Development of a Micro-computer Based Optimization Model for Pavement Management

by

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JHR 91-202 Project 89-4

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
	VOLUME			
fl oz	fluid ounces	29.57	mililitres	mL
gal	gallons	3.785	Litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

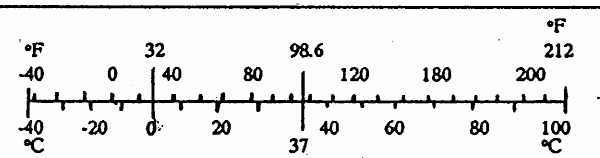
NOTE: Volumes greator than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

*SI is the symbol for the International System of Measurement

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



ACKNOWLEDGEMENTS

The authors wish to acknowledge, with thanks, the considerable assistance provided in the conduct of this study by the Division of Research, Bureau of Highways, Connecticut Department of Transportation. In particular, thanks are due Dr. Charles E. Dougan, Charles D. Larson, Donald A. Larsen, David G. Bowers, and James M. Sime.

CONTENTS

LIST OF SYMBOLS

B^* = Total budget for treatments over the planning period ($)

B^+_y = Maximum allowable budget in year y ($)

B^-_y = Minimum allowable budget in year y ($)

C = Roadway condition (1 to 10)

C_t = Treatment unit costs ($ per 2-lane mile)

D_{uk} = Probability that a roadway in state u will deteriorate to state k in one year

$\frac{dC}{dt}$ = Yearly rate of change of condition

E_{stu} = Probability that a roadway in state s will improve to state u if given treatment t

G_s = User unit disutility

K = Constant in Equation (12)

S = Total number of states

T = Total number of types of treatment

T^+_{ty} = Maximum allowable miles of treatment t in year y

T^-_{ty} = Minimum allowable miles of treatment t in year y

x_{sy} = Miles of roadway in state s in year y

x_{sty} = Miles of roadway in state s to be given treatment t in year y

Y = Total number of years in planning period

Z = Objective Function. Total user disutility over the planning period

1. Introduction

The decline in constant-dollar value of the budgets of those who manage the maintenance and reconstruction of the State's 4000-mile highway system has reduced the system's serviceability and led higher authorities to insist that programs and strategies adopted by ConnDOT maximize cost effectiveness, not only of individual projects, but also over the network as a whole. In response, ConnDOT has developed an active program of "pavement management". A critical element in the overall program is a computer model for optimization at the network level. In order to be of maximum benefit to ConnDOT, it is important for the model to be operational on the ConnDOT system.

A technique to optimize highway pavement maintenance and reconstruction based on serviceability and fiscal constraints was developed in JHRP 82-4. In JHRP 83-1 the technique was implemented on the IBM mainframe computer at the University of Connecticut. Unfortunately, as the Draft Final Report for JHRP 83-1 was being revised to address ConnDOT comments, the operating system of the UConn computer center was modified with the result that the program would no longer run. The consequences of the modification are more fully described in JHR 89-186. Subsequent to the publication of JHR 89-186, a modified program became fully operational on the new UConn system. Nevertheless, the experience has provided additional evidence of the need for completely "in-house" capability for ConnDOT. This need has been addressed in the present project by developing a micro-computer version of the optimization program.

As described in the proposal for the present project, the major objectives of the research were to:

- Evaluate and select a packaged micro-computer program capable of performing the linear programming solution of the optimization model.
- Convert the optimization model developed in JHRP 83-1 to a form compatible with the selected micro-computer program and test.
- Develop a user manual, with examples, and train ConnDOT personnel in the use of the model.

In addition, as more fully described below, the mainframe version was subjected to numerous additional runs to test it for reasonableness and to address several ConnDOT concerns.

It should also be noted that, while the proposed research is aimed at addressing ConnDOT's specific needs, there is every reason to believe that the results could also be made available to local agencies through the Technology Transfer Program.

After this introductory section, the present report presents a brief description of the optimization model in Section 2. Much of this material was covered in JHRP 83-1 and so is only briefly covered here. Also given in this section is a rather detailed description of model output.

In Section 3, the evaluation, selection, and adaption of a microcomputer package is described. This includes a description of conversion of the mainframe version and differences between the mainframe and microcomputer versions. Finally, given in this section, are important notes regarding hardware requirements and the distribution disks.

As called for in the proposal, an interim "User's Manual" was developed during the course of the study. Several revisions of the manual were produced in response to user comments. This process constituted the "training of ConnDOT personnel" referred to in the proposal. <u>The present report constitutes the "Final User's Manual".</u> Section 4 provides a tutorial for the use of the program.

In Section 5, several typical applications of the program are presented. Included are demonstrations of network deterioration given no treatment, determination of the optimum budget required to minimize user disutilties, the effect of relaxing budget constraints, and the budget required to achieve and maintain a minimum condition.

2. <u>The Optimization Model</u>

<u>2.1 Model Structure</u>

The model formulation begins by assigning each segment of roadway to a particular pavement "state" determined by physical condition, time rate of change of physical condition, traffic volume, and environment (rural or urban). With each state is associated a unit user "disutility" or generalized cost. User disutility for the roadway segment over a period of time is simply the product of the unit disutility, the length of the segment, and the traffic volume over the period. Total user disutility for the network is simply the sum of the link disutilities.

The model logic further assumes that, given no treatment, the condition of a roadway will deteriorate over time, thus changing its state. The condition can be improved at any time by application of any one of several possible maintenance/reconstruction options at, of course, at some cost.

The basic objective of the optimization is to determine <u>which</u> of the several available treatments should be applied to <u>how many</u> miles in each state and <u>when</u> it should be applied. The technique of linear programming is used to perform the optimization.

The model recognizes the probabilistic nature of both the deterioration of the pavement condition over time and the improvement following treatment. The complete formulation thus requires specification of a set of deterioration probabilities and a set of "treatment effectiveness" probabilities.

In routine use of the model, the <u>input</u> required consists of the initial number of miles in each state, minimum and maximum budgets by year for the analysis period, maximum total budget over the entire analysis period, and maximum and minimum total yearly output of each treatment.

Mathematically, the technique seeks to minimize some "objective function" subject to a series of constraints. A description of the mathematical formulation is given in JHR-186.

2.2 Computer Output

Figures 1 through 6 show representative portions of a typical output from the program.

Title Page (Figure 1). Shown in this figure are:

A. Case name
B. Date and time of run
C. State structure
D. Input files
E. Linear programming statistics

First Pages (Figures 2 and 3). These pages summarize the program input, giving:

A. Years in the analysis period
B. Treatments used (maximum of 8 including "do-nothing")
C. Treatment effectiveness probabilities (printout optional)
D. Deterioration probabilities (printout optional)
E. User disutility by state
F. Initial network statistics
G. Initial network mileage by state
H. Notes
I. Summary of results

Note that, for the example shown, the optimization was for a 4-year period with the yearly treatment budget constrained to a maximum of $50 million. The total allowable budget for the two-year period was constrained to be no more than $ 200 million.

Annual Strategies (Figures 4 and 5). Shown here, for each year in the analysis period, are:

A. Recommended total treatment budget
B. Maximum and minimum allowable treatment budget
C. Annual user disutility

Also shown, for each treatment, are:

D. Treatment
E. Cost per mile
F. Total number of miles of the treatment
G. Maximum and minimum allowable number of miles of the treatment
H. Total cost of the treatment for the year
I. Recommended number of miles in each state to be given the treatment
J. Average condition of the network at the end of the year
K. Number of miles in each state at the end of the year

```
CONNECTICUT PAVEMENT MANAGEMENT OPTIMIZATION                          (B) → Feb  2, 1991    12:30p
cfd20 ← (A)                                                                      Output Title Page

Microprocessor Version 2.2              Copyright (C) 1989, 1990. All rights reserved.
This program was prepared under the sponsorship of
 The Joint Highway Research Advisory Council
   The Connecticut Department of Transportation
   The University of Connecticut

 Authors: Christian F. Davis, Professor of Civil Engineering
          C. Peter Van Dine, Consultant

This module is preset to run 120 States                          (C)
             Broken down by:  10 Condition Levels
                               3 ADT Levels
                               2 Cracking Rate Levels
                             and Urban & Rural Environments

MODELS USED:
 BUDGET                         File Name: budget.sd7
  Standard Budget Test File 1-24-91b
 TREATMENTS USED                File Name: treatuse.sd3
  Standard Treatment 2-2-91
 USER DISUTILITIES              File Name: DISUTILS.SD1
  STANDARD USER DISUTILITIES 10/89 - New Order (10G12.2 FORMAT)
 INITIAL NETWORK                File Name: NETWORK.SD1
  Level Standard Network
 DETERIORATION PROBABILITIES    File Name: DETER.SD1                         (D)
  120 STATE DETERIORATION MODEL - AUGUST 1989 (fixed field)
 TREATMENT EFFECTIVENESS
  1        Do-Nothing
   No Change in Condition due to Treatment
  2        Chip Seal              File Name: CHIPSEAL.SD2
   CHIPSEAL 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
  3        2 1/2" Overlay         File Name: OVERLAYA.SD2
   2.5" OVERLAY 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
  4        4" Overlay             File Name: OVERLAYB.SD2
   4" OVERLAY 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
  5        Reconstruction         File Name: RECONST.SD2
   RECONSTRUCTION 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)

PROBLEM STATISTICS:
       486 ROWS
      2400 STRUCTURAL COLUMNS
         1 RHS COLUMNS
     15896 NON-ZERO MATRIX ELEMENTS                                    (E)
     DENSITY =     1.13 PERCENT
     15900 NON-ZERO ELEMENTS: MATRIX ELEMENTS + RANGE + BOUND VALUES
MIN DJ =     .326E-04
 Quality of solution: EXCELLENT
Problem Status:     Unique OPTIMAL Basic Solution

Elapsed Time:  0:39:30.15
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Figure 1.   Output Title Page

CONNECTICUT PAVEMENT MANAGEMENT OPTIMIZATION — Feb 2, 1991 12:30p
cfd20 — page 1

INPUT:

YEARS: 4 (A)

TREATMENTS: 5

1	Do-Nothing	No Change in Condition due to Treatment
2	Chip Seal	CHIPSEAL 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
3	2 1/2" Overlay	2.5" OVERLAY 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
4	4" Overlay	4" OVERLAY 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
5	Reconstruction	RECONSTRUCTION 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)

(B)

TREATMENT EFFECTIVENESS MODELS DETAIL NOT PRINTED (C)

DETERIORATION MODEL: 120 STATE DETERIORATION MODEL - AUGUST 1989 (fixed field)
DETAIL NOT PRINTED (D)

(E)

USER DISUTILITY MODEL: STANDARD USER DISUTILITIES 10/89 - New Order (10G12.2 FORMAT)
USER DISUTILITIES PER 2-LANE MILE PER YEAR

		RATE OF	CONDITION									
ENVIRONMENT	ADT	CRACKING	1	2	3	4	5	6	7	8	9	10
RURAL	LOW	LOW	1.11	1.05	1.00	.91	.83	.77	.73	.71	.70	.68
RURAL	LOW	HIGH	1.11	1.05	1.00	.91	.83	.77	.73	.71	.70	.68
RURAL	MEDIUM	LOW	3.34	3.18	3.02	2.73	2.50	2.32	2.21	2.13	2.10	2.06
RURAL	MEDIUM	HIGH	3.34	3.18	3.02	2.73	2.50	2.32	2.21	2.13	2.10	2.06
RURAL	HIGH	LOW	5.49	5.22	4.93	4.45	4.07	3.80	3.61	3.48	3.43	3.38
RURAL	HIGH	HIGH	5.49	5.22	4.93	4.45	4.07	3.80	3.61	3.48	3.43	3.38
URBAN	LOW	LOW	2.28	2.00	1.68	1.38	1.22	1.16	1.10	1.09	1.08	1.07
URBAN	LOW	HIGH	2.28	2.00	1.68	1.38	1.22	1.16	1.10	1.09	1.08	1.07
URBAN	MEDIUM	LOW	5.28	4.62	4.03	3.40	3.00	2.81	2.68	2.62	2.57	2.49
URBAN	MEDIUM	HIGH	5.28	4.62	4.03	3.40	3.00	2.81	2.68	2.62	2.57	2.49
URBAN	HIGH	LOW	6.93	6.21	5.56	4.91	4.42	4.68	3.84	3.71	3.62	3.54
URBAN	HIGH	HIGH	6.93	6.21	5.56	4.91	4.42	4.68	3.84	3.71	3.62	3.54

Figure 2. First Page of Output

CONNECTICUT PAVEMENT MANAGEMENT OPTIMIZATION — Feb 2, 1991 12:30p
cfd20 — page 2

(F) INITIAL NETWORK MODEL: Level Standard Network

INITIAL NETWORK -- AVERAGE CONDITION 5.50 TOTAL MILES 1200.0 ANNUAL USER DISUTILITY 3418.4

(G)

ENVIRONMENT	ADT	RATE OF CRACKING	CONDITION 1	2	3	4	5	6	7	8	9	10
RURAL	LOW	LOW	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
RURAL	LOW	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
RURAL	MEDIUM	LOW	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
RURAL	MEDIUM	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
RURAL	HIGH	LOW	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
RURAL	HIGH	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
URBAN	LOW	LOW	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
URBAN	LOW	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
URBAN	MEDIUM	LOW	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
URBAN	MEDIUM	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
URBAN	HIGH	LOW	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
URBAN	HIGH	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

(H) NOTES:
TREATMENT 1 IS DEFINED AS DO-NOTHING. ITS EFFECTIVENESS IS NO-CHANGE.
USER DISUTILITIES IN MILLIONS OF $.
TREATMENT COSTS IN THOUSANDS OF $.
INITIAL NETWORK ANNUAL USER DISUTILITY IS NOT PART OF OPTIMIZATION.

(I) RESULTS:
MINIMUM USER DISUTILITY 11199. TOTAL TREATMENT $ 200000. TREATMENT BUDGET $ 200000.

Figure 3. Second Page of Output

ANNUAL PAVEMENT TREATMENT STRATEGIES:

(A) YEAR 1 TOTAL TREATMENT $ 50000. (B) MAX $ 50000. MIN $ 0. (C) ANNUAL USER DISUTILITY 3036.8

YEAR 1 Do-Nothing $/MILE 0. MILES 260.0 MAX MILES 1200. MIN MILES 0. TOTAL COST 0.

ENVIRONMENT	ADT	RATE OF CRACKING	CONDITION 1	2	3	4	5	6	7	8	9	10
RURAL	LOW	LOW	.00	.00	.00	.00	.00	.00	10.00	10.00	10.00	10.00
RURAL	LOW	HIGH	.00	.00	.00	.00	.00	.00	10.00	10.00	10.00	10.00
RURAL	MEDIUM	LOW	.00	.00	.00	.00	.00	.00	.00	.00	10.00	10.00
RURAL	MEDIUM	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	10.00	10.00
RURAL	HIGH	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	10.00
RURAL	HIGH	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	10.00
URBAN	LOW	LOW	.00	.00	.00	.00	.00	.00	10.00	10.00	10.00	10.00
URBAN	LOW	HIGH	.00	.00	.00	.00	.00	.00	10.00	10.00	10.00	10.00
URBAN	MEDIUM	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	10.00
URBAN	MEDIUM	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	10.00
URBAN	HIGH	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	10.00
URBAN	HIGH	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	10.00

(D) YEAR 1 Chip Seal (E) $/MILE 12. (F) MILES 720.3 (G) MAX MILES 1200. MIN MILES 0. (H) TOTAL COST 8643.

(I)

ENVIRONMENT	ADT	RATE OF CRACKING	CONDITION 1	2	3	4	5	6	7	8	9	10
RURAL	LOW	LOW	10.00	10.00	10.00	10.00	10.00	10.00	.00	.00	.00	.00
RURAL	LOW	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	.00	.00	.00	.00
RURAL	MEDIUM	LOW	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	.00	.00
RURAL	MEDIUM	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	.00	.00
RURAL	HIGH	LOW	10.00	.00	.00	.29	10.00	10.00	10.00	10.00	10.00	.00
RURAL	HIGH	HIGH	10.00	.00	.00	.00	10.00	10.00	10.00	10.00	10.00	.00
URBAN	LOW	LOW	10.00	10.00	10.00	10.00	10.00	10.00	.00	.00	.00	.00
URBAN	LOW	HIGH	10.00	10.00	10.00	10.00	10.00	10.00	.00	.00	.00	.00
URBAN	MEDIUM	LOW	.00	.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	.00
URBAN	MEDIUM	HIGH	.00	.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	.00
URBAN	HIGH	LOW	.00	.00	.00	.00	.00	.00	10.00	10.00	10.00	.00
URBAN	HIGH	HIGH	.00	.00	.00	.00	.00	.00	10.00	10.00	10.00	.00

YEAR 1 2 1/2" Overlay $/MILE 150. MILES 79.7 MAX MILES 1200. MIN MILES 0. TOTAL COST 11957.

ENVIRONMENT	ADT	RATE OF CRACKING	CONDITION 1	2	3	4	5	6	7	8	9	10
RURAL	LOW	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
RURAL	LOW	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
RURAL	MEDIUM	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
RURAL	MEDIUM	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
RURAL	HIGH	LOW	.00	.00	.00	9.71	.00	.00	.00	.00	.00	.00
RURAL	HIGH	HIGH	.00	.00	.00	10.00	.00	.00	.00	.00	.00	.00
URBAN	LOW	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
URBAN	LOW	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
URBAN	MEDIUM	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
URBAN	MEDIUM	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
URBAN	HIGH	LOW	.00	.00	.00	10.00	10.00	10.00	.00	.00	.00	.00
URBAN	HIGH	HIGH	.00	.00	.00	10.00	10.00	10.00	.00	.00	.00	.00

YEAR 1 4" Overlay $/MILE 210. MILES 140.0 MAX MILES 1200. MIN MILES 0. TOTAL COST 29400.

ENVIRONMENT	ADT	RATE OF CRACKING	CONDITION 1	2	3	4	5	6	7	8	9	10
RURAL	LOW	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
RURAL	LOW	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
RURAL	MEDIUM	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
RURAL	MEDIUM	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
RURAL	HIGH	LOW	.00	10.00	10.00	.00	.00	.00	.00	.00	.00	.00
RURAL	HIGH	HIGH	.00	10.00	10.00	.00	.00	.00	.00	.00	.00	.00
URBAN	LOW	LOW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
URBAN	LOW	HIGH	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
URBAN	MEDIUM	LOW	10.00	10.00	.00	.00	.00	.00	.00	.00	.00	.00
URBAN	MEDIUM	HIGH	10.00	10.00	.00	.00	.00	.00	.00	.00	.00	.00
URBAN	HIGH	LOW	10.00	10.00	10.00	.00	.00	.00	.00	.00	.00	.00
URBAN	HIGH	HIGH	10.00	10.00	10.00	.00	.00	.00	.00	.00	.00	.00

YEAR 1 Reconstruction $/MILE 800. MILES .0 MAX MILES 1200. MIN MILES 0. TOTAL COST 0.

Figure 4. Annual Strategies

YEAR 1 RESULTANT NETWORK BY STATE AVERAGE CONDITION 6.49 TOTAL MILES 1200.0

ENVIRONMENT	ADT	RATE OF CRACKING	CONDITION 1	2	3	4	5	6	7	8	9	10
RURAL	LOW	LOW	1.25	6.75	7.00	7.00	7.25	10.75	12.00	8.00	10.00	9.00
RURAL	LOW	HIGH	1.50	15.25	15.00	15.00	13.75	16.75	17.25	8.00	9.50	9.00
RURAL	MEDIUM	LOW	1.75	6.50	4.50	9.00	7.00	6.50	5.75	7.00	13.00	9.00
RURAL	MEDIUM	HIGH	3.00	15.50	15.25	15.25	14.00	12.50	12.25	13.50	20.25	8.50
RURAL	HIGH	LOW	2.50	3.75	.00	.09	5.80	12.50	16.93	9.68	5.25	12.75
RURAL	HIGH	HIGH	4.00	9.75	.00	.11	9.04	20.25	30.66	22.69	14.25	20.00
URBAN	LOW	LOW	1.75	6.50	6.75	6.75	7.00	11.00	11.00	8.00	9.00	9.00
URBAN	LOW	HIGH	3.00	15.50	15.25	15.25	14.00	18.50	16.25	8.00	9.00	8.50
URBAN	MEDIUM	LOW	.00	.00	5.25	13.25	9.25	12.50	8.00	5.25	6.00	12.75
URBAN	MEDIUM	HIGH	.00	.00	7.25	21.75	18.00	20.25	16.25	10.75	13.50	20.00
URBAN	HIGH	LOW	.00	.00	.00	5.00	1.75	4.25	13.75	13.25	10.00	17.00
URBAN	HIGH	HIGH	.00	.00	.00	8.75	4.50	9.50	30.00	26.75	23.50	32.00

Figure 5. Network After One Year

CONNECTICUT PAVEMENT MANAGEMENT OPTIMIZATION
cfd20

SUMMARY TABLES:

NETWORK CONDITION	YEAR 0	1	2	3	4
AVG. CONDITION	5.50	6.49	7.54	8.66	9.58
USER DISUTILITY	3418.4	3036.8	2804.5	2700.0	2657.9

BUDGET DOLLARS	YEAR 1	2	3	4
MIN	0.	0.	0.	0.
ACTUAL	50000.	50000.	50000.	50000.
MAX	50000.	50000.	50000.	50000.

TREATMENT STRATEGIES			YEAR 1	2	3	4
Do-Nothing		$	0.	0.	0.	0.
	MIN	MILES	0.	0.	0.	0.
	ACTUAL	MILES	260.	229.	255.	474.
	MAX	MILES	1200.	1200.	1200.	1200.
Chip Seal		$	8643.	8869.	8233.	5348.
	MIN	MILES	0.	0.	0.	0.
	ACTUAL	MILES	720.	739.	686.	446.
	MAX	MILES	1200.	1200.	1200.	1200.
2 1/2" Overlay		$	11957.	18923.	31536.	35737.
	MIN	MILES	0.	0.	0.	0.
	ACTUAL	MILES	80.	126.	210.	238.
	MAX	MILES	1200.	1200.	1200.	1200.
4" Overlay		$	29400.	22208.	10230.	8873.
	MIN	MILES	0.	0.	0.	0.
	ACTUAL	MILES	140.	106.	49.	42.
	MAX	MILES	1200.	1200.	1200.	1200.
Reconstruction		$	0.	0.	0.	42.
	MIN	MILES	0.	0.	0.	0.
	ACTUAL	MILES	0.	0.	0.	0.
	MAX	MILES	1200.	1200.	1200.	1200.

Figure 6. Summary Tables

Note that only three of the five treatments (including"do-nothing") specified for this run are shown in this sample of the output. Similar statistics for 2 1/2" and 4" overlays are also produced.

Summary Tables (Figure 6). The final pages of the output give:

A. A summary of the network condition by year
B. A summary of the user disutility by year
C. Budget constraints by year
D. Treatment constraints by treatment and year
E. Optimal amount of each treatment by year

2.3 Pavement State

Central to an understanding of the model is the concept of pavement "state". As noted above, the state of a given section of roadway is defined by the four parameters: condition, rate of change of condition, traffic volume, and environment. Although the model is perfectly general, at the present time it utilizes 120 possible states as defined in Table 1.

Table 1. State Definitions

Environ-ment	ADT	Delta Crack**	Condition* 1	2	3	4	5	6	7	8	9	10
Rural	Low	Low	1	2	3	4	5	6	7	8	9	10
Rural	Low	High	31	32	33	34	35	36	37	38	39	40
Rural	Med	Low	11	12	13	14	15	16	17	18	19	20
Rural	Med	High	41	42	43	44	45	46	47	48	49	50
Rural	High	Low	21	22	23	24	25	26	27	28	29	30
Rural	High	High	51	52	53	54	55	56	57	58	59	60
Urban	Low	Low	61	62	63	64	65	66	67	68	69	70
Urban	Low	High	91	92	93	94	95	96	97	98	99	100
Urban	Med	Low	71	72	73	74	75	76	77	78	79	80
Urban	Med	High	101	102	103	104	105	106	107	108	109	110
Urban	High	Low	81	82	83	84	85	86	87	88	89	90
Urban	High	High	111	112	113	114	115	116	117	118	119	120

Notes:
*See Table 2 for correspondence with ConnDOT 1-100 scale.
**Time rate of change in cracking. Category "low" or "high" depends on condition. See Table 2.

Condition

Shown in Table 2 is the correspondence between the ten levels of condition used in the model and the 1 to 100 scale developed by ConnDOT.

Rate of Change of Condition

This parameter is introduced to account for the fact that two pavements

Table 2. Correspondence of 1 - 10 Condition Rating with ConnDOT 1 - 100 Scale		
Condition C	ConnDOT Condition	Critical Yearly Rate of Change of ConnDOT Condition*
1	1 - 15	- 1.0
2	16 - 25	- 2.0
3	26 - 35	- 4.0
4	36 - 45	- 5.0
5	46 - 55	- 6.0
6	56 - 65	- 6.0
7	66 - 75	- 6.0
8	76 - 85	- 5.0
9	86 - 95	- 3.0
10	96 - 100	- 1.0

* If the observed rate of change in condition is equal to or greater than the critical rate, the observed rate is considered high. Otherwise, it is considered "low".

having the same appearance at any given time can be deteriorating at quite different rates depending on a number of factors. This situation is recognized by designating the rate of change of condition of any roadway pavement roadway as being either "low" or "high" as compared to the rate of deterioration of a "typical" pavement.

The "high"/"low" determination is made using Table 2. The rationale for this procedure is more fully described in JHR 186. To use Table 2, it is necessary to first determine the ConnDOT condition and the change in ConnDOT condition in one year. For example, suppose the condition of a roadway is observed at two points in time three years apart with the following results:

Case 1 -

Condition at year y = 84

Condition at year y+3 = <u>78</u>

Change over 3 years = -6

Yearly change = -6/3 = -2

From Table 2, the critical yearly rate of change at condition 78 is -5.0. Since 2.0 is less than 5.0, the observed rate is considered "low".

Case 2 -

Condition at year y	=	93
Condition at year y+3	=	77
Change over 3 years	=	-16
Yearly change	=	-16/3 = -5.3

From Table 2, the critical yearly rate of change at condition 77 is -5.0. Since 5.3 is greater than 5.0, the observed rate is considered "high".

Note that in these examples, the time between observations was assumed to be 3 years. However, this could have been any reasonable time period since the rate of concern is the annual rate.

Traffic Volume

This parameter can take on one of three values: low (0 to 10,000 vpd), medium (10,001 to 20,000 vpd), and high (greater than 20,000 vpd). Note that traffic volume is likely to have a significant impact on the rate of pavement deterioration. In addition, it is required in order to calculate total user disutility. For both of these reasons, a complete definition of pavement state must include specification of traffic volume.

Environment

Two environments, rural and urban, are used in the definition of pavement state. These two are used primarily because, as discussed in JHR-186, the available user disutility data were stratified in this manner.

2.4 Decision Variables

The solution of an optimization problem consists of finding the required values of the "decision variables". In the present case, these are the optimal number of miles of roadway in each state to be given each of the treatments in each of the years of the analysis period. Note that the specific roadway section to be treated is not given. Rather, it is left to the judgement of the user who can then include additional considerations, external to the optimization, in his selection.

2.5 Deterioration Matrix

As noted earlier, one of the difficulties associated with development of a pavement management system is the lack of historical data on variation of condition with time. Recognizing this, the model employs probability in the prediction of future roadway state. Specifically, it employs a 120 by 120 matrix which gives, for each of the possible pairs of states (u,k) the probability that a roadway in state u will deteriorate to state k in one year's time. The matrix is required input to the model and hence is at the analyst's discretion. However, many of the transformations, while mathematically possible, are logically impossible. These include the entire set of transformations from a lower condition to a higher condition. In addition, transformations between rural and urban environments, and between traffic volume groups may be assumed not to occur. Finally, the estimated probability of many of the other transformations may be taken to be zero. Thus the matrix of January 1991 contains only 333 non-zero terms. This matrix, DETER.SD1, is shown in Table 3. Note that Table 3 is organized in sets of three entries. The first entry identifies the initial state; the second, the resultant state; and the third, the probability that the particular transformation will occur. Clearly, as performance data are collected, the probabilities in the deterioration matrix should be changed to reflect these new data.

2.6 Treatment Effectiveness

A treatment applied to any pavement improves the condition of that pavement. However, as with deterioration, many factors contribute to uncertainty in forecasting the effectiveness of a given treatment. At any point in time, those roadways in a specific observed condition represent a nearly infinite number of combinations of age and past treatments. The model can account for the probabilistic nature of treatment effectiveness through the matrix E_{stu}, which gives the probability that a roadway in state s will improve to state u if given a treatment t. This matrix is required input to the program. The February 1991 version of the treatment effectiveness matrix, TREATUSE.SD3 is shown in Table 4. Again many of the tabular entries are zero. Entries in Table 4 are given in the order: treatment, initial state, resultant state, and transition probability. As with deterioration, the probability estimates of treatment effectiveness will improve as performance data are collected.

While the treatment effectiveness is considered a single matrix in the analysis, it is input as a separate matrix for each treatment. The combined treatment effectiveness matrix is formulated by the program for each analysis from the information provided in the Treatment Used file. The Treatment Used file identifies each treatment (and its Treatment Effectiveness Matrix file) as well as defining its cost per mile and any annual constraints on its application. This approach allows for different mixes of treatments to be analyzed easily once the treatment effectiveness has been defined for each treatment in the mix. For more information, see Section 4.

The treatments used and their unit costs are given in Table 5. At the present time, five treatments (including "do-nothing") are considered. However, the program allows the analyst to use fewer or up to eight if he so chooses.

2.7 User Disutility

As now structured, the model requires user disutilities as input. The assignment of numerical values of user disutilities is somewhat subjective and varies from user to user. While there is an appeal to having absolute values of disutilities, it is not necessary since only the relative values are required. The specific numerical values of disutilities we suggest are contained in the file DISTUTILS.SD1 given in Table 6 and are based on user

Table 3. The 120-State Deterioration Model DETER.SD1

INITIAL STATE - RESULTANT STATE - PROBABILITY

1	1	1.000	2	1	.100	2	2	.900	3	2	.150	3	3	.800	3	32	.050	4	3	.150	4	4	.700	4	33	.150
5	4	.250	5	5	.600	5	34	.150	6	5	.250	6	6	.550	6	35	.200	7	6	.200	7	7	.600	7	36	.200
8	7	.200	8	8	.700	8	37	.100	9	8	.050	9	9	.900	9	38	.050	10	9	.050	10	10	.900	10	39	.050
11	11	1.000	12	11	.200	12	12	.800	13	12	.200	13	13	.700	13	42	.100	14	13	.200	14	14	.600	14	43	.200
15	14	.300	15	15	.500	15	44	.200	16	15	.300	16	16	.450	16	45	.250	17	16	.250	17	17	.500	17	46	.250
18	17	.200	18	18	.600	18	47	.200	19	18	.100	19	19	.800	19	48	.100	20	19	.050	20	20	.900	20	49	.050
21	21	1.000	22	21	.200	22	22	.750	22	51	.050	23	22	.200	23	23	.550	23	52	.250	24	23	.300	24	24	.450
24	53	.250	25	24	.350	25	25	.350	25	54	.300	26	25	.400	26	26	.300	26	55	.300	27	26	.350	27	27	.350
27	56	.300	28	27	.300	28	28	.450	28	57	.250	29	28	.150	29	29	.650	29	58	.200	30	29	.050	30	30	.850
30	59	.100	31	31	1.000	32	1	.050	32	31	.100	32	32	.850	33	2	.100	33	32	.150	33	33	.750	34	3	.150
34	33	.200	34	34	.650	35	4	.150	35	34	.300	35	35	.550	36	5	.200	36	35	.300	36	36	.500	37	6	.200
37	36	.250	37	37	.550	38	7	.100	38	37	.250	38	38	.650	39	8	.050	39	38	.100	39	39	.850	40	9	.050
40	39	.050	40	40	.900	41	41	1.000	42	11	.050	42	41	.200	42	42	.750	43	12	.100	43	42	.250	43	43	.650
44	14	.150	44	43	.300	44	44	.550	45	14	.150	45	44	.400	45	45	.450	46	15	.200	46	45	.400	46	46	.400
47	16	.200	47	46	.350	47	47	.450	48	17	.150	48	47	.300	48	48	.550	49	18	.100	49	48	.150	49	49	.750
50	19	.050	50	49	.100	50	50	.850	51	51	1.000	52	21	.100	52	51	.250	52	52	.650	53	22	.250	53	52	.300
53	53	.450	54	23	.250	54	53	.400	54	54	.350	55	24	.250	55	54	.450	55	55	.300	56	25	.250	56	55	.500
56	56	.250	57	26	.250	57	56	.450	57	57	.300	58	27	.200	58	57	.400	58	58	.400	59	28	.150	59	58	.250
59	59	.600	60	29	.050	60	59	.150	60	60	.800	61	61	1.000	62	61	.200	62	62	.800	63	62	.200	63	63	.700
63	92	.100	64	63	.200	64	64	.600	64	93	.200	65	64	.300	65	65	.500	65	94	.200	66	65	.300	66	66	.450
66	95	.250	67	66	.250	67	67	.500	67	96	.250	68	67	.200	68	68	.600	68	97	.200	69	68	.100	69	69	.800
69	98	.100	70	69	.050	70	70	.900	70	99	.050	71	71	1.000	72	71	.200	72	72	.750	72	101	.050	73	72	.200
73	73	.550	73	102	.250	74	73	.300	74	74	.450	74	103	.250	75	74	.350	75	75	.350	75	104	.300	76	75	.400
76	76	.300	76	105	.300	77	76	.350	77	77	.350	77	106	.300	78	77	.300	78	78	.450	78	107	.250	79	78	.150
79	79	.650	79	108	.200	80	79	.100	80	80	.850	80	109	.050	81	81	1.000	82	81	.150	82	82	.750	82	111	.100
83	82	.250	83	83	.500	83	112	.250	84	83	.350	84	84	.400	84	113	.250	85	84	.400	85	85	.350	85	114	.250
86	85	.450	86	86	.300	86	115	.250	87	86	.400	87	87	.350	87	116	.250	88	87	.350	88	88	.450	88	117	.200
89	88	.200	89	89	.600	89	118	.200	90	89	.100	90	90	.850	90	119	.050	91	91	1.000	92	61	.050	92	91	.200
92	92	.750	93	62	.100	93	92	.250	93	93	.650	94	63	.150	94	93	.300	94	94	.550	95	64	.150	95	94	.400
95	95	.450	96	65	.200	96	95	.400	96	96	.400	97	66	.200	97	96	.350	97	97	.450	98	67	.150	98	97	.300
98	98	.550	99	68	.100	99	98	.150	99	99	.750	100	69	.050	100	99	.100	100	100	.850	101	101	1.000	102	71	.100
102	101	.250	102	102	.650	103	72	.250	103	102	.300	103	103	.450	104	73	.250	104	103	.400	104	104	.350	105	74	.250
105	104	.450	105	105	.300	106	75	.250	106	105	.500	106	106	.250	107	76	.250	107	106	.450	107	107	.300	108	77	.200
108	107	.400	108	108	.400	109	78	.150	109	108	.250	109	109	.600	110	79	.050	110	109	.150	110	110	.800	111	111	1.000
112	81	.100	112	111	.300	112	112	.600	113	82	.250	113	112	.350	113	113	.400	114	83	.250	114	113	.450	114	114	.300
115	84	.200	115	114	.500	115	115	.300	116	85	.150	116	115	.600	116	116	.250	117	86	.150	117	116	.550	117	117	.300
118	87	.150	118	117	.500	118	118	.350	119	88	.150	119	118	.300	119	119	.550	120	89	.050	120	119	.150	120	120	.800

```
TREATMENT - INITIAL STATE - RESULTANT STATE - PROBABILITY
2   1   2  .500 2   1  32  .500 2   2   3  .500 2   2  33  .500 2   3   4  .500 2   3  34  .500 2   4   5  .500 2   4  35  .50
2   5   6  .500 2   5  36  .500 2   6   7  .500 2   6  37  .500 2   7   8  .500 2   7  38  .500 2   8   9  .500 2   8  39  .50
2   9  10  .500 2   9  40  .500 2  10  10 1.000 2  11  12  .500 2  11  42  .500 2  12  13  .500 2  12  43  .500 2  13  14  .50
2  13  44  .500 2  14  15  .500 2  14  45  .500 2  15  16  .500 2  15  46  .500 2  16  17  .500 2  16  47  .500 2  17  18  .50
2  17  48  .500 2  18  19  .500 2  18  49  .500 2  19  20  .500 2  19  50  .500 2  20  20 1.000 2  21  22  .500 2  21  52  .50
2  22  23  .500 2  22  53  .500 2  23  24  .500 2  23  54  .500 2  24  25  .500 2  24  55  .500 2  25  26  .500 2  25  56  .50
2  26  27  .500 2  26  57  .500 2  27  28  .500 2  27  58  .500 2  28  29  .500 2  28  59  .500 2  29  30  .500 2  29  60  .50
2  30  30 1.000 2  31  32 1.000 2  32  33 1.000 2  33  34 1.000 2  34  35 1.000 2  35  36 1.000 2  36  37 1.000 2  37  38 1.00
2  38  39 1.000 2  39  40 1.000 2  40  40 1.000 2  41  42 1.000 2  42  43 1.000 2  43  44 1.000 2  44  45 1.000 2  45  46 1.00
2  46  47 1.000 2  47  48 1.000 2  48  49 1.000 2  49  50 1.000 2  50  50 1.000 2  51  52 1.000 2  52  53 1.000 2  53  54 1.00
2  54  55 1.000 2  55  56 1.000 2  56  57 1.000 2  57  58 1.000 2  58  59 1.000 2  59  60 1.000 2  60  60 1.000 2  61  62  .50
2  61  92  .500 2  62  63  .500 2  62  93  .500 2  63  64  .500 2  63  94  .500 2  64  65  .500 2  64  95  .500 2  65  66  .50
2  65  96  .500 2  66  67  .500 2  66  97  .500 2  67  68  .500 2  67  98  .500 2  68  69  .500 2  68  99  .500 2  69  70  .50
2  69 100  .500 2  70  70 1.000 2  71  72  .500 2  71 102  .500 2  72  73  .500 2  72 103  .500 2  73  74  .500 2  73 104  .50
2  74  75  .500 2  74 105  .500 2  75  76  .500 2  75 106  .500 2  76  77  .500 2  76 107  .500 2  77  78  .500 2  77 108  .50
2  78  79  .500 2  78 109  .500 2  79  80  .500 2  79 110  .500 2  80  80 1.000 2  81  82  .500 2  81 112  .500 2  82  83  .50
2  82 113  .500 2  83  84  .500 2  83 114  .500 2  84  85  .500 2  84 115  .500 2  85  86  .500 2  85 116  .500 2  86  87  .50
2  86 117  .500 2  87  88  .500 2  87 118  .500 2  88  89  .500 2  88 119  .500 2  89  90  .500 2  89 120  .500 2  90  90 1.00
2  91  92 1.000 2  92  93 1.000 2  93  94 1.000 2  94  95 1.000 2  95  96 1.000 2  96  97 1.000 2  97  98 1.000 2  98  99 1.00
2  99 100 1.000 2 100 100 1.000 2 101 102 1.000 2 102 103 1.000 2 103 104 1.000 2 104 105 1.000 2 105 106 1.000 2 106 107 1.00
2 107 108 1.000 2 108 109 1.000 2 109 110 1.000 2 110 110 1.000 2 111 112 1.000 2 112 113 1.000 2 113 114 1.000 2 114 115 1.00
2 115 116 1.000 2 116 117 1.000 2 117 118 1.000 2 118 119 1.000 2 119 120 1.000 2 120 120 1.000 3   1   3  .500 3   1  33  .50
3   2   4  .500 3   2  34  .500 3   3   6  .500 3   3  36  .500 3   4   8  .500 3   4  38  .500 3   5   9  .500 3   5  39  .50
3   6  10  .500 3   6  40  .500 3   7  10  .500 3   7  40  .500 3   8  10  .500 3   8  40  .500 3   9  10  .500 3   9  40  .50
3  10  10 1.000 3  11  13  .500 3  11  43  .500 3  12  14  .500 3  12  44  .500 3  13  16  .500 3  13  46  .500 3  14  18  .50
3  14  48  .500 3  15  19  .500 3  15  49  .500 3  16  20  .500 3  16  50  .500 3  17  20  .500 3  17  50  .500 3  18  20  .50
3  18  50  .500 3  19  20  .500 3  19  50  .500 3  20  20 1.000 3  21  23  .500 3  21  53  .500 3  22  25  .500 3  22  55  .50
3  23  26  .500 3  23  56  .500 3  24  28  .500 3  24  58  .500 3  25  29  .500 3  25  59  .500 3  26  30  .500 3  26  60  .50
3  27  30  .500 3  27  60  .500 3  28  30  .500 3  28  60  .500 3  29  30  .500 3  29  60  .500 3  30  30 1.000 3  31  33 1.00
3  32  34 1.000 3  33  36 1.000 3  34  38 1.000 3  35  39 1.000 3  36  40 1.000 3  37  40 1.000 3  38  40 1.000 3  39  40 1.00
3  40  40 1.000 3  41  43 1.000 3  42  44 1.000 3  43  46 1.000 3  44  48 1.000 3  45  49 1.000 3  46  50 1.000 3  47  50 1.00
3  48  50 1.000 3  49  50 1.000 3  50  50 1.000 3  51  53 1.000 3  52  55 1.000 3  53  56 1.000 3  54  58 1.000 3  55  59 1.00
3  56  60 1.000 3  57  60 1.000 3  58  60 1.000 3  59  60 1.000 3  60  60 1.000 3  61  63  .500 3  61  93  .500 3  62  65  .50
3  62  95  .500 3  63  66  .500 3  63  96  .500 3  64  68  .500 3  64  98  .500 3  65  69  .500 3  65  99  .500 3  66  70  .50
3  66 100  .500 3  67  70  .500 3  67 100  .500 3  68  70  .500 3  68 100  .500 3  69  70  .500 3  69 100  .500 3  70  70 1.00
3  71  73  .500 3  71 103  .500 3  72  75  .500 3  72 105  .500 3  73  76  .500 3  73 106  .500 3  74  78  .500 3  74 108  .50
```

Table 4. The Treatment Effectiveness Model TREATUSE.SD3

3	75	79	.500	3	75	109	.500	3	76	80	.500	3	76	110	.500	3	77	80	.500	3	77	110	.500	3	78	80	.500	3	78	110	.50
3	79	80	.500	3	79	110	.500	3	80	80	1.000	3	81	83	.500	3	81	113	.500	3	82	85	.500	3	82	115	.500	3	83	86	.50
3	83	116	.500	3	84	88	.500	3	84	118	.500	3	85	89	.500	3	85	119	.500	3	86	90	.500	3	86	120	.500	3	87	90	.50
3	87	120	.500	3	88	90	.500	3	88	120	.500	3	89	90	.500	3	89	120	.500	3	90	90	1.000	3	91	93	1.000	3	92	95	1.00
3	93	96	1.000	3	94	98	1.000	3	95	99	1.000	3	96	100	1.000	3	97	100	1.000	3	98	100	1.000	3	99	100	1.000	3	100	100	1.00
3	101	103	1.000	3	102	105	1.000	3	103	106	1.000	3	104	108	1.000	3	105	109	1.000	3	106	110	1.000	3	107	110	1.000	3	108	110	1.00
3	109	110	1.000	3	110	110	1.000	3	111	113	1.000	3	112	115	1.000	3	113	116	1.000	3	114	118	1.000	3	115	119	1.000	3	116	120	1.00
3	117	120	1.000	3	118	120	1.000	3	119	120	1.000	3	120	120	1.000	4	1	5	.500	4	1	35	.500	4	2	7	.500	4	2	37	.50
4	3	8	.500	4	3	38	.500	4	4	9	.500	4	4	39	.500	4	5	10	.500	4	5	40	.500	4	6	10	.500	4	6	40	.50
4	7	10	.500	4	7	40	.500	4	8	10	.500	4	8	40	.500	4	9	10	.500	4	9	40	.500	4	10	10	1.000	4	11	15	.50
4	11	45	.500	4	12	17	.500	4	12	47	.500	4	13	18	.500	4	13	48	.500	4	14	19	.500	4	14	49	.500	4	15	20	.50
4	15	50	.500	4	16	20	.500	4	16	50	.500	4	17	20	.500	4	17	50	.500	4	18	20	.500	4	18	50	.500	4	19	20	.50
4	19	50	.500	4	20	20	1.000	4	21	25	.500	4	21	55	.500	4	22	27	.500	4	22	57	.500	4	23	28	.500	4	23	58	.50
4	24	29	.500	4	24	59	.500	4	25	30	.500	4	25	60	.500	4	26	30	.500	4	26	60	.500	4	27	30	.500	4	27	60	.50
4	28	30	.500	4	28	60	.500	4	29	30	.500	4	29	60	.500	4	30	30	1.000	4	31	35	1.000	4	32	37	1.000	4	33	38	1.00
4	34	39	1.000	4	35	40	1.000	4	36	40	1.000	4	37	40	1.000	4	38	40	1.000	4	39	40	1.000	4	40	40	1.000	4	41	45	1.00
4	42	47	1.000	4	43	48	1.000	4	44	49	1.000	4	45	50	1.000	4	46	50	1.000	4	47	50	1.000	4	48	50	1.000	4	49	50	1.00
4	50	50	1.000	4	51	55	1.000	4	52	57	1.000	4	53	58	1.000	4	54	59	1.000	4	55	60	1.000	4	56	60	1.000	4	57	60	1.00
4	58	60	1.000	4	59	60	1.000	4	60	60	1.000	4	61	65	.500	4	61	95	.500	4	62	67	.500	4	62	97	.500	4	63	68	.50
4	63	98	.500	4	64	69	.500	4	64	99	.500	4	65	70	.500	4	65	100	.500	4	66	70	.500	4	66	100	.500	4	67	70	.50
4	67	100	.500	4	68	70	.500	4	68	100	.500	4	69	70	.500	4	69	100	.500	4	70	70	1.000	4	71	75	.500	4	71	105	.50
4	72	77	.500	4	72	107	.500	4	73	78	.500	4	73	108	.500	4	74	79	.500	4	74	109	.500	4	75	80	.500	4	75	110	.50
4	76	80	.500	4	76	110	.500	4	77	80	.500	4	77	110	.500	4	78	80	.500	4	78	110	.500	4	79	80	.500	4	79	110	.50
4	80	80	1.000	4	81	85	.500	4	81	115	.500	4	82	87	.500	4	82	117	.500	4	83	88	.500	4	83	118	.500	4	84	89	.50
4	84	119	.500	4	85	90	.500	4	85	120	.500	4	86	90	.500	4	86	120	.500	4	87	90	.500	4	87	120	.500	4	88	90	.50
4	88	120	.500	4	89	90	.500	4	89	120	.500	4	90	90	1.000	4	91	95	1.000	4	92	97	1.000	4	93	98	1.000	4	94	99	1.00
4	95	100	1.000	4	96	100	1.000	4	97	100	1.000	4	98	100	1.000	4	99	100	1.000	4	100	100	1.000	4	101	105	1.000	4	102	107	1.00
4	103	108	1.000	4	104	109	1.000	4	105	110	1.000	4	106	110	1.000	4	107	110	1.000	4	108	110	1.000	4	109	110	1.000	4	110	110	1.00
4	111	115	1.000	4	112	117	1.000	4	113	118	1.000	4	114	119	1.000	4	115	120	1.000	4	116	120	1.000	4	117	120	1.000	4	118	120	1.00
4	119	120	1.000	4	120	120	1.000	5	1	10	1.000	5	2	10	1.000	5	3	10	1.000	5	4	10	1.000	5	5	10	1.000	5	6	10	1.00
5	7	10	1.000	5	8	10	1.000	5	9	10	1.000	5	10	10	1.000	5	11	20	1.000	5	12	20	1.000	5	13	20	1.000	5	14	20	1.00
5	15	20	1.000	5	16	20	1.000	5	17	20	1.000	5	18	20	1.000	5	19	20	1.000	5	20	20	1.000	5	21	30	1.000	5	22	30	1.00
5	23	30	1.000	5	24	30	1.000	5	25	30	1.000	5	26	30	1.000	5	27	30	1.000	5	28	30	1.000	5	29	30	1.000	5	30	30	1.00
5	31	10	1.000	5	32	10	1.000	5	33	10	1.000	5	34	10	1.000	5	35	10	1.000	5	36	10	1.000	5	37	10	1.000	5	38	10	1.00
5	39	10	1.000	5	40	10	1.000	5	41	20	1.000	5	42	20	1.000	5	43	20	1.000	5	44	20	1.000	5	45	20	1.000	5	46	20	1.00
5	47	20	1.000	5	48	20	1.000	5	49	20	1.000	5	50	20	1.000	5	51	30	1.000	5	52	30	1.000	5	53	30	1.000	5	54	30	1.00
5	55	30	1.000	5	56	30	1.000	5	57	30	1.000	5	58	30	1.000	5	59	30	1.000	5	60	30	1.000	5	61	70	1.000	5	62	70	1.00
5	63	70	1.000	5	64	70	1.000	5	65	70	1.000	5	66	70	1.000	5	67	70	1.000	5	68	70	1.000	5	69	70	1.000	5	70	70	1.00
5	71	80	1.000	5	72	80	1.000	5	73	80	1.000	5	74	80	1.000	5	75	80	1.000	5	76	80	1.000	5	77	80	1.000	5	78	80	1.00
5	79	80	1.000	5	80	80	1.000	5	81	90	1.000	5	82	90	1.000	5	83	90	1.000	5	84	90	1.000	5	85	90	1.000	5	86	90	1.00
5	87	90	1.000	5	88	90	1.000	5	89	90	1.000	5	90	90	1.000	5	91	70	1.000	5	92	70	1.000	5	93	70	1.000	5	94	70	1.00
5	95	70	1.000	5	96	70	1.000	5	97	70	1.000	5	98	70	1.000	5	99	70	1.000	5	100	70	1.000	5	101	80	1.000	5	102	80	1.00
5	103	80	1.000	5	104	80	1.000	5	105	80	1.000	5	106	80	1.000	5	107	80	1.000	5	108	80	1.000	5	109	80	1.000	5	110	80	1.00
5	111	90	1.000	5	112	90	1.000	5	113	90	1.000	5	114	90	1.000	5	115	90	1.000	5	116	90	1.000	5	117	120	1.000	5	118	120	1.00
5	119	120	1.000	5	120	120	1.000																								

Table 4 (Cont). The Treatment Effectiveness Model TREATUSE.SD3

Table 5.	Treatment Unit Costs	
Treatment No.	Treatment	Cost ($ per 2-lane mile)
1	Do Nothing	0
2	Seal Coat	12,000
3	2 1/2" Overlay	150,000
4	4" Overlay	210,000
5	Reconstruction	800,000

costs given by Witczak and Rada*. Obviously, the analyst is free to input whatever set of user disutilities he thinks appropriate.

We demonstrate below how the user disutilities may be used to determine the budget and strategies required to bring the minimum network condition to a desired level.

Table 6. Standard User Disutilities DISUTILS.STD

USER DISUTILITY MODEL: STANDARD USER DISUTILITIES 10/89 - New Order (10G12.2 FORMAT)

USER DISUTILITIES PER 2-LANE MILE PER YEAR

		RATE OF	CONDITION									
ENVIRONMENT	ADT	CRACKING	1	2	3	4	5	6	7	8	9	10
RURAL	LOW	LOW	1.11	1.05	1.00	.91	.83	.77	.73	.71	.70	.68
RURAL	LOW	HIGH	1.11	1.05	1.00	.91	.83	.77	.73	.71	.70	.68
RURAL	MEDIUM	LOW	3.34	3.18	3.02	2.73	2.50	2.32	2.21	2.13	2.10	2.06
RURAL	MEDIUM	HIGH	3.34	3.18	3.02	2.73	2.50	2.32	2.21	2.13	2.10	2.06
RURAL	HIGH	LOW	5.49	5.22	4.93	4.45	4.07	3.80	3.61	3.48	3.43	3.38
RURAL	HIGH	HIGH	5.49	5.22	4.93	4.45	4.07	3.80	3.61	3.48	3.43	3.38
URBAN	LOW	LOW	2.28	2.00	1.68	1.38	1.22	1.16	1.10	1.09	1.08	1.07
URBAN	LOW	HIGH	2.28	2.00	1.68	1.38	1.22	1.16	1.10	1.09	1.08	1.07
URBAN	MEDIUM	LOW	5.28	4.62	4.03	3.40	3.00	2.81	2.68	2.62	2.57	2.49
URBAN	MEDIUM	HIGH	5.28	4.62	4.03	3.40	3.00	2.81	2.68	2.62	2.57	2.49
URBAN	HIGH	LOW	6.93	6.21	5.56	4.91	4.42	4.68	3.84	3.71	3.62	3.54
URBAN	HIGH	HIGH	6.93	6.21	5.56	4.91	4.42	4.68	3.84	3.71	3.62	3.54

*Witczak, M. W. and G. R. Rada. "Microcomputer Simulation of the Project Level PMS Life Cycle Cost Model". Univ. of Maryland, C.E. Dept., Dec. 1984

2.8 Objective Function

Formulation of an optimization problem requires the specification of an "objective function", Z. The present model minimizes total user disutility. Mathematically:

$$\text{Minimize: } Z = \sum_{y=1}^{Y} \sum_{s=1}^{120} G_s x_{sy} \qquad (15)$$

Where:

G_s = User unit disutility,

x_{sy} = Miles of roadway in state s in year y

2.9 Constraints

There are several possible constraints on the solution. The first three of these are budgetary:

$$\sum_{y=1}^{Y} \sum_{s=1}^{120} \sum_{t=1}^{5} C_t x_{sty} \leq B^* , \qquad (16)$$

$$\sum_{s=1}^{120} \sum_{t=1}^{5} C_t x_{sty} \leq B^+_y \text{ for all } y, \qquad (17)$$

and

$$\sum_{s=1}^{120} \sum_{t=1}^{5} C_t x_{sty} \geq B^-_y \text{ for all } y, \qquad (18)$$

where B^* = total budget

B_y^+ = maximum budget in year y, and

B_y^- = minimum budget in year y.

Equation (16) is the constraint in the overall budget during the analysis period. Equations (17) and (18) are the constraints on each of the yearly budgets. We note in passing that $\sum_{y=1}^{Y} B_y$ may be larger than B^*.

Two additional constraints are imposed by production capacity:

$$\sum_{s=1}^{120} x_{sty} = x_{ty} \leq T^{+}_{ty}, \qquad (19)$$

and

$$x_{ty} \geq T^{-}_{ty}, \qquad (20)$$

where T_{ty}^{+} and T_{ty}^{-} are the maximum and minimum production capacities of treatment t in year y respectively.

Equation (19) sets a maximum on the amount of a certain treatment that is employed in any one year. Equation (20), which sets a minimum on this amount, has been introduced to avoid a solution that would lead to extreme shifts in production from year to year.

Another constraint is furnished by

$$\sum_{t=1}^{5} x_{sty} = x_{sy} \qquad (21)$$

This is a consequence of the inclusion of the "do-nothing" option in the list of treatments. It simply says that the total number of miles treated (including do-nothing) in any given state in any given year must be equal to the total number of miles in that state.

The remaining constraints are supplied by the recursive relation which reflects the yearly cycle of treatment and deterioration:

$$\sum_{t=1}^{5} \sum_{s=1}^{120} \sum_{u=1}^{120} X_{sty} E_{stu} D_{uk} \qquad (22)$$

3. <u>Selection of a Micro-Computer Linear Program Solver</u>

Task A of this project consisted of "Evaluation and selection of packaged micro-computer program". This task was performed concurrently with Task B, "Conversion of the optimization model". Both are described in this section.

A survey of the literature yielded few candidate programs. Of the three candidates found, the package by Applied Automated Engineering Corporation (AAEC)* appeared to offer all of the required capability. (A program by David Ahfeld, Assistant Professor of Civil Engineering

* 65 S. Main Street, Bldg. B, Pennington, N.J. 08534

was also considered. While basically very sound, the special purpose nature of the program ruled out further consideration.) Simply put, the AAEC package provided the required capacity and wasuser-friendly. While not a primary concern, the price of the AAEC package was also attractive. The final agreement provided for the purchase of both the 286 and 386 versions of the package (LPS-867) for $1500.

3.1 Description of LPS-867

A brief description of the linear program solver, extracted from the AAEC literature, is given below.

Modules

LPS-867 is comprised of two subsystems:

- FLP867, the LP solver, and
- JANUS, a utility which permits problems to be structured in a LOTUS spreadsheet and solutions to be output to a spreadsheet.

Configurations

- The smallest version will solve problems with up to 500 rows and 1,000 columns.
- The largest versions will solve problems with a maximum size of 5,000 rows and 15,000 columns.

Key features

- LPS-867 will accept either input in MPS format or input from a LOTUS spreadsheet.
- The system is numerically stable even when problems reach the maximum size allowed by the system.
- LPS-867 will store a basis (at periodic intervals set by the user) and allow a warm restart with parameter changes.
- LPS-867 may be executed in batch mode or interactively.
- An OS/2 version of LPS-867 is available.
- Support for the Weitek coprocessor is available.

Options

- Right Hand Side Ranging;
- Non-Basic Variable Cost Ranging
- Basic Variable Cost Ranging;
- Writing the iteration log to a file; and
- Changing tolerances used by the system.
- Source code for the main program, and input/output routines, is available for users needing to employ the LP as a subroutine from FORTRAN executive routines or for users needing to customize solution reports.

Source Code Availability

The LP solver FLP867 is coded primarily in FORTRAN. The program is licensed as an executable program; the user does not need a FORTRAN compiler to use LPS-867. However, users wishing to customize the solution reports, or modify the input formats, or use linear programming as a subroutine in their own algorithms can purchase source code to do these things. The source code for the main program and the input/output routines of FLP867 may be purchased for $200 by licensees of the DOS, OS2 or 386 versions. To work with the source code for the DOS or OS2 versions, you must also use version 4.1 of Microsoft's FORTRAN compiler. To work with the source code for the 386 version, Phar|Lap's 386|ASM/Link package and MicroWay's NDP FORTRAN-386 compiler. are required. AAEC can provide them to you at cost plus a handling fee.

Requirements

- LPS-867 will run on any IBM-PC or compatible.
- Minimum requirements are that the PC has 256K RAM and MS/PC DOS 2.0 or higher.
- LPS-867 supports the 8087, 80287, and 80387 Math coprocessors. (We recommend that LPS-867 users install a coprocessor in order to reduce solution time.)
- LPS-867 supports the Motorola 68020 and the 68881 coprocessor as installed on the Definicon Systems DSI boards. (These boards plug into a PC.)
- The newest version of LPS-867 supports the 80386 and 80387 processors and accesses the native instruction set of the 80386. This permits the solution of problems which require more than 640K of RAM in substantially less time.

Source: "LPS-867". Promotional Brochure Applied Automated Engineering Corporation. No date.

3.2 Conversion of the Mainframe Version

As part of the conversion process, the FORTRAN code to analyze the output file for the Linear Program Solver and to reformat it into the Pavement Management output was ported from FORTVS on the UCONN mainframe to Microsoft (c) FORTRAN on an AT class PC running under DOS. The output file from the 5-year benchmark case run by AAEC was used to check the program. Some changes in file and data structure were necessary to create an effective PC-based program.

Also during the conversion, three levels of pavement management usage with the related input to be varied at each level were identified:

(1) Analysis level. At this level, the following can be changed:
- o Budgets
- o Budget constraints
- o Production constraints
- o Treatment cost
- o Number and nature of treatments
- o Number of years in the optimization period
- o Initial network
- o User disutilities

(2) Engineering level. Here, the following can be changed:
- o Definition of additional treatments
- o Deterioration probabilities
- o Treatment effectiveness probabilities

(3) System level. At this level, the entire state structure can be changed. Programming at this level is somewhat difficult, requiring a fair degree of expertise.

Miscellaneous improvements during this phase included:

- o Inclusion of sponsorship credits on the screen
- o Creation of a compressed print option for narrow printers
- o User instructions to view and/or print the output
- o State-attribute-based input for the Initial Network and User Disutilities
- o Number of treatments increased to 8
- o Individual treatments made independent
- o User friendly data input system created
- o Spreadsheet output interface created

During conversations with ConnDOT personnel, it was established that certain characteristics were required of the program. An

- OPTOUT7.EXE: Program to process optimization solution and prepare Pavement System Output
- READ.COM: Read utility to view ASCII files
- CONFIG.LPS: Control file for FLP7
- MM.EXE: Utility to check system memory usage
- ASK.EXE: Utility for questions within the BAT file
- MANUAL: An ASCII file containing user's instructions
- PREPAVE.EXE: Program to create and edit input files
- PREPAVE.HLP: Help file for PREPAVE
- PAVEPRT.EXE: Program to format and print output files
- POSTPAVE.WK1: Spreadsheet template to process output files
- TEMPLATE.1: Backup for POSTPAVE.WK1
- FLP-512.EXE: 512K linear program solver from AAEC for memory limited 286 based systems
- FLPWR4MB.EXE: 4Mb linear program solver from AAEC for 386 based systems

The following files are also on the distribution disk and should be copied to the program directory for use either as input files or as examples of input files to edit using PREPAVE. The first five files have the default names used by the PAVEMENT system. They can, of course, be replaced by whatever default input files (with the same names) desired at a given installation.

- BUDGET.SD1: Example Budget file
- TREATUSE.SD1: Standard Treatment Used file
- NETWORK.SD1: Level (10 miles per state) Initial Network file
- DISUTILS.SD1: Standard User Disutility file
- DETER.SD1: Standard Deterioration file
- CHIPSEAL.SD1: Standard Chipseal Treatment Effectiveness file
- OVERLAYA.SD1: Standard 2 1/2" Overlay Treatment Effectiveness file
- OVERLAYB.SD1: Standard 4" Overlay Treatment Effectiveness file

- o RECONST.SD1: Standard Reconstruction Treatment Effectiveness file

3.5 The File CONFIG.LPS

The file CONFIG.LPS is used by the AAEC linear program solver and is documented in their manual. One line is of particular interest to the PAVEMENT user, that is, "Iteration Log Print Frequency: 10". This command causes a screen message to appear every tenth iteration of the problem solver. The frequency of the message can be changed to any integer including zero. The message contains several field, the most interesting of which are:

- o COUNT: The current iteration count
- o STAT: The current problem status
  INFE - Infeasible solution
  FEAS - Feasible solution
  OPT - Optimum solution
- o #INF: The current number of infeasible equations remaining
- o OBJ VALUE: The current objective value for the feasible solutions

3.6 Installation

(1) Reboot the system to obtain maximum memory (no TSRs*). Use the utility MM to determine free memory. If more memory is desired, change CONFIG.SYS.

(2) Create hard disk directory C:\PAVEMENT.

(3) Copy installation files to hard disk directory created in step (3)

(4) If a 386 machine is available, or if memory is limited, COPY appropriate FLPxxxxx.EXE file to FLP7-FIT.EXE in the directory C:\PAVEMENT.

4. Tutorial

In this section we give a step-by-step description of the use of the program. At each step we show the actual screens displayed. This material should be of sufficient detail to allow the novice user to easily follow as a hands-on exercise.

4.1 Input File Creation and Editing - the Program PREPAVE

The program PREPAVE is invoked as part of the program PAVEMENT or it can be used as a stand alone program. It is used to edit existing input files or to create new ones. It features user friendly input

---

*Terminate and Stay Resisdent e.g. "Sidekick" screens and low level input validity checking. In this case, we will simply be looking at some existing files. First be sure you are in the Directory PAVEMENT. Then type <PREPAVE>. The screen shown in Figure 7 should appear.

Before proceeding, let us review some features common to all of the input file types.

File Name and Description Fields

For all file types, the first two fields have the same format and meaning. The first field is a file name, which may be a full path name of up to 36 characters. This file name is used in both the read and write operations described below. Notice that if an existing file is to be edited and then rewritten with a new file name (saving the old file) the file name field must be edited between the read and write operations. The second field is a 78 character file description record which always appears as the first record of every PAVEMENT input file to provide for documentation of the purpose of the file.

The Function Keys

The function keys are also common to all the edit screens.

- F1: Help - Allows on-line viewing of instructions.
- F2: Edit - Opens the field the cursor is on for editing.
- F3: Delete - Deletes the field the cursor is on.
- F4: DOS - Enables the use of DOS commands, for example DIR.
- F5: Read File - Reads the file in the File Name Field.
- F6: Write File - Writes to the file named in the File Name Field.
- F9: Select File Type - Returns to the original menu.
- F10: Quit - Leave the PREPAVE program.

Moving around the edit screens:

The cursor is moved from field to field around the edit screen by using the arrow keys. The Home and End keys move the cursor to the first and last field of a given screen respectively. Most files require more than one screen, and the Page Up and Page Down keys are used to move up and down the file. The Tab and Back Tab (Shift-Tab) keys are used to move left and right when the file is too wide for the screen.

Edit commands:

The edit mode is entered either by using function key F2 or by

```
BUDGET      TREAT USED   NETWORK      PROBABILITY
Create or Edit Budget File









   F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

Figure 7. Main Menu for PREPAVE

```
* CREATE OR EDIT DETERIORATION OR TREATMENT EFFECTIVENESS FILE * Page  1 of 60
File Name:
Description:

For RURAL ENVIRONMENT & LOW    ADT                               SUMs Must = 1.000
 Probability That LOW RATE OF CRACKING CONDITION  1 Becomes          SUM = 0.000
  LOW RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  HIGH RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

 Probability That HIGH RATE OF CRACKING CONDITION  1 Becomes         SUM = 0.000
  LOW RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  HIGH RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

  F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

Figure 8. Blank Deterioration Screen

typing a character. If F2 is used, the current contents of the cursor field are placed in the edit window at the top of the screen; typing a character merely puts the character in the edit window. In either case, <Esc> cancels the edit and <Return> places the contents of the edit window back in the cursor field. The following commands are used to manipulate the text in the edit window.

- Character: Places that character at the cursor.
- Left Arrow: Moves the cursor left.
- Right Arrow: Moves the cursor right.
- Home: Moves the cursor to the left margin.
- End: Moves the cursor to the right margin.
- Delete: Deletes the character at the cursor.
- Backspace: Deletes the character to the left of the cursor.

The following commands duplicate the Edit <Return> function and move the cursor to a neighboring field on the screen.

- Tab: Moves to the right on the screen.
- Back Tab: Moves to the left on the screen.
- Up Arrow: Moves up on the screen.
- Down Arrow: Moves down on the screen.

While editing numeric fields, only the characters 0, 1 through 9, ., +, -, e, and E can be entered. Before the results of the edit can be returned, the program verifies that a valid number appears in the edit window. If the characters do not represent a valid number, the cursor is placed at the first problem character. Note that a numeric field can be edited to a zero but not to a blank. To erase a numeric field, use the field delete function, F3.

Continuing with our tutorial, we first look at a DETERIORATION file. Select PROBABILITY. The screen shown in Figure 8 should appear. At this time, a file can be built from scratch (a tedious process) or it can be created by editing an existing file. To demonstrate the latter method, place the cursor in the file name field and type DETER.SD1 <Return> followed by <F5> to read the file. The question "OK to overwrite data on the screen?" will appear at the top of the screen. Typing Y produces the screen shown at the top of Figure 9. Note that the PROBABILITY file contains 60 screens, each providing the means to input the state transition probabilities for the low and high time rate of change of cracking levels for a given condition at a specific environment-ADT combination. Whether through deterioration or treatment, these states can only move to other states in the same environment-ADT set. To make the task of specifying the

```
* CREATE OR EDIT DETERIORATION OR TREATMENT EFFECTIVENESS FILE * Page  1 of 60
File Name: deter.sd1
Description:
120 STATE DETERIORATION MODEL - AUGUST 1989 (fixed field)

For RURAL ENVIRONMENT & LOW    ADT                                SUMs Must = 1.000
 Probability That LOW RATE OF CRACKING CONDITION  1 Becomes             SUM = 1.000
  LOW RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 1.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  HIGH RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

 Probability That HIGH RATE OF CRACKING CONDITION  1 Becomes            SUM = 1.000
  LOW RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  HIGH RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 1.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

  F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

```
* CREATE OR EDIT DETERIORATION OR TREATMENT EFFECTIVENESS FILE * Page  2 of 60
File Name: deter.sd1
Description:
120 STATE DETERIORATION MODEL - AUGUST 1989 (fixed field)

For RURAL ENVIRONMENT & LOW    ADT                                SUMs Must = 1.000
 Probability That LOW RATE OF CRACKING CONDITION  2 Becomes             SUM = 1.000
  LOW RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.100   0.900   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  HIGH RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

 Probability That HIGH RATE OF CRACKING CONDITION  2 Becomes            SUM = 1.000
  LOW RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.050   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  HIGH RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.100   0.850   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

  F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

Figure 9.   Two of the 60 Screens from DETER.SD1

probabilities easier, the identity transition state is highlighted in red and the sums of the transition probabilities for each input state are computed after each edit. These sums must be equal to 1.

To view a TREATMENT EFFECTIVENESS file, place the cursor in the file name field and type CHIPSEAL.SD2 <Return> followed by <F5>. Again typing Y produces the screen shown in Figure 10. Note that form of this screen is exactly the same as the previous screen. Again there are 60 screens to this file. Similar files exist, or would be created, for each type of treatment envisioned.

To view a TREAT USED file, type <F9> to return to the PREPAVE main menu and select TREAT USED. The process of reading an existing file is the same as before. At the top of Figure 11 is shown the screen that should appear after reading the file TREATUSE.SD3. This file contains from one to 7 screens depending on the number of treatments to be considered in the optimization. The screen shown at the top of Figure 11 is that for chipsealing and uses the same CHIPSEAL.SD2 that we viewed previously. Page Down gives the screen shown at the bottom of Figure 11 for a 2-1/2 in. overlay and uses the TREATMENT EFFECTIVENESS file OVERLAYA.SD2. Note that in all of these files, the user must specify the cost per mile for the particular treatment as well as the minimum and maximum number of miles of treatment allowed for each year of the optimization period. The zero in the screens shown in the Year column will cause the same constraints to be applied for each year. The zero in the Maximum Miles column removes the constraint on the upper limit.

To view a NETWORK file, type <F9> to return to the PREPAVE main menu and select NETWORK. Two general types of NETWORK files are required. The first of these gives the number of miles in each state at the beginning of the optimization period. To view such a file, read NETWORK.SD1 and produce the screen shown in Figure 12. Note that this file consists of two screens, the left one (this one) and the right one which is accessed by <Tab>. To return back from the right to the left, type <Back Tab> or <Shift-Tab>.

The second type of NETWORK file gives user disutilities for each of the 120 states. To view such a file, read in DISUTILS.SD1 and produce the screen shown in Figure 13. Figure 14 shows the file DISUTILS.LV4, which is used in Section 5 in a demonstration of a procedure for optimization while achieving and maintaining condition 4 or better.

The final file type that may be edited through PREPAVE is the BUDGET file. To view such a file, select BUDGET from the PREPAVE main menu and read in BUDGET.SD1. The screen should appear as in Figure 15.

4.2 <u>PAVEMENT Batch Program</u>

The program PAVEMENT provides an interactive environment for the user to create new input files, define an optimization run, assemble the input stream, check the input, submit the run, and view the output. At most points within PAVEMENT, the system can be aborted by

```
* CREATE OR EDIT DETERIORATION OR TREATMENT EFFECTIVENESS FILE * Page  1 of 60
File Name: chipseal.sd2
Description:
CHIPSEAL 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)

For RURAL ENVIRONMENT & LOW    ADT                                SUMs Must = 1.000
 Probability That LOW RATE OF CRACKING CONDITION  1 Becomes              SUM = 1.000
  LOW RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.500   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  HIGH RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.500   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

 Probability That HIGH RATE OF CRACKING CONDITION  1 Becomes             SUM = 1.000
  LOW RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
  HIGH RATE OF CRACKING CONDITION:
  1       2       3       4       5       6       7       8       9       10
 0.000   1.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

  F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

Figure 10.   First of 60 Screens from CHIPSEAL.SD2

```
*** CREATE OR EDIT TREATMENT USED FILE ***        Treatment 1 of 4, Maximum 7
File Name: treatuse.sd3
Description:
Standard Treatment 2-2-91
   Treatment Name: Chip Seal             Cost/Mile:                    12
   Treatment Effectiveness File Name: CHIPSEAL.SD2

   Constraints
   Year    Minimum Miles         Maximum Miles (0 or blank is no constraint.)
       0                       0                       0

                                                          F7-DELETE TREATMENT
                                                          F8-ADD TREATMENT
Year 0 applies same constraints to every year in problem.

  F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

```
*** CREATE OR EDIT TREATMENT USED FILE ***        Treatment 2 of 4, Maximum 7
File Name: treatuse.sd3
Description:
Standard Treatment 2-2-91
   Treatment Name: 2 1/2" Overlay        Cost/Mile:                    150
   Treatment Effectiveness File Name: OVERLAYA.SD2

   Constraints
   Year    Minimum Miles         Maximum Miles (0 or blank is no constraint.)
       0                       0                       0

                                                          F7-DELETE TREATMENT
                                                          F8-ADD TREATMENT
Year 0 applies same constraints to every year in problem.

  F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

Figure 11. Two Screens from TREATUSE.SD3

*** CREATE OR EDIT INITIAL MILES OR USER DISUTILITIES FILE *** Left Page
File Name: network.sd1
Description:
Level Standard Network

		RATE OF	CONDITION				
ENVIRONMENT	ADT	CRACKING	1	2	3	4	5
RURAL	LOW	LOW	10.00	10.00	10.00	10.00	10.00
RURAL	LOW	HIGH	10.00	10.00	10.00	10.00	10.00
RURAL	MEDIUM	LOW	10.00	10.00	10.00	10.00	10.00
RURAL	MEDIUM	HIGH	10.00	10.00	10.00	10.00	10.00
RURAL	HIGH	LOW	10.00	10.00	10.00	10.00	10.00
RURAL	HIGH	HIGH	10.00	10.00	10.00	10.00	10.00
URBAN	LOW	LOW	10.00	10.00	10.00	10.00	10.00
URBAN	LOW	HIGH	10.00	10.00	10.00	10.00	10.00
URBAN	MEDIUM	LOW	10.00	10.00	10.00	10.00	10.00
URBAN	MEDIUM	HIGH	10.00	10.00	10.00	10.00	10.00
URBAN	HIGH	LOW	10.00	10.00	10.00	10.00	10.00
URBAN	HIGH	HIGH	10.00	10.00	10.00	10.00	10.00

F1-Help F2-Edit F3-Erase F4-DOS F5-Read F6-Write F9-Select F10-Quit

*** CREATE OR EDIT INITIAL MILES OR USER DISUTILITIES FILE *** Right Page
File Name: network.sd1
Description:
Level Standard Network

		RATE OF	CONDITION				
ENVIRONMENT	ADT	CRACKING	6	7	8	9	10
RURAL	LOW	LOW	10.00	10.00	10.00	10.00	10.00
RURAL	LOW	HIGH	10.00	10.00	10.00	10.00	10.00
RURAL	MEDIUM	LOW	10.00	10.00	10.00	10.00	10.00
RURAL	MEDIUM	HIGH	10.00	10.00	10.00	10.00	10.00
RURAL	HIGH	LOW	10.00	10.00	10.00	10.00	10.00
RURAL	HIGH	HIGH	10.00	10.00	10.00	10.00	10.00
URBAN	LOW	LOW	10.00	10.00	10.00	10.00	10.00
URBAN	LOW	HIGH	10.00	10.00	10.00	10.00	10.00
URBAN	MEDIUM	LOW	10.00	10.00	10.00	10.00	10.00
URBAN	MEDIUM	HIGH	10.00	10.00	10.00	10.00	10.00
URBAN	HIGH	LOW	10.00	10.00	10.00	10.00	10.00
URBAN	HIGH	HIGH	10.00	10.00	10.00	10.00	10.00

F1-Help F2-Edit F3-Erase F4-DOS F5-Read F6-Write F9-Select F10-Quit

Figure 12. The Two Screens from NETWORK.SD1

*** CREATE OR EDIT INITIAL MILES OR USER DISUTILITIES FILE *** Left Page
File Name: disutils.sd1
Description:
STANDARD USER DISUTILITIES 10/89 - New Order (10G12.2 FORMAT)

		RATE OF	CONDITION				
ENVIRONMENT	ADT	CRACKING	1	2	3	4	5
RURAL	LOW	LOW	1.11	1.05	1.00	0.91	0.83
RURAL	LOW	HIGH	1.11	1.05	1.00	0.91	0.83
RURAL	MEDIUM	LOW	3.34	3.18	3.02	2.73	2.50
RURAL	MEDIUM	HIGH	3.34	3.18	3.02	2.73	2.50
RURAL	HIGH	LOW	5.49	5.22	4.93	4.45	4.07
RURAL	HIGH	HIGH	5.49	5.22	4.93	4.45	4.07
URBAN	LOW	LOW	2.28	2.00	1.68	1.38	1.22
URBAN	LOW	HIGH	2.28	2.00	1.68	1.38	1.22
URBAN	MEDIUM	LOW	5.28	4.62	4.03	3.40	3.00
URBAN	MEDIUM	HIGH	5.28	4.62	4.03	3.40	3.00
URBAN	HIGH	LOW	6.93	6.21	5.56	4.91	4.42
URBAN	HIGH	HIGH	6.93	6.21	5.56	4.91	4.42

F1-Help F2-Edit F3-Erase F4-DOS F5-Read F6-Write F9-Select F10-Quit

*** CREATE OR EDIT INITIAL MILES OR USER DISUTILITIES FILE *** Right Page
File Name: disutils.sd1
Description:
STANDARD USER DISUTILITIES 10/89 - New Order (10G12.2 FORMAT)

		RATE OF	CONDITION				
ENVIRONMENT	ADT	CRACKING	6	7	8	9	10
RURAL	LOW	LOW	0.77	0.73	0.71	0.70	0.68
RURAL	LOW	HIGH	0.77	0.73	0.71	0.70	0.68
RURAL	MEDIUM	LOW	2.32	2.21	2.13	2.10	2.06
RURAL	MEDIUM	HIGH	2.32	2.21	2.13	2.10	2.06
RURAL	HIGH	LOW	3.80	3.61	3.48	3.43	3.38
RURAL	HIGH	HIGH	3.80	3.61	3.48	3.43	3.38
URBAN	LOW	LOW	1.16	1.10	1.09	1.08	1.07
URBAN	LOW	HIGH	1.16	1.10	1.09	1.08	1.07
URBAN	MEDIUM	LOW	2.81	2.68	2.62	2.57	2.49
URBAN	MEDIUM	HIGH	2.81	2.68	2.62	2.57	2.49
URBAN	HIGH	LOW	4.68	3.84	3.71	3.62	3.54
URBAN	HIGH	HIGH	4.68	3.84	3.71	3.62	3.54

F1-Help F2-Edit F3-Erase F4-DOS F5-Read F6-Write F9-Select F10-Quit

Figure 13. The Two Screens from DISUTILS.SD1

```
*** CREATE OR EDIT INITIAL MILES OR USER DISUTILITIES FILE ***       Left Page
File Name: disutils.lv4
Description:
STAND. USER DISUTIL. 1/25/91 - New Order (10G12.2 FORMAT) Maintain level 4
```

ENVIRONMENT	ADT	RATE OF CRACKING	CONDITION 1	2	3	4	5
RURAL	LOW	LOW	100.00	100.00	100.00	0.91	0.83
RURAL	LOW	HIGH	100.00	100.00	100.00	0.91	0.83
RURAL	MEDIUM	LOW	100.00	100.00	100.00	2.73	2.50
RURAL	MEDIUM	HIGH	100.00	100.00	100.00	2.73	2.50
RURAL	HIGH	LOW	100.00	100.00	100.00	4.45	4.07
RURAL	HIGH	HIGH	100.00	100.00	100.00	4.45	4.07
URBAN	LOW	LOW	100.00	100.00	100.00	1.38	1.22
URBAN	LOW	HIGH	100.00	100.00	100.00	1.38	1.22
URBAN	MEDIUM	LOW	100.00	100.00	100.00	3.40	3.00
URBAN	MEDIUM	HIGH	100.00	100.00	100.00	3.40	3.00
URBAN	HIGH	LOW	100.00	100.00	100.00	4.91	4.42
URBAN	HIGH	HIGH	100.00	100.00	100.00	4.91	4.42

```
F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

Figure 14. Left Page of DISUTILS.LV4

```
*** CREATE OR EDIT BUDGET FILE ***                               Page 1 of 1
File Name: budget.sd1
Description:
Standard Budget Test File 8-20-90
Total Budget $:              500000

   Constraints
   Year    Minimum $            Maximum $ (0 or blank is no constraint.)
      0                                       100000

Year 0 applies same constraints to every year in problem.

  F1-Help  F2-Edit  F3-Erase  F4-DOS  F5-Read  F6-Write  F9-Select  F10-Quit
```

Figure 15. Screen for BUDGET.SD1

typing <Control-c>. To run the program, first be sure you are in the PAVEMENT subdirectory and type PAVEMENT <Return>. You will first be asked whether you wish to edit or create input files. Selecting this option would invoke the program PREPAVE discussed in the previous section. Since we have already examined that program, type "n" <Return>. The screen should appear as in Figure 16.

You next are asked a series of questions defining the optimization. The questions (and answers for this tutorial) are shown in Figure 17. Note that we have opted to use the "standard" BUDGET, DISUTILITIES, NETWORK, and DETERIORATION files, but have chosen TREATUSE.SD3 for the TREATMENTS USED file. Note also that you are asked whether or not you would like to have the deterioration and treatment effectiveness probability matrices printed with the output. For this example, assume we don't require their printing, leave out the "Y", and simply type <Return> for each question.

The next screen that will appear is shown in Figure 18. Here the input is summarized, giving the number of years of the optimization, the number of treatments, the number of states, and 5 of the models used. Typing <Return> gives the screen shown in the top of Figure 19 listing the Treatment Effectivenes files and summarizing the number of errors detected. Again typing <Return> gives the description of errors detected shown toward the bottom of Figure 19. Note that the program will not run with errors of severity 3*. In this example, we choose to run the case with the "error". Type "A" <Return> and the last three lines of Figure 19 will appear. After several seconds, the screen shown in Figure 20 appears. This is followed by a variety of screens during which time the input is read and information describing the application of the Revised Simplex Algorithm to the solution of the linear program is given. In the present example, this takes about 7 minutes on a 286 class machine.

Upon completion of the solution, you are given the opportunity to view and/or print the output file. This file, CONNPAVE.OUT is a temporary system file (as are all files with names CONNPAVE) and is overwritten when the next case is run. It is ASCII format eye readable, with title page, input, results, and summary tables. For a complete description of the output file, See Section 2.2.

4.3 Spreadsheet Creation Template (POSTPAVE)

A spreadsheet template which contains Lotus 1-2-3 (c) macros is provided with the system. This template can create a spreadsheet with all the state and summary tables broken out into separate numerical cells from a standard output file. Once this step is accomplished, optimization output can be combined, analyzed, and displayed in any of the many ways available in a spreadsheet program.

To use this template, retrieve the file POSTPAVE from 1-2-3 or any other macro-compatible spreadsheet program. A note of caution is in order. Since it is very easy to store the spreadsheet POSTPAVE with

---

* For a complete discussion of errors see Section 4.4.

```
Copyright (C) 1989, 1990. All rights reserved

This program was prepared under the sponsorship of
 The Joint Highway Research Advisory Council
   The Connecticut Department of Transportation
   The University of Connecticut

 Authors: Christian F. Davis, Professor of Civil Engineering
          C. Peter Van Dine, Consultant

This module is preset to run: 10 Condition Levels
                               3 ADT Levels
                               2 Cracking Rate Levels
                               Urban & Rural Environments

It can run: Up to 8 Treatment Types
            (Treatment 1 is "Do-Nothing" at 0 Cost)
            Up to 10 Years
            The system includes: Input File Generator,
                                 Spreadsheet Output Analysis
                                 Custom Output Print Routine
            For Larger Cases a 386 or 486 Machine is Required

Enter Case Name:
```

Figure 16.   Initial Screen in PAVEMENT

```
Enter Case Name: cfd
Enter Number of Years: 2
Enter File Name for Budgets
    or <Enter> to use BUDGET.SD1

Enter File Name for Treatments to be Used
    or <Enter> to use TREATUSE.SD1
treatuse.sd3
Enter File Name for User Disutilities
    or <Enter> to use DISUTILS.SD1

Enter File Name for Initial Network
    or <Enter> to use NETWORK.SD1

Enter File Name for Deterioration Probabilities
    or <Enter> to use DETER.SD1

Type Y <Enter> to Print Deterioration Probability Detail with Output:
-- Processing Deterioration Probability Matrix
-- Processing Treatment Effectiveness Matrices
Type Y <Enter> to Print Treatment Effectiveness Detail with Output:
```

Figure 17.   Defining a Case in PAVEMENT

```
Input Complete Case:
 cfd
  2 Years     5 Treatments    120 States

                    MODELS.
BUDGET                          File Name: BUDGET.SD1
 Standard Budget Test File 8-20-90
TREATMENTS USED                 File Name: treatuse.sd3
 Standard Treatment 2-2-91
USER DISUTILITIES               File Name: DISUTILS.SD1
 STANDARD USER DISUTILITIES 10/89 - New Order (10G12.2 FORMAT)
INITIAL NETWORK                 File Name: NETWORK.SD1
 Level Standard Network
DETERIORATION PROBABILITIES     File Name: DETER.SD1
 120 STATE DETERIORATION MODEL - AUGUST 1989 (fixed field)
 <RETURN> for TREATMENT EFFECTIVENESS MODELS
```

Figure 18. Input Summary in PAVEMENT

```
                    TREATMENT EFFECTIVENESS MODELS
 2   Chip Seal              File Name: CHIPSEAL.SD2
 CHIPSEAL 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
 3   2 1/2" Overlay         File Name: OVERLAYA.SD2
 2.5" OVERLAY 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
 4   4" Overlay             File Name: OVERLAYB.SD2
 4" OVERLAY 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)
 5   Reconstruction         File Name: RECONST.SD2
 RECONSTRUCTION 120 STATE TREATMENT EFFECTIVENESS - JANUARY 1991 (fixed field)

There are   1 Input Errors
Highest Error Severity is 2
Errors are on file: CONNPAVE.ERR
Ready to review errors

<Return> for more . . .

ERROR SEVERITY 2 - ANNUAL BUDGET SUM LESS THAN TOTAL
Type "A" <Return> to continue to run case: a
Start
-- Writing Input for LPS
-- Writing ROWS
```

Figure 19. Summary of Input Errors and Start of LPS

```
              FLP867 Version 3.15    1/06/89
            Single User License 315121234

            Requires 562200 bytes free and an 8087
          and handles LPs with bounded variables and
     # rows ≤1500, # columns ≤5000, # NZ elements ≤18000

    Coded by Craig M. Jannusch and W. Charles Mylander
             Copyright (c) 1986,1987 by AAEC
                   All Rights Reserved

Problem File:  CONNPAVE.INP
Solution File: CONNPAVE.SLN
Min-Max:       Min
Iteration Log Print Frequency: 10

          Start reading input   -->  15:28:14.72

          cfd

 Row section being read...
 Column section being read...
```

Figure 20. Title Screen for FLP867

```
Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
A1:
1      A       B       C       D       E       F       G       H
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
SHEET1.WK1   [1]                                          NUM        READY
```

Figure 21. Blank Spreadsheet for POSTPAVE

case-specific output in it, a copy of POSTPAVE.WK1 named TEMPLATE.1 is also provided. Should POSTPAVE become corrupted, use the DOS Copy command, "Copy TEMPLATE.1 POSTPAVE.WK1" to restore it.

For this tutorial, begin with the spreadsheet as displayed in Figure 21*. From the spreadsheet, select "File" and change the directory to PAVEMENT (Figure 22).

Next, retrieve the template POSTPAVE. The screen should appear as shown in Figure 23. The menu shown in the upper left corner is at level "s" and can be reaccessed by typing <Alt-s>.

On selecting "Read", you are prompted for an output file name. For this example, use CONNPAVE.OUT as shown in Figure 24. On most computers, the macro commands to read and convert the output file take a significant amount of time. The named file is not altered, but the worksheet file will now contain a copy of the output file in spreadsheet format. Be careful not to store this spreadsheet with its input file name POSTPAVE. Should you inadvertently do this, see the instructions above for restoring POSTPAVE.

The screen then appears as shown in Figure 25. Note that the title appears on line 21. This is because, at this stage, the spreadsheet still contains the macros as shown in Figure 26. These can be removed and a "clean" spreadsheet created by again accessing the menu by typing <Alt-s> and selecting the "clean" option.

You are next prompted to enter an "xtract" file name as shown in Figure 27. This can be selected from the existing list or a new file in the subdirectory PAVEMENT can be created. In Figure 28, we are creating a QUATTRO PRO(c) file in the subdirectory QPRO.

<u>The Output Command</u>

The "Output" command creates a network file from any network table in a spreadsheet created from PAVEMENT output. Its principal purpose is to provide a means of using the resultant network of one optimization as the initial network for a subsequent optimization.

While in POSTPAVE, access the menu by typing <Alt-s> and then select "Output". After doing so, place the cell pointer on the upper left entry (RURAL LOW LOW) of the desired network table as shown in Figure 29. Immediately on entry of this macro, there is a built-in pause to allow this cursor placement to be made. Unfortunately, there is no way to prompt the user about the purpose of this pause. Once the cursor is in the correct position, type <Return> and the macro will continue. As shown in Figure 30, prompts will occur asking for the NETWORK file name to be created and the description record which appears as the first line of the file. In this case, we create a file named NETTEST.SD1.

---

* Note that, in this case, we are using Quattro Pro (c) with a 123 - compatible menu tree.

```
 Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
A1:
1       A        B        C     Retrieve
1                               Save                                Ctrl-S
2                               Combine
3                               Xtract
4                               Erase
5                               List
6                               Import
7                               Directory                 C:\QPRO\
8
9                          Enter name of directory:
10                         c:\pavement
11
12
13                                   °Enter°        Esc
14
15
16
17
18
19
20
Change temporary directory                                             EDIT
```

Figure 22.   Change the Directory to PAVEMENT

```
Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit

 Read             A                 B        C        D        E
 Output
 Clean
 Quit

25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
Read a Pavement Optimization Output File                          MACRO MENU
```

Figure 23.   Menu in POSTPAVE

```
 Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
[Enter] [Esc] Enter Pavement Output File Name: connpave.out
1                  A                  B        C        D        E
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

A21: [W30]                                                        MACRO EDIT
```

Figure 24.   Select CONNPAVE.OUT

```
 Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
A21: [W30] ' CONNECTICUT PAVEMENT MANAGEMENT OPTIMIZATION
1                  A                  B        C        D        E
21   CONNECTICUT PAVEMENT MANAGEMENT OPTIMIZATION
22   cfd26
23
24   Microprocessor Version 2.2                    Copyright (C) 1989, 1990.
25   This program was prepared under the sponsorship of
26    The Joint Highway Research Advisory Council
27      The Connecticut Department of Transportation
28      The University of Connecticut
29
30    Authors: Christian F. Davis, Professor of Civil Engineering
31             C. Peter Van Dine, Consultant
32
33   This module is preset to run 120 States
34                 Broken down by:  10 Condition Levels
35                                   3 ADT Levels
36                                   2 Cracking Rate Levels
37                                 and Urban & Rural Environments
38
39   MODELS USED:
40    BUDGET                          File Name: BUDGET.SD1

POSTPAVE.WK1 [1]                                        NUM            READY
```

Figure 25.   CONNPAVE.OUT

```
 Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
A1: [W30] '{goto}a8192~{end}{up}{let a2,@cellpointer("address")}/fx~{?}~k21.
1                    A                     B         C         D         E
1   {goto}a8192~{end}{up}{let a2,@cellpointer("address")}/fx~**L>>>>>>>>>>>>>
2                                                              L>>>>>>>>>>>>>>>
3   ~
4                                                              L>>>>>>>>>>>>>>>
5   {goto}file~
6   {menubranch special}
7   {goto}file~
8
9   Read                          Output   Clean    Quit
10  Read a Pavement Optimization OCreate a Create a Return to READY mode
11  {branch readfile}             {branch o{branch c{goto}file~
12
13
14
15
16
17
18
19
20
POSTPAVE.WK1 [1]                                                NUM          READY
```

Figure 26. Macros in POSTPAVE

```
 Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
A1: [W30] '{goto}a8192~{end}{up}{let a2,@cellpointer("address")}/fx~{?}~k21.
1                    A                     B         C         D         E
1   {goto}a8192~{end}{up}{let a2,@cellpointer("address")}/fx~**L>>>>>>>>>>>
2                                                                       >>>>>
3   ~               Enter xtract file name:
4                   C:\PAVEMENT\*.WK1                                   >>>>>
5   {goto}file~     CFD.WK1         CFD10.WK1       CFD11.WK1
6   {menubranch spe CFD12.WK1       CFD13.WK1       CFD15.WK1
7   {goto}file~     CFD16.WK1       CFD17.WK1       CFD18.WK1
8                   CFD19.WK1       CFD20.WK1       CFD21.WK1
9   Read
10  Read a Pavement Optimization OCreate a Create a Return to READY mode
11  {branch readfile}             {branch o{branch c{goto}file~
12
13
14
15
16
17
18
19
20
POSTPAVE.WK1 [1]                                                NUM    MACRO FILES
```

Figure 27. Prompt to Enter Xtract File Name

```
 Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
A1: [W30] '{goto}a8192~{end}{up}{let a2,@cellpointer("address")}/fx~{?}~k21.
                 A                 B       C        D        E
1   {goto}a8192~{end}{up}{let a2,@cellpointer("address")}/fx~**L>>>>>>>>>>>>
2                                                                       >>>>>>
3   ~               Enter xtract file name:
4                   C:\QPRO\TEST.WQ1                                    >>>>>>
5   {goto}file~
6   {menubranch spe
7   {goto}file~                    *Enter*       *Esc*
8
9   Read
10  Read a Pavement Optimization OCreate a Create a Return to READY mode
11  {branch readfile}              {branch o{branch c{goto}file~
12
13
14
15
16
17
18
19
20

POSTPAVE.WK1 [1]                                                NUM     MACRO EDIT
```

Figure 28. Creating a QUATTRO PRO (c) File

```
 Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
B221: (F2) 1.5
                  A                   B        C        D         E
217
218  YEAR  1  RESULTANT NETWORK BY STATE   AVERAGE CONDITION   6.44   TOTA
219                      RATE OF
220 ENVIRONMENT   ADT   CRACKING         1        2        3         4
221    RURAL     LOW      LOW          1.50    12.00    19.00     12.50
222    RURAL     LOW      HIGH        11.00     9.50     3.50     14.00
223    RURAL     MEDIUM   LOW          0.50     0.00     2.00     10.50
224    RURAL     MEDIUM   HIGH        12.00     7.50     2.00      6.00
225    RURAL     HIGH     LOW          0.72     0.00     3.00     10.50
226    RURAL     HIGH     HIGH         1.79     4.65     2.50      7.50
227    URBAN     LOW      LOW          0.50     0.00     3.50     13.50
228    URBAN     LOW      HIGH        12.00     7.50     5.00     19.50
229    URBAN     MEDIUM   LOW          0.00     0.00     3.00     10.50
230    URBAN     MEDIUM   HIGH         0.00     0.00     2.50      7.50
231    URBAN     HIGH     LOW          0.00     0.00     3.50     10.00
232    URBAN     HIGH     HIGH         0.00     0.00     2.50      7.50
233
234  SUMMARY TABLES:
235
236   NETWORK CONDITION                     YEAR

POSTPAVE.WK1 [1]                                                NUM     MACRO POINT
```

Figure 29. Cursor Must be on Upper Left Entry

```
 Worksheet  Range  Copy  Move  File  Print  Graph  Data  View  System  Quit
[Enter] [Esc] Enter Output File Name: nettest.sd1
1                   A                  B        C        D        E
217
218   YEAR  1  RESULTANT NETWORK BY STATE    AVERAGE CONDITION   6.44     TOTA
219                         RATE OF
220 ENVIRONMENT   ADT    CRACKING           1        2        3        4
221     RURAL     LOW      LOW            1.50    12.00    19.00    12.50
222     RURAL     LOW      HIGH          11.00     9.50     3.50    14.00
223     RURAL     MEDIUM   LOW            0.50     0.00     2.00    10.50
224     RURAL     MEDIUM   HIGH          12.00     7.50     2.00     6.00
225     RURAL     HIGH     LOW            0.72     0.00     3.00    10.50
226     RURAL     HIGH     HIGH           1.79     4.65     2.50     7.50
227     URBAN     LOW      LOW            0.50     0.00     3.50    13.50
228     URBAN     LOW      HIGH          12.00     7.50     5.00    19.50
229     URBAN     MEDIUM   LOW            0.00     0.00     3.00    10.50
230     URBAN     MEDIUM   HIGH           0.00     0.00     2.50     7.50
231     URBAN     HIGH     LOW            0.00     0.00     3.50    10.00
232     URBAN     HIGH     HIGH           0.00     0.00     2.50     7.50
233
234  SUMMARY TABLES:
235
236   NETWORK CONDITION                         YEAR
B221: (F2) 1.5                                                          MACRO WRITE
```

Figure 30.   Creating and Output File NETTEST.SD1

4.4 Other Considerations

PAVEPRT

As demonstrated above, the PAVEMENT program affords the opportunity to print the ASCII output file. This is accomplished by the use of the printer program PAVEPRT. It provides pagination with user-specified page length, left margin offset (for loose leaf punching and binding), and supporting narrow (80 column) or wide(132 column) carriages. It can also be used as a stand-alone program with the command line parameters <filename> <printerport or filename>.

Input Logic Errors

The input is checked for both logic and typographical errors. The input checking program requires the user to name (or accept a default name) several input files. If any of the named files do not exist, the user is prompted to try again. In addition, the following logic errors are checked, recorded, and reported:

Severity 1 - Warning
- Annual Budget Limit is greater than Total Budget.
- Annual Treatment Limit is greater than Total Network Miles.
- Deterioration Probability decreases Condition level by more than 3.

Severity 2 - Error
- Sum of Annual Budget Limits is less than Total Budget.
- Deterioration Probability changes ADT level.
- Deterioration Probability changes Environment level
- Treatment Effectiveness Probability changes ADT level.
- Treatment Effectiveness Probability changes Environment level.

Severity 3 - Fatal Error
- Treatment Effectiveness Probabilities for a given Treatment and state do not sum to 1.
- Deterioration Probabilities from a given State do not sum to 1.
- Deterioration Probability increases the Condition level.
- Treatment Effectiveness Probability decreases Condition Level.
- Annual Treatment Constraint for a given year is in error.
- Annual Budget Constraint for a given year is in error.
- Sum of Treatment Minimums for a given year greater than Total Network Miles.
- Number of Treatments greater than fixed Maximum.
- Treatment Effectiveness File for a given Treatment does not exist.

The details of the errors appear on the temporary file CONNPAVE.ERR, and if any errors appear, the user is given the opportunity to view this file before making a decision to run the case being entered. Note that the case will run with logic errors of

Severity 1 or 2 but will not run with errors of Severity 3.

PAVEMENT Temporary Files

The following files are produced by the PAVEMENT program. CONNPAVE.INP and CONNPAVE.SLN are rather large. They are overwritten each time a case is run. To save one of them rename or copy the file using DOS.

- CONNPAVE.ERR: Listing of input errors.
- CONNPAVE.INP: Input formatted for LPS867.
- CONNPAVE.SLN: Solution file from LPS867.
- CONNPAVE.CMB: Input formatted for solution file processor.
- CONNPAVE.OUT: Pavement system output file.

5. Test Runs

As of February 1991, numerous runs of the model have been made by ConnDOT and at the University of Connecticut. The types of analyses and displays that are possible are many. Presented in this section are several that we feel are typical and valuable. In each case, the graphical displays were developed from spreadsheets created using POSTPAVE.

5.1 20-Year Deterioration

In order to test the reasonableness of the Deterioration model, five 4-year runs were made. (Five runs were required for the 286 class machine used. A 386 class machine can handle a 20-year problem in two runs.) The initial network for the first 4-year period, NETWORK.S10, consisted of 100 miles of roadway in each of the 12 categories in condition 10. Deterioration was then accomplished by specifying zero total budget for the 4-year period. The final "Resultant Network by State" was then used as the "initial" network in the subsequent 4-year period. This process was repeated for a total period of 20 years. The results are shown in Figure 31 using the "average" network condition at the end of each year as the ordinate.

5.2 Determination of Optimum Budget

The model directly optimizes the use of funds given a specific total budget and yearly budget constraints. In order to determine the "optimum" budget to be used, it is necessary to make several runs of the model assuming different total budgets.

Figure 32 results from five runs using total budgets ranging from \$20M to \$400M (with yearly constraints). The ordinate in this figure, "Relative Disutility", is the percentage above the total disutility for four years for NETWORK.S10 described above. Note that the curve asymptotically approaches zero. The "optimum" budget is then a matter

Figure 31. Deterioration over 20 Years

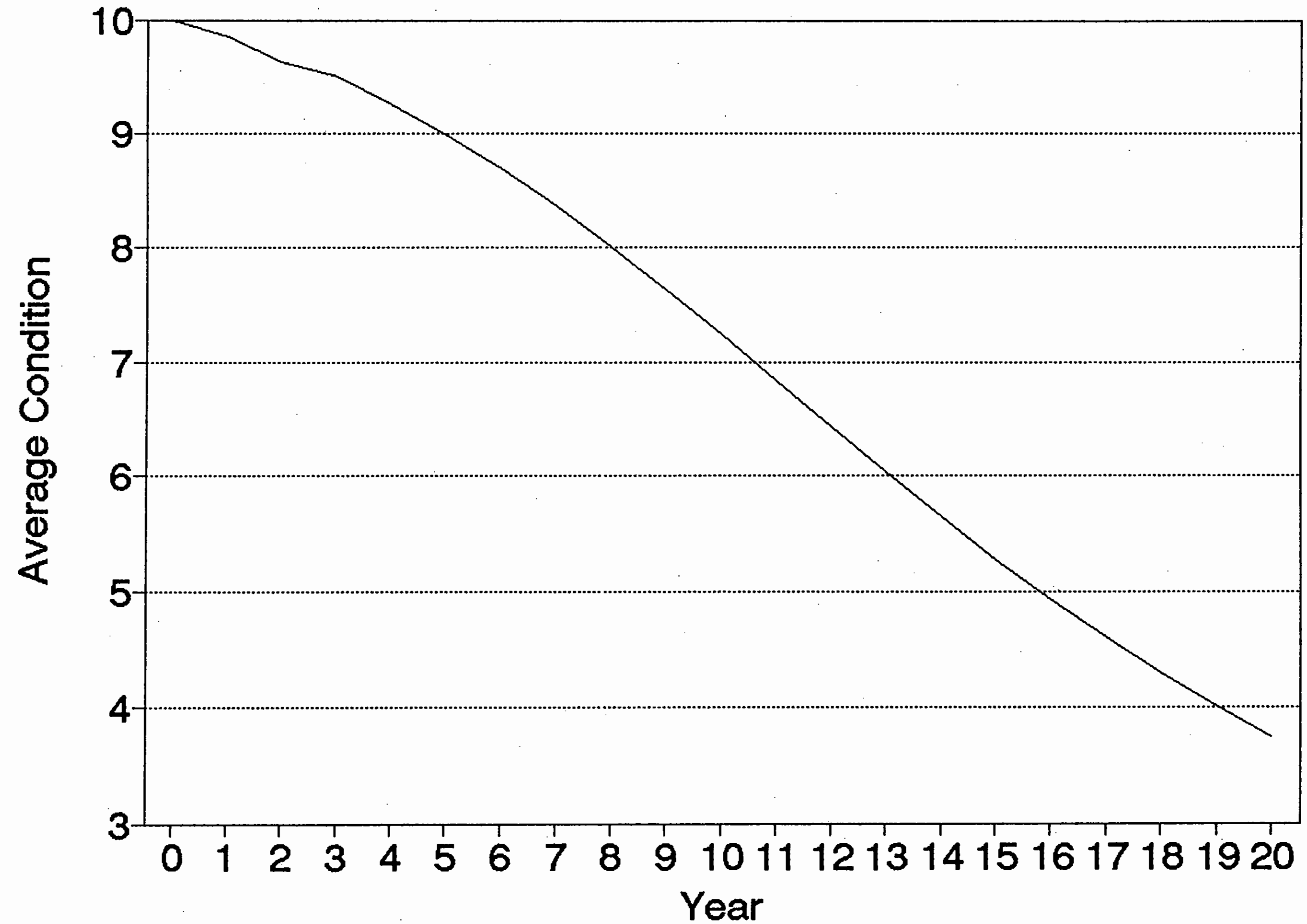
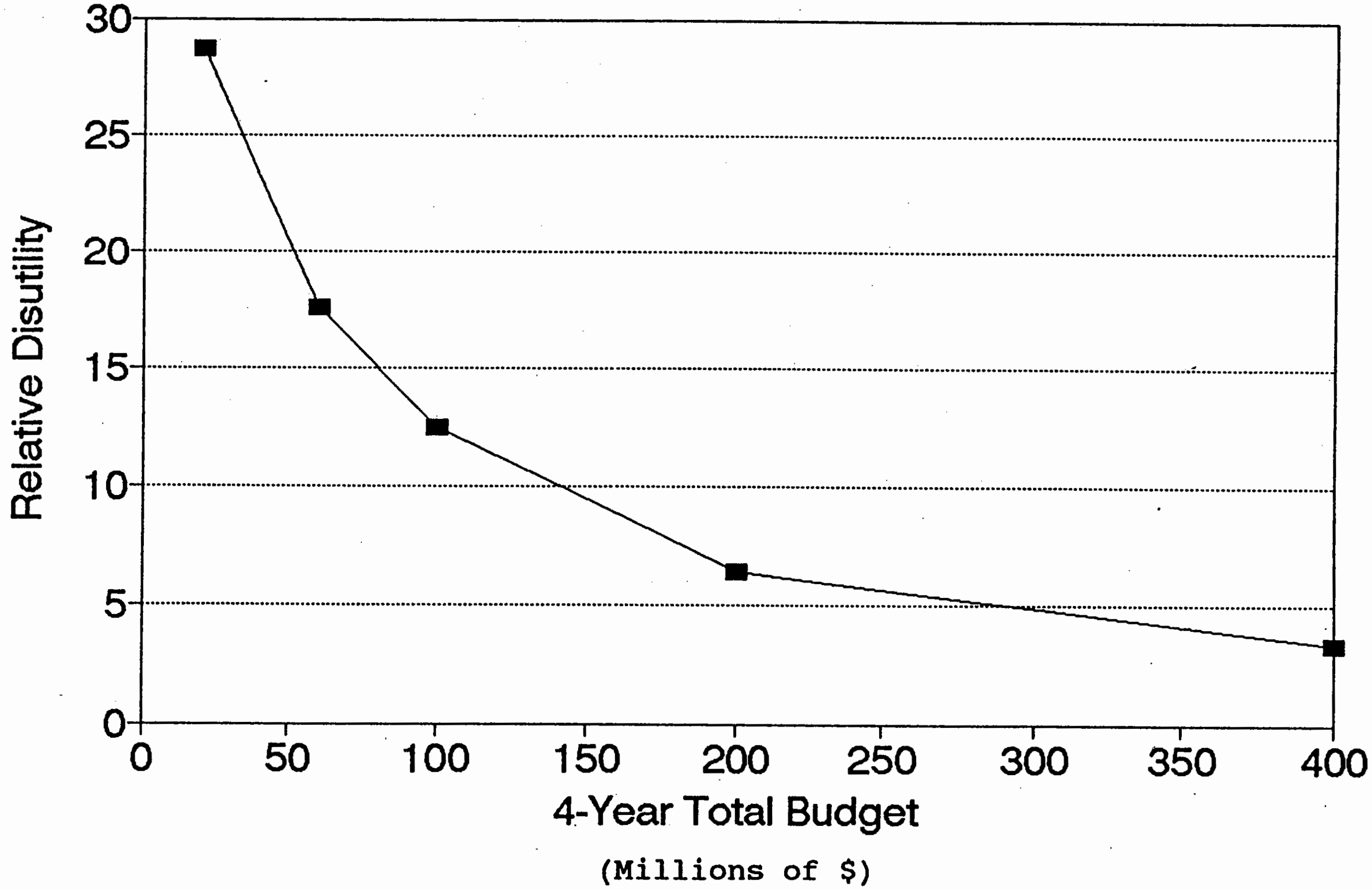


Figure 32. Determination of Optimum Budget



of judgement similar to that used in the "knee-of-the-curve" concept for design hourly volumes. The optimum could be based on an "allowable" relative disutility or by selecting a point where the curve starts to rise sharply. In the example shown, the optimum would appear to be about $120M.

It is important to note that this (and all of the following figures) are intended to demonstrate the concepts involved and are examples only. They are based on the initial network NETWORK.SD1, which assumes 10 miles in each of the 120 states. While helpful for presentation purposes, this distribution is obviously not the existing actual distribution for Connecticut highways.

5.3 Budget to Maintain a Given Condition Level

The technique described in the preceding section can also be used to determine the budget required to achieve and maintain a given condition level. Shown in Figure 33 are two curves resulting from several runs using the Disutilities file DISUTIL.LV4. In this file, very high disutilities (100) were assigned to all states in condition levels 1, 2, and 3. The cases represented by the solid curve had yearly budget constraints (equal to one-fourth the total) while those represented by the dashed curve had no yearly budget constraints. Note that, while the knee of the curve (identifying an "optimum" budget) is not apparent for the solid curve, it is clear for the dashed curve. That is, total budgets of more than about $200 M provide very little reduction in disutility. The value of flexibility in timing of expenditures is obvious.

5.4 Treatments by Year

Figures 34 and 35 were created using the graphic capabilities of Quattro Pro (c) and represent just one of the many possible displays of the results of a single run of the model. The run whose results are displayed in Figure 34 corresponded to a total budget of $100M constrained to a maximum yearly budget of $25M. Note that the full $25M was used in each year and (not surprisingly, given the initial network) results in very nearly identical strategies for each year. Figure 35 is a bit more interesting. Here, the yearly budget constraints have been removed, with the result that treatment strategies vary from year to year.

5.5 A Note on TREATUSE.SD3

Since the creation of the most recent version of the main menu, several slight adjustments were made to the Treatment Effectiveness files. Thus, we suggest that TREATUSE.SD3 be considered the present default Treatment Used input file.

6. Summary

The mainframe version of the linear programming optimization model has been successfully converted to a microcomputer version which is fully operational at ConnDOT and at UCONN. During the conversion

Figure 33. Budget to Maintain
Level 4 or Better

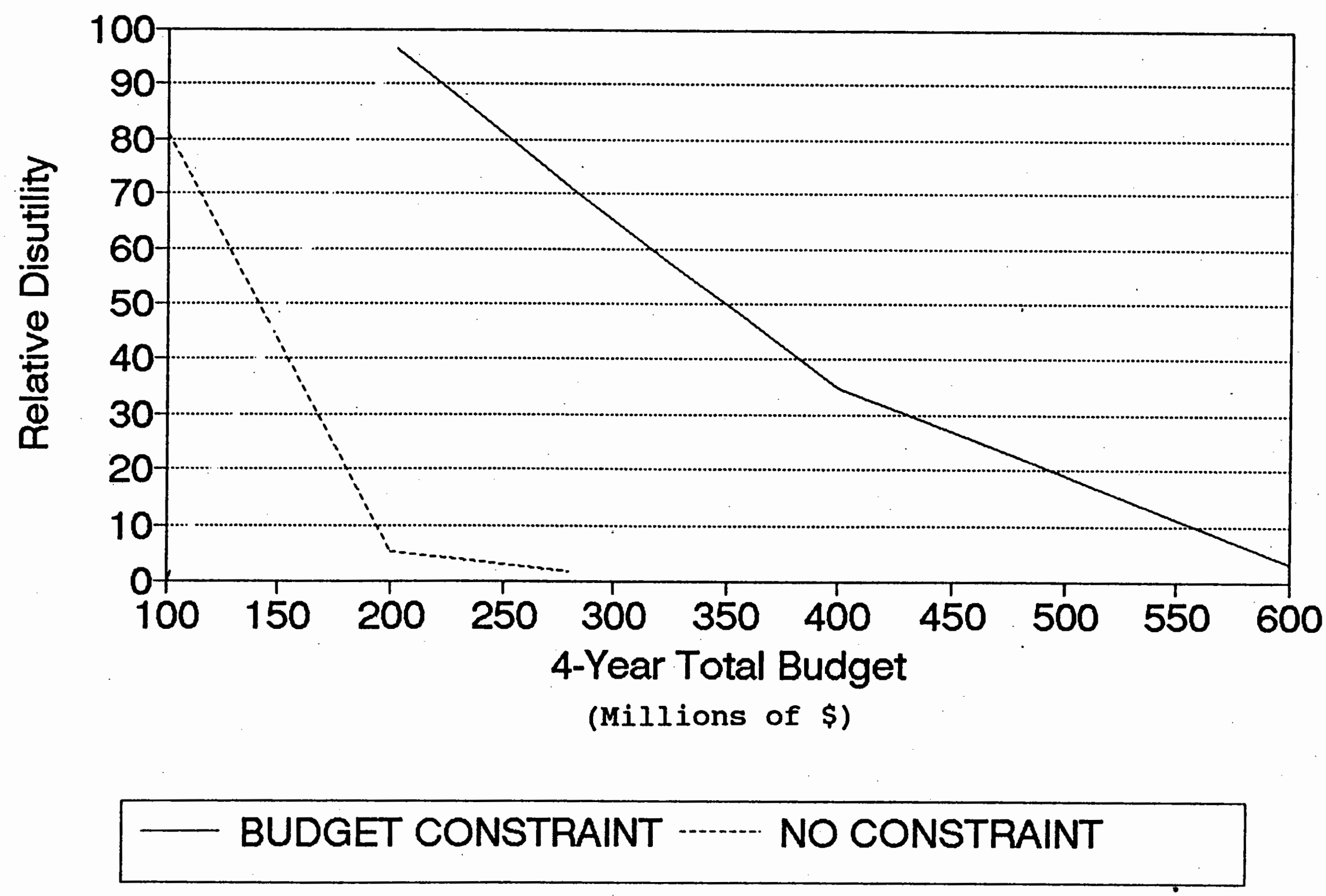


Figure 34. Treatments by Year

$25M per Year

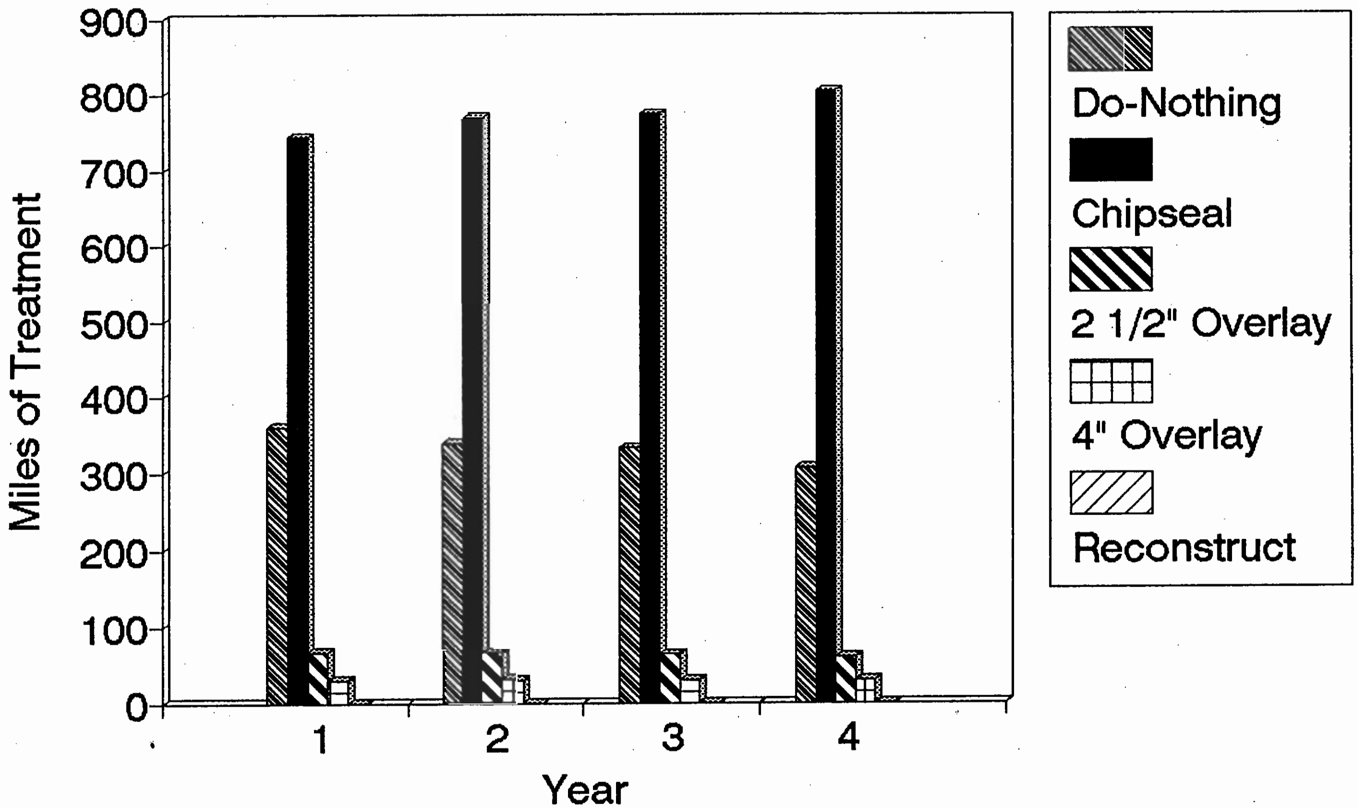
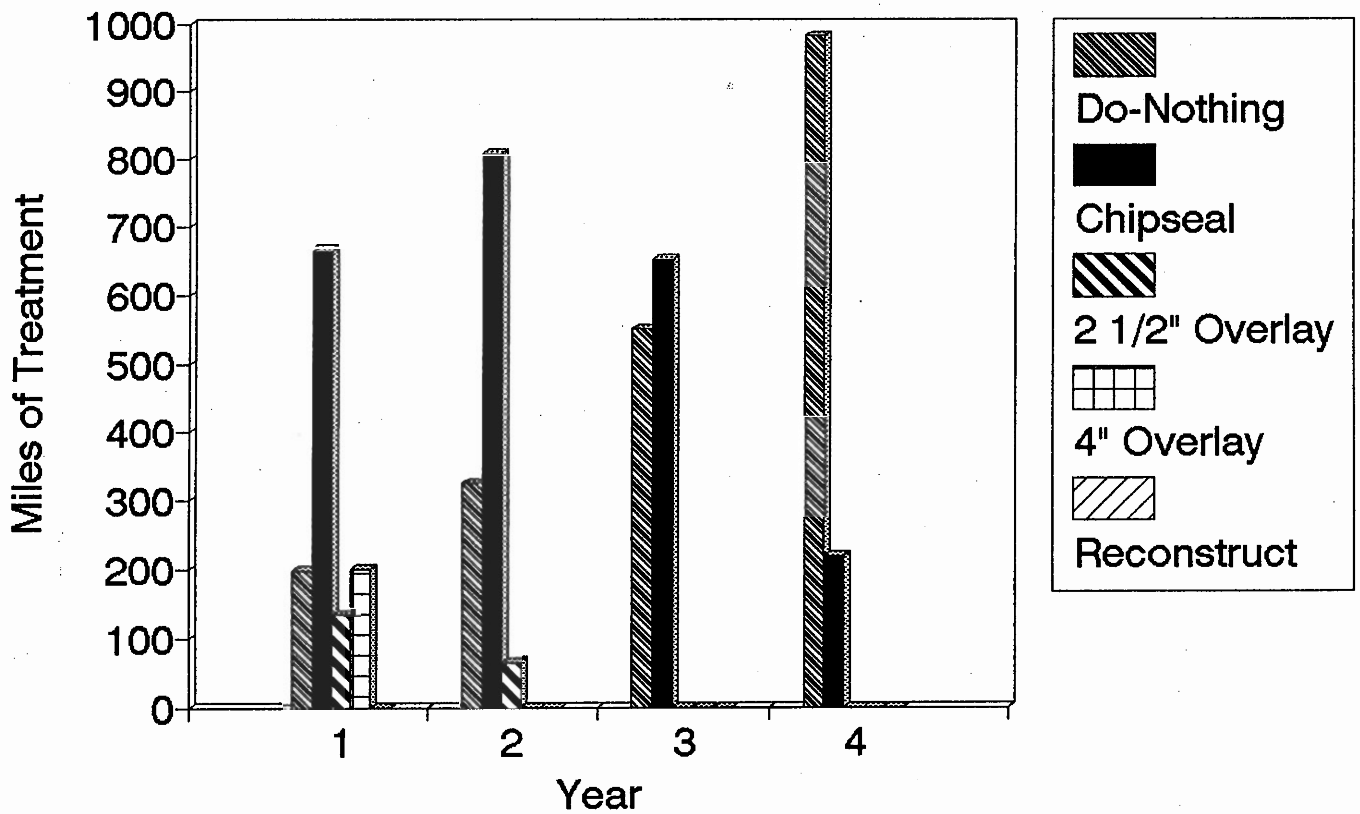


Figure 35. Treatments by Year

$100M Total Budget



process, numerous refinements and improvements were made. The most notable improvements have been the incorporation of many user-friendly features including convenient means of creating and editing network files, spreadsheet creation, and use of resulting networks as input to subsequent optimizations.

It is important to recognize that the accuracy of the model will improve with time as field data provide more accurate representation of deterioration and treatment effectiveness. In addition, the concept of "disutility" can be further refined. Finally, it would appear to be worth investigating changing the environmental level of state specification to reflect, perhaps, different pavement types such as flexible, rigid, and composite.