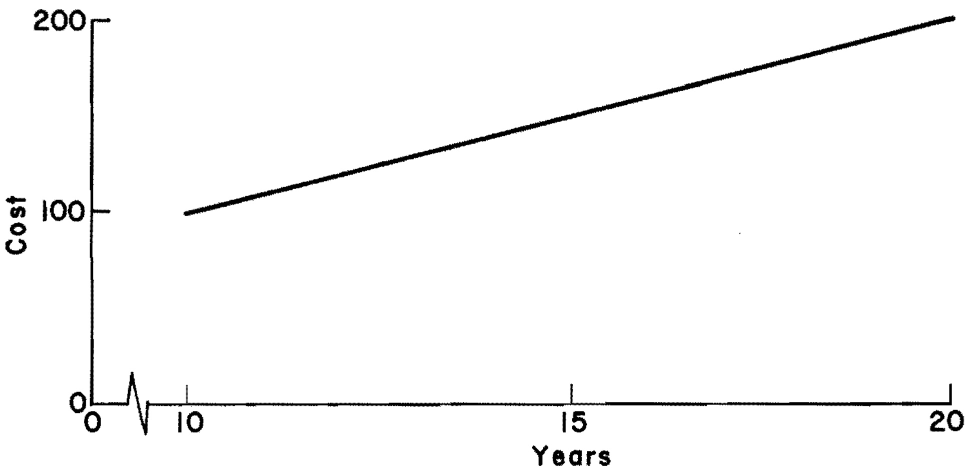


Fig 2.4. Annual routine maintenance cost versus time.

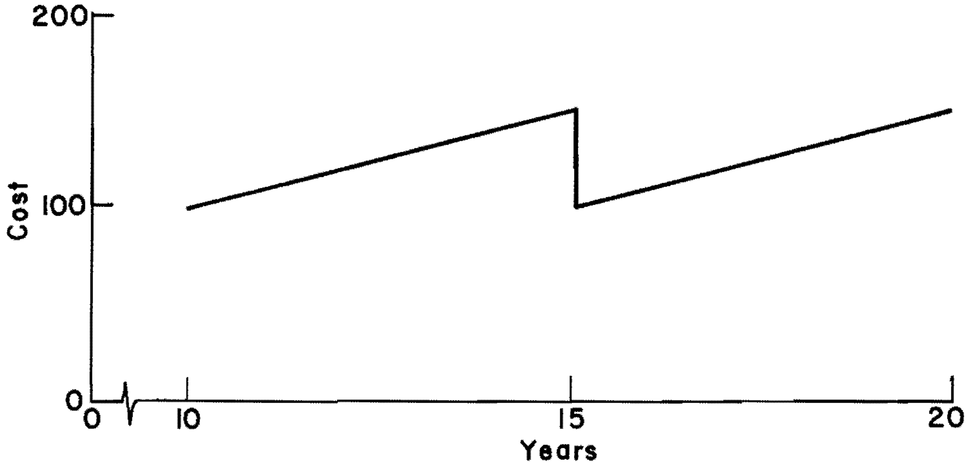


Fig 2.5. Annual routine maintenance cost versus time with adjustment due to overlay at the beginning of the fifteenth year.

It may be desired to have a sharp increase or decrease in routine maintenance at the beginning or end of a period of heavy traffic, such as a logging sale. Suppose, for example, that the annual routine maintenance cost per lane mile was expected to increase from $100 to $200 during the first five years of the analysis period, but due to a subsequent decrease in traffic volume, to be a uniform $50 per year thereafter. This would be specified as follows:

Time	Annual Routine Maintenance Cost
0.00	$100
5.00	$200
5.01	$ 50
25.00	$ 50

This is exactly the same scheme that is used to model the sharp changes in ADT at the beginning or end of a logging period as shown in Fig 2.3.

USER DELAY MODEL

A user delay model has been incorporated into the program to account for excess time and vehicle operating costs due to maintenance operations on both bituminous and aggregate surfaced roads. These costs are determined at all points of either major or minor maintenance and are based on certain user inputs.

The maintenance operations covered by this model consist of overlays and seal coats for bituminous surfaced roads, and aggregate additions and gradings for aggregate surfaced roads. Except for gradings, all of these operations are modeled similarly, in that all types of traffic are affected by the maintenance operations. For grading, however, the traffic is split into two types, trucks and non-trucks as defined in the non-linear traffic model. Non-trucks are assumed to follow the grader at a greatly reduced speed until the grader pulls off the road to allow them to pass. Trucks, however, are assumed to be capable of crossing the windrow produced by the grading operation, and pass the grader at only a slightly reduced speed. In order for this grading model to be applicable, it is necessary that the road be at least 20 feet wide.

The user delay models included in LVR are basically taken from a report entitled "A Systems Approach to the Flexible Pavement Design Problem" (9). This report provides five detour models for which delay costs may be computed, however, only two of these models are used in LVR. Cost accumulate as the affected vehicles, approaching and leaving the restricted zone caused by the maintenance operation, decelerate, continue at a reduced speed or stop, and accelerate back to normal speed. Costs for each of these components were reported in table form in Reference 8. These cost were determined for vehicles operating on a level, tangent roadway with a vehicle distribution obtained from a "1966 Texas Highway Department Vehicle Classification Study." LVR uses an update of these costs with (1) aggregate surfaced road costs coming from tables for rural roads and (2) bituminous surfaced road costs coming from tables for urban roads. These cost tables will be revised during subsequent work in order to account for the steep grades and sharp curvature present on some Forest Service roads.

A study will then be performed on the sensitivity of the total cost of constructing, maintaining, and using a low-volume road to user delay costs. If this sensitivity is very small, it may be possible to eliminate the user cost calculations from the program. In addition, the vehicle distribution will be adjusted to more accurately reflect traffic on typical Forest Service roads.

Model 2 routes traffic around the maintenance operation by means of alternating traffic flow in the remaining width of the lane. During this time, traffic is stopped in the direction opposite traffic flow. This is the applicable detour model for most forest roads. However, it is necessary that the width of the lane be at least 20 feet wide in order to allow traffic to pass the maintenance equipment. It is also necessary to keep the time required for a vehicle to pass through the restricted zone equal to or less than the time between arrivals of vehicles. Failure to observe this time constraint will result in large waiting times and exorbitant user delay costs. This point is discussed in more detail in the Appendix.

VEHICLE OPERATING COST MODEL

The vehicle operating cost model is designed to give the user the total cost of operating vehicles during the design life of the proposed roadway. The two input parameters supplied by the user are the costs in dollars per lane mile of operating (1) trucks and (2) non-trucks. Using other input parameters supplied by the user, the model outputs expected costs in dollars per lane mile or dollars per square yard at net present value.

Vehicle operating costs are a part of LVR because these costs are such a major cost item for planning purposes. These total costs do not vary with the design and rehabilitation parameters which are analyzed by a particular run of LVR, but will vary between analyses involving comparisons of designs using ACP and aggregate surfaces.

The user can obtain his input costs for trucks and non-trucks in dollars per mile from any source available. One likely source for the future will be the model under development at the University of California (10) for the Forest Service. According to this model, vehicle operating costs are determined by:

(1) the geometrics of the road, including the grade and curvature,

(2) the type of road surface, and

(3) several traffic parameters, including the types of vehicles and the corresponding speed versus distance through the road section for each type of vehicle for each direction.

In order to obtain input costs from this program for comparisons of costs of aggregate surfaced roads and bituminous surfaced roads the user will make two runs using the University of California model. One of the runs will generate operating costs appropriate for a bituminous surfaced road while the other run will generate costs appropriate for an aggregate surfaced road.

BRIEF DESCRIPTION OF PROGRAM LVR

The conceptual flowchart, shown in Fig 2.6, is provided to enable the reader to envision the operation of program LVR. As stated on the flowchart the basic purpose of the program is to calculate and store all feasible design strategies, disregarding the number of layers in particular designs, then print the 40 most economical designs after arranging them in ascending order by total cost. LVR accomplishes its purposes by following the procedures set out in Fig 2.6. The number 40 was chosen simply because this is a sufficiently large number of candidate designs to examine for reasonable purposes, but the information for 40 designs do not constitute excessive output, as would, say, the information for 400 designs.

Block 1 of Fig 2.6 describes the selection process for initial construction designs. In determining feasible designs the program follows a "strong-arm" factorial evaluation technique. First it calculates the length of time that the minimum specified surface thickness would last, given the specified traffic, and assuming a single layer. If the calculated time is less than the specified minimum time to the first rehabilitation, then the design is discarded as not feasible and the thickness is increased by a specified increment. This procedure is repeated until the incremented thickness exceeds the maximum specified thickness of the surface layer.

For each design, satisfying the thickness constraints, whose calculated life exceeds the minimum time to the first rehabilitation, a rehabilitation strategy is calculated, as discussed in Block 2 of Fig 2.6.

When designs involve two layers, the following factorial design is generated for calculating feasible initial designs. The minimum thickness for both the surface and second layer are selected; the time such a design would last is calculated, given the specified traffic; if the calculated time is less than the specified minimum time to the first rehabilitation, then the design is discarded as not feasible and thicknesses are increased by specified increments, in accordance with the following. Holding the surface thickness constant, the second layer is incremented, each incremented design is evaluated followed by rehabilitation strategies if appropriate. Designs continue to be evaluated by incrementing the second layer unitl its maximum specified thickness is exceeded. The next step involves incrementing the surface layer and allowing the second layer to vary from its minimum to maximum at each increment of the surface layer. This incrementing process continues until the thickness of the surface reaches the maximum.

Designs involving more than two layers proceed similarly to the procedures of the two layer description. Because of this factorial calculation procedure, the user should specify realistic input data for both the minimum

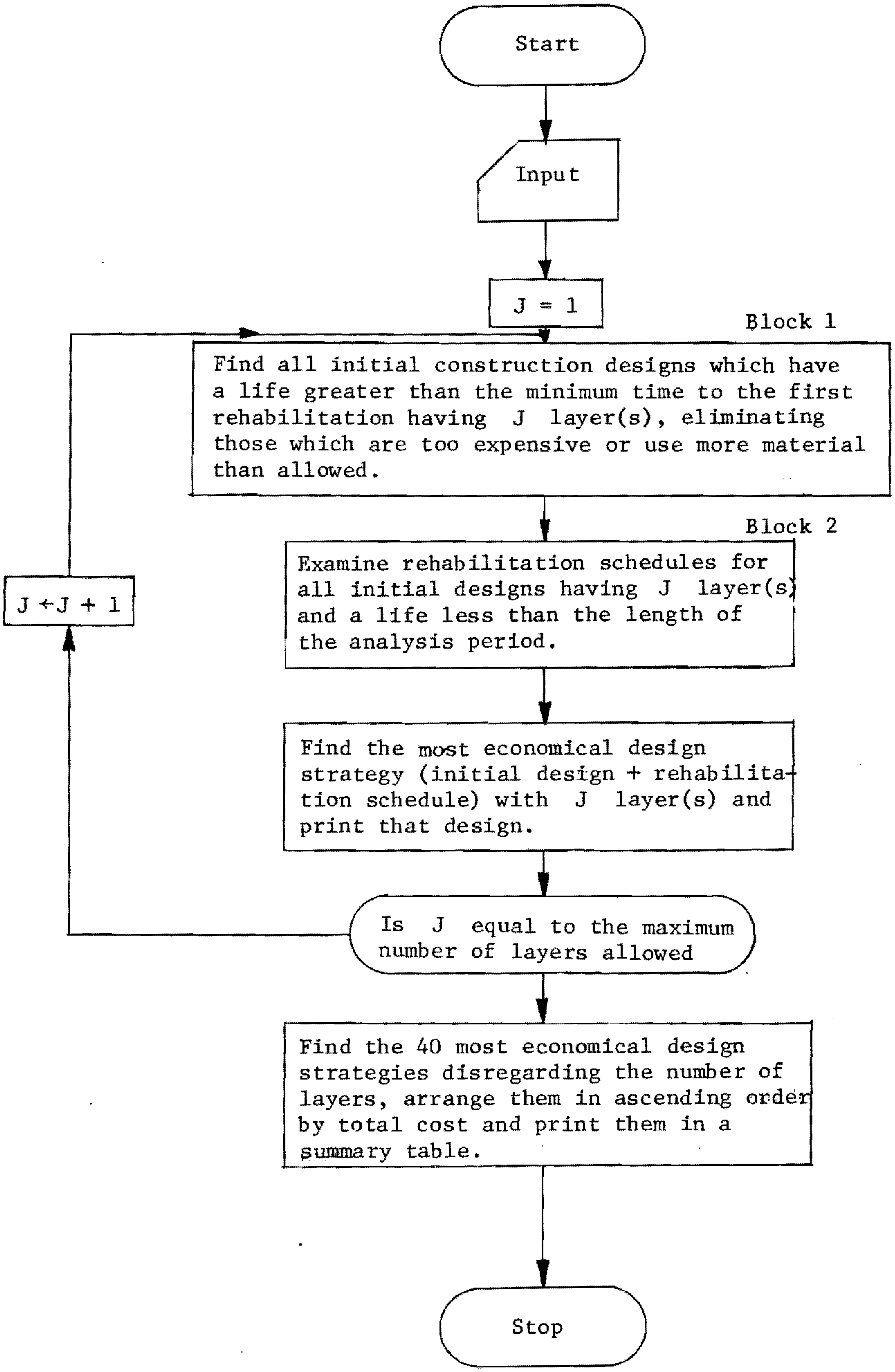


Fig 2.6. Conceptual Flow Chart of Program LVR.

and maximum thicknesses of each layer and type of material to be considered in the design.

In calculating the time that a particular design will last, LVR uses the performance model, which has been described in a previous section. Rehabilitation strategies also make use of the performance model. In the case of aggregate surfaced designs, additional criteria for a feasible design are set by the aggregate loss model and the rutting model, both models have also been described. Another feasibility criterion for all types of designs, is the requirement on initial construction and all rehabilitations that the top layer of a road design must not fail before the overall structure fails. Similar checks are made for the top "k" layers for k = 1, 2, etc. up to the total number of layers. This prevents the program from classifying a design as feasible if the overall design lasts the length of the performance period but a particular layer fails prematurely.

CHAPTER 3. EXAMPLE PROBLEMS

INTRODUCTION

To demonstrate the capabilities of the LVR program, three example problems are presented. Two of the example problems illustrate the design of aggregate surfaced roads and the third illustrates the design of an asphalt concrete surfaced road. The three examples demonstrate the types of pavement combination problems that can be solved using the existing computer program. These pavement combinations can be described by surface types as

(1) bituminous surfaced roads,
(2) aggregate surfaced roads, and
(3) aggregate surfaced roads that are subsequently resurfaced using a bituminous surface treatment.

Two different sets of input information will be developed to provide solutions to these three types of problems and demonstrate the procedures that a user must follow in utilizing the program.

BITUMINOUS SURFACED ROADS (ACP)

PROBLEM DESCRIPTION AND INPUT VARIABLES

The problem chosen to demonstrate this feature of LVR is one that may be typical of the design of a major road that collects traffic from the branch lines going into the actual timber sale areas. The traffic that has been generated is hypothetical and is designed to demonstrate the flexibility of the program in handling variations in both traffic volume and 18-kip equivalent single axle loads. It is assumed that two periods of intense logging operations occur between years 0 through 5 and 8 through 20, that logging operations terminate at the end of year 5, and the number of logging trucks increases from 0 per day at 5 years to 200 per day at 8 years.

The traffic at the end of the analysis period is assumed to be all passenger or light truck vehicles that produce a very small number of 18-kip equivalent single axle loads. Because of the timber sale schedule, no overlays are permitted before the eighth year.

The subgrade soil is assumed to have a R-value of 20 run at an exudation pressure of 300 psi and is assumed subject only to normal subgrade movements. The road section is located in an area that has a regional factor of 2.0. The materials available for construction consist of a hot-mix asphaltic concrete, a high-stability crushed stone base and a select material available from local sources with R-value strengths of 80, 75 and 60 respectively. These R-values tests were also run at 300 psi exudation pressure. Cost information on the pavement and maintenance materials were obtained from suppliers in the Austin, Texas area during the summer of 1976.

The performance and user delay variables selected were thought to be representative of normal construction and operational practices for low volume roads. An interest rate of 6 percent was selected for computation of net present value.

The following values for input variables were selected as representative of values that might be typical of the situation described above. The values are presented as discussed and arranged in the draft User's Manual included in the Appendix. To be consistent with the presentation of material in the Appendix, the input data and, in some cases, brief descriptions of how the data were developed are presented as they occur by card.

(a) Card 1 - Program and Problem Description
See echo print in Table 3.3

(b) Card 2 - Miscellaneous Inputs
Costs in dollars per lane mile
Print 40 designs
3 materials available: ACP, crushed stone base and selected material
20 year analysis period
12 ft. lanes
7 Card Number 4's. The user must wait until 18-kip equivalent single axle load (SAL) traffic data is developed before this entry can be determined.
6 percent interest rate
Paved road: Type 1
1 Entry on Card Number 5. The user must wait until minimum times between performance periods are established before this entry can be determined.
YES Delay cost will be considered.

(c) Card 3 - Performance Variables
Serviceability values chosen for this problem are compatible with those built into the Design Chart for Flexible Pavements used by the Forest Service (5).
Regional Factor is given as 2.0. For other problems use Appendix A or Reference 5 to determine an appropriate value for R.
Initial PSI = 4.2. This is the value built into the Design Chart for Flexible Pavements (5) by the Forest Service and was obtained from the AASHTO Road Test.
PSI after an overlay is assumed equal to 4.2. This value will depend on the quality of resurfacing work produced by local contractors.
Terminal PSI = 2.0, see Design Chart for Flexible Pavements (5).
Non-Traffic Deterioration Parameters - in the performance equation used in LVR, the basic AASHTO Interim Guide (2) design equation has been modified to reflect changes in PSI that may occur due to non-traffic related variables (See Eq 4). Two factors have been introduced to permit the engineer to include the effect of these non-traffic associated deterioration factors. The effect of these two factors, P2' and b_1 (P2P and BONE in the User's Manual) on PSI with time is shown in Figure 1 of the Appendix. P2' is the level of PSI that could be reached in infinite time if no traffic was permitted on the road, and b_1 defines the rate at which PSI approaches P2'.
In choosing values for these two variables, the engineer must rely on past experience or perhaps an educated guess until he develops more experience with these two variables. Table 1 of the Appendix is included to give assistance in selecting values for these variables. Some situations that may produce non-traffic associated deterioration due to changes in vertical profile of the road are:

1. Frost-heave,
2. Permanent uneven settlement of embankments,
3. Local slips on side-hill sections, or
4. Soils that swell or shrink with moisture content changes.

Lower bound for PSI at infinite time with no traffic, P2P, is assumed to be 3.6.
Rate at which PSI approaches P2P, BONE, is 0.02 (See Fig 1 of Appendix for a graphical illustration of the general effects of P2P and BONE).
Since this is an ACP design, P34 and IFC are left blank.

(d) Card 4 - Time Dependent Variables
This card includes the values of variables that may vary with time. For this problem, the appropriate variables are time point, TIMNL(I), in years; daily volume of non-logging vehicles, RNL(I,1); daily volume of logging trucks, RNL(I,2); and cumulative 18-kip equivalent SAL at TIMNL(I), CUM18K(I). The values included in Table 3.1 were generated as appropriate for the conditions described in the problem statement. Traffic data for Card 4 may be generated using the procedures described in Section 1 - Traffic Analysis of Reference 5. Values for the other variables were not needed in the solution of this problem. The reader should notice that the routine maintenance cost, CM(I), does not include seal cost costs. For this problem, seal coat rehabilitations and overlays are assumed to be the only future pavement costs.

TABLE 3.1. CARD 4 INPUT DATA FOR ACP EXAMPLE PROBLEM

TIML(I)	Daily Non-Logging RNL(I,1)	Daily Logging RNL(I,2)	CUM 18K SAL CUM 18K (I)	Routine Maintenance CM(I)	Timber Hauled MBF BDFT(I)	Aggregate Surface Loss, in./MBF BDF TIN(I)
0	70	300	0	0	0	0
5.0	70	300	702,100	0	0	0
5.1	10	0	702,100	0	0	0
8.0	100	200	842,550	0	0	0
8.1	100	300	842,550	0	0	0
20.1	80	300	2,527,450	0	0	0
21.0	50	0	2,527,495	0	0	0

(e) Card 5 - Minimum Time Between Performance Periods
Values selected for minimum time between performance periods would normally be selected based on timber sale constraints. Since monies for rehabilitation activities will normally be available only during timber sales, these values are selected so that the computer program will schedule rehabilitation activities at appropriate times. For this problem all times between rehabilitations are assumed to be the same and equal to 8 years.

(f) Card 6 - Values of Restriction Variables
These input values should be chosen with care because they restrict and control the number of strategies considered in the optimization process. These restriction variables include those that vary from maximum available funds for initial construction to the maximum permissible aggregate loss due to erosion.
Maximum funds available for initial construction (units must be compatible with variable 1 on Card 2) = $50,000/lane mile.
Maximum allowable total thickness of initial construction = 25 inches
Minimum thickness of an individual rehabilitation = 1.0 inch
Accumulated maximum thickness of all rehabilitation = 12 inches
Maximum thickness of an individual rehabilitation = 5 inches
The other two variables are for use with aggregate surfaced roads and are left blank

(g) Card 7 - Overlay Parameters Associated with Overlay and Road Geometrics
The values selected for variables contained in Cards 7 and 8 are thought to be typical for rural highways. The values selected by the user for a particular problem should be based on local construction practices. These variables are specified only if delay costs are desired. Distance over which traffic is slowed in the:
(1) rehabilitation direction is assumed to be 1.5 miles
(2) non-rehabilitation direction is assumed to be 1.5 miles
Percent of ADT which will pass through the rehabilitation zone during each hour of this activity is assumed to be 10.

(h) Card 8 - Other Parameters Associated with Traffic Speeds and Delays
Specify values for these variables only if delay costs are desired; otherwise insert a blank card in the input data.
Percent of vehicles stopped by construction equipment and personnel in the:
(1) rehabilitation direction is assumed to be 35
(2) non-rehabilitation direction is assumed to be 35
Average delay per vehicle due to rehabilitation equipment and personnel in the:
(1) rehabilitation direction is assumed to be 0.1 hours
(2) non-rehabilitation direction is assumed to be 0.1 hours
Average approach speed to the rehabilitation area is assumed to be 35 mph.
Average speed through the rehabilitation area:
(1) rehabilitation direction is assumed to be 20 mph
(2) non-rehabilitation direction is assumed to be 20 mph
Model describing the traffic control situation during rehabilitations is assumed to be Model 2 as shown in Fig 3 of the Appendix.

(i) Card 9 - Grading or Seal Coat Construction Considerations
The values selected for these input variables should be based on experience with local contractors and equipment available for grading and seal cost operations. The values selected for this example problem are typical for conditions in Texas.
Number of passes the seal coat truck makes on a section for coverage is 1.
Average speed of the seal coat truck is 10 mph.
Average speed of trucks in the seal coat direction is 10 mph
Construction cost of a seal coat is $1200/lane mile.
Time between seal coats is 2 years. This value reflects the effect of a combination of soft, polish susceptible aggregate and heavy traffic.
Such an aggregate is assumed in this problem.
The other variable on this card is appropriate only for aggregate surfaced roads.

(j) Card 10 - Vehicle Operating Cost
The values for these input variables must be selected or calculated from published reports or data available from the Washington Office of the Forest Service. New calculation procedures for vehicle operating costs are under development at the San Dimas Equipment Development Center and the University of California at Berkeley. These new procedures should be available within the next few years.

These values are not used in the economic calculations of the program but are included to provide the user the opportunity of showing the total vehicle operating costs in the summary output table.

(k) Card 11 - Construction Materials and Their Properties
The values chosen for these input variables should be selected using procedures outlined in Reference 5, Tables 3 thru 11, and local experience. The user will not be familiar with some of these variables but each is important in selection of optimum strategies. For this example problem the values selected may not necessarily conform to those outlined in Reference 5 but were considered appropriate for the assumed conditions. The layer identification, material code letter and material name are selected by the user in order to provide quick identification and differientation between materials available for this construction project. The user should recognize that it is possible to enter more than one material for any one or all layers. If there are two surfacing materials available, both should have an ID of 1 but different codes and names. Values for all Card 11 input variables are included in Table 3.2.
These values were selected as typical values and do not necessarily follow the recommendations of Reference 5. Costs are those typical of materials in the Austin, Texas area during 1976.
Layer coefficients selected are assumed typical of high quality materials available in the Austin, Texas area. For other problems the user should follow guidelines suggested in Tables 4 through 11 of Reference 5.

TABLE 3.2. CARD 11 INPUT DATA FOR ACP EXAMPLE PROBLEM

ID	Code	Name	Cost $/SY	Layer Coefficient	Layer Thickness		Salvage Value, (percent)	Soil Support Value
					Minimum	Maximum		
1	A	ACP	25.00	0.40	3.0	10.0	40	
2	B	Crush Stone Base	6.00	0.13	4.0	15.0	60	7.90
3	C	Select Base	2.50	0.09	4.0	15.0	60	6.55
		Subgrade						5.55

The selected minimum layer thicknesses were based on local construction practice. For other problems the user should follow guidelines suggested in Table 3 of Reference 5.

Maximum layer thicknesses selected were based on local construction practice. The selection of these values are critical because of their effect on computer run time. The user should select values large enough to include all normal thicknesses but not so large that excessive computer time is required to consider all feasible designs. As a guide in selecting the maximum layer thickness the user may consider values in the range of 2 to 4 times the minimum layer thickness specified.

Salvage value of a layer represents the residual value of the layer after the design life as a percentage of the initial construction cost. The percentage selected will depend on the level of deterioration to which the pavement is permitted to go. Such factors as cracking and rutting expected in the surface, subgrade intrusion into the base, etc. will affect the residual value of particular materials in particualr environments. The user should depend on local experience to develop appropriate salvage value percentages. The values selected for this problem are typical of those where good maintenance practices are observed and are appropriate for state highways in Texas.

Soil support values are required for all materials in order to evaluate thicknesses required for multilayer designs. Since there are no direct laboratory tests available for determining soil support value, the user must rely on correlations relating results from other laboratory test methods to soil support value. Figure 5 of Reference 5 has been used in this problem to relate R-value at 300 psi exudation pressure to soil support value.

DISCUSSION OF SOLUTION

Table 3.4 contains the designs that were generated by LVR for the input data recorded in Table 3.3. The table contains only the 10 lowest cost designs of the 40 designs printed for this problem. Note that the designs are printed in order of lowest cost with the lowest cost designated as design strategy 1. The lowest cost design involves the use of three layers with 5.50 inches of ACP, 4.0 inches of crushed stone base and 4.0 inches of a select material. This initial construction had a design life of 8.7 years at which time a one-inch overlay (with one-inch level up course) extended the life of the pavement through the 20 year design life. For the best 10 design strategies the total cost varies from $40,359 to $41,723/lane mile. The total cost includes the initial construction cost, overlay construction cost, delay costs for both overlay and seal coat operations, seal coat costs, routine maintenance cost and a salvage value to reflect the expected value of the road at the end of the current design period.

TABLE 3.3. INPUT DATA FOR AN ACP EXAMPLE PROBLEM

```
   PROB     1B       ASPHALT-CONCRETE PAVEMENT EXAMPLE PROBLEM

            THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE
          MATERIALS              COST    LAYER     MIN.     MAX.  SALVAGE    SS
LAYER CODE        NAME          PER CY  COEFF.    DEPTH    DEPTH    PCT.   VALUE
  1     A   ACP                 25.00     .40      3.00    10.00    40.0    9.00
  2     B   CRUSH STONE BASE     6.00     .13      4.00    15.00    60.0    7.90
  3     C   SELECT BASE          2.50     .09      4.00    15.00    60.0    6.55
            SUBGRADE             0.00    0.00      0.00     0.00     0.0    5.55

        THIS IS A PAVED ROAD.

   TOTAL NUMBER OF INPUT MATERIALS,EXCLUDING SUBGRADE                           3
   LENGTH OF THE ANALYSIS PERIOD (YEARS)                                     20.0
   WIDTH OF EACH LANE (FEET)                                                 12.0
   INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                             6.0
   REGIONAL FACTOR                                                            2.0

   SERVICEABILITY INDEX OF THE INITIAL STRUCTURE                              4.2
   SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                   4.2
   MINIMUM SERVICEABILITY INDEX P2                                            2.5
   SWELLING CLAY PARAMETERS -- P2 PRIME                                      3.60
                               B1                                           .0200

   MAX FUNDS AVAILABLE FOR INITIAL DESIGN (DOLLARS PER LN.ML.)           50000.00
   MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)                25.0
   MINIMUM OVERLAY THICKNESS (INCHES)                                         1.0
   ACCUMULATED MAXIMUM DEPTH OF ALL OVERLAYS (INCHES)                        12.0
   MAXIMUM OVERLAY THICKNESS (INCHES)                                         5.0

   C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE O.D. (MILES)            1.50
   C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE N.O.D. (MILES)          1.50
   PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN O.D. (PERCENT)        35.0
   PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN N.O.D. (PERCENT)      35.0
   AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN O.D. (HOURS)                    .100
   AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS)                  .100

   AVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH)                          35.0
   AVERAGE SPEED THROUGH OVERLAY ZONE IN O.D. (MPH)                          20.0
   AVERAGE SPEED THROUGH OVERLAY ZONE IN N.O.D. (MPH)                        20.0
   AVERAGE SPEED OF THE GRADER OR S.C.TRUCK. (MPH)                           10.0
   TRAFFIC MODEL USED IN THE ANALYSIS                                           2

   OPERATING COST FOR NON-TRUCKS (DOLLARS/MILE)                               .15
   OPERATING COST FOR TRUCKS (DOLLARS/MILE)                                  1.25

   TIME BETWEEN SEAL COAT (YEARS)                                             2.0
   VALUES FOR THE MINIMUM TIME BETWEEN REHABILITATIONS (YEARS)

    8.0
```

TABLE 3.3. (Continued)

```
PROB    1B       ASPHALT-CONCRETE PAVEMENT EXAMPLE PROBLEM

GRAVEL LOSS DUE TO EROSION (INCHES/YEAR)                                  0.00
MINIMUM THICKNESS OF THE TOP LAYER BEFORE A GRAVEL ADD. (INCHES)          0.0
COST OF A SEAL COAT (DOLLARS/LANE MILE)                                1200.00
NUMBER OF PASSES THE GRADER OR SEAL COAT TRUCK MAKES                         1
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)            10.0

                            TIME-DEPENDENT VARIABLES

 TIME    NON-TRUCKS  TRUCKS   18-KIP EQUIV. ROUT. MAINT. LUMBER HAULED  GRAVEL LOSS
(YEARS)  (PER DAY)  (PER DAY)    AXLES      (DOL./LNML)      (MBF)       (IN./MBF)
  0.0        70        300           0          0.00          -0.0          -0.0
  5.0        70        300      702100          0.00          -0.0          -0.0
  5.1        10          0      702100          0.00          -0.0          -0.0
  8.0       100        200      842550          0.00          -0.0          -0.0
  8.1       100        300      842550          0.00          -0.0          -0.0
 20.0        80        300     2527450          0.00          -0.0          -0.0
 21.0        50          0     2527495          0.00          -0.0          -0.0


   IF THE EXPECTED LIFE OF THE ROAD IS GREATER THAN
   THE ANALYSIS PERIOD (CL) + 5 YEARS, THEN THE LIFE IS
   SET TO CL + 5 BEFORE THE RESULTS ARE PRINTED.
   LIGHT TRAFFIC AFTER THE ANALYSIS PERIOD PRODUCES A
   SMALL NO. OF 18-KIP-EQUIV. AXLE LOADS RESULTING IN
   LONG TIMES TO FAILURE.
```

TABLE 3.4. OUTPUT FOR ACP EXAMPLE PROBLEM

```
  PROB    1B       ASPHALT-CONCRETE PAVEMENT EXAMPLE PROBLEM

                      SUMMARY OF THE BEST DESIGN STRATEGIES
                        IN ORDER OF INCREASING TOTAL COST
                               (DOLLARS PER LN.ML.)

                               LANE WIDTH = 12.0 FT.

                            1          2          3          4          5
********************************************************************************
MATERIAL ARRANGEMENT       ABC        ABC        ABC        ABC        ABC
INIT. CONST. COST       33538.25   34760.47   34711.58   34760.76   40773.80
OVERLAY CONST. COST      5787.45    5459.86    5787.45    5787.45       0.00
DELAY COST OVERLAY        777.01     722.28     774.96     774.96       0.00
DELAY COST SEAL COAT       14.97      15.02      14.85      14.85      17.17
SEAL COAT COST           5448.82    5640.95    5414.53    5414.53    6307.34
ROUTINE MAINT. COST         0.00       0.00       0.00       0.00       0.00
SALVAGE VALUE           -5207.37   -5359.80   -5426.88   -5436.08   -5646.39
********************************************************************************
********************************************************************************
TOTAL COST              40359.13   41238.77   41276.50   41316.48   41451.93
********************************************************************************
NON-TRUCK OPER. COST    51150.87   51150.87   51150.87   51150.87   51150.87
TRUCK OPERATING COST  1468823.55 1468823.55 1468823.55 1468823.55 1468823.55
********************************************************************************
********************************************************************************
NUMBER OF LAYERS            3          3          3          3          3
********************************************************************************
LAYER DEPTH (INCHES)
     D(1)                  5.50       5.75       5.50       5.50       6.50
     D(2)                  4.00       4.00       5.00       4.00       6.00
     D(3)                  4.00       4.00       4.00       6.50       4.00
********************************************************************************
********************************************************************************
NO. OF PERF. PERIODS        2          2          2          2          1
********************************************************************************
PERF. TIME (YEARS)
     T(1)                  8.7       10.0        8.9        8.9       25.0
     T(2)                 25.0       25.0       25.0       25.0
********************************************************************************
OVERLAY STRAT.(INCHES)
(INCLUDING LEVEL-UP)
     O(1)                  2.0        2.0        2.0        2.0
********************************************************************************
NUMBER OF SEAL COATS        8          8          8          8          9
********************************************************************************
SEAL COAT SCHEDULE
   (YEARS)
   SC( 1)                  2.0        2.0        2.0        2.0        2.0
   SC( 2)                  4.0        4.0        4.0        4.0        4.0
   SC( 3)                  6.0        6.0        6.0        6.0        6.0
   SC( 4)                 10.7        8.0       10.9       10.9        8.0
   SC( 5)                 12.7       12.0       12.9       12.9       10.0
   SC( 6)                 14.7       14.0       14.9       14.9       12.0
   SC( 7)                 16.7       16.0       16.9       16.9       14.0
   SC( 8)                 18.7       18.0       18.9       18.9       16.0
   SC( 9)                                                             18.0
********************************************************************************
```

TABLE 3.4 (Continued)

```
   PROB    18       ASPHALT-CONCRETE PAVEMENT EXAMPLE PROBLEM

                         SUMMARY OF THE BEST DESIGN STRATEGIES
                          IN ORDER OF INCREASING TOTAL COST
                                (DOLLARS PER LN.ML.)

                                LANE WIDTH = 12.0 FT.

                            6          7          8          9         10
********************************************************************************
MATERIAL ARRANGEMENT      ABC        ABC        AB        ABC        ABC
INIT. CONST. COST      40822.98   40822.69   35102.22   40871.87   35933.80
OVERLAY CONST. COST        0.00       0.00    5787.45       0.00    5150.81
DELAY COST OVERLAY         0.00       0.00     774.96       0.00     673.76
DELAY COST SEAL COAT      17.17      17.17      14.85      17.17      14.64
SEAL COAT COST          6307.34    6307.34    5414.53    6307.34    5529.02
ROUTINE MAINT. COST        0.00       0.00       0.00       0.00       0.00
SALVAGE VALUE          -5655.59   -5579.31   -5499.96   -5588.51   -5579.31
********************************************************************************
********************************************************************************
TOTAL COST             41491.91   41567.89   41594.06   41607.87   41722.72
********************************************************************************
NON-TRUCK OPER. COST   51150.87   51150.87   51150.87   51150.87   51150.87
TRUCK OPERATING COST 1468823.55 1468823.55 1468823.55 1468823.55 1468823.55
********************************************************************************
********************************************************************************
NUMBER OF LAYERS            3          3          2          3          3
********************************************************************************
LAYER DEPTH (INCHES)
     D(1)                 6.50       6.75       5.50       6.75       5.75
     D(2)                 5.00       5.00       7.00       4.00       5.00
     D(3)                 6.50       4.00                  6.50       4.00
********************************************************************************
********************************************************************************
NO. OF PERF. PERIODS        1          1          2          1          2
********************************************************************************
PERF. TIME (YEARS)
     T(1)                 25.0       24.6        8.9       25.0       10.9
     T(2)                                       25.0                  25.0
********************************************************************************
OVERLAY STRAT.(INCHES)
(INCLUDING LEVEL-UP)
     D(1)                                        2.0                   2.0
********************************************************************************
NUMBER OF SEAL COATS        9          9          8          9          8
********************************************************************************
SEAL COAT SCHEDULE
   (YEARS)
    SC( 1)                 2.0        2.0        2.0        2.0        2.0
    SC( 2)                 4.0        4.0        4.0        4.0        4.0
    SC( 3)                 6.0        6.0        6.0        6.0        6.0
    SC( 4)                 8.0        8.0       10.9        8.0        8.0
    SC( 5)                10.0       10.0       12.9       10.0       12.9
    SC( 6)                12.0       12.0       14.9       12.0       14.9
    SC( 7)                14.0       14.0       16.9       14.0       16.9
    SC( 8)                16.0       16.0       18.9       16.0       18.9
    SC( 9)                18.0       18.0                  18.0
********************************************************************************
```

The reader should notice that the most economical design involves use of the minimum thickness of both the base and subbase layers. These minimums are dictated by normal and proper construction practice. The program orders design strategies based on total cost only; therefore, the user must be careful to specify proper values for these minimum thicknesses or unreasonable layer thicknesses from a construction standpoint may be generated. The user should also recognize that the really critical factors governing selection of thicknesses is the ratio of layer cost to layer relative strength coefficient. If the user has available an ACP at a cost of $40/ton with a strength coefficient of 0.4 and a crushed stone material at a cost of $30/ton (perhaps due to high transportation charges) with a strength coefficient of 0.14, the best design strategy will probably involve a single layer design of ACP because of the superior ratio of cost to strength coefficient of the ACP as compared to the stone.

Notice also that of the five best designs four have the same surface thickness, 5.5 inches. Of these four designs, three have the same length of time to the end of the first performance period, 8.9 years, while design 1 has a life of 8.7 years. The occurrence of the same life for several initial structures which have the same surface thickness but different total thicknesses results from the criteria for choosing the length of time to the first overlay (or the end of the first performance period). Three criteria are used to calculate this time. A discussion of this calculation procedure is included in the section titled Aggregate Surfaced Roads Failure Criteria of Chapter 2. For design 1, the life of the total structure controls, but for designs 3, 4 and 8 the controlling criterion is the maximum life of the surface layer; therefore, T(1) is equal for all three of these designs. This conclusion can be verified by using the procedure described in Method 2, pages 50 - 41 and 42 of the Forest Service Transportation Engineering Handbook (5).

Time T(2) is the length of the second performance period. Notice that for the first eight designs, T(2) equals 25 years, and for designs 9 and 10 T(1) is 25 years. The 25 years results from a decision by project staff to limit the recorded life of a design to the input value of design life plus 5.0 years. Lives in excess of this limiting value occur because the traffic at the end of the design life usually consists of only automobile and pickup traffic and no logging trucks. Since approximately 2500 automobiles are required to produce one 18-kip equivalent single axle load, the design life can be extended for a very long period of time if only a few 18-kip equivalent single axle loads remain after the design life and before failure. To eliminate possible computer problems produced by these long times, the project staff arbitrarily limited the length of the last performance period to the design life plus five years. The user must recognize that the period of time the roadway lasts after the end of the analysis period is a function of both the traffic and non-traffic deterioration input for that period.

AGGREGATE SURFACED ROADS

PROBLEM DESCRIPTION AND INPUT VARIABLES

The problem chosen to demonstrate this part of LVR involves a road designed to service three modest timber sales over a period of 20 years. The schedule of activities is:

(1) the first timber sale involves 8 million board feet (MMBF) and lasts from year 0 to year 4;
(2) 2 years of no logging activity;
(3) a second sale involving 10 MMFB lasting from year 6 to year 11;
(4) 4 years of no logging activity;
(5) the last sale involves 12 MMBF and lasts from year 15 to year 20;
(6) after 20 years traffic is recreational and Forest Service administrative.

The annual traffic for this road has been assumed and is shown in Table 3.5 under time dependent variables. Since funds for reconstruction and major rehabilitation are available only during the period immediately preceeding a timber sale, the minimum times to the first overlay (regravelling) and between overlays (regravellings) have been set equal to 6 and 9, respectively.

The subgrade soil is assumed to have a CBR value of 3.0 and the soil is subject to some minor movements; therefore, the value of P2 prime is assumed to be 2.5. This value of P2 prime is lower than that selected for the ACP problem, but the rate, defined by variable B1, at which the PSI approaches P2 prime has been set to 0.02 as in the previous example. The site is located in an area with a regional factor of 2.3. For this aggregate road, a minimum serviceability level (PSI) of 1.5 was chosen as appropriate. Three materials are available for the initial construction:

(1) Material A, a dense-graded crushed rock for the surface,

(2) Material B, an open-graded crushed rock for the base (the same material as in the surface but with a different grading), and

(3) Material C, a cinder material for the base.

These three materials A, B and C, are assumed to have been laboratory tested with resulting CBR values of 80, 55, and 30, and soil support values of 9.35, 8.60, and 7.40, respectively. The layer coefficients selected for the three materials A, B, and C are assumed to be 0.13, 0.10, and 0.09, respectively. Two types of materials are used to produce the three materials available. The differences between the surface material and base material for the crushed rock is gradation, with the finer gradation used as the surface. Costs for these materials are typical of 1976 costs in Regions where such materials are available.

Performance and user delay variables are representative of normal construction and operational practices for aggregate surfaced roads. An interest rate of 7.0 percent was selected for computation of net present value. Rather than burden the reader with a repetition of the detailed development of values for other input variables, it is sufficient to say that the same logic was applied in developing input values for this problem. All input values are included in Table 3.5.

DISCUSSION OF SOLUTION

Table 3.6 contains ten of the designs generated by LVR for the input data recorded in Table 3.5. Of the forty designs contained in the summary table, the first 18 designs involved use of the dense graded crushed rock surface and cinders base. Design 19 involved the use of both the dense and the open graded crushed rock.

The lowest cost design involves 8.0 inches of dense graded crushed rock with 10.0 inches of cinder base. This design has an initial life of 6.5 years, at which time a one-inch gravel addition extends the life to 17.8 years, and then a final one-inch gravel addition permits the structure to last through the analysis period. For the ten most economical design strategies the total costs range from $18,691 to $20,829/14 ft. lane-mile. These total costs include the seven previously mentioned cost categories. Notice that the grading costs vary among the strategies. This variation

TABLE 3.5. INPUT FOR AN AGGREGATE SURFACED ROAD EXAMPLE PROBLEM

```
   PROB    1A      AGGREGATE SURFACED PAVEMENT DESIGN EXAMPLE PROBLEM

           THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE
         MATERIALS             COST   LAYER    MIN.    MAX.  SALVAGE   SS
LAYER CODE       NAME         PER CY  COEFF.  DEPTH   DEPTH   PCT.   VALUE
  1     A  CR ROCK DENSE       6.00     .13    3.00   12.00   50.0    9.35
  2     B  CR ROCK OPEN        5.00     .10    4.00   15.00   80.0    8.60
  2     C  CINDERS BASE        2.50     .09    4.00   15.00   80.0    7.40
           SUBGRADE            0.00    0.00    0.00    0.00    0.0    3.00

           THIS IS AN UNPAVED ROAD EQUALLY IN CUT AND FILL
          (OVERLAYS FOR UNPAVED ROADS ARE GRAVEL ADDITIONS)

   TOTAL NUMBER OF INPUT MATERIALS,EXCLUDING SUBGRADE                         3
   LENGTH OF THE ANALYSIS PERIOD (YEARS)                                   20.0
   WIDTH OF EACH LANE (FEET)                                               14.0
   INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                           7.0
   REGIONAL FACTOR                                                          2.3

   SERVICEABILITY INDEX OF THE INITIAL STRUCTURE                            4.0
   SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                 4.0
   MINIMUM SERVICEABILITY INDEX P2                                          1.5
   SWELLING CLAY PARAMETERS -- P2 PRIME                                    2.50
                                 B1                                       .0200

   MAX FUNDS AVAILABLE FOR INITIAL DESIGN (DOLLARS PER LN,ML.)         25000.00
   MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)              32.0
   MINIMUM OVERLAY THICKNESS (INCHES)                                       1.0
   ACCUMULATED MAXIMUM DEPTH OF ALL OVERLAYS (INCHES)                      12.0
   MAXIMUM OVERLAY THICKNESS (INCHES)                                       6.0
   DISTANCE GRADER OPERATES BEFORE LETTING VEHICLES PASS. (MILES)            .2
   PERCENT OF ROAD SURFACING SMALLER THAN 3/4 IN. IN DIAMETER             100.0

   C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE O.D. (MILES)          1.00
   C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE N.O.D. (MILES)        1.00
   PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN O.D. (PERCENT)     100.0
   PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN N.O.D. (PERCENT)   100.0
   AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN O.D. (HOURS)                  .200
   AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS)                .200

   AVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH)                        25.0
   AVERAGE SPEED THROUGH OVERLAY ZONE IN O.D. (MPH)                        10.0
   AVERAGE SPEED THROUGH OVERLAY ZONE IN N.O.D. (MPH)                      10.0
   AVERAGE SPEED OF THE GRADER OR S.C.TRUCK. (MPH)                          5.0
   AVERAGE SPEED OF TRUCKS IN THE GRADING DIRECTION (MPH)                  20.0
   TRAFFIC MODEL USED IN THE ANALYSIS                                         2

   OPERATING COST FOR NON-TRUCKS (DOLLARS/MILE)                             .20
   OPERATING COST FOR TRUCKS (DOLLARS/MILE)                                1.50

   TIME BETWEEN GRADING   (YEARS)                                            .3
   VALUES FOR THE MINIMUM TIME BETWEEN REHABILITATIONS (YEARS)

     6.0      9.0
```

TABLE 3.5. (Continued)

```
PROB    1A       AGGREGATE SURFACED PAVEMENT DESIGN EXAMPLE PROBLEM

GRAVEL LOSS DUE TO EROSION (INCHES/YEAR)                                  0.00
MINIMUM THICKNESS OF THE TOP LAYER BEFORE A GRAVEL ADD. (INCHES)           2.0
COST OF A GRADING   (DOLLARS/LANE MILE)                                 100.00
NUMBER OF PASSES THE GRADER OR SEAL COAT TRUCK MAKES                         3
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)             8.0

                         TIME-DEPENDENT VARIABLES

 TIME    NON-TRUCKS  TRUCKS   18-KIP EQUIV. ROUT. MAINT. LUMBER HAULED  GRAVEL LOSS
(YEARS)  (PER DAY)  (PER DAY)     AXLES      (DOL./LNML)      (MBF)       (IN./MBF)
  0.0        19          3             0         0.00          -0.0          -0.0
  4.0        19          3          5760         0.00          -0.0          -0.0
  4.1        27          0          5760         0.00          -0.0          -0.0
  5.9        27          0          5765         0.00          -0.0          -0.0
  6.0        19          4          5765         0.00          -0.0          -0.0
 11.0        19          4         12960         0.00          -0.0          -0.0
 11.1        22          0         12960         0.00          -0.0          -0.0
 14.9        32          0         12965         0.00          -0.0          -0.0
 15.0        32          5         12965         0.00          -0.0          -0.0
 20.0        32          5         18720         0.00          -0.0          -0.0
 20.1        32          0         18720         0.00          -0.0          -0.0
 25.0        32          0         18725         0.00          -0.0          -0.0

    IF THE EXPECTED LIFE OF THE ROAD IS GREATER THAN
    THE ANALYSIS PERIOD (CL) + 5 YEARS, THEN THE LIFE IS
    SET TO CL + 5 BEFORE THE RESULTS ARE PRINTED.
    LIGHT TRAFFIC AFTER THE ANALYSIS PERIOD PRODUCES A
    SMALL NO. OF 18-KIP-EQUIV. AXLE LOADS RESULTING IN
    LONG TIMES TO FAILURE.
```

TABLE 3.6. OUTPUT FOR AN AGGREGATE SURFACED RUN EXAMPLE PROBLEM

```
  PROB     1A        AGGREGATE SURFACED PAVEMENT DESIGN EXAMPLE PROBLEM

                      SUMMARY OF THE BEST DESIGN STRATEGIES
                        IN ORDER OF INCREASING TOTAL COST
                               (DOLLARS PER LN.ML.)

                               LANE WIDTH = 14.0 FT.

                            1          2          3          4          5
********************************************************************************
MATERIAL ARRANGEMENT      AC         AC         AC         AC         AC
INIT. CONST. COST       16654.81   17795.56   18023.70   18251.85   19164.44
GRAVEL ADDITION COST     1257.48     744.58     744.58     796.71     405.00
DELAY CST GRVL. ADD.       41.39      20.30      20.30      21.72      18.14
DELAY COST GRADING        142.03     144.10     144.21     144.28     142.67
GRADING COST             3543.54    3588.53    3593.08    3596.38    3570.22
ROUTINE MAINT. COST         0.00       0.00       0.00       0.00       0.00
SALVAGE VALUE           -2947.89   -3006.85   -2947.89   -2888.93   -3183.72
********************************************************************************
********************************************************************************
TOTAL COST              18691.37   19286.22   19577.99   19922.00   20116.76
********************************************************************************
NON-TRUCK OPER. COST    19022.84   19022.84   19022.84   19022.84   19022.84
TRUCK OPERATING COST    16953.96   16953.96   16953.96   16953.96   16953.96
********************************************************************************
********************************************************************************
NUMBER OF LAYERS            2          2          2          2          2
********************************************************************************
LAYER DEPTH (INCHES)
     D(1)                  8.00       8.00       9.00      10.00       9.00
     D(2)                 10.00      12.00      10.00       8.00      12.00
********************************************************************************
********************************************************************************
NO. OF PERF. PERIODS        3          2          2          2          2
********************************************************************************
PERF. TIME (YEARS)
     T(1)                  6.5        8.5        8.8        7.8       17.6
     T(2)                 17.8       25.0       25.0       25.0       25.0
     T(3)                 25.0
********************************************************************************
GRAVEL ADD. STRAT.
  (INCHES)
    GA(1)                  1.0        1.0        1.0        1.0        1.0
    GA(2)                  1.0
********************************************************************************
NUMBER OF GRADINGS         65         66         66         66         65
********************************************************************************
A GRADING IS TO BE DONE EVERY  .3 YEARS
********************************************************************************
```

TABLE 3.6. (Continued)

```
PROB    1A       AGGREGATE SURFACED PAVEMENT DESIGN EXAMPLE PROBLEM

                        SUMMARY OF THE BEST DESIGN STRATEGIES
                         IN ORDER OF INCREASING TOTAL COST
                               (DOLLARS PER LN.ML.)

                             LANE WIDTH = 14.0 FT.

                               6          7          8          9         10
*****************************************************************************
MATERIAL ARRANGEMENT         AC         AC         AC         AC         AC
INIT. CONST. COST          18936.30   18480.00   19392.59   19506.67   18708.15
GRAVEL ADDITION COST         744.58    1230.98     463.69     744.58    1345.50
DELAY CST GRVL. ADD.          20.30      40.20      20.77      20.30      44.28
DELAY COST GRADING           144.10     142.56     142.47     144.10     141.83
GRADING COST                3588.53    3562.65    3566.79    3588.53    3537.62
ROUTINE MAINT. COST            0.00       0.00       0.00       0.00       0.00
SALVAGE VALUE              -3242.68   -3006.85   -3124.76   -3360.60   -2947.89
*****************************************************************************
*****************************************************************************
TOTAL COST                 20191.13   20449.54   20461.55   20643.59   20829.49
*****************************************************************************
NON-TRUCK OPER. COST       19022.84   19022.84   19022.84   19022.84   19022.84
TRUCK OPERATING COST       16953.96   16953.96   16953.96   16953.96   16953.96
*****************************************************************************
*****************************************************************************
NUMBER OF LAYERS               2          2          2          2          2
*****************************************************************************
LAYER DEPTH (INCHES)
    D(1)                     8.00      11.00      10.00       8.00      12.00
    D(2)                    14.00       6.00      10.00      15.00       4.00
*****************************************************************************
*****************************************************************************
NO. OF PERF. PERIODS           2          3          2          2          3
*****************************************************************************
PERF. TIME (YEARS)
    T(1)                     8.5        7.0       15.8        8.5        6.2
    T(2)                    25.0       19.1       25.0       25.0       17.0
    T(3)                               25.0                              25.0
*****************************************************************************
GRAVEL ADD. STRAT.
  (INCHES)
   GA(1)                     1.0        1.0        1.0        1.0        1.0
   GA(2)                                1.0                              1.0
*****************************************************************************
NUMBER OF GRADINGS             66         65         65         66         65
*****************************************************************************
A GRADING IS TO BE DONE EVERY  .3 YEARS
*****************************************************************************
```

occurs because the strategies require a different number of gradings at different times in the life of the pavement. If a gravel addition occurs within one month of a scheduled grading, the grading is eliminated from consideration. Therefore the number of gradings is affected by both the number and time of occurrence of other rehabilitation.

Designs 2, 6, and 9 have a surface thickness of 8.0 inches of dense graded crushed rock for which the time to the first performance period is 8.5 years. In this case, the life of the surface thickness controls. For designs 3, 5, 12 and 16 (last two not included in Table 3.6), the surface thickness is 9.0 inches. In designs 3 and 5, the requirements for the total structure control the length of the first performance period, but for designs 12 and 16 the surface thickness criterion controls and the time is 18.3 years.

AGGREGATE SURFACED ROAD WITH SUBSEQUENT APPLICATION OF BITUMINOUS SURFACING

PROBLEM DESCRIPTION AND INPUT VARIABLES

The previous aggregate surfaced problem input data are used in order to demonstrate the capabilities of the existing program to design an initial construction using an aggregate surface and then an overlay using a surface treatment at the beginning of a subsequent performance period. The user must modify the input data for Run 2 in order to reflect accurately the previous traffic and cost conditions. This modification can be handled in the following manner:

Run 1 - Select initial construction parameters.

(1) The design life is equal to the length of the first performance period (time until second timber sale or other time at which a surface treatment is desired). It is adequate to include only traffic and associated time-dependent variables for the first performance period; however, the user may include the data for the entire design.

(2) The surface type is aggregate.

Run 2 - Select the desired rehabilitation policy:

(1) The design life is the actual required design life minus the length of the first performance period.

(2) The surface type is bituminous.

(3) The desired initial construction design is selected for the aggregate layers from Run 1. The aggregate surface thickness should be reduced by the amount of aggregate loss in the first performance period. This thickness loss can be obtained by evaluating the aggregate loss function (8) as discussed in the previous chapter or by estimating the loss using a ratio such as one inch of loss per 40 million board feet of timber.

(4) The effect of accumulated traffic for the existing structure can be handled in two ways:

  (a) Ignore the previous traffic and assume that the existing structure has the same capacity for traffic at the beginning of the second performance period that it did at the beginning of the first performance period or

  (b) Reduce the layer coefficients of the initial structure to reflect the effect of traffic during the first performance period. This reduction would be appropriate only if the engineer can describe the loss of layer coefficient with time based on local experience with aggregates.

(5) For the structure existing at the end of the first performance period,

  (a) The cost assigned for each material in Run 2 is set to zero. These costs have already been converted to net present value for time zero and should not be included again.

  (b) The thickness assigned to these materials is set so that the minimum and maximum thicknesses are equal to each other.

  (c) The layer number assigned to these materials is set equal to the number used in Run 1 plus one

(6) For the new surface that is to be a surface treatment, the cost should be included and the layer coefficient should be larger than that for the layer immediately below it, the "effective" thickness should be set to reflect the added structural integrity produced by that material. (Suggested values for: layer coefficient are 0.20 to 0.25 for an effective thickness of one-fourth inch.)

(7) The thickness of overlay material should reflect the "effective" thickness of additional structural integrity that a surface treatment would provide. The minimum and maximum thicknesses of individual overlays should be set equal in order to reflect normal surface treatment construction practice.

(8) If no seal coats are desired during the performance periods, the time between seal coats should be set equal to a value greater than the design life.

(9) The costs for both Runs 1 and 2 should be combined to produce a total net present value cost at time zero for Run 1. This conversion can be accomplished by dividing the costs from Run

2 by $(1 + r)^n$, where r is the interest rate and n is the time to the beginning of the second performance period in years, and then adding such costs to the costs obtained in Run 1.
An additional correction term must be included to account for the fact that the salvage value is accured at the end of the analysis period, not at the end of the first performance period as in Run 1; the end of the first performance period is treated as if it were the end of an analysis period for purely computational purposes.
Thus, if the first performance period is n years and the entire analysis period is n_T years,

$$\begin{array}{l}\text{true salvage value}\\ \text{for initial structure}\end{array} = \frac{\text{salvage value printed in Run 1}}{(1 + r)^{n_T - n}}$$

If the expression on the right is denoted S_T and "salvage value printed in Run 1" is denoted S_p, the correction term which must be added to the Run 1 cost plus the Run 2 cost over $(1 + r)^n$ to get the total cost is

$$S_p - S_T$$

This procedure, which is rather difficult to explain but is simple computationally, is illustrated numerically in the following section.

For the problem described in the previous section, the input data have been modified as shown in Tables 3.7 and 3.9. The reader should carefully note that in Table 3.9 traffic for years after the first performance is simply the total acumulated traffic minus the traffic during the first performance period. The other variables have been modified as indicated in the above discussion.

DISCUSSION OF SOLUTION

Run 1 - Select initial construction parameters. The only change of consequence in the input data from the previous example problem is in the length of the analysis period, from 20.0 to 4.0 years, as shown in Table 3.7. The resulting output from Run 1 is shown in Table 3.8. Notice that a

TABLE 3.7. INPUT DATA FOR THE FIRST RUN OF A SURFACE TREATMENT EXAMPLE PROBLEM

```
   PROB     1C        SURFACE TREATMENT RUN 1 - UNPAVED

            THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE
          MATERIALS             COST   LAYER    MIN.     MAX.  SALVAGE    SS
LAYER CODE        NAME         PER CY  COEFF.   DEPTH    DEPTH    PCT.   VALUE
  1      A  CR ROCK DENSE       6.00     .13     4.00    20.00    50.0    9.35
  2      B  CR ROCK OPEN        5.00     .10     4.00    15.00    80.0    8.60
  2      C  CINDERS BASE        2.50     .09     4.00    15.00    80.0    7.40
            SUBGRADE            0.00    0.00     0.00     0.00     0.0    3.00

           THIS IS AN UNPAVED ROAD EQUALLY IN CUT AND FILL
          (OVERLAYS FOR UNPAVED ROADS ARE GRAVEL ADDITIONS)

   TOTAL NUMBER OF INPUT MATERIALS,EXCLUDING SUBGRADE                          3
   LENGTH OF THE ANALYSIS PERIOD (YEARS)                                     4.0
   WIDTH OF EACH LANE (FEET)                                                14.0
   INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                            7.0
   REGIONAL FACTOR                                                           2.3

   SERVICEABILITY INDEX OF THE INITIAL STRUCTURE                             4.0
   SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                  4.0
   MINIMUM SERVICEABILITY INDEX P2                                           1.5
   SWELLING CLAY PARAMETERS -- P2 PRIME                                     2.50
                               B1                                          .0200

   MAX FUNDS AVAILABLE FOR INITIAL DESIGN (DOLLARS PER LN.ML.)          25000.00
   MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)               32.0
   MINIMUM OVERLAY THICKNESS (INCHES)                                        1.0
   ACCUMULATED MAXIMUM DEPTH OF ALL OVERLAYS (INCHES)                       12.0
   MAXIMUM OVERLAY THICKNESS (INCHES)                                        6.0
   DISTANCE GRADER OPERATES BEFORE LETTING VEHICLES PASS. (MILES)             .2
   PERCENT OF ROAD SURFACING SMALLER THAN 3/4 IN. IN DIAMETER              100.0

   C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE O.D. (MILES)           1.00
   C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE N.O.D. (MILES)         1.00
   PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN O.D. (PERCENT)      100.0
   PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN N.O.D. (PERCENT)    100.0
   AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN O.D. (HOURS)                   .200
   AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS)                 .200

   AVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH)                         25.0
   AVERAGE SPEED THROUGH OVERLAY ZONE IN O.D. (MPH)                         10.0
   AVERAGE SPEED THROUGH OVERLAY ZONE IN N.O.D. (MPH)                       10.0
   AVERAGE SPEED OF THE GRADER OR S.C.TRUCK. (MPH)                           5.0
   AVERAGE SPEED OF TRUCKS IN THE GRADING DIRECTION (MPH)                   20.0
   TRAFFIC MODEL USED IN THE ANALYSIS                                          2

   OPERATING COST FOR NON-TRUCKS (DOLLARS/MILE)                              .20
   OPERATING COST FOR TRUCKS (DOLLARS/MILE)                                 1.50

   TIME BETWEEN GRADING   (YEARS)                                             .3
   VALUES FOR THE MINIMUM TIME BETWEEN REHABILITATIONS (YEARS)

     5.9
```

TABLE 3.7. (Continued)

```
PROB    1C       SURFACE TREATMENT RUN 1 - UNPAVED

GRAVEL LOSS DUE TO EROSION (INCHES/YEAR)                                 0.00
MINIMUM THICKNESS OF THE TOP LAYER BEFORE A GRAVEL ADD. (INCHES)          2.0
COST OF A GRADING   (DOLLARS/LANE MILE)                                100.00
NUMBER OF PASSES THE GRADER OR SEAL COAT TRUCK MAKES                        3
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)            8.0

                          TIME-DEPENDENT VARIABLES

 TIME    NON-TRUCKS  TRUCKS   18-KIP EQUIV. ROUT. MAINT. LUMBER HAULED  GRAVEL LOSS
(YEARS)  (PER DAY)  (PER DAY)    AXLES      (DOL./LNML)      (MBF)       (IN./MBF)
  0.0       19          3             0         0.00          -0.0         -0.0
  4.0       19          3          5760         0.00          -0.0         -0.0
  4.1       27          0          5760         0.00          -0.0         -0.0
  5.9       27          0          5765         0.00          -0.0         -0.0
  6.0       19          4          5765         0.00          -0.0         -0.0
 11.0       19          4         12960         0.00          -0.0         -0.0
 11.1       22          0         12960         0.00          -0.0         -0.0
 14.9       32          0         12965         0.00          -0.0         -0.0
 15.0       32          5         12965         0.00          -0.0         -0.0
 20.0       32          5         18720         0.00          -0.0         -0.0
 20.1       32          0         18720         0.00          -0.0         -0.0
 25.0       32          0         18725         0.00          -0.0         -0.0

    IF THE EXPECTED LIFE OF THE ROAD IS GREATER THAN
    THE ANALYSIS PERIOD (CL) + 5 YEARS, THEN THE LIFE IS
    SET TO CL + 5 BEFORE THE RESULTS ARE PRINTED.
    LIGHT TRAFFIC AFTER THE ANALYSIS PERIOD PRODUCES A
    SMALL NO. OF 18-KIP-EQUIV. AXLE LOADS RESULTING IN
    LONG TIMES TO FAILURE.
```

TABLE 3.8. OUTPUT FROM RUN 1 OF A SURFACE TREATMENT EXAMPLE PROBLEM

```
  PROB     1C        SURFACE TREATMENT RUN 1 - UNPAVED

                          SUMMARY OF THE BEST DESIGN STRATEGIES
                           IN ORDER OF INCREASING TOTAL COST
                                (DOLLARS PER LN.ML.)

                                 LANE WIDTH = 14.0 FT.

                              1          2          3          4          5
*************************************************************************************
MATERIAL ARRANGEMENT        AC         AC         AC         AC         AC
INIT. CONST. COST        16654.81   17795.56   18023.70   18936.30   19506.67
GRAVEL ADDITION COST         0.00       0.00       0.00       0.00       0.00
DELAY CST GRVL. ADD.         0.00       0.00       0.00       0.00       0.00
DELAY COST GRADING          38.73      38.73      38.73      38.73      38.73
GRADING COST              1131.07    1131.07    1131.07    1131.07    1131.07
ROUTINE MAINT. COST          0.00       0.00       0.00       0.00       0.00
SALVAGE VALUE            -7658.34   -8354.55   -8180.50   -9050.76   -9398.87
*************************************************************************************
*************************************************************************************
TOTAL COST               10166.27   10610.80   11013.00   11055.33   11277.59
*************************************************************************************
NON-TRUCK OPER. COST      5026.93    5026.93    5026.93    5026.93    5026.93
TRUCK OPERATING COST      5952.94    5952.94    5952.94    5952.94    5952.94
*************************************************************************************
*************************************************************************************
NUMBER OF LAYERS              2          2          2          2          2
*************************************************************************************
LAYER DEPTH (INCHES)
     D(1)                  8.00       8.00       9.00       8.00       8.00
     D(2)                 10.00      12.00      10.00      14.00      15.00
*************************************************************************************
*************************************************************************************
NO. OF PERF. PERIODS          1          1          1          1          1
*************************************************************************************
PERF. TIME (YEARS)
     T(1)                   6.6        8.6        8.9        8.6        8.6
*************************************************************************************
GRAVEL ADD. STRAT.
  (INCHES)
*************************************************************************************
NUMBER OF GRADINGS           13         13         13         13         13
*************************************************************************************
A GRADING IS TO BE DONE EVERY  .3 YEARS
*************************************************************************************
```

TABLE 3.8. (Continued)

```
  PROB    1C       SURFACE TREATMENT RUN 1 - UNPAVED

                               SUMMARY OF THE BEST DESIGN STRATEGIES
                                 IN ORDER OF INCREASING TOTAL COST
                                      (DOLLARS PER LN.ML.)

                                       LANE WIDTH = 14.0 FT.

                                6          7          8          9         10
********************************************************************************
MATERIAL ARRANGEMENT           AC         AC         AB         AB         AC
INIT. CONST. COST          18251.85   19164.44   20989.63   21902.22   18480.00
GRAVEL ADDITION COST           0.00       0.00       0.00       0.00       0.00
DELAY CST GRVL. ADD.           0.00       0.00       0.00       0.00       0.00
DELAY COST GRADING            38.73      38.73      38.73      38.73      38.73
GRADING COST                1131.07    1131.07    1131.07    1131.07    1131.07
ROUTINE MAINT. COST            0.00       0.00       0.00       0.00       0.00
SALVAGE VALUE              -8006.44   -8876.71  -10617.24  -11487.51   -7832.39
********************************************************************************
********************************************************************************
TOTAL COST                 11415.20   11457.53   11542.19   11584.51   11817.41
********************************************************************************
NON-TRUCK OPER. COST        5026.93    5026.93    5026.93    5026.93    5026.93
TRUCK OPERATING COST        5952.94    5952.94    5952.94    5952.94    5952.94
********************************************************************************
********************************************************************************
NUMBER OF LAYERS                2          2          2          2          2
********************************************************************************
LAYER DEPTH (INCHES)
     D(1)                    10.00       9.00       7.00       6.00      11.00
     D(2)                     8.00      12.00      10.00      12.00       6.00
********************************************************************************
********************************************************************************
NO. OF PERF. PERIODS            1          1          1          1          1
********************************************************************************
PERF. TIME (YEARS)
     T(1)                     7.9        9.0        6.2        7.2        7.1
********************************************************************************
GRAVEL ADD. STRAT.
  (INCHES)
********************************************************************************
NUMBER OF GRADINGS             13         13         13         13         13
********************************************************************************
A GRADING IS TO BE DONE EVERY  .3 YEARS
********************************************************************************
```

structure consisting of 8.0 inches of dense graded crushed rock over 10.0 inches of cinders is the most economical design. In comparing strategies 1 and 2, the reader may verify that the life of the total structure is the limiting criteria in the design for strategy 1, but the limiting criteria for strategies 2, 4, and 5 is the thickness of layer one. Strategy 1 has been chosen as the initial structure for Run 2.

Run 2 - Select the desired rehabilitation policy. From Run 1, the life of the initial structure was found to be 6.6 years. Remember that for periods between logging sales, low volumes of passenger vehicle and light truck traffic produce significant extensions of the design life of a structure if only a few 18-kip equivalent single axle loads are available.

The second logging period begins at year 6 and reconstruction funds are available at that time; therefore, the time for the start of the second run is 6 years. The resulting design life for Run 2 is 14 years. The aggregate loss for the first logging period is estimated to be less than 0.25 inches and will be ignored. The resulting input layer thicknesses for the existing materials are 8.0 inches of dense graded crushed rock and 10.0 inches of cinders, as shown in Table 3.9. Other input data were generated as per the discussion in the previous section of the report and are included in Table 3.9.

Table 3.10 contains the nine feasible design strategies for a surface treatment applied at the beginning of the second timber sale for this example problem. The reader should note that of the nine feasible designs only six are of practical consequence. Strategies 5, 7 and 9 are viable strategies, but they would never be selected for construction because they do not include 10 inches of existing material. Of course, because these "no cost" materials are not used in the design, other feasible designs were generated at a lower cost. In Table 3.10, notice that the first three designs involve increments of thickness of the dense graded crushed rock from 6.0 through 8.0 inches while the costs vary from $6,815 to $8,703 per 14-ft. lane-mile. It may seem unusual that the pavement section thickness increases from a total of 18.0 inches for a gravel surfaced road to 24.25 inches for a surface treated road that is to serve only an additional 13,000 18-kip equivalent single axle loads. This large increase in thickness results because of a change from the rutting model which controlled in Run 1 to the AASHO Performance model which controls for the bituminous surfaced road case. This apparent inconsistency can be rectified if one realizes that the AASHTO design was

TABLE 3.9. INPUT FOR RUN 2 OF A SURFACE TREATMENT EXAMPLE PROBLEM

```
   PROB     2C        SURFACE TREATMENT RUN 2 - PAVED

           THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE
         MATERIALS               COST   LAYER     MIN.     MAX.  SALVAGE    SS
LAYER CODE        NAME          PER CY  COEFF.   DEPTH    DEPTH    PCT.    VALUE
  1     A  ST                   25.00     .20      .25      .25    50.0    8.22
  2     B  CR ROCK DENSE         6.00     .13     2.00    10.00    80.0    9.35
  3     C  CR ROCK DENSE         0.00     .13     8.00     8.00    80.0    9.35
  4     D  CINDERS BASE          0.00     .09    10.00    10.00    80.0    7.40
           SUBGRADE              0.00    0.00     0.00     0.00     0.0    3.00

        THIS IS A PAVED ROAD.

   TOTAL NUMBER OF INPUT MATERIALS,EXCLUDING SUBGRADE                           4
   LENGTH OF THE ANALYSIS PERIOD (YEARS)                                     14.0
   WIDTH OF EACH LANE (FEET)                                                 14.0
   INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                             7.0
   REGIONAL FACTOR                                                            2.3

   SERVICEABILITY INDEX OF THE INITIAL STRUCTURE                              4.0
   SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                   4.0
   MINIMUM SERVICEABILITY INDEX P2                                            2.5
   SWELLING CLAY PARAMETERS -- P2 PRIME                                      2.50
                               B1                                           .0200

   MAX FUNDS AVAILABLE FOR INITIAL DESIGN (DOLLARS PER LN.ML.)           25000.00
   MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)                32.0
   MINIMUM OVERLAY THICKNESS (INCHES)                                          .2
   ACCUMULATED MAXIMUM DEPTH OF ALL OVERLAYS (INCHES)                        12.0
   MAXIMUM OVERLAY THICKNESS (INCHES)                                         3.0

   C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE O.D. (MILES)            1.00
   C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE N.O.D. (MILES)          1.00
   PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN O.D. (PERCENT)       100.0
   PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN N.O.D. (PERCENT)     100.0
   AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN O.D. (HOURS)                     .200
   AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS)                   .200

   AVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH)                          35.0
   AVERAGE SPEED THROUGH OVERLAY ZONE IN O.D. (MPH)                          10.0
   AVERAGE SPEED THROUGH OVERLAY ZONE IN N.O.D. (MPH)                        10.0
   AVERAGE SPEED OF THE GRADER OR S.C.TRUCK. (MPH)                           10.0
   TRAFFIC MODEL USED IN THE ANALYSIS                                           2

   OPERATING COST FOR NON-TRUCKS (DOLLARS/MILE)                               .15
   OPERATING COST FOR TRUCKS (DOLLARS/MILE)                                  1.25

   TIME BETWEEN SEAL COAT (YEARS)                                            14.0
   VALUES FOR THE MINIMUM TIME BETWEEN REHABILITATIONS (YEARS)

     9.0
```

TABLE 3.9. (Continued)

```
PROB    2C       SURFACE TREATMENT RUN 2 - PAVED

GRAVEL LOSS DUE TO EROSION (INCHES/YEAR)                                 0.00
MINIMUM THICKNESS OF THE TOP LAYER BEFORE A GRAVEL ADD. (INCHES)          0.0
COST OF A SEAL COAT (DOLLARS/LANE MILE)                               1200.00
NUMBER OF PASSES THE GRADER OR SEAL COAT TRUCK MAKES                        1
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)            8.0

                          TIME-DEPENDENT VARIABLES

TIME     NON-TRUCKS  TRUCKS   18-KIP EQUIV. ROUT. MAINT. LUMBER HAULED  GRAVEL LOSS
(YEARS)  (PER DAY)  (PER DAY)    AXLES       (DOL./LNML)      (MBF)       (IN./MBF)
  0.0       19         4             0           0.00          -0.0          -0.0
  5.0       19         4          7195           0.00          -0.0          -0.0
  5.1       22         0          7195           0.00          -0.0          -0.0
  8.9       32         0          7200           0.00          -0.0          -0.0
  9.0       32         5          7200           0.00          -0.0          -0.0
 14.0       32         5         12955           0.00          -0.0          -0.0
 14.1       32         0         12955           0.00          -0.0          -0.0
 19.0       32         0         12960           0.00          -0.0          -0.0

   IF THE EXPECTED LIFE OF THE ROAD IS GREATER THAN
   THE ANALYSIS PERIOD (CL) + 5 YEARS, THEN THE LIFE IS
   SET TO CL + 5 BEFORE THE RESULTS ARE PRINTED.
   LIGHT TRAFFIC AFTER THE ANALYSIS PERIOD PRODUCES A
   SMALL NO. OF 18-KIP-EQUIV. AXLE LOADS RESULTING IN
   LONG TIMES TO FAILURE.
```

TABLE 3.10. OUTPUT FROM RUN 2 OF A SURFACE TREATMENT EXAMPLE PROBLEM

```
  PROB    2C       SURFACE TREATMENT RUN 2 - PAVED

                      SUMMARY OF THE BEST DESIGN STRATEGIES
                        IN ORDER OF INCREASING TOTAL COST
                              (DOLLARS PER LN.ML.)

                               LANE WIDTH = 14.0 FT.

                            1          2          3          4          5
********************************************************************************
MATERIAL ARRANGEMENT      ABCD       ABCD       ABCD       ABCD       ABC
INIT. CONST. COST        9639.26   11008.15   12377.04    8270.37   13745.93
OVERLAY CONST. COST         0.00       0.00       0.00    3251.75       0.00
DELAY COST OVERLAY          0.00       0.00       0.00      33.45       0.00
DELAY COST SEAL COAT        0.00       0.00       0.00       0.00       0.00
SEAL COAT COST              0.00       0.00       0.00       0.00       0.00
ROUTINE MAINT. COST         0.00       0.00       0.00       0.00       0.00
SALVAGE VALUE           -2824.72   -3249.42   -3674.12   -2621.21   -4098.83
********************************************************************************
********************************************************************************
TOTAL COST               6814.54    7758.73    8702.91    8934.36    9647.10
********************************************************************************
NON-TRUCK OPER. COST    12527.40   12527.40   12527.40   12527.40   12527.40
TRUCK OPERATING COST    13581.97   13581.97   13581.97   13581.97   13581.97
********************************************************************************
********************************************************************************
NUMBER OF LAYERS            4          4          4          4          3
********************************************************************************
LAYER DEPTH (INCHES)
     D(1)                   .25        .25        .25        .25        .25
     D(2)                  6.00       7.00       8.00       5.00       9.00
     D(3)                  8.00       8.00       8.00       8.00       8.00
     D(4)                 10.00      10.00      10.00      10.00
********************************************************************************
********************************************************************************
NO. OF PERF. PERIODS        1          1          1          2          1
********************************************************************************
PERF. TIME (YEARS)
     T(1)                 19.0       19.0       19.0       10.5       19.0
     T(2)                                                  19.0
********************************************************************************
OVERLAY STRAT.(INCHES)
(INCLUDING LEVEL-UP)
     O(1)                                                   1.2
********************************************************************************
NUMBER OF SEAL COATS        0          0          0          0          0
********************************************************************************
SEAL COAT SCHEDULE
   (YEARS)
********************************************************************************
```

TABLE 3.10 (Continued)

```
PROB    2C       SURFACE TREATMENT RUN 2 - PAVED

                        SUMMARY OF THE BEST DESIGN STRATEGIES
                         IN ORDER OF INCREASING TOTAL COST
                               (DOLLARS PER LN.ML.)

                               LANE WIDTH = 14.0 FT.

                             6           7           8           9
********************************************************************************
MATERIAL ARRANGEMENT       ABCD        ABC         ABCD        ABC
INIT. CONST. COST        13745.93    15114.81    15114.81    12377.04
OVERLAY CONST. COST          0.00        0.00        0.00     3251.75
DELAY COST OVERLAY           0.00        0.00        0.00       33.45
DELAY COST SEAL COAT         0.00        0.00        0.00        0.00
SEAL COAT COST               0.00        0.00        0.00        0.00
ROUTINE MAINT. COST          0.00        0.00        0.00        0.00
SALVAGE VALUE            -4098.83    -4523.53    -4523.53    -3895.32
********************************************************************************
********************************************************************************
TOTAL COST                9647.10    10591.29    10591.29    11766.91
********************************************************************************
NON-TRUCK OPER. COST     12527.40    12527.40    12527.40    12527.40
TRUCK OPERATING COST     13581.97    13581.97    13581.97    13581.97
********************************************************************************
********************************************************************************
NUMBER OF LAYERS             4           3           4           3
********************************************************************************
LAYER DEPTH (INCHES)
     D(1)                  .25         .25         .25         .25
     D(2)                 9.00       10.00       10.00        8.00
     D(3)                 8.00        8.00        8.00        8.00
     D(4)                10.00                   10.00
********************************************************************************
********************************************************************************
NO. OF PERF. PERIODS         1           1           1           2
********************************************************************************
PERF. TIME (YEARS)
     T(1)                19.0        19.0        19.0        11.2
     T(2)                                                    19.0
********************************************************************************
OVERLAY STRAT.(INCHES)
(INCLUDING LEVEL-UP)
     O(1)                                                     1.2
********************************************************************************
NUMBER OF SEAL COATS         0           0           0           0
********************************************************************************
SEAL COAT SCHEDULE
   (YEARS)
********************************************************************************


        THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS      9
```

established to provide design thickness for high quality roads while the rutting model was developed for aggregate surfaced roads. The result of this difference is a more severely deteriorated road at failure for a road design using the rutting failure criterion than one designed using the performance failure criterion.

To complete the total cost for this combination of aggregate and bituminous surfaced road, the user must make the following calculations after results from Run 1 and 2 have been obtained:

$$\text{Total Cost} = \text{Run 1 Cost} + (S_p - S_T) + \text{Run 2 Cost}/(1 + r)^n$$

r = interest rate expressed as a fraction, 0.07

n = time to the beginning of the second performance period = 6.0 years.

$$\text{Total Cost} = \$10{,}166 + (\$7{,}658 - \$7{,}658/(1 + 0.07)^{20 - 6}) + \$6{,}815/(1 + 0.07)^{6.0}$$

$$\text{Total Cost} = \$19{,}394 \text{ per 14-foot-wide lane-mile.}$$

If the user prefers inclusion of ACP for surfacing instead of a surface treatment during a subsequent performance period, the inputs and procedures are substantially the same. The primary difference will be in the type of surfacing available, layer coefficient, and constraints on thickness for that type of surfacing.

CHAPTER 4. IMPLEMENTATION

OBJECTIVE

The objective of an implementation study is to take the developed LVR pavement management program and refine it to the point that its use becomes a part of the standard Forest Service operating procedure. It is proposed that this objective can be realized by performing the following tasks:

(1) conduct a sensitivity analysis,
(2) investigate RDS interaction,
(3) conduct a trial usage of LVR program,
(4) plan program revisions,
(5) prepare user's manual,
(6) estimate vehicle operating cost, and
(7) extend the trial usage.

CONDUCT A SENSITIVITY ANALYSIS

One of the first tasks should be to perform a sensitivity analysis on the LVR computer program. The basic concept for this task is to evaluate the effect of change in the magnitude of a variable on the total project cost and rehabilitation strategy. Thus, the relative effects of the different input variables can be compared. This could provide the following guidelines for future users:

(1) The variables having only a small effect on the final answer can be fixed at a mean value; thus, reducing the total number of input variables that must be developed by the user.
(2) Provide guidance to the user in budgeting resources for characterizing the various input variables. Obviously, more time should be spent on the most sensitive variables. Without this type of

guidance, there may be a tendency to spend excessive resources in characterizing variables that have very little effect on the final answer.

(3) Provide guidelines for establishing priorities for future research studies. Obviously, the most sensitive variables could be given priority in future studies.

The sensitivity analyses could be performed in two phases. The first phase could be a simple sensitivity analysis, where a realistic range and average value for each of the variables would be selected. For the simple sensitivity analysis, one of the variables would be selected and solutions run at the low value and high value with all the other variables fixed at the average value. Solutions would be made for the next variable in the same manner.

The second phase of the sensitivity analysis would be a more complex factorial analysis using sound statistical techniques. Rather than run a 2^N factorial for the large number of variables which would permit an analysis of all main effects and all interactions, a reduced experiment would permit an analysis of main effects and first order interactions and also conserve both time and natural resources. Some of the variables that have either a minimal total effect on the solution or the interactions with other variables are probably not significant could be lumped together in groups. Variables that may fall into group categories are:

(1) user delay variables,
(2) performance variables,
(3) swelling clay variables,
(4) thickness constraints,
(5) cost constraints,
(6) constraints on length of performance periods,
(7) cost per compacted cubic yard for different materials, and
(8) traffic history variables.

In the sensitivity analysis all variables in a group will be varied simultaneously in order to determine their maximum combined effect under reasonable circumstances. If one set of group variables proves to be important, then the variables in the indicated group will be investigated individually. In addition, the maximum effects of the interactions of these variables in a given category will be investigated in order to produce a maximum effect. A fractional factorial experimental design would be employed to estimate main effects and first order interactions.

INTERACTION WITH ROAD DESIGN SYSTEM (RDS)

An important consideration for extensive use of the LVR computer program is that it effectively interact with the RDS system developed by the Forest Service. Proper interaction between the present components of RDS and the LVR program could be accomplished by:

(1) Determining the entry points at which pavement design should be considered before making earthwork quantity calculations. This would permit accurate total cost predictions to be made since thicker pavement sections would require more material removal for side slopes and cut on side hill sections.

(2) Determining the effect of the use of pavement design program on overall running efficiency of the RDS - LVR combination system.

(3) Developing a strategy for selecting or incorporating different pavement thickness designs into a given trial highway geometric alignment.

CONDUCT TRIAL USAGE OF LVR

Prior to an extensive use of the LVR program by the Forest Service, a trial usage could be made of the program in order to solve practical problems that will develop when engineers in the field begin to use the program. In this way, any irrationalities or programming errors would be discovered and corrected. It is essential during this phase that the Forest Service staff selected be fully cooperative and feel that the system would be of value to them, if implemented in their Region. Following are the general work items proposed for this task:

(1) Select Regions for trial usage,

(2) Train Regional personnel who will use programs ,

(3) Survey users to determine desirable modifications to the program, bugs that have been found, or alterations in user's manual to make explanations clearer,

(4) Report results of trial usage and survey in the form a Technical Memorandum.

PLAN PROGRAM REVISIONS

The following work tasks were discussed as desirable computer program revisions and additions during a meeting of the Forest Service Advisory Committee at Fort Collins, Colorado during May 25-27, 1976:

(1) Develop a plotting option for the PSI curve for the optimum design.

(2) Include a deflection design method along with the present AASHTO and modified Corps of Engineers (2-inch rut depth) equations presently in the program.

(3) Include an operating cost versus PSI curve in order to reflect more accurately the operating cost as affected by the overlay or gravel addition strategies considered in all candidate designs. Since substantial effort will be required, this item can only be accomplished if the data is developed independently of this study.

PREPARE USER'S MANUAL

Continue inclusion of information into the User's Manual as experience in the trial usage regions indicates. The object is to provide to the user a document that will be self-sufficient in providing all tables, charts and written documentation necessary for selection of input values for all variables required to run the program.

Development of the User's Manual will reflect all information collected from a survey of users to determine modifications or clarifications in the manual that will enhance the usability of the program. In addition, comments that are received during the period of extended usage will be considered for inclusion in the final version of the User's Manual. A User's Manual of a preliminary version of the program is given in the Appendix of this report.

ESTIMATE VEHICLE OPERATING COST

Coordination with the University of California at Berkeley should continue in an attempt to utilize information developed for estimating vehicle operating cost. When a usage program is developed and available, input statements are available in LVR for use of these costs in making more rational choices between paved and unpaved designs for a given alignment.

EXTEND THE TRIAL USAGE

After the user's manual has been expanded into a completed draft form, the trial usage of the system could be extended. It is anticipated that two additional regions could be reached with training sessions and trial usage. These regions should be selected based on interest expressed by other regions that were not included in the initial trial usage. Training sessions should be conducted to familiarize the users with the program and could possibly be coordinated with other training scheduled by the Region.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This report contains the results of a first attempt to assimilate and program technical information suitable for use in a pavement management system for low-volume Forest Service roads. The program in its present form contains the essential elements for such a system; however, the component models utilized for some of the subsystems are not as accurate as those that will be developed in the future as a result of this effort. One of the really valuable contributions of this type of development work is that it acts as a catalyst to produce interaction between people from a variety of backgrounds for the purpose of dealing with the problem as a system rather than as a group of pieces. In putting the pieces together, any gaps or areas of marginal work become apparent and a concerted effort can be directed toward obtaining necessary information to fill in the gaps. In addition, sensitivity analyses of the system permit the evaluation of selected variables to determine those that most affect the solution and for which the best input information is required. As a result of these studies, coordinated research programs can be developed to fill the gaps in present knowledge in the most efficient and cost-effective manner.

CONCLUSIONS

The primary conclusion of this report is that a pavement management system has been planned, developed and made operational for designing low-volume roads typical of those constructed by the Forest Service. However, it is apparent from the discussions in Chapter 2 that many of the component models are very tentative in nature and that a concerted effort should be made to collect suitable data to upgrade the quality of these models.

Total cost comparisons between aggregate and bituminous surfaced roads can validly be made only if the vehicle operating costs are included, since these costs vary between the two surface types. An extensive vehicle operating cost program is now being developed under contract to the Forest Service, and provisions have been made to employ in the pavement management system the basic cost information computed from this program. Until this development is completed, comparisons can be made on the basis of cost estimates.

RECOMMENDATIONS

In order to make the fullest use of this pavement management system, the U. S. Forest Service plans to begin implementing the system during a third phase of this cooperative study. This implementation phase has been discussed in detail in Chapter 4. Included in the implementation phase is an emphasis on:

(1) improving the component models,

(2) conducting a sensitivity analysis to determine the most crucial input parameters with regard to their effect on the output,

(3) preparation of a user's manual and documentation of the program to facilitate upgrading of the component models in time,

(4) conducting training session and trial usage by Forest Service field personnel,

(5) making the LVR program operational at the Forest Service computation center at Fort Collins, Colorado.

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APPENDIX
FOREST SERVICE
PAVEMENT MANAGEMENT SYSTEM
LVR
USER'S MANUAL

FOREST SERVICE
PAVEMENT MANAGEMENT SYSTEM
PROGRAM LVR

PROGRAM AND PROBLEM DESCRIPTION

CARD NO. 1

1.1 NPROB - Problem number — 1 2 3 4

(Any combination of letter and/or numbers)

1.2 AN2 - Description of current problem — 11 12 • • • 80

(Any combination of letters and/or numbers)

MISCELLANEOUS INPUTS

CARD NO. 2

2.1 CSTSCL(1) - Type of costs printed in the output summary table ——— 1 2 3 4

= SQYD if costs to be in dollars/sq.yd.

= MILE if costs in dollars/lane mile.

Default value is dollars/sq.yd.

2.2 NMBEST* - Number of designs to be output in the summary table ——— 9 10

8 designs/page for dollars/sq.yd.

5 designs/page for dollars/lane mile.

($1 \leq$ NMBEST ≤ 40)

Default value is 40

2.3 NM* - Total number of materials available, excluding subgrade ——— 14 15

($1 \leq$ NM ≤ 10)

2.4 CL - Length of the analysis period (years) ——— 16 17 18 19 20 21 22 23 •24 25

2.5 XLW - Width of each lane (feet)

(18.0 ft is the minimum for a one-lane road) ——— 26 27 28 29 30 31 32 33 •34 35

2.6 NNL* - Number of card No. 4's

$2 \leq$ NNL ≤ 50 ——— 39 40

2.7 RATE - Interest rate or time value of money (percent) ——— 41 42 43 44 45 46 47 48 •49 50

2.8 ITYPE - Type of road under construction ——— 55

= 1 designates an ACP road on a subsequent run when a rehabilitation involves placing an ACP over another surface type

= 2 designates an aggregate surfaced road

= 3 designates a surface treated road or a subsequent run when a rehabilitation involves placing a surface treatment over another surface type.

(See Appendix C section III of the User's Manual for a further explanation of aggregate surfaced roads with surface treatment or ACP)

CARD NO. 2 (Continued)

2.9 NOVL* - Number of entries on Card No. 5 ———— 59 60

$1 \leq \text{NOVL} \leq 16$

2.10 IDELCT - Flag for calculation of delay cost ———— 63 64 65

= YES if delay costs are desired

= NO if delay costs are not desired

Default value is YES

*Right justify in the field

PERFORMANCE VARIABLES

CARD NO. 3

3.1 R - Regional factor

See Appendix A

							●		
1	2	3	4	5	6	7	8	9	10

3.2 PSI - Initial serviceability index

$0.0 < PSI \leq 5.0$

							●		
11	12	13	14	15	16	17	18	19	20

3.3 P1 - Serviceability index after an overlay $0.0 < P1 \leq 5.0$

							●		
21	22	23	24	25	26	27	28	29	30

3.4 P2 - Terminal serviceability index

point at which rehabilitation must be performed.

$0.0 < P2 \leq 5.0$

							●		
31	32	33	34	35	36	37	38	39	40

3.5 P2P - Lower bound of the serviceability index which would be achieved in infinite time with no traffic, a non-traffic deterioration parameter. $0.0 < P2P \leq 5.0$

							●		
41	42	43	44	45	46	47	48	49	50

3.6 BONE - Constant determining the rate at which PSI approaches P2P, a non-traffic deterioration parameter (See Fig 1)

					●				
51	52	53	54	55	56	57	58	59	60

3.7 P34* - Percent of road surface material less than 3/4 inch in diameter

			●	
61	62	63	64	65

3.8 IFC* - flag

70

= 1 if the road has fills
= 2 if the road has side casts
= 3 if the road has cuts
= 4 if the road is equally in cuts and fills

---

*For aggregate surface roads only - variables used in predicting aggregate surface loss.

TIME DEPENDENT VARIABLES

CARD NO. 4
(There will be NNL Card No. 4's)

4.1 TIMNL(I)* - Values in the array of of time points (years)

								●	
1	2	3	4	5	6	7	8	9	10

This array contains time points used to define all other piecewise linear curves.

TIMNL (1) must = 0.0

TIMNL (NNL) should exceed the length of the analysis period by at least 1.0 year

4.2 RNL(I,1)* - First value in the array of daily traffic volumes of vehicles other than logging trucks

								●	
11	12	13	14	15	16	17	18	19	20

4.3 RNL(I,2)* - First value in the array of daily traffic volumes-logging trucks per day

								●	
21	22	23	24	25	26	27	28	29	30

RNL(I,1) and RNL(I,2) are the arrays of one directional ADT values at time TIMNL (I), if the road is a two lane and two directional ADT if the road is one lane

4.4 CUM18K(I) - Cumulative 18-Kip equivalent single-axle loads at time TIMNL(I).

CUM18K(1) = 0.0

								●	
31	32	33	34	35	36	37	38	39	40

4.5 CM(I)* - Ith in annual routine maintenance cost per lane mile at time TIMNL(I)

								●	
41	42	43	44	45	46	47	48	49	50

4.6 BDFT(I)** - The number of thousand board feet of lumber hauled during the time interval TIMNL(I) and TIMNL(I+1)

								●	
51	52	53	54	55	56	57	58	59	60

CARD NO. 4 (Continued)

4.7 BDFTIN(I)** - The aggregate surface loss in inches per thousand board feet during the interval TIMNL(I) and TIMNL(I+1)

								•	
61	62	63	64	65	66	67	68	69	70

---

*These variables vary linearly between time points.

**4.6 and 4.7 enable the user to input aggregate surface loss directly rather than using the aggregate surface loss equation (by John Lund) in the program. If the Lund equation is used all values for these variables should be zero.

MINIMUM TIME BETWEEN PERFORMANCE PERIODS*

CARD NO. 5

5.1 XTTO(1) - Minimum length of the first performance period* (years) ______

			●	
1	2	3	4	5

5.2 XTTO(2) - Minimum length of the second performance period ______

			●	
6	7	8	9	10

.
.
.
.
.

5.NOVL XTTO(NOVL) - Minimum time between performance period number (NOVL-1) and performance period number NOVL.

(NOTE: if more than NOVL performance periods occur then XTTO(NOVL) will be used for all succeeding performance periods)

*Performance period is defined as the length of time between:

(1) the initial construction and the first major rehabilitation,
(2) two major rehabilitations, or
(3) the initial construction and a subsequent construction when the surface type is changed.

VALUES OF THE RESTRICTION VARIABLES

CARD NO. 6

6.1 CMAX - Maximum funds available for initial construction (units are specified by variable 2.1)

							•		
1	2	3	4	5	6	7	8	9	10

6.2 TCKMAX - Maximum allowable total thickness of initial construction (inches)

							•		
11	12	13	14	15	16	17	18	19	20

6.3 OVMIN* - Minimum thickness of an individual rehabilitation (inches)

							•		
21	22	23	24	25	26	27	28	29	30

6.4 OVMAX - Accumulated maximum thickness of all rehabilitation (inches)

							•		
31	32	33	34	35	36	37	38	39	40

6.5 OVMAXL* - Maximum thickness of an individual rehabilitation (inches)

							•		
41	42	43	44	45	46	47	48	49	50

6.6 TLMIN - Minimum thickness of the top layer (inches) for a bituminous surface road this should be 0.0, for an aggregate surface road the FS suggests 4.0 inches. Default value is 0.0

							•		
51	52	53	54	55	56	57	58	59	60

6.7 AGNONT - Aggregate surface loss due to erosion (inches/year) Default value is 0.0 This is an additional increment of aggregate surface loss which is added to either the aggregate surface loss computed by the program or the user supplied aggregate surface loss (4.7), whichever is used.

							•		
61	62	63	64	65	66	67	68	69	70

*The difference between variables 6.3 and 6.5 should be as small as is reasonable; a large difference can greatly increase the execution time of the program. A maximum difference of 4.0 to 7.0 inches is suggested for bituminous and aggregate surface roads, respectively.

OVERLAY PARAMETERS ASSOCIATED WITH OVERLAY AND ROAD GEOMETRICS

CARD NO. 7

7.1 XLSO - Distance, along center line, over which traffic is slowed in the lane in which rehabilitation occurs (miles)

							●		
1	2	3	4	5	6	7	8	9	10

7.2 XLSN - Distance, along the center line, over which traffic is slowed in the opposite lane from the rehabilitation (miles)

							●		
11	12	13	14	15	16	17	18	19	20

7.3 PROP - Percent of ADT which will pass through the rehabilitation zone during each hour of this activity

							●		
21	22	23	24	25	26	27	28	29	30

OTHER OVERLAY PARAMETERS ASSOCIATED WITH TRAFFIC SPEEDS AND DELAYS

CARD NO. 8

8.1 PPO2 - Percent of vehicles stopped by construction equipment and personnel, rehabilitation direction

							●		
1	2	3	4	5	6	7	8	9	10

8.2 PPN2 - Percent of vehicles stopped by construction equipment and personnel, non-rehabilitation direction

							●		
11	12	13	14	15	16	17	18	19	20

8.3 DDO2 - Average delay per vehicle due to rehabilitation equipment and personnel, rehabilitation direction (hours)

					●				
21	22	23	24	25	26	27	28	29	30

8.4 DDN2 - Average delay per vehicle due to rehabilitation equipment and personnel, non-rehabilitation direction (hours)

							●		
31	32	33	34	35	36	37	38	39	40

8.5 AAS - Average approach speed to the rehabilitation area (mph)

							●		
41	42	43	44	45	46	47	48	49	50

8.6 ASO - Average speed through the rehabilitation area, rehabilitation direction (mph)

							●		
51	52	53	54	55	56	57	58	59	60

8.7 ASN - Average speed through the rehabilitation area, non-rehabilitation direction (mph)

							●		
61	62	63	64	65	66	67	68	69	70

8.8 MODEL - Model which describes the traffic situation (see Figs 2,3, and warning): for most F.S. roads model 2 is appropriate; this includes the capability to handle both one and two-lane roads. Model 1 could be appropriate for some major trunk line routes.
(Default value is 2)

80

GRADING OR SEAL COAT CONSTRUCTION CONSIDERATIONS
CARD NO. 9

9.1 NGRSC - Number of passes the grader or seal coat truck makes on the section (right justified in the field)

09	10

9.2 ASGRH - Average speed of the grader or seal coat truck (mph)

						●			
11	12	13	14	15	16	17	18	19	20

9.3 GRDIS* - Distance the grader moves before letting cars behind it pass on spacing between turnouts (miles)

						●			
21	22	23	24	25	26	27	28	29	30

9.4 ASOTR - Average speed of trucks in the grading or seal coat direction (mph)

						●			
31	32	33	34	35	36	37	38	39	40

9.5 SC - The construction cost of a seal coat or grading (dollar/lane mile)

							●		
41	42	43	44	45	46	47	48	49	50

9.6 TBSC - The time between gradings or seal coats (years)
Default value is the length of the analysis period.

							●		
51	52	53	54	55	56	57	58	59	60

* Aggregate surface roads only

VEHICLE OPERATING COST

CARD NO. 10

10.1 OPC - Average operating costs for vehicles other than logging trucks (dollar/mile)

							●		
1	2	3	4	5	6	7	8	9	10

10.2 OPCTR - Average operating costs for logging trucks (dollar/mile)

							●		
11	12	13	14	15	16	17	18	19	20

CONSTRUCTION MATERIALS AND THEIR PROPERTIES

CARD NO. 11

(one card for each material and one for the subgrade* in ascending order by layer ID with the subgrade last)

11.1** Layer ID

4

The layer number in which the material is to be used. A different layer ID should be used for the same material if it occurs in more than 1 layer.

11.2 Material code letter (any letter)

8

(used to identify the materials used in a particular design in the summary table)

11.3 Name of the type of material

11									28

(any combination of letters and/ numbers)

11.4 In-place cost per compacted cubic yard

			•		
29	30	31	32	33	34

11.5 Layer coefficient for the material based on its location in the pavement structure. See Appendix B of the User's Manual

					•		
35	36	37	38	39	40	41	42

11.6 Minimum layer thickness (inches)

					•		
43	44	45	46	47	48	49	50

11.7 Maximum layer thickness (inches)

					•		
51	52	53	54	55	56	57	58

11.8 Salvage value (percentage of initial cost)

				•		
59	60	61	62	63	64	65

11.9 Soil support value, (See Fig 5)

(no soil support value is necessary for any material with a layer ID of 1)

				•		
69	70	71	72	73	74	75

* Only variables 11.3 and 11.9 are required for the subgrade.

** If more than one material is input for a given layer ID they must be grouped together.

Warning for variable 8.8

In traffic model 2, it is assumed that cars from only one direction at a time can pass through the overlay zone. If the time required for a vehicle to pass through this zone is large compared to the time between arrivals of vehicles, very long queues of vehicles are produced and the waiting times and the resulting user delay cost due to overlays are extremely large. The following paragraph provides a method for making a check on these times.

The time in hours required for a vehicle to pass through the zone is

$\frac{XLS0}{AS0}$ for the overlay direction and

$\frac{XLSN}{ASN}$ for the non-overlay direction,

where XLS0, AS0 , XLSN , and ASN are input variables. During rehabilitation, the average time in hours between arrivals of vehicles from one direction is

$$\frac{1}{(ADT)(PR0P)}$$

where PR0P is an input variable, and ADT , the one-directional average daily traffic, is defined as a function of time by input arrays.

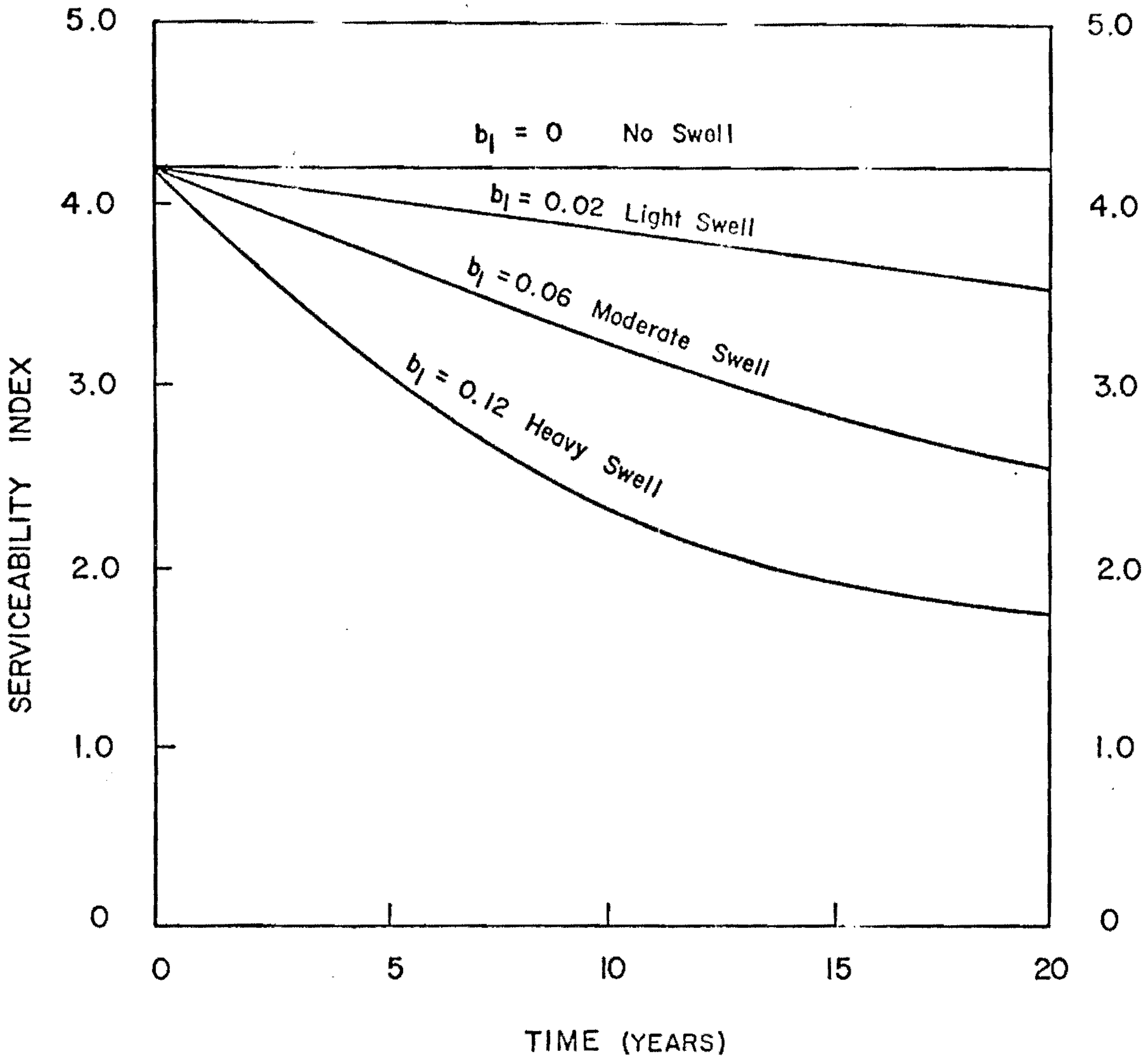


Fig 1. Performance curves illustrating serviceability loss not caused by traffic for a P2P of 1.5 (1).

TABLE 1. CLAY SWELL CONSTANTS (1)

Expected Non-traffic associated loss of serviceability	Suggested value of b_1, rate at which PSI approaches P2P	Rehabilitation required for a combination of traffic and non-traffic associated loss of PSI
Light	0.02	None in 20 years
Moderate	0.06	One between 10 & 20 years
Heavy	0.12	At least one before 10 years

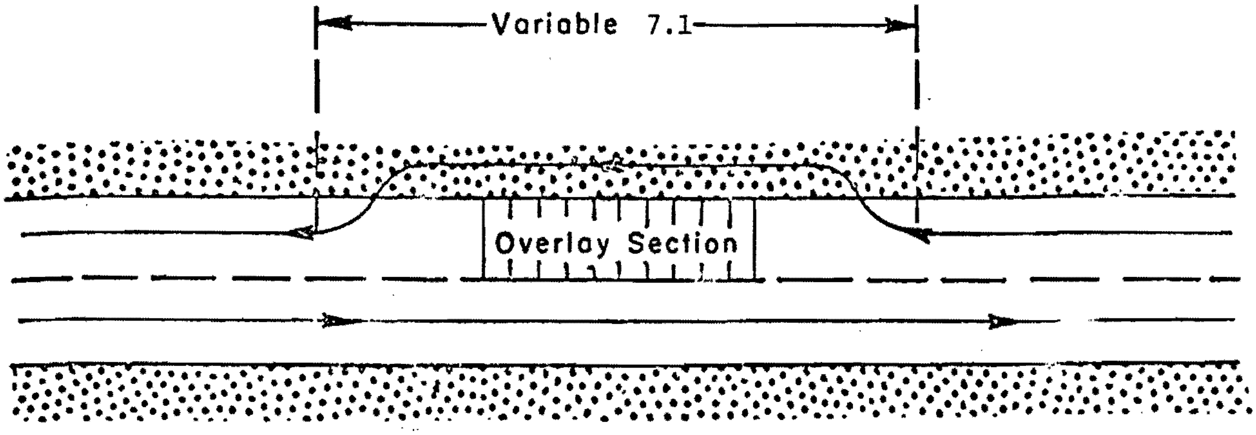


Fig 2. Traffic model No. 1 (2).

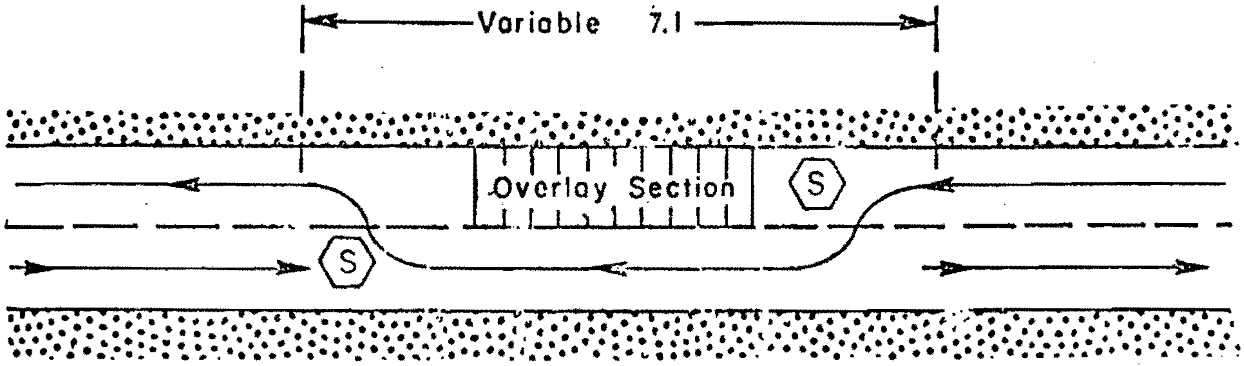
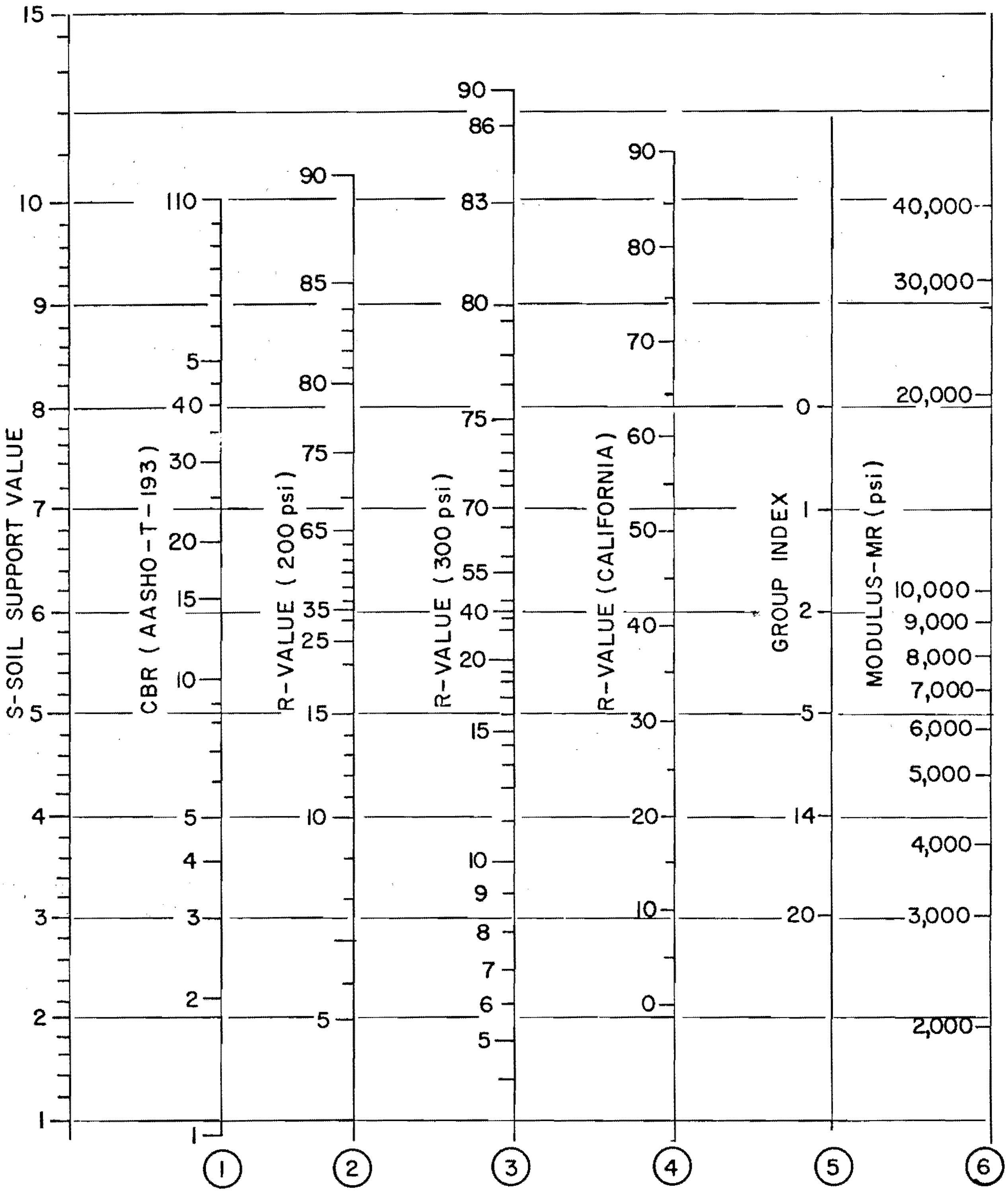


Fig 3. Traffic model No. 2 (2).



NOTE: ○ means correlation taken from source . . . See next page.

Fig. 4 . Correlation chart for estimating soil support value(s).

(Continued)

Fig. 4 . (Continued)

① From "Transportation Engineering Handbook, Chapter 50" Page 73, 1974.(3)

② From Region 1 correlation chart, Forest Service, 1974.

③ From "Transportation Engineering Handbook, Chapter 50," page 73, 1974. (3)

④ The correlation is with the design curves used by California; AASHO designation is T-173-60 and exudation pressure is 240 psi. See Hveem, F. M., and Carmany, R. M., "The Factors Underlying the Rational Design of Pavement," Highway Research Board Proceedings, Vol 28, (1948), pp 101-136, (3)

⑤ From Region 3 correlation chart, U. S. Forest Service.

⑥ Scale derived on NCHRP No. 128.

REFERENCES

1. Texas Highway Department Pavement Design System, Part 1 Flexible Pavement Designer's Manual, Texas Highway Department, 1972.
2. Scrivner, F. H., McFarland, W. F., "A System Approach to the Flexible Pavement Design Problem", Res. Rep. 32-11, Texas Trans. Inst. (1968).
3. "Transportation Engineering Handbook" , Chapter 50, R-6 Supplement No. 20, U. S. Forest Service, Department of Agriculture, January 1974.
4. Van Til, C. J., McCullough, B. F., Vallerga, B. A., and Hicks, R. G., "Evaluation of AASHTO Interim Guides for Design of Pavement Structures" NCHRP Rep. 128, 1972.
5. AASHTO, "AASHTO Interim Guide for the Design of Pavement Structures - 1972" Washington, D. C., 1972.
6. Lund, J. W., "Surfacing Loss Study" Region 6, U. S. Forest Service, Department of Agriculture, 1973.

APPENDIX A OF THE USER'S MANUAL

METHOD USED FOR DETERMINING THE REGIONAL FACTOR

Regional Factor

This is a numerical factor used to adjust the expected life of a road to account for variations in climatic and environmental conditions.

Following are two methods for determining the numerical value of this factor. The first is taken both from the 1972 edition of the "AASHTO Interim Guide for Design of Pavement Structures" (5) and from NCHRP No. 128 (4), and refers to Figure 5. The second method is taken from Chapter 50 of the January 1974 Edition of the Forest Service "Transportation Engineering Handbook," (3) and refers to the attached Table 2.

1. Method 1 - AASHTO

It is generally recognized that when conditions are adverse, such as during a period of strength loss of the roadbed materials which may occur during spring thaw, there will be greater damage inflicted to the pavement by traffic than during more favorable conditions. This variation in rate of reduction of serviceability with season has been averaged for the AASHO Road Test period to arrive at an approximate regional factor for the AASHO Road Test. The seasonal values varied between 0.1 and 4.8, and with an annual value of regional factor of about 1.0. The lower values apply to both the solidly frozen and the relatively dry conditions of roadbed soils when the rate of loss of serviceability was very low, and the higher values apply to spring conditions at the AASHO Road Test site when roadbed soils were weakened and rate of loss of serviceability was highest.

At present, there is no way to determine directly the regional factor for other locations and conditions. It may be estimated, as it was for AASHO Road Test conditons, by analyzing the duration of certain conditions during a typical year. Based on AASHO Road Test information, values that may be used as a guide for such an analysis are

Roadbed material frozen to depth of 5 inches (130mm) or more	0.2 to 1.0
Roadbed materials dry, summer and fall	0.3 to 1.5
Roadbed materials wet, spring thaw	4.0 to 5.0

Many other procedures have been used to estimate regional factors. A survey of all 50 states indicated that one or more of the following are used by states in assigning a regional factor (See Fig 5):

1. Topography
2. Similarity to Road Test location
3. Rainfall
4. Frost penetration
5. Temperature
6. Groundwater table
7. Subgrade type

8. Engineering judgment
9. Type of highway facility
10. Subsurface drainage

There are other conditions, somewhat related to the above, that may require consideration in establishing a Regional Factor, such as:

1. Number of annual freeze-thaw cycles
2. Steep grades with large volume of heavy truck traffic
3. Areas of concentrated turning and stopping movements

In general, the regional factor should not exceed about 4.0, or be less than about 0.5 for conditions in the United States. The regional factor may not adjust for special conditions, such as serious frost conditions, or other local problems.

Even with the various guidelines presented above, considerable judgment must still be exercised in evaluating their effects and in selecting an appropriate regional factor for design. The regular use of a pavement rating system would provide valuable background data for determining a regional factor (5).

2. Method 2 - Forest Service Transportation Engineering Handbook

Table 2 may be used as a guide in selecting appropriate values for the regional factor (R). Considerable judgment must be exercised in properly selecting the value of R. It should be recognized that certain severe conditions are outside the scope of this guide. Two examples might be unusual frost and drainage problems.

For conditions of high water table, special drainage must be designed. In this guide, a high water table is arbitrarily defined as a free water level at an elevation within 3 feet of the subgrade elevation. Special drainage can consist of any acceptable design practice which lowers the water table to an acceptable level. It might consist of underdrains, layers of free draining materials, or any number of other accepted practices.

When frost conditions are present along with frost susceptible soils, a special design must be instigated. In this guide, a somewhat arbitrary condition of 10 inches of frost penetration has been selected to indicate severe conditions. It should be recognized that snow is a good insulation and, therefore, on roads that do not have snow removal frost may never penetrate 10 inches. If a road is not used or if it can be closed during frost breakup, it is not required that special design be used and this guide is adequate. When conditions such as 10 inches of frost penetration warrant special design, it is recommended that the Corps of Engineers Frost Design Procedure be used. In using this procedure, it should be kept in mind that it is possible to change a soil from frost susceptible to nonsusceptible by some soil stabilization treatments.

For conditons found in Region 6, R will generally vary between 1.5 and 2.5, with 2.0 fitting perhaps 90 percent of the time. Before values outside of the above range are assigned, the designer should seek the advice of a Materials Engineer (3).

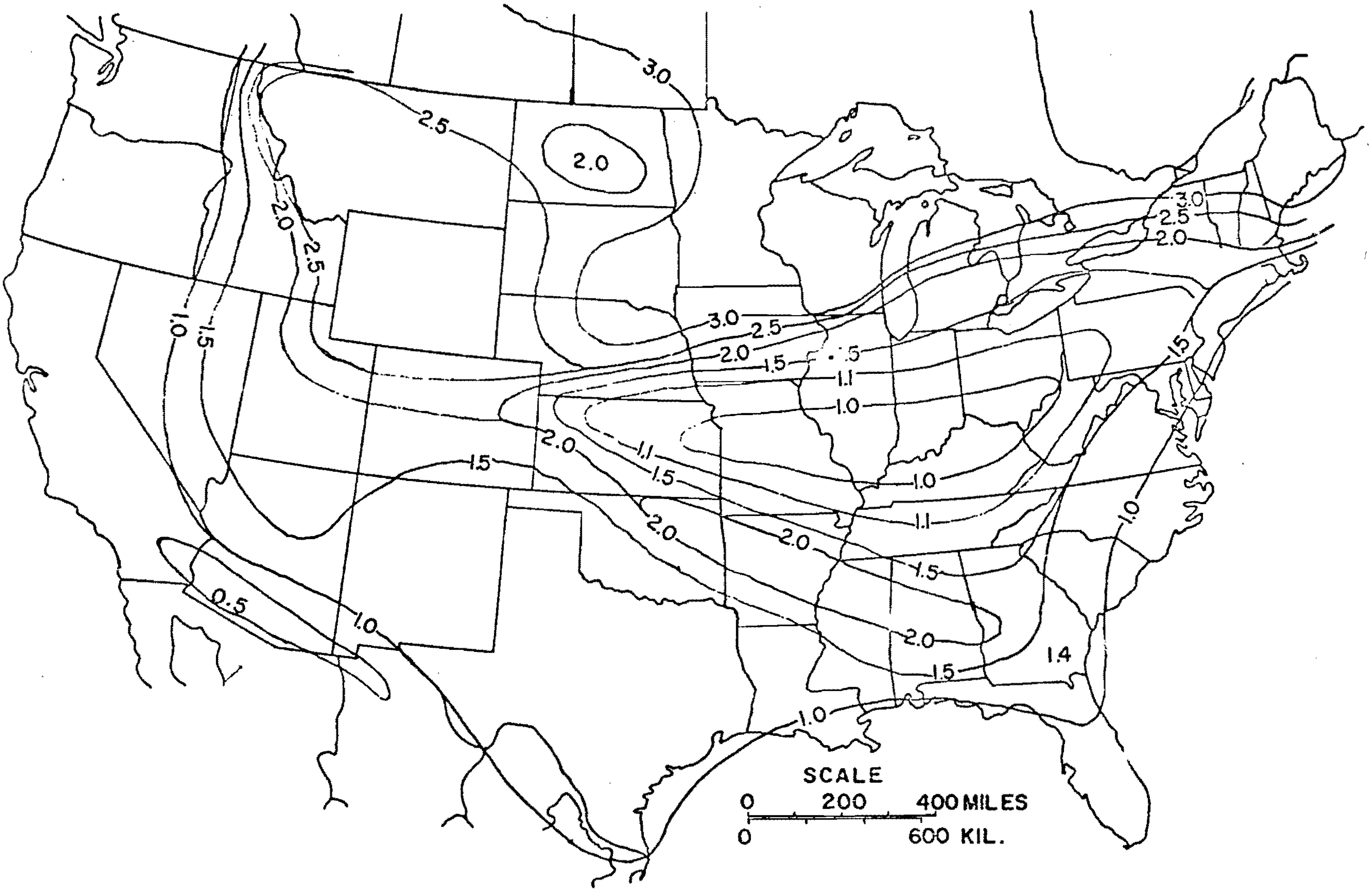


Fig 5. Contours of Equal Regional Factors (4).

*TABLE 2

REGIONAL FACTOR "R"

Use Base "R" of 1

	Use Values From Both Columns			Use Only 1				
				Frost Heave (2)				
				W/O Snow Removal		With Snow Removal		
Additional to Base R	Annual Precipitation (Inches)	Average % Grade	Swelling Soil	Agg. S.	Paved	Agg. S.	Paved	Shoulders Width
+ 0.1	50-60	7-8						
0.2	60-70	8-9						
0.3	70-80	9-10						
0.4	80-90	10-11						
0.5	90-100	11-12						
0.6	>100	>12						
0.5			>3%					
0.2				CL,CH(1)				
0.3					CL,CH			
0.4				SMu,ML,MH		CL,CH		
0.5					SMu,ML,MH		CL,CH	
0.7						SMu,ML,MH		
1.0							SMu,ML,MH	
0.0								>2 feet
0.3								<2 feet

(1) Unified Classification System.

(2) When frost penetration exceeds 10 inches in frost susceptible soils, this guide will not yield adequate structural thickness for conditions indicated. Use Corps of Engineers Frost Design Method. Frost susceptible soils are ones having Unified Soil Classifications's of SM_u, ML, MH, CL, and CH. The Guide also assumes drainage is adequate to keep water table 3 feet below top of subgrade. -*

Some regions have refined the regional factor to be more representative of their particular condition. The following is an example of the refinement made by Region 1 for internal use. This material has been provided compliments of Mr. Bob Hinshaw, Region 1, Missoula, Montana.

PROCEDURE FOR DETERMINING REGIONAL FACTOR AS PRESENTLY USED BY REGION 1

The Regional Factor used for the Idaho portion of Region 1 is taken directly from the Idaho Department of Highways. For those portions of the Region outside of Idaho, we have extrapolated our own values, based on the Idaho method as much as possible.

The method used by Idaho was to determine first the AASHO Regional Fact for various conditions in Idaho. District maintenance engineers were given an outline of the AASHO Regional Factor curves and were asked to determine independently the factors for their area. Correlation between districts was good. In summarizing the data, it was felt that Regional Factors for Idaho might range from 1.0 for some canyons and valleys to 2.5 for some areas of high precipitation and snowfall and severe spring breakup periods.

The next step involved a study of 30-year weather records for all stations within the State. Average monthly temperature and precipitation were used. A plot of cumulative precipitation and cumulative degree days above or below 32°F. during the winter period was made. A sample of one of these plots is shown in Fig. 6. This information was used to determine areas of similar climatic severity.

The weather data, together with the district maintenance engineer's evaluation, were then used to derive the map of Regional Factors. For easier usage, the Idaho Regional Factor was reduced to a direct multiplier to be applied to the total required thickness. The increase in thickness varies from 0 to 15 percent as follows:

AASHO Regional Factor	Idaho Regional Factor
1.0	1.0
1.5	1.05
2.0	1.10
2.5	1.15

In extending the Idaho factors to other areas within the Region, we used the same weather analysis technique, but did not have the benefit of district maintenance engineer's experience. Therefore, our extension of the factors outside of Idaho is based only on weather information, with no local experience feedback. The one other tool used in drawing up the map was elevation. This was relied upon heavily in areas where no weather data were available.

In order to extend the Idaho weather data to other parts of the Region, several mathematical combinations of winter precipitation and degree days were tested for correlation to Regional Factor. The combination selected was a unitless number derived by adding the degree days, D, to 100 times the winter precipitation, P, or (D + 100 P). For the portion of Idaho north of the Salmon River, the portion of Montana west of the Continental Divide, and that portion of Washington in Region 1, the following criteria were used:

D + 100 P	Regional Factor
0-350	1.00
350-500	1.05
500-1700	1.10
Over 1700	1.15

For the portion of Idaho south of the Salmon River, the portion of Montana east of the Continental Divide, and the portions of North and South Dakota in Region 1, the following criteria were made:

D + 100 P	Regional Factor
0-350	1.00
350-1200	1.05
1200-1700	1.10
Over 1700	1.15

The map (Fig 8) thus derived is necessarily quite general and will require further refinement at the local level. It is doubtful whether this specific method is applicable to other sections of the country.

	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL
MONTHLY PRECIPITATION (IN.)	1.26	2.03	2.26	2.42	2.18	1.55	1.42	1.02
CUMULATIVE PRECIPITATION (IN.)	1.26	3.29	5.55	7.97	10.15	11.70	13.12	14.14
AVERAGE TEMPERATURE (°F)	56.5	45.6	33.9	28.5	24.0	27.6	35.7	46.3
DEGREES ABOVE OR BELOW 32°F	+24.5	+13.6	+1.9	-3.5	-8.0	-4.4	+3.7	+14.3
DEGREE DAYS ABOVE OR BELOW 32°F	+735	+421	+57	-108.5	-248	-123.2	+114.7	+429
CUMULATIVE DEGREE DAYS	735	1156	1214	1105	857	734	849	1278

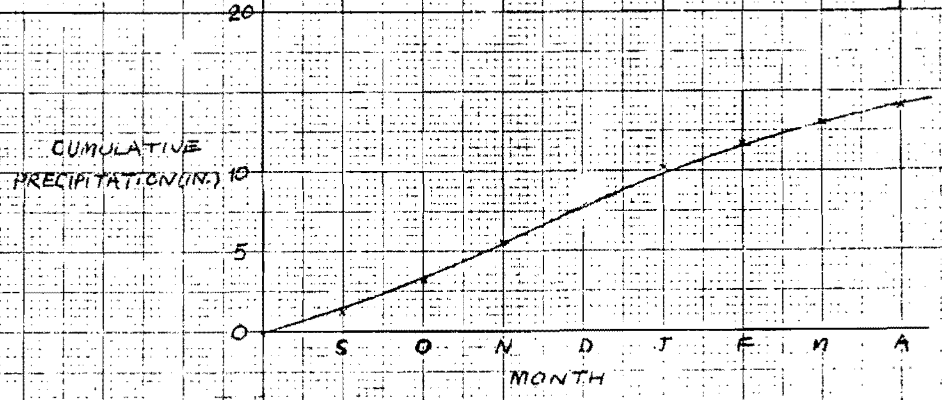


Fig 6a. Plot of cumulative precipitation.

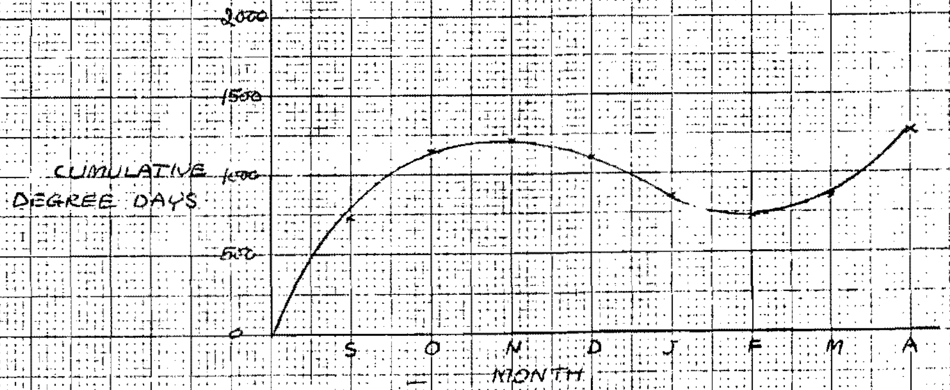


Fig 6b. Plot of cumulative degree days.

Fig 6. Plot of weather record.

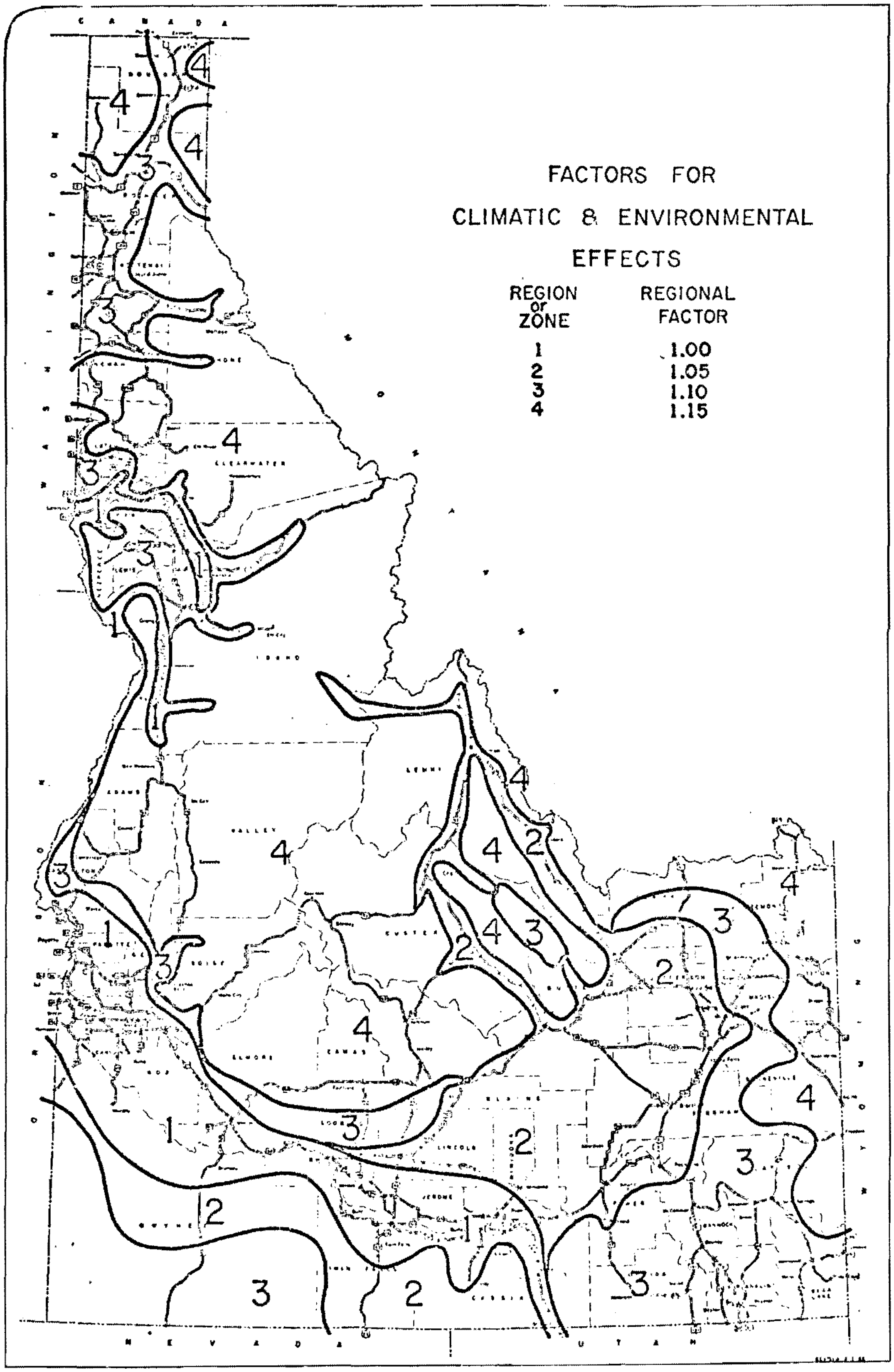


Fig 7. Factors for climatic and environmental effects.

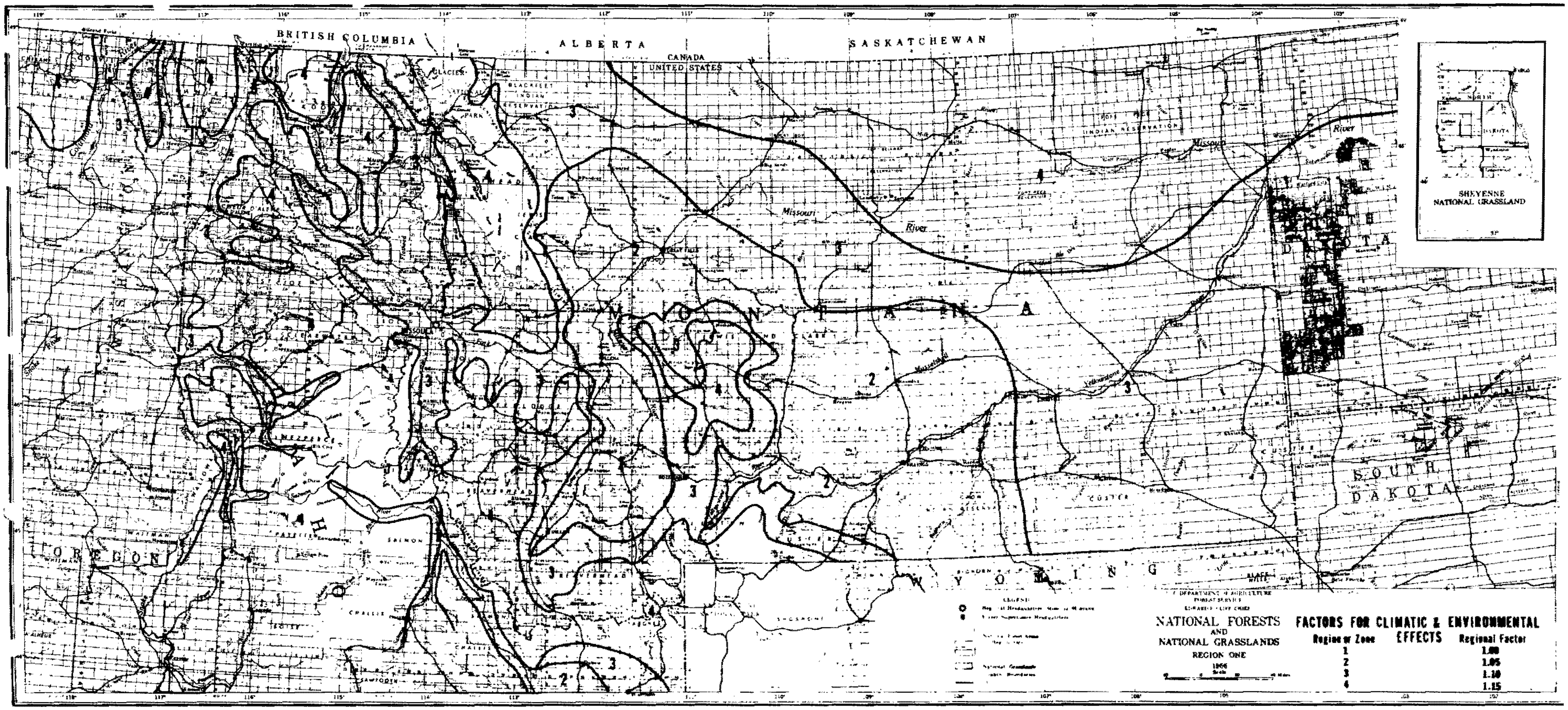
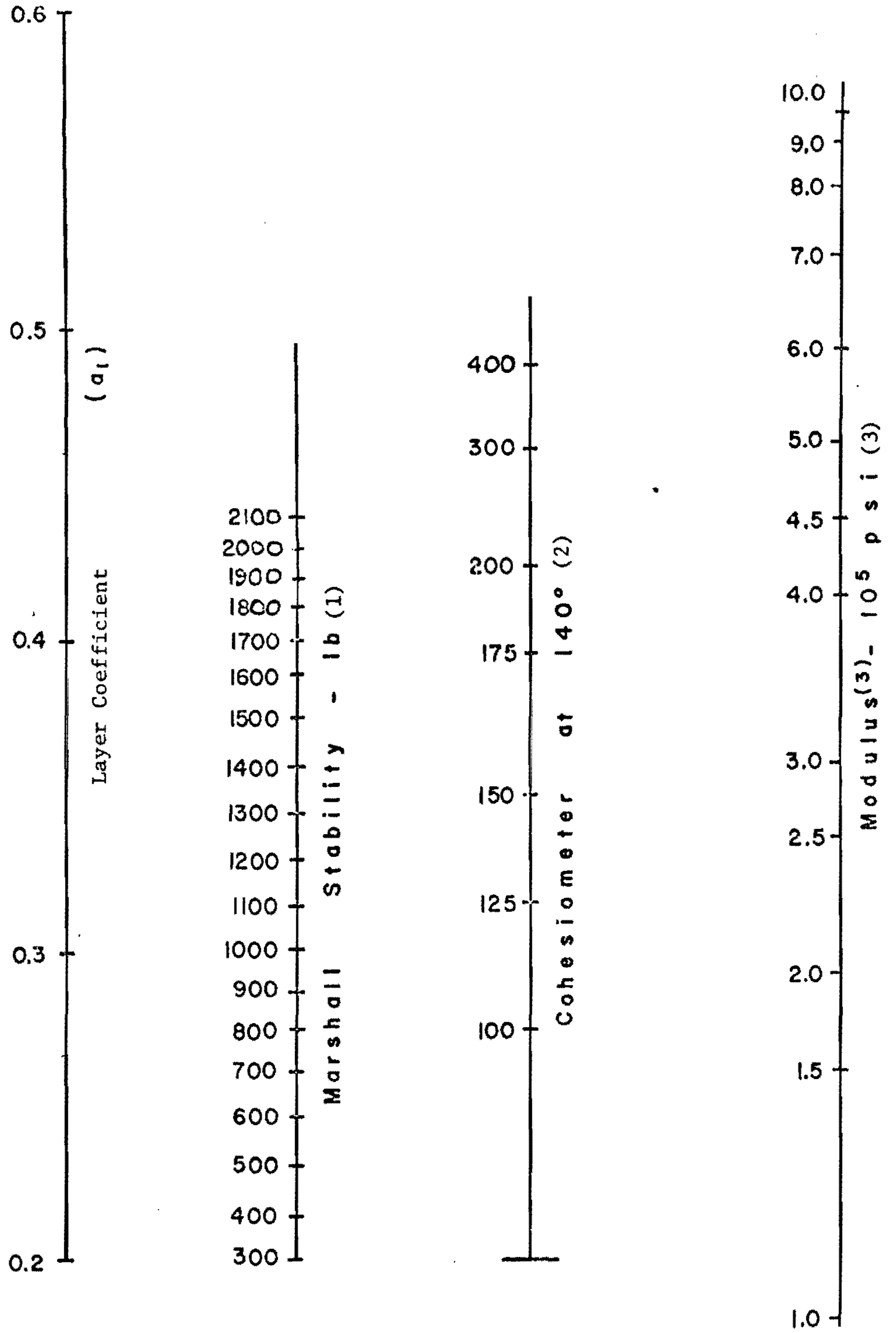


Fig 8. Factors for climatic and environmental effects.

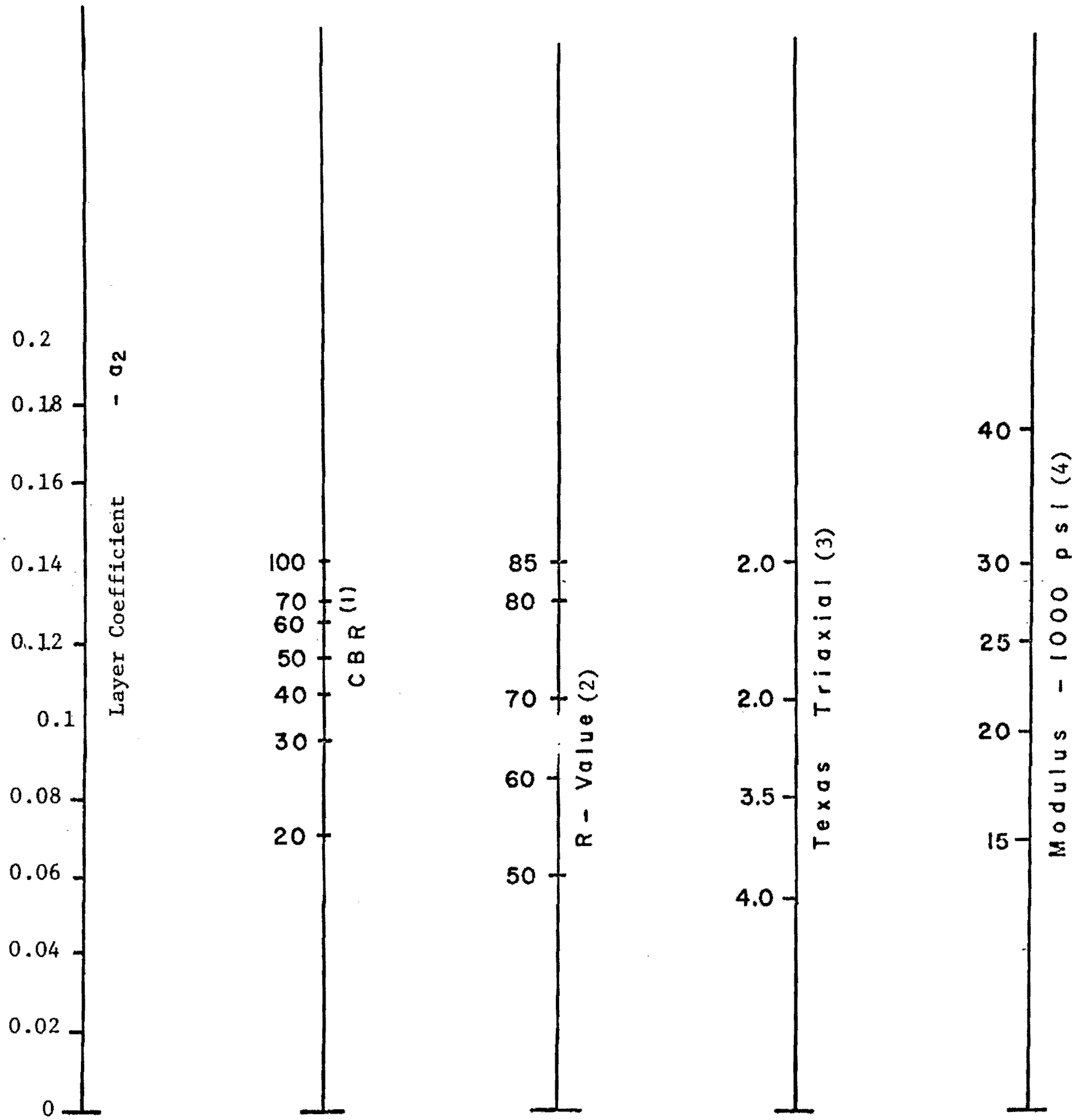
APPENDIX B OF THE USER'S MANUAL

LAYER COEFFICIENTS



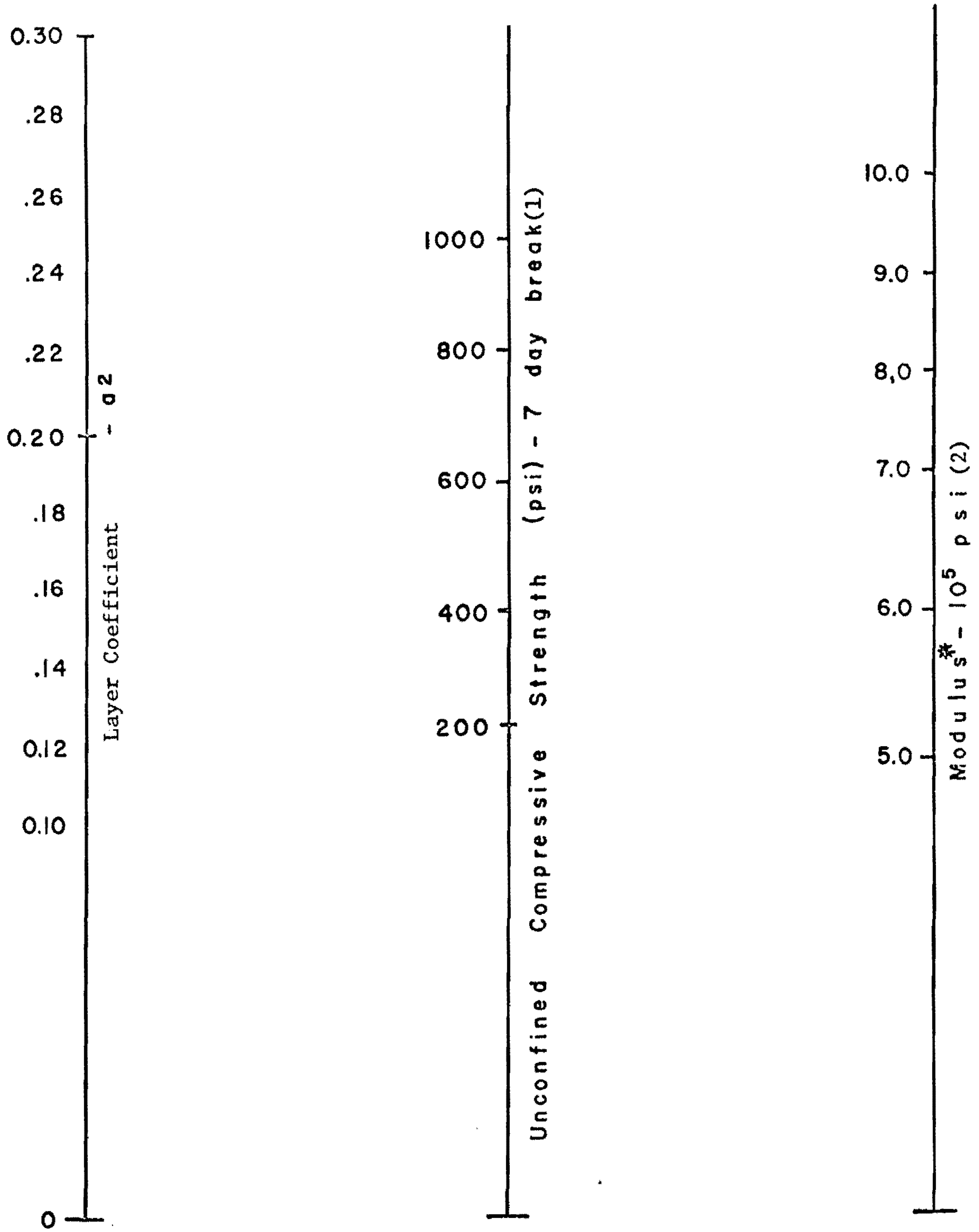
NOTE: (1) Scale derived by averaging correlations obtained from the Asphalt Institute, Illinois, Louisiana, New Mexico, and Wyoming.
(2) Scale derived by averaging correlations obtained from California and Texas.
(3) Scale derived on NCHRP 128 Report.

Fig 9. Variation in (a_1) with Surface Course Strength Parameter (4).



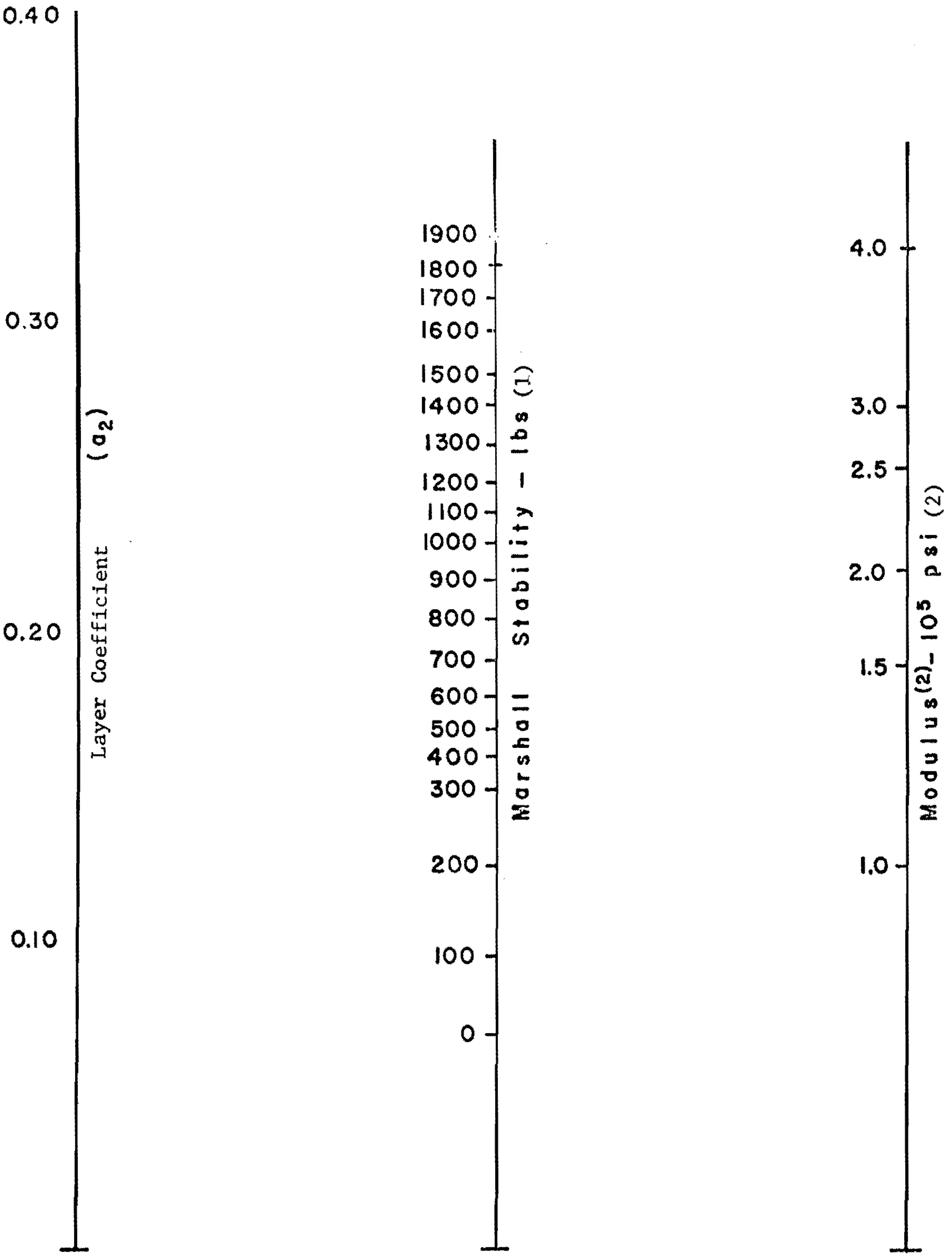
(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico, and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on Project NCHRP 128.

Fig 10. Variation in Granular Coefficient (a_2) with Base Strength Parameters (4).



NOTE: (1) Scale derived by averaging correlations from Illinois, Louisiana, and Texas.
(2) Scale derived on NCHRP 128.

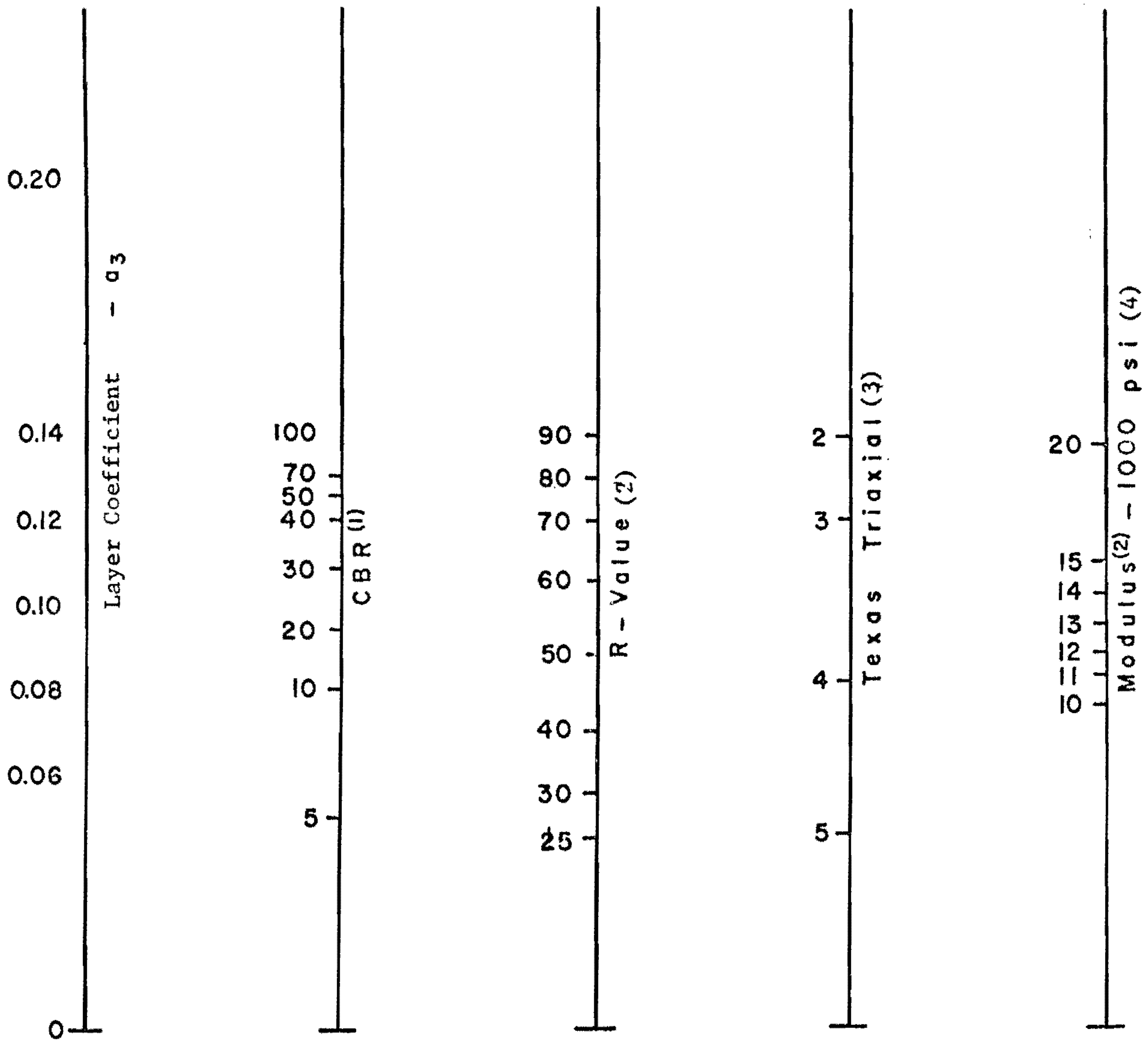
Fig 11. Variation in (a_2) for Cement Treated Bases with Base Strength Parameters (4).



NOTE: (1) Scale derived by correlation obtained from Illinois

(2) Scale derived on project NCHRP 128

Fig 12. Variation in (a_2) for Bituminous Treated Bases with Base Strength Parameter (4).



NOTE: (1) Scale derived from correlations from Illinois.
(2) Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico, and Wyoming.
(3) Scale derived from correlations obtained from Texas.
(4) Scale derived on project NCHPR 128.

Fig 13. Variation in (a_3) in Granular Coefficient (a_3) with Subbase Strength Parameters (4).

*TABLE 3

LAYER COEFFICIENTS*

Materials	Layer Coefficient	
1. **Bases and Subbases**		
Select Material (see Table 5)	.04 - .11	
F. Contract - Item 305 T.S. Contract - Items 50, 51, 55, 50+6-50-1, 51+6-51-1		
Dense Graded Aggregate Base (Untreated)	"a_2"	"a_3"
F. Contract - Item 304(1)	0.11	0.12
T.S. Contract - Item 52(2)	0.10	0.12
Item 52+XX52-2(3)	0.14	0.14
Item 52+6-52-2(1)	0.12	0.13
For reconstruction, see Table 6 to evaluate existing material.		
Open Graded Aggregate Base (Untreated)	"a_2"	"a_3"
T.S. Contract - Item 52(2)	0.07	0.11
Item 52+XX52-2(3)	0.11	0.12
Item 52+6-52-2(1)	0.09	0.12
Item 6-53	0.07	0.11
Bituminous Treated Base (see Table 7)	0.15 - 0.36	
F. Contract - Item 301 T.S. Contract - Item 62		
Lime Treated Bases (see Table 8)	0.12 - 0.30	
Includes both aggregate base and subgrade soil or borrow materials. F. Contract - Item 310		
Cement Treated Bases (see Table 8)	0.12 - 0.30	
Includes both aggregate base and subgrade soil or borrow materials. F. Contract - Item 308		

Coefficients are based on specifications in effect on August 1973. As specification changes, it will be necessary for a Materials Engineer to update this table. -

*TABLE 3. (Continued)

Materials	Layer Coefficient	
2. Surfaces		
Aggregate Surface (untreated)		
F. Contract - Item 412(1)	0.12	
T.S. Contract - Item 56(1)	0.13	
Item 56+6-56-2(1)	0.13	
Bituminous Surfaces		
Miscellaneous Surface Treatments	Max. Aggregate Size	
	< 1"	> 1"
F. Contract - Items 409, 410, 411 T.S. Contract - Item 64	Include with underlying layer	0.25
Road Mix (see Table 9)	0.17 -	0.34
F. Contract - Item 405		
T.S. Contract - Item 65		
Plant Mix-Cold		
Dense or Intermediate Graded (See Table 9)		
F. Contract - Item 404	0.32	
T.S. Contract - Item X66-1, Item 6-66	0.20 -	0.37
Open Graded (See Table 10)		
T.S. Contract - Item X66-1, Item 6-66,	0.18 -	0.30
Plant Mix-Hot (see Table 11)	0.30 -	0.42
F. Contract - Item 403		
T.S. Contract - Item X68-1, Item 6-68		

(1) Compacted to 95% of AASHO T 99.
(2) Compacted to 90% of AASHO T 99.
(3) Compacted to 95% of AASHO T 180.

Note: Tables 5-11 are intended to aid in selecting "a" values. Changes in compaction may be evaluated using the CBR and "a" value scales in Figure 5 along with the density and CBR relationships given in the "Design Criteria" section, paragraph 4.

-*

*TABLE 4

SELECT MATERIAL (a_3)

Use Base Coefficient of 0.04 for Cinders; 0.05 for Sand and Gravel; 0.06 for Fractured Rock

	P.I.			Grading		
				Pass 200		
Additional Coefficient	Base or Subbase	Surfacing	Quality	Base or Subbase	Surfacing	Pass 4
+ .01	< 2	2-9				
.00			Marginal			
.01			Good			
.02			Excellent			
.01				0-10	2-10	
.01						25-60

Note: 1. Coefficients based on compaction at 100% of AASHO T 99.

2. Coefficients may be adjusted to other compaction levels by using CBR and "a" value scales in Figure 5 along with the density and CBR relationships given in Section 1, paragraph 4. -*

*TABLE 5

AGGREGATE BASE (a_2) AND SURFACING (a_1)(UNTREATED)

Use Base Coefficient 0.06 for Cinders; 0.07 for S&G; 0.08 for Fractured Rock

	PLASTICITY				GRADING			
	S.E.	P.I.			Pass 200		Pass 4	Pass 1½"
Additional Coefficient	Base Only	Base	Surfacing	Quality	Base	Surfacing	Base and Surfacing	Base and Surfacing
+ .01	> 35	< 6	2-9					
.00				Marginal				
.01				Good				
.02				Excellent				
.01					0-8	3-15		
.01							30-65	
.01								100

Note: 1. Coefficients based on compaction at 100% of AASHO T 99.

2. Coefficients may be adjusted to other compaction levels by using CBR and "a" value scales in Figure 5 along with the density and CBR relationship given in Section 1, paragraph 4. -*

*TABLE 6

BITUMINOUS TREATED BASE (a_2)(3)

Use base coefficient of 0.15 when total 18-kip equivalent axle > 1,000,000
Use base coefficient of 0.16 when total 18-kip equivalent axle from 350,000 to 1,000,000
Use base coefficient of 0.17 when total 18-kip equivalent axle from 60,000 to 350,000
Use base coefficient of 0.18 when total 18-kip equivalent axle < 60,000

Additional Coefficients	Mixing	Asphalt		Grading		P.I.	Additives Cement, Lime, etc.	Aggregate Quality	Additional (2) Considerations
		Pen.	% of Opt.(1)	Pass 200	Pass 4				
+ .03	Plant Mix-Hot								
.02	Plant Mix-Cold								
.01	Plant-Travel								
.00	Blade Mix								
.01		< 100							
.00		> 100							
.00		Cutback							
.04			100						
.02			65						
.00			30						
.01				2-10					
.01					35-60				
.01						< 2			
.01							Improved curing		
.02							25-50% Inc.Strength		
.03							> 50% Inc. Strength		
.00								Marginal	
.01								Good	
.02								Excellent	
.00									Marginal
.01									Good
.02									Excellent

(1) Optimum (Opt.) is defined as the % of asphalt (dry aggregate basis) yielding maximum stability in laboratory mix design procedures.

(2) Include such things as curing conditions, traffic control, compaction requirements, stockpile or aggregate uniformity requirements, etc.

(3) Coefficients based on compaction at 100% of maximum laboratory density.
Table not applicable to OPEN GRADED bituminous treated bases with less than 100% optimum (1) asphalt content and their use is not recommended. For open graded bases treated to 100% the design must provide a filter layer to prevent intrusion of subgrade. -*

*TABLE 7

LIME OR CEMENT TREATED MATERIAL (a_2)

(INCLUDED BOTH SOIL AND CRUSHED ROCK)

Use Base Coefficient of 0.12

Additional Coefficient	Mixing	P.I.		Compressive Strength (1)
		Cement	Lime	
+ 0.05	Central Plant			
0.00	Road Mix			
0.01		N.P.	> 4	
0.12				> 1,000
0.08				650 - 1,000
0.05				300 - 650
0.00				< 300

(1) Unconfined Compression Test, Cement - 7-day break; Lime - 21-day break. Specimens prepared for compression test using mold and compaction effort specified in AASHO T 134.

Normal range of compressive strength is 250 to 650 psi. Within this range, few problems are encountered with durability and flexibility. For designs outside this range, contact a Materials Engineer. -*

*TABLE 8

COLD BITUMINOUS PAVEMENT _ DENSE AND INTERMEDIATE GRADED (a_1)

See footnote when total 18-kip equivalent axles are > 1,000,000 (1)
Do not use when total 18-kip equivalent axles are from 350,000 to 1,000,000 without additives (1)
Use base coefficient of 0.17 when total 18-kip equivalent axles from 120,000 to 350,000
Use base coefficient of 0.19 when total 18-kip equivalent axles from 60,000 to 120,000
Use base coefficient of 0.21 when total 18-kip equivalent axles from 10.000 to 60,000
Use base coefficient of 0.23 when total 18-kip equivalent axles < 10,000.

Additional Coefficient	Mixing	STABILITY					Aggregate Quality	Additional Considerations (2)
			Grading					
		Asphalt	Pass 4	Pass 200	P.I.	Additives Cement, Lime, etc.		
+ .03	Plant Mix-Hot							
.02	Plant Mix-Cold							
.01	Traveling Mixer							
.00	Blade Mix							
.01		< 100 Pen						
.00		> 100 Pen						
.00		Cutbacks						
.01			35-60					
.01				2-10				
.01					< 2			
.01						Improved Curing		
.02						25-50% Inc.Strength		
.03						> 50% Inc. Strength		
.00							Marginal	
.01							Good	
.02							Excellent	
.00								Marginal
.01								Good
.02								Excellent

(1) When the equivalent axles are > 350,000, a relatively high standard road is justified. To assure a high probability of success, tighter controls are needed than are normally required in cold mix specifications. An economic analysis will almost always reveal an additive or hot mix are justified.

(2) Includes such things as curing conditions, traffic control, compaction requirements, stockpile or aggregate uniformity requirements, etc. -*

*TABLE 9

COLD BITUMINOUS PAVEMENTS - OPEN GRADED (a_1)

See footnote when total 18-kip equivalent axles > 350,000 (1)
Use base coefficient of 0.18 when total 18-kip equivalent axles from 120,000 to 350,000
Use base coefficient of 0.20 when total 18-kip equivalent axles from 60,000 to 120,000
Use base coefficient of 0.22 when total 18-kip equivalent axles from 10,000 to 60,000
Use base coefficient of 0.24 when total 18-kip equivalent axles < 10,000

Additional Coefficient	Stability		Aggregate Quality	Additional Considerations (2)
	Asphalt	P.I.		
+ .01	<100 Pen			
.00	>100 Pen			
.01		<2		
.00			Marginal	
.01			Good	
.02			Excellent	
.00				Marginal
.01				Good
.02				Excellent

(1) When the equivalent axles are > 350,000, a relatively high standard road is justified. To assure a high probability of success, tighter controls are needed than are normally required in cold mix specifications. An economic analysis will almost always reveal a dense graded cold mix with additive or hot mix are justified.

(2) Includes such items as curing conditions, traffic control, compaction requirements, stockpile or aggregate uniformity requirements, etc.

Note: Open graded mixes with a single seal coat are extremely free draining. Practically all rainfall passes through the mix to the layers below. This may result in weakening the base layers or subgrade and must be considered in the design.

Silt and clay materials have low wet strength, and the degree of weakening may be dramatic when they exist in the subgrade. The use of open graded mixes as surfacing over these subgrades is questionable and a Materials Engineer should be consulted.

When using open graded mix as surfacing, paving should extend full width and include shoulders. Untreated dense aggregate will trap water within the roadway, and open graded untreated aggregate is so unstable it will be displaced by traffic as well as create a safety hazard. Open graded mixes are not recommended when tire chain use is expected.-*

*TABLE 10

PLANT MIX - HOT (a_1)

TOTAL 18-KIP AXLES	LAYER COEFFICIENT "a"
< 10,000	0.42
10,000 - 60,000	0.40
60,000 - 120,000	0.38
120,000 - 350,000	0.36
350,000 - 1,000,000	0.34
1,000,000 - 3,000,000	0.32
> 3,000,000	0.30

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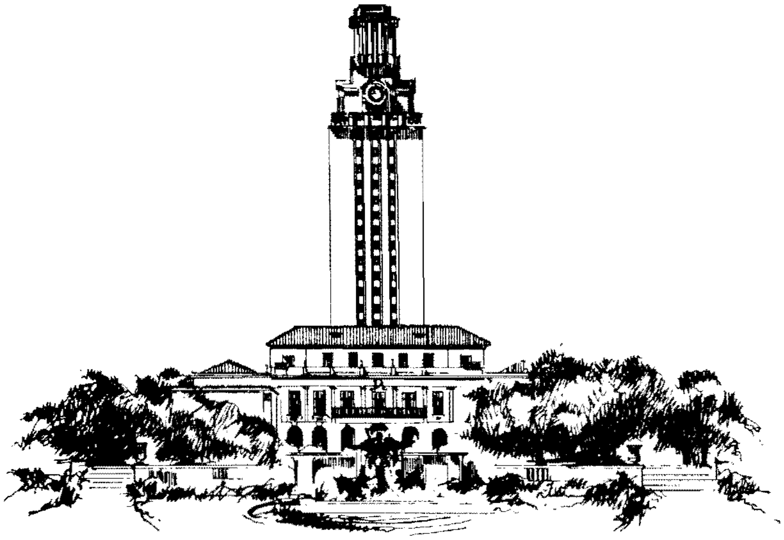
Council for Advanced Transportation Studies
A Pavement design and management system for Forest Service raods-a working model. Austin, University of Texas,
132 pp. illus. 21.59 by 27.94 cm. (Council for Advanced Transportation Studies, Res. Rept. 43)
Conducted and prepared for Forest Service, U.S. Department of Agriculture, Washington, DC under Agreement No. 13-794.
Final Report-Phase II
1. Low Volume roads. 2. Pavements 3. Roads-Design 4. Forest roads I. U.S. Forest Service. II. University of Texas
TE251.C6 No. 43



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