LVR PAVEMENT DESIGN AND MANAGEMENT SYSTEM-
USER'S MANUAL

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COUNCIL FOR ADVANCED TRANSPORTATION STUDIES

The University of Texas at Austin

DAVE LUHR

FOREST SERVICE
PAVEMENT MANAGEMENT SYSTEM
LVR
USER'S MANUAL

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This User's Manual describes the inputs to LVR, a computer program which can be used to compute the most economical designs for an asphaltic concrete or aggregate-surfaced road which meets certain requirements specified by the user. These requirements include the desired life, constraints regarding the cost of initial construction, the frequency of rehabilitation, and others, as defined explicitly by the complete list of input variables included herein. The "most economical designs" are considered to be those whose total costs on a net present value basis at the time of construction are smallest. The total cost includes the cost of initial construction, major rehabilitation, regularly scheduled seal coats for asphalt roads and grading for aggregate-surfaced roads and minor maintenance, as well as user-delay costs associated with rehabilitations. Additionally, the program will calculate the vehicle operating cost if specified by the user.

The first section of this manual includes a complete list of input variables organized to indicate the data card and columns in which each variable is input. The variables are defined in physical terms, and limits on their values are given where applicable. At the end of the section, several figures are given illustrating the meaning or effect of certain input variables. References are given for figures derived from a published source.

Appendix A includes a discussion of the determination of the regional factor, which is used to account for regional differences in the deterioration rate of riding quality. Appendix B includes a number of charts which can be used to determine the layer coefficients, and a set of example runs are presented in Appendix C. Appendix C should be useful in demonstrating the mechanics of setting up a data deck and illustrating the type of information which is obtained from the program and how it should be interpreted.

VARIABLE IDENTIFICATION GUIDE FOR DATA INPUT

NPROB	AN2												
1	NMBEST	NM	CL	XLW	NXLW	NNL	RATE	ITYPE	NOVL	NLAY	2	3	4
R	PSI	P1	P2	P2P	BONE	P34	IFC						
TIMNL(I)	RNL(I,1)	RNL(I,2)	CUM18K(I)	CM(I)	BDFT(I)	BDFTIN(I)							
XTTO(1)	XTTO(2)	XTTO(3)	.	.	.								
CMAX	TCKMAX	OVMIN	OVMAX	OVMAXL	TLMIN	AGNONT							
XLSO	XLSN	XBW	SB	PROP									
PPO2	PPN2	DDO2	DDN2	AAS	ASO	ASN	MODEL						
NGRSC	ASGRH	GRDIS	ASOTR	SC	TBSC								

OPC	OPCTR

			TYPE OF MATERIAL		LAYER COEFFICIENT			SALVAGE VALUE		SOIL SUPPORT

- Layer ID
- Material Code Letter
- In-place Cost of Material
- Minimum Layer Thickness
- Maximum Layer Thickness

NPDEFL	CNLEVL	DA	SF	EP	RCA	TIREP	4
DEFLP(1)	DEFSCL(1)	TEMPTR(1)	DEFLP(2)	DEFSCL(2)	TEMPTR(2)		
DR	STD						

1 - CSTSCL (1)

2 - IDELFT

3 - IDELCT

4 - DEFPRT

FORESTSERVICE

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/mile

= BOTH if both scales are wanted

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/mile

3 designs/page for BOTH

(1 ≤ NMBEST ≤ 40)

Default value is 40

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

(1 ≤ 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) —— [26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 • | 35]

2.6 NXLW - Number of lanes
Default value is 2 —— [40]

2.7 NNL* - Number of card No. 4's
2 ≤ NNL ≤ 50 —— [44 | 45]

2.8 RATE - Interest rate or time value of money (percent) —— [46 | 47 | 48 | 49 • | 50]

CARD NO. 2. (Continued)

2.9 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)

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

$1 \leq NOVL \leq 16$

2.11 NLAY - Number of layers of material previously constructed (NLAY < NM) — 65

Default value is 0

2.12 IDELFT - Flag for determining the time of pavement failure — 68 69 70

= YES if pavement deflection equations are to be used

= NO if ASSHTO equations are used

Default value is AASHTO equations

2.13 IDELCT - Flag for calculation of delay cost — 73 74 75

= 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

$0.0 < PSI \le 5.0$

							•		
11	12	13	14	15	16	17	18	19	20

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

							•		
21	22	23	24	25	26	27	28	29	30

3.4 P2 - Terminal serviceability index point at which rehabilitation must be performed.

$0.0 < P2 \le 5.0$

							•		
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. $0.0 < P2P \le 5.0$

							•		
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)* - 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, if 2.1 is BOTH, units are dollars/mile)

							•		
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). This variable is used to determine time of pavement failure. 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). 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.

Default value is 0.0

							•		
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.

**Aggregate surfaced roads only.

OVERLAY PARAMETERS ASSOCIATED WITH OVERLAY AND

ROAD GEOMETRICS

CARD NO. 7

7.1 XLSO* - Distance, along the 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 XBW** - width of the base (feet) (for an aggregate surfaced road XBW = NXLW*XLW)

							•		
21	22	23	24	25	26	27	28	29	30

7.4 SB** - Slope of the base in relation to 1.0 (E.G. 4.0 to 1.0)

							•		
31	32	33	34	35	36	37	38	39	40

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

							•		
41	42	43	44	45	46	47	48	49	50

*May be omitted if delay costs not desired

**See Figure 2

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 3, 4, 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

*May be replaced by a blank card if delay costs are not desired

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 (CL).

							•		
51	52	53	54	55	56	57	58	59	60

*May be omitted if delay costs are not desired

**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

*May be replaced by a blank card if operating cost is not desired.

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. There can be no more than 8 layers

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) — [69 70 71 72 • 73 74 75]

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

* 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.

PARAMETERS FOR THE PAVEMENT DEFLECTION MODEL

CARD NO. 12

(this card must be omitted if variable 2.12 is set to NO)

12.1 NPDEFL* ______ | 3 | 4 | 5 |

if > 1: this variable is the number of deflection readings, scales, and temperatures the user will input on Card No. 13. The program will use these values to compute representative rebound.

if = 1: the user must supply the average temperature corrected bb. deflection and the standard deviation.

Default value is 1

12.2 CNLEVL - Confidence level ______ | 6 | 7 | 8 | 9 | 10 | (decimal point in column 9)

The value used for the deflection will be the (mean + CNLEVL* standard deviation)

Default value is 2.0

12.4 SF - Seasonal factor ______ | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | (decimal point in column 28)

12.5 EP - Elastic modulus of the pavement (PSI) ______ | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | (decimal point in column 40)

Default value is 500000.0

12.6 RCA - Radius of the contact area (inches) ______ | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | (decimal point in column 48)

Default value is 7.9

12.7 TIREP - Tire contact pressure (PSI) ______ | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | (decimal point in column 58)

Default value is 70.0

CARD NO. 12 (Continued)

12.8 DEFPRT - flag to print the deflection data ________ 63 64 65

= YES if an echo print of the data is desired (NPDEFL > 1)

= NO if the print is not desired

Default value is NO

*Right justify in the field

DEFLECTION DATA FROM THE DYNAFLECT

CARD NO. 13
(2 sets of values per card)
(this card must be omitted if NPDEFL = 1 or if IDELFT = NO)

13.1 DEFLP(1) - deflection reading from the dynaflect at the first geophone

1	2	3	4	5	6	7	8	9	10

13.2 DEFSCL(1) - scale factor for the deflection reading (converts volts to inches)

11	12	13	14	15	16	17	18	19	20

13.3 TEMPTR(1) - Pavement temperature during measurement (°F)
Default is 70'F

21	22	23	24	25	26	27	28	29	30

13.4 DEFLP(2)

31	32	33	34	35	36	37	38	39	40

13.5 DEFSCL(2)

41	42	43	44	45	46	47	48	49	50

13.6 TEMPTR(2)

51	52	53	54	55	56	57	58	59	60

TEMPERATURE CORRECTED DEFLECTION AND STANDARD DEVIATION

CARD NO. 14

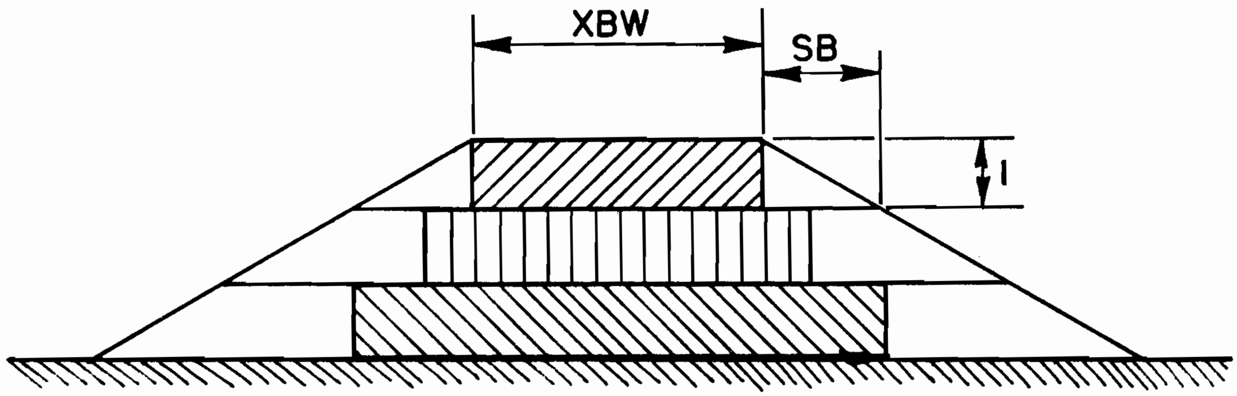
(this card is used only if NPDEFL = 1 and IDELFT = YES)

14.1 DR - Average temperature corrected deflection (Scaled)

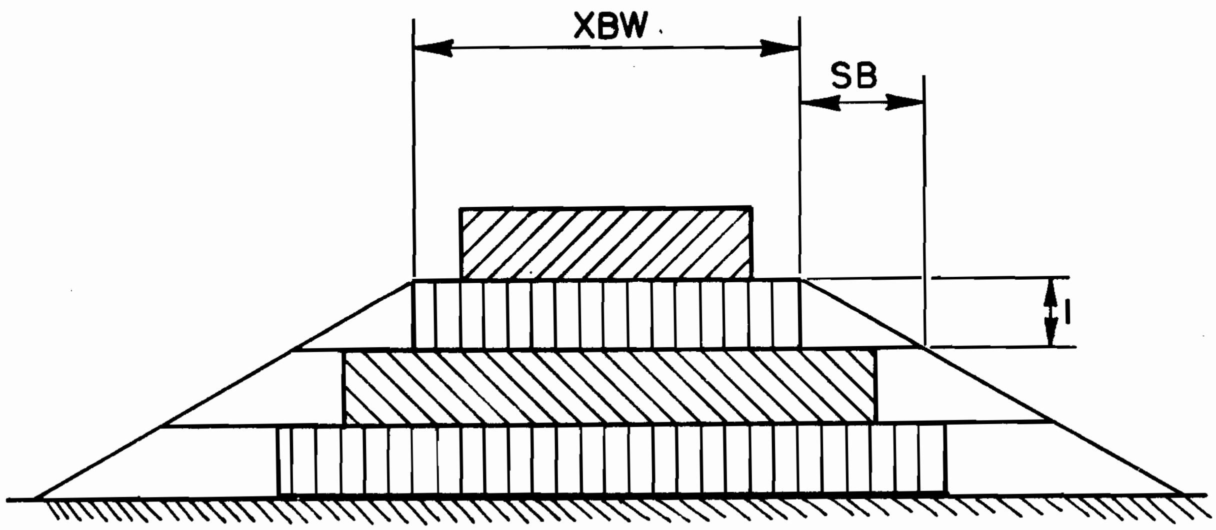
					•				
1	2	3	4	5	6	7	8	9	10

14.2 STD - Standard deviation of DR

					•				
11	12	13	14	15	16	17	18	19	20



Aggregate Surfaced



ACP

Figure 2

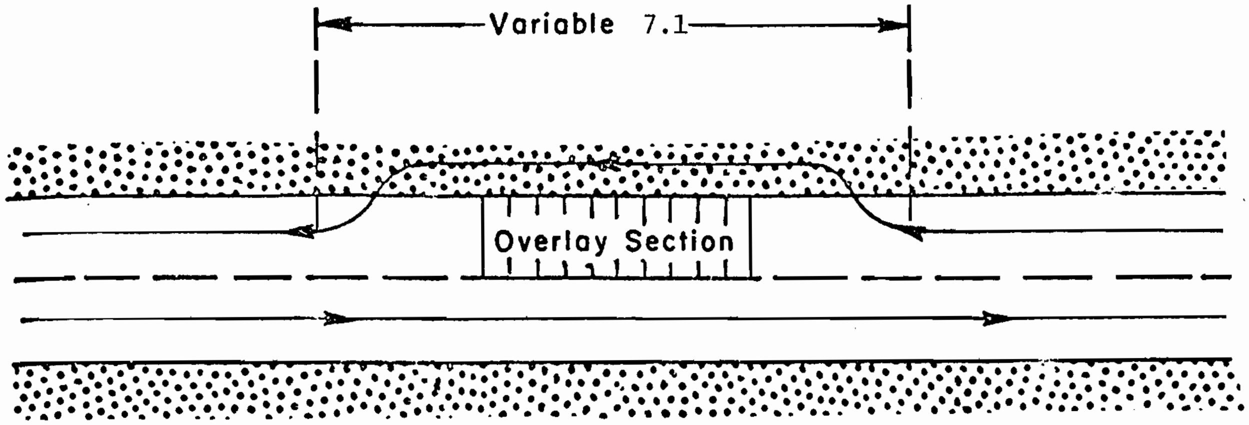


Fig. 3. Traffic model No. 1 (2).

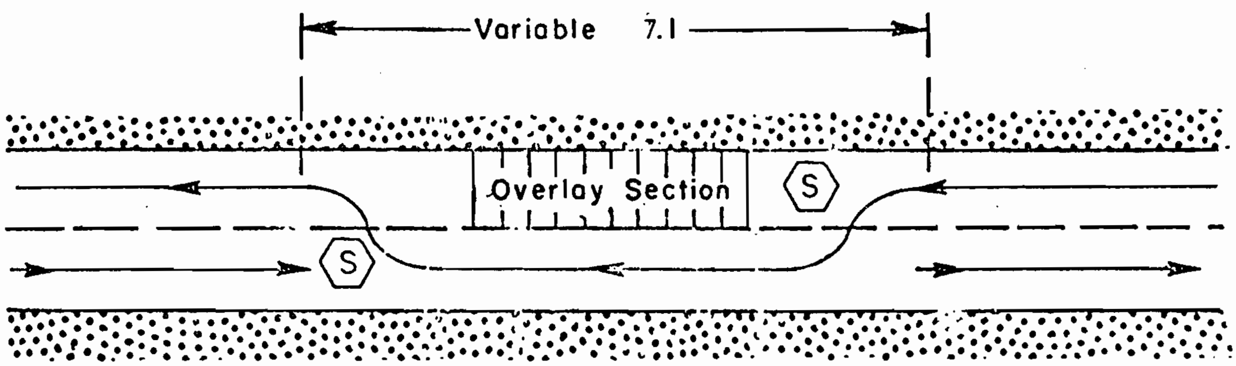
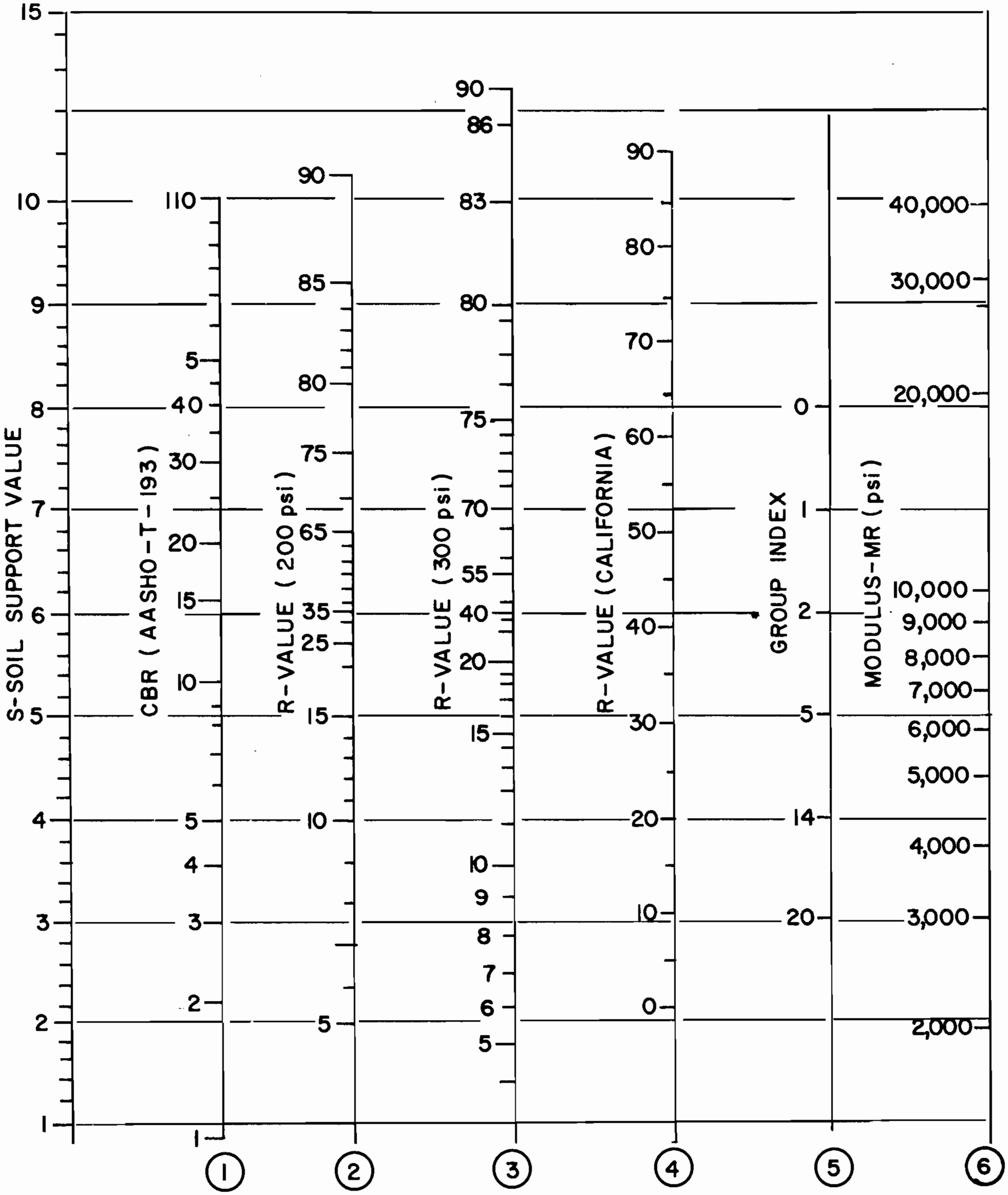


Fig. 4. Traffic model No. 2 (2).



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

Fig. 5. Correlation chart for estimating soil support value(s).

(Continued)

Fig. 5 . (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.

7. Roberts, F. L., McCullough, B. F., Williamson, H. J. and Wallin, W. R., "A Pavement Design and Management System for Forest Service Roads-A Working Model," Final Report - Phase II, Research Report 43, Council for Advanced Transportation Studies, The University of Texas at Austin, Austin, Texas, February 1977.

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 6. 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 6):

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).

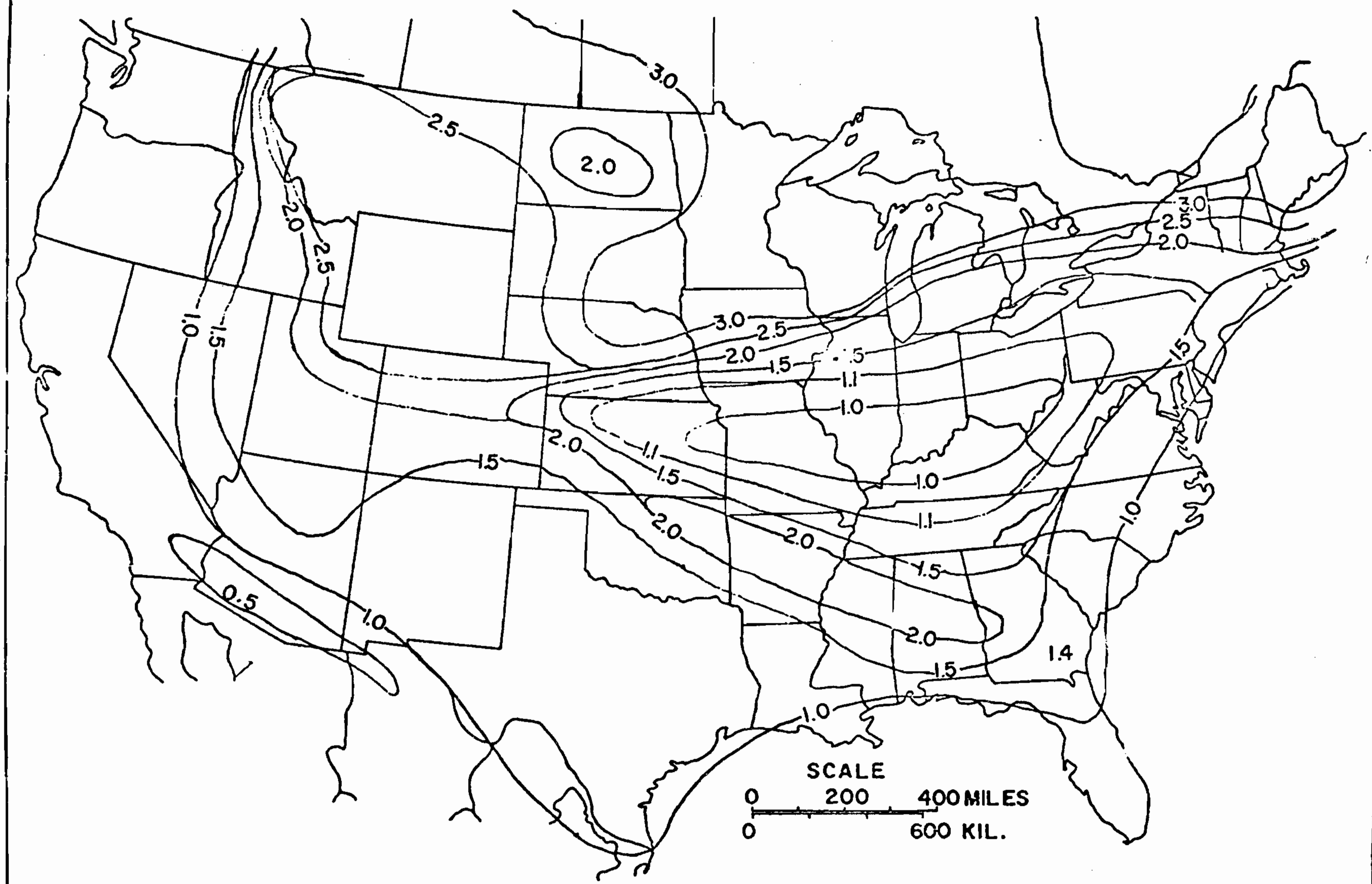


Fig 6. Contours of Equal Regional Factors (4).

*TABLE 2

REGIONAL FACTOR "R"

Use Base "R" of 1

Additional to Base R	Use Values From Both Columns: Annual Precipitation (Inches)	Use Values From Both Columns: Average % Grade	Swelling Soil	Use Only 1 – Frost Heave (2): W/O Snow Removal – Agg. S.	Use Only 1 – Frost Heave (2): W/O Snow Removal – Paved	Use Only 1 – Frost Heave (2): With Snow Removal – Agg. S.	Use Only 1 – Frost Heave (2): With Snow Removal – 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 (See Fig 8).

The method used by Idaho was to determine first the AASHO Regional Factor 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. 7. 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:

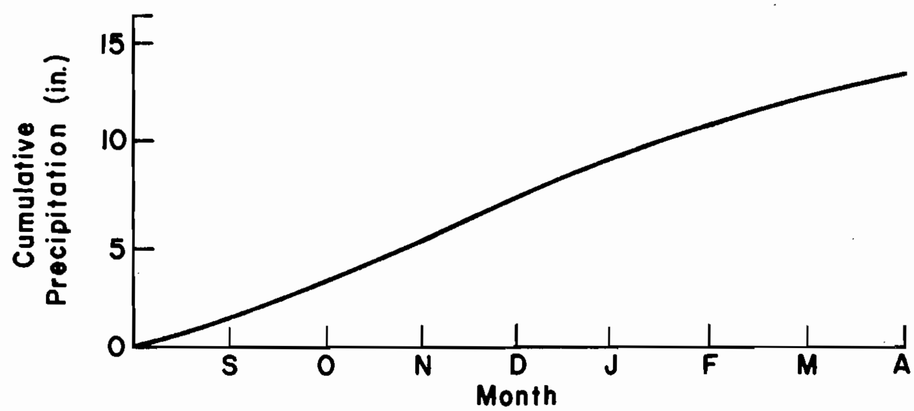
D + 100 P	Regional Factor
0-350	1.00
350-500	1.05
500-1700	1.10
Over 1700	1.15

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

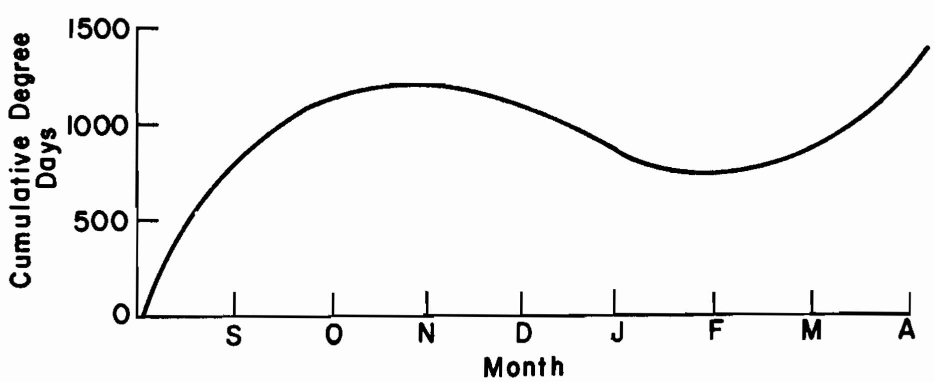
D + 100 P	Regional Factor
0-350	1.00
350-1200	1.05
1200-1700	1.10
Over 1700	1.15

The map (Fig 9) 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	7.47	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	847	1278



(a) Plot of cumulative precipitation



(b) Plot of cumulative degree days

Fig 7. Plot of weather record.

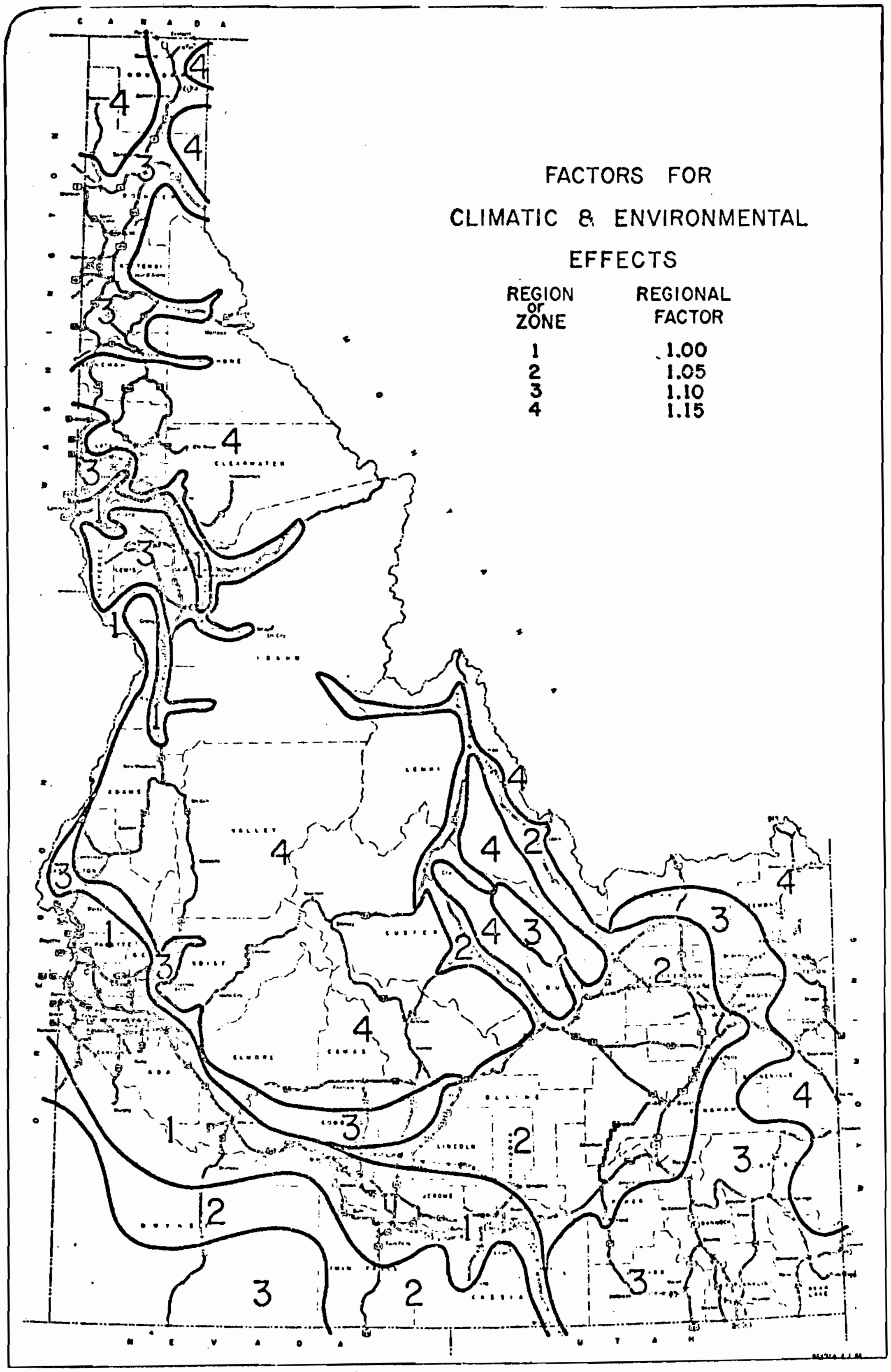


Fig 8. Factors for climatic and environmental effects.

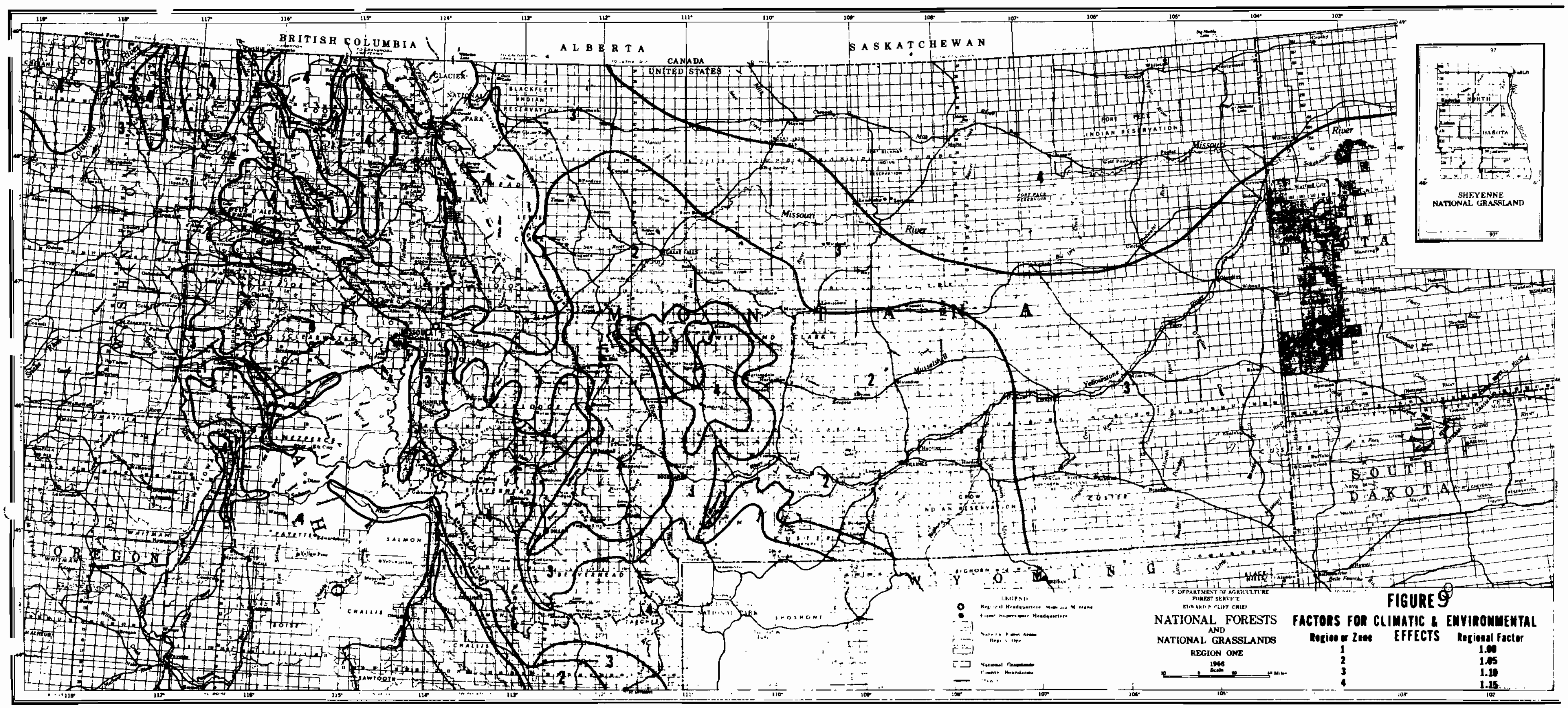


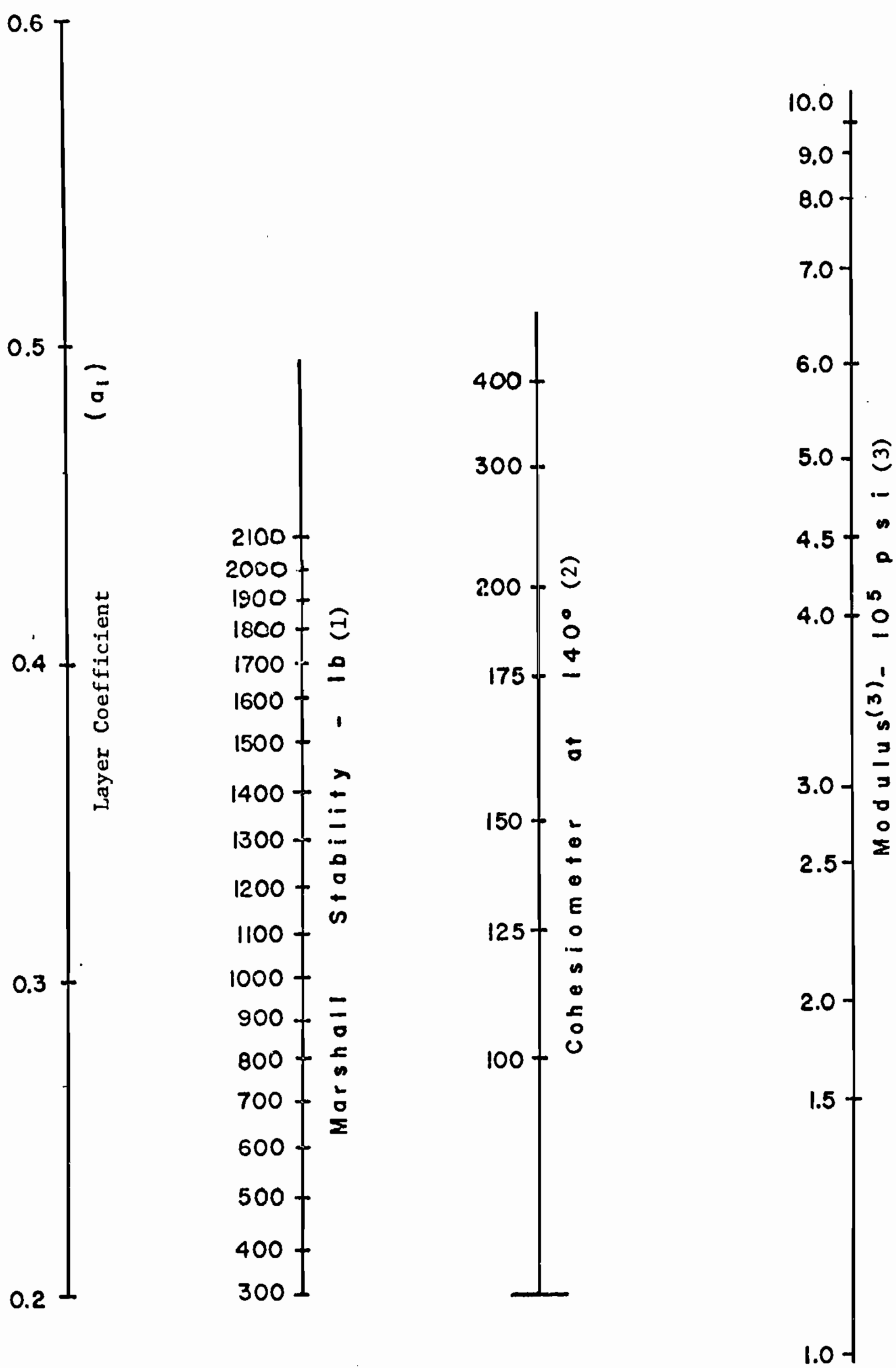
FIGURE 9

FACTORS FOR CLIMATIC & ENVIRONMENTAL EFFECTS

Region or Zone	Regional Factor
1	1.00
2	1.05
3	1.10
4	1.15

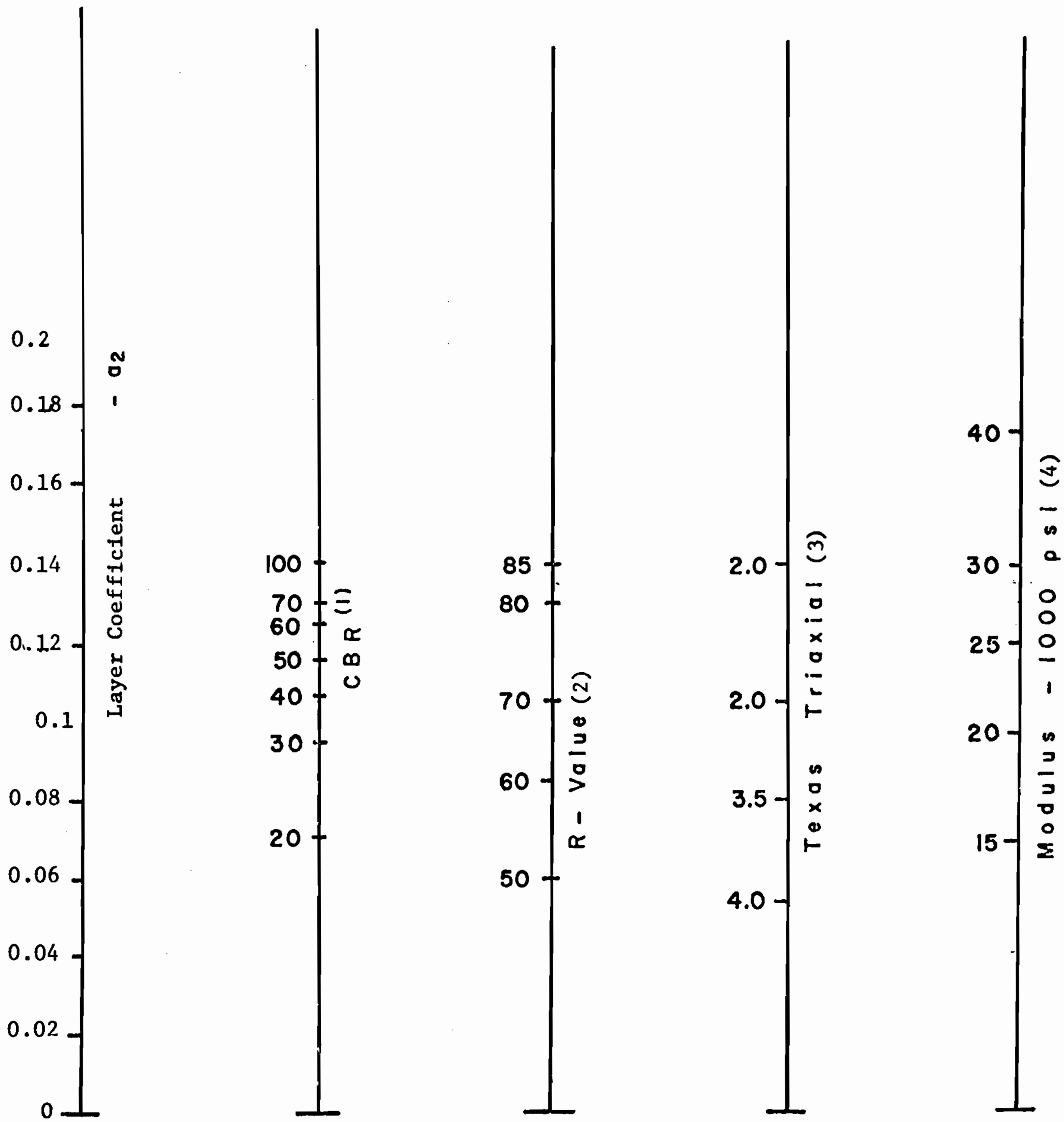
APPENDIX B OF THE USER'S MANUAL

LAYER COEFFICIENTS



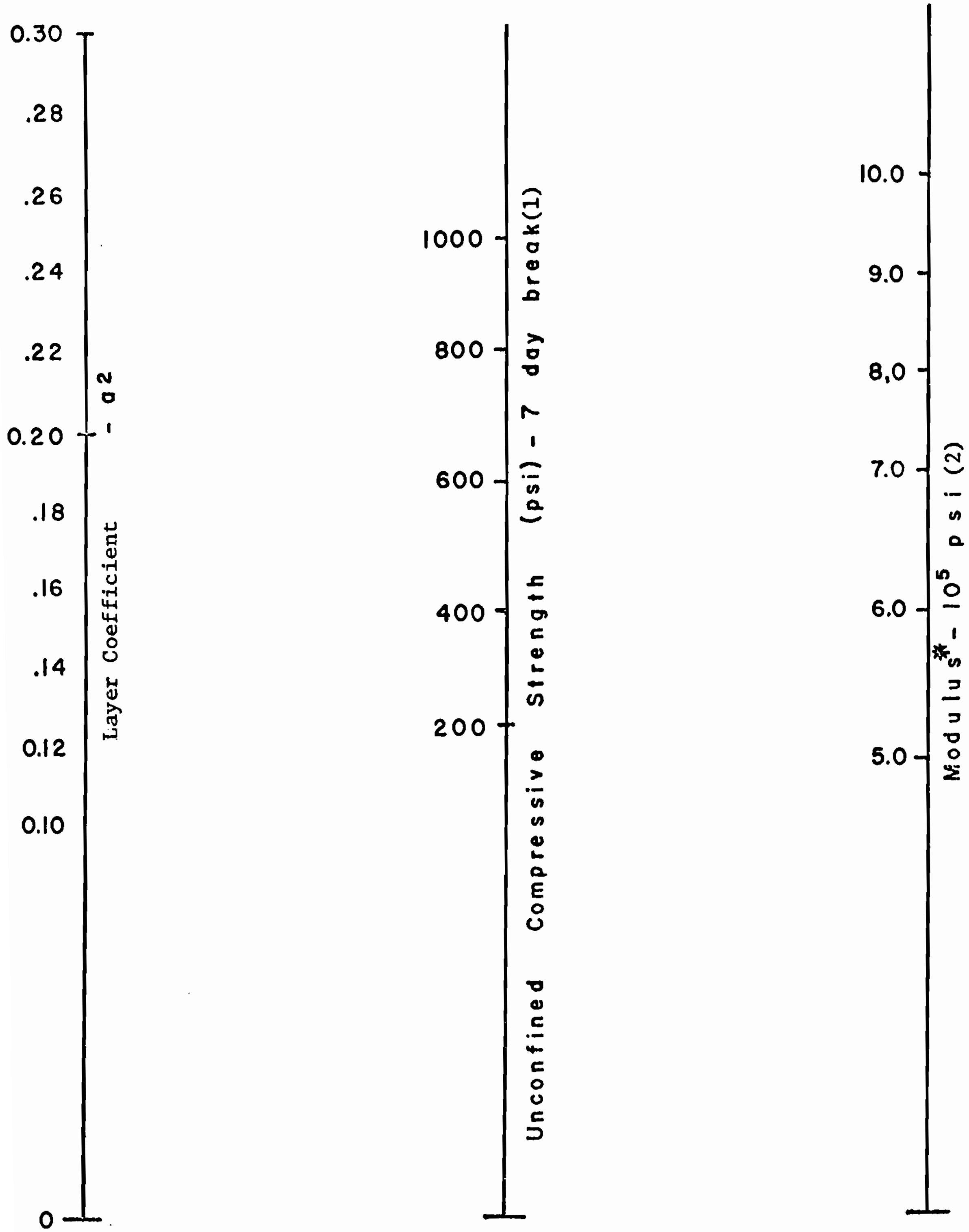
NOTE: (1) Scale derived by averaging correlations obtained from the Asphalt Institute, Illinois, Louisiana, New Mexico, and Wyoming.
(2) Scale derived by averaging correlations obtained from California and Texas.
(3) Scale derived on NCHRP 128 Report.

Fig 10. Variation in (a_1) with Surface Course Strength Parameter (4).



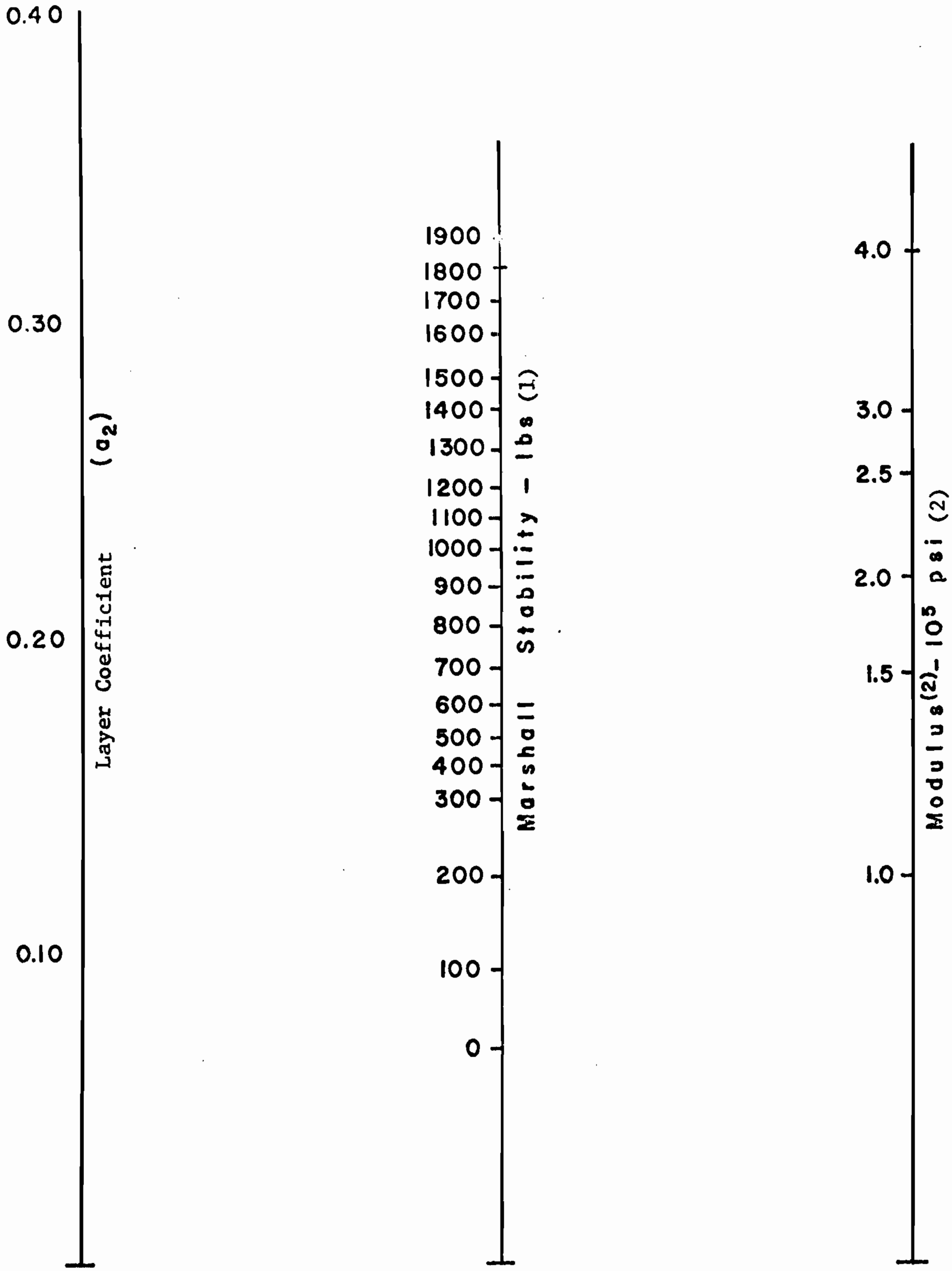
(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico, and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on Project NCHRP 128.

Fig 11. 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.

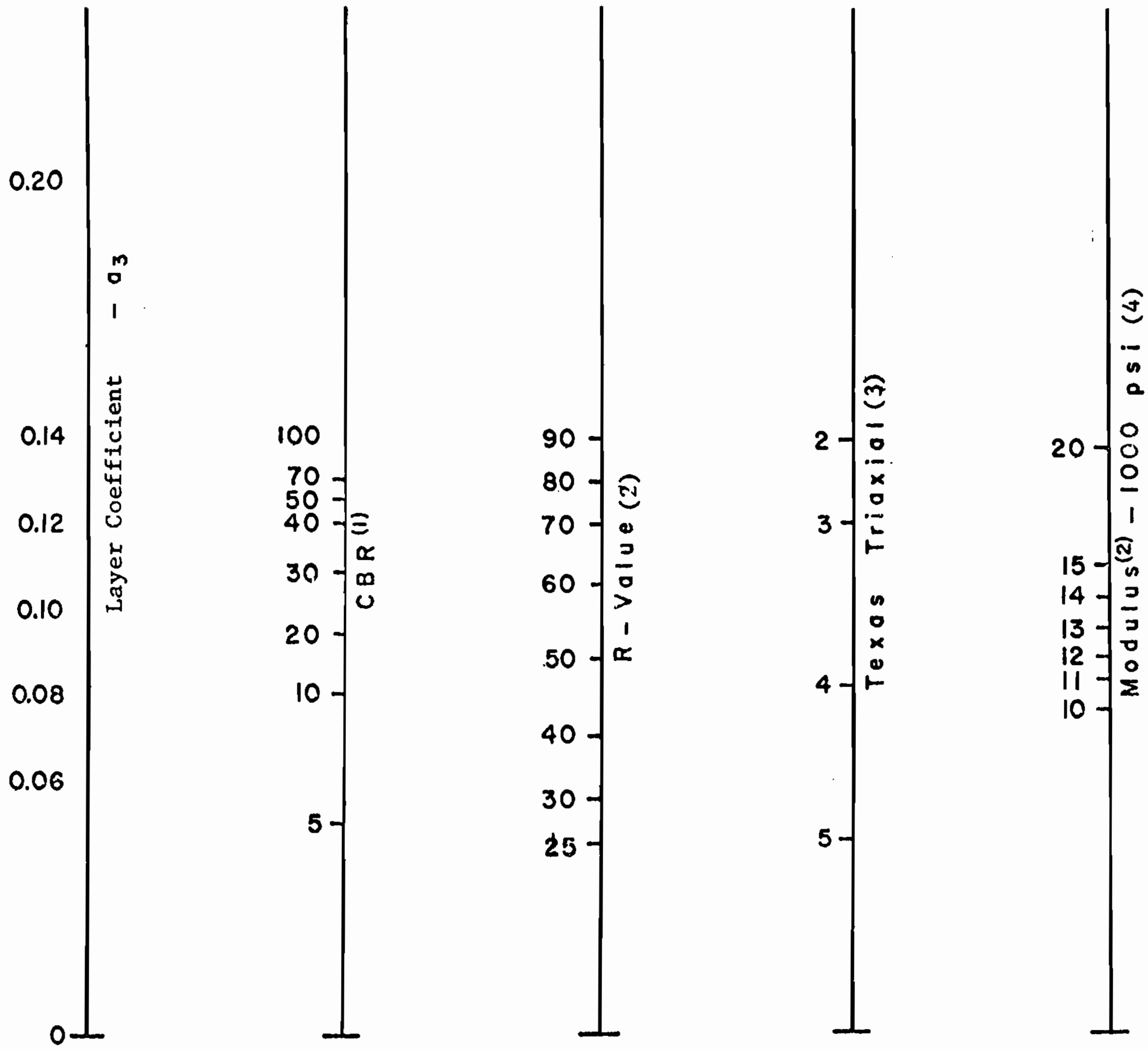
Fig 12. Variation in (a_2) for Cement Treated Bases with Base Strength Parameters (4).



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

(2) Scale derived on project NCHRP 128

Fig 13. 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 14. 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"	Max. Aggregate Size > 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

Additional Coefficient	P.I.		Quality	Grading		
				Pass 200		
	Base or Subbase	Surfacing		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			
					Pass 200		Pass 4	Pass 1½"
Additional Coefficient	S.E. Base Only	P.I. Base	P.I. 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 Pen.	Asphalt % of Opt.(1)	Grading Pass 200	Grading Pass 4	P.I.	Additives Cement, Lime, etc.	Aggregate Quality	Additional (2) Considerations
+ .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.

		STABILITY						
			Grading					
Additional Coefficient	Mixing	Asphalt	Pass 4	Pass 200	P.I.	Additives Cement, Lime, etc.	Aggregate Quality	Additional Considerations (2)
+ .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 (2) Considerations
	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

-*

APPENDIX C OF THE USER'S MANUAL

EXAMPLE PROBLEMS

NOTICE:

The example problems included in this Appendix were developed for the User's Manual of the Phase II report. Therefore, some inputs required in this version (September 1977) of the User's Manual were not required in these examples. The resulting differences will make slight changes in the answers if the same basic data are used, with appropriate values for the additional variables included in this User's Manual.

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 may be described by surface types as:

(1) Bituminous surfaced roads
(2) Aggregate surfaced roads
(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. The traffic information developed for this problem is included in the example problem input contained in Table 11 . Notice that there are two periods of intense logging operations between years 0 through 5 and 8 through 20, a termination of logging operations at

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 13

(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 (3).
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 (3) 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 (3).
Non-Traffic Deterioration Parameters - in the performance equation used in LVR, the basic AASHTO Interim Guide (5) design equation has been modified to reflect changes in PSI that may occur due to non-traffic related variables. 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 Fig 1. 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 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 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 11 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 3. 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 11. 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 4.

(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 3, 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 3 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 12.
These values were selected as typical values and do not necessarily follow the recommendations of Reference 3. 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 3.

TABLE 12. CARD 11 INPUT DATA FOR ACP EXAMPLE PROBLEM

ID	Code	Name	Cost $/SY	Layer Coefficient	Layer Thickness Minimum	Layer Thickness Maximum	Salvage Value, (percent)	Soil Support Value
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 3.

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 particular 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 3 has been used in this problem to relate R-value at 300 psi exudation pressure to soil support value.

DISCUSSION OF SOLUTION

Table 14 contains the designs that were generated by LVR for the input data recorded in Table 13. 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 13. INPUT DATA FOR AN ACP EXAMPLE PROBLEM

PROB 1B ASPHALT-CONCRETE PAVEMENT EXAMPLE PROBLEM

THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE

LAYER	MATERIALS CODE	NAME	COST PER CY	LAYER COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.	SS 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 13. (Continued)

PROB 18 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 (YEARS)	NON-TRUCKS (PER DAY)	TRUCKS (PER DAY)	18-KIP EQUIV. AXLES	ROUT. MAINT. (DOL./LNML)	LUMBER HAULED (MBF)	GRAVEL LOSS (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 14. 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 14. (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)					
O(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 Reference 7. 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 (3).

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 15 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 15.

DISCUSSION OF SOLUTION

Table 16 contains ten of the designs generated by LVR for the input data recorded in Table 15. 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 15. INPUT FOR AN AGGREGATE SURFACED ROAD EXAMPLE PROBLEM

PROB 1A AGGREGATE SURFACED PAVEMENT DESIGN EXAMPLE PROBLEM

THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE

LAYER	MATERIALS CODE	NAME	COST PER CY	LAYER COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.	SS 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 15. (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 (YEARS)	NON-TRUCKS (PER DAY)	TRUCKS (PER DAY)	18-KIP EQUIV. AXLES	ROUT. MAINT. (DOL./LNML)	LUMBER HAULED (MBF)	GRAVEL LOSS (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 16. 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 16. (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 16), 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 (6) 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,

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

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 17 and 19. The reader should carefully note that in Table 19 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 17. The resulting output from Run 1 is shown in Table 18. Notice that a

TABLE 17. 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

LAYER	MATERIALS CODE	NAME	COST PER CY	LAYER COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.	SS 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 17. (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 (YEARS)	NON-TRUCKS (PER DAY)	TRUCKS (PER DAY)	18-KIP EQUIV. AXLES	ROUT. MAINT. (DOL./LNML)	LUMBER HAULED (MBF)	GRAVEL LOSS (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 18. 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 18.. (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 19. Other input data were generated as per the discussion in the previous section of the report and are included in Table 19.

Table 20 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 20, 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 19. INPUT FOR RUN 2 OF A SURFACE TREATMENT EXAMPLE PROBLEM

PROB 2C SURFACE TREATMENT RUN 2 - PAVED

THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE

LAYER	MATERIALS CODE	NAME	COST PER CY	LAYER COEFF.	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.	SS 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 19. (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 (YEARS)	NON-TRUCKS (PER DAY)	TRUCKS (PER DAY)	18-KIP EQUIV. AXLES	ROUT. MAINT. (DOL./LNML)	LUMBER HAULED (MBF)	GRAVEL LOSS (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 20. 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 20. (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:

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

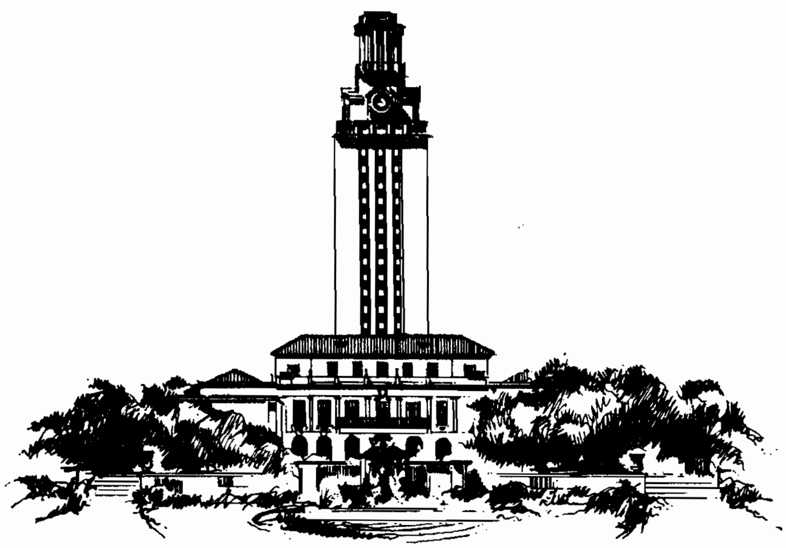
r = interest rate expressed as a fraction, 0.07

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

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

Total Cost = $19,394 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.



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