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16. Abstract

This report describes the development of the State Cost Estimating Program which is a part of the Rehabilitation and Maintenance System (RAMS). This system has been developed by the Texas Transportation Institute for the Texas State Department of Highways and Public Transportation. The State Cost Estimating program provides procedures to a) calculate the current pavement score, b) calculate an appropriate funding strategy for these sections below a minimum score and c) calculate a reinspection date for those sections above a minimum score.

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THE DEVELOPMENT OF
THE RAMS - STATE COST ESTIMATING PROGRAM

by

T. Scullion

R. L. Lytton

Research Report 239-6F

Research Study 2-18-79-239
Pavement Rehabilitation Fund Allocation

Conducted for

The Texas State Department of Highways and Public Transportation

by the

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

November 1984

ABSTRACT

This report describes the development of the State Cost Estimating program which is part of the Rehabilitation and Maintenance System (RAMS). This system has been developed by the Texas Transportation Institute for the Texas Department of Highways and Public Transportation. The State Cost Estimating program provides procedures to a) calculate the current pavement score, b) calculate an appropriate funding strategy for those sections below a minimum score and c) calculate a reinspection date for those sections above a minimum score.

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The current PES system is viewed as a first-level system in the Department's continuing efforts to implement a Pavement Management System. This year's (1984) efforts are underway to a) incorporate rigid pavements into the system and b) predict maintenance requirements.

ACKNOWLEDGEMENTS

Many people have contributed significantly to the development and implementation of the RAMS-State Cost Estimating System. Joe P. Mahoney, now with the University of Washington, did much of the initial work. Many people within the Texas SDHPT also made significant contributions including Jim Brown (D-8), Bob Guinn (D-18), and Joel Young (D-19), to name but a few.

IMPLEMENTATION STATEMENT

The procedures described in this report have been implemented within the Department's Pavement Evaluation System. This system is being used to estimate funding levels for rehabilitation and reconstruction activities. However in an attempt to expand this system, the Texas Transportation Institute is currently developing decision trees which will be used to predict routine and preventative maintenance strategies for distressed pavements. It is anticipated that these decision trees will be incorporated into the system in the near future.

This current system does not include safety or capacity considerations in the pavement score calculations. Other current TTI projects are addressing these issues. An improved wet-weather safety index is being developed in Project 2342, and the applicability of the Highway Performance Monitoring System (HPMS) framework is being studied in Project 2480.

DESCRIPTION OF DEVELOPMENT OF THE RAMS-STATE COST ESTIMATING PROGRAM

Introduction

The Rehabilitation and Maintenance System - State Cost Estimating (RAMS-SCE) System is shown in flow chart in Figure 1. It is important to understand how the overall system works before the individual components are discussed in detail.

Referring to Figure 1, one highway segment is shown being processed through the complete system. First, the Current Pavement Score (PSC) is calculated for the highway segment being considered. This score is defined as a function of visual defects rating, roughness as measured with the Mays Ride Meter, skid number, and routine maintenance costs. The PSC is compared to the Minimum Pavement Score (PSM) which has been assigned to the highway segment being considered. If the PSC is less than PSM (i.e., the minimum), then maintenance or rehabilitation must be considered for this segment. Otherwise, if the PSC is larger than PSM, this segment is considered acceptable for the current budget cycle and a date at which the pavement should be reinspected is calculated. The next highway segment is selected and processed in the same manner.

If the PSC is less than the acceptable minimum, then various funding strategies must be considered for this highway segment. Funding strategies are approximately equivalent to maintenance or rehabilitation strategies, but selection of a funding strategy does

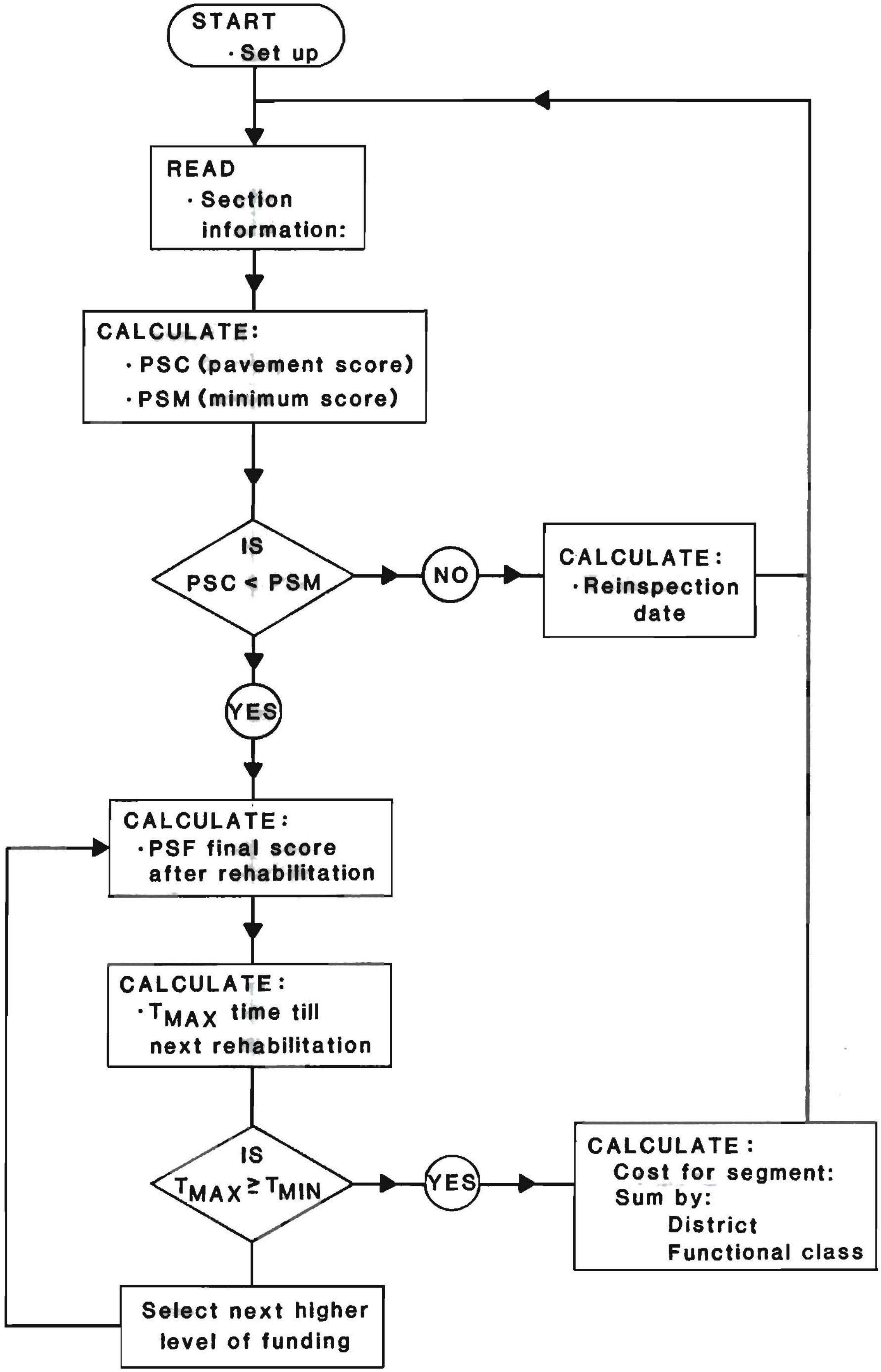

FIGURE 1. Maintenance and Rehabilitation System Flow Chart

imply that a specific type of maintenance or rehabilitation must be used. A funding strategy is an attempt to make available the proper amount of money required to maintain a highway segment. The detailed design of a specific maintenance or rehabilitation technique should be done (as in the past) at the resident or district level.

Figure 2 shows graphically how a given funding strategy can affect the highway segment being considered. The ordinate axis is Pavement Score (PSC) and the abscissa is time in years. The following definitions apply to this figure:

1. PSF: Pavement Score immediately after a maintenance or rehabilitation funding strategy is applied to a highway segment.
2. PSM: Minimum acceptable PSC and is a function of the highway functional classification.
3. PSC: Pavement Score prior to application of any maintenance or rehabilitation funding strategy to the highway segment. This is the current PSC.
4. TC: Time of constant service after a maintenance or rehabilitation funding strategy is applied to a highway segment.
5. TMAX: Time a maintenance or rehabilitation funding strategy will last until the PSM (minimum acceptable) is reached.
6. DS: Funding strategy deterioration rate or slope.

This figure shows in a somewhat idealized way how a given maintenance or rehabilitation funding strategy deteriorates after being applied to a highway segment. Since the PSC is based on a 0 to 1 utility scale,

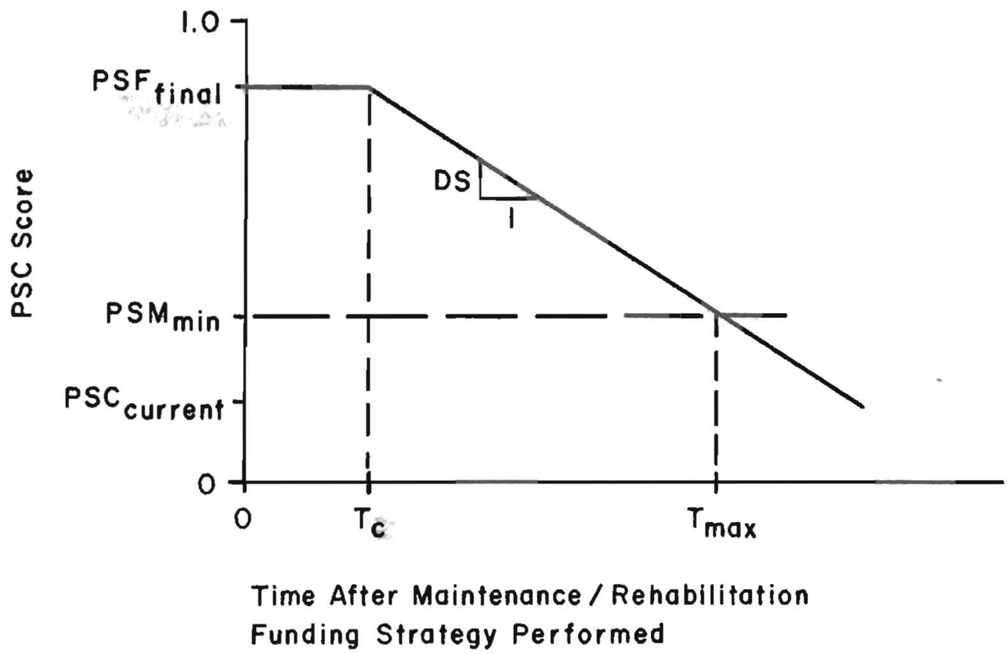

FIGURE 2. Idealized Pavement Performance Cycle in PES System. T_{max} is time in years for the rehabilitated pavement to reach a minimum acceptable level.

the best a funding strategy can do is to achieve a PSF equal to one. It is further assumed that a funding strategy will maintain a constant pavement score for a period of time after it is applied (TC). Following this constant pavement score level, the funding strategy will begin to deteriorate with a constant slope (DS). The time it takes to reach the minimum acceptable pavement score (PSM) is the life of the funding strategy. At this point, another funding strategy must be considered.

Once all of the required information for Figure 2 has been developed for a highway segment, a final comparison is made (Figure 1). The TMAX is compared to the minimum acceptable time the SDHPT is willing to tolerate between funding strategies (TMIN). The funding strategy that produces a TMAX which just equals or exceeds this TMIN is selected for use, i.e., less expensive funding strategies are not acceptable and more expensive funding strategies are not necessary.

Following the selection of the appropriate funding strategy, the total cost per lane-mile is calculated for the highway segment being considered. This amount is added to the existing totals for presentation in the District summary tables. The next highway segment is then selected for processing in a similar manner.

There are a number of input variables required to use the system outlined in Figure 1. These variables range from the different kinds of pavement types to deterioration slopes for various funding strategies. Each of these sets of variables are discussed separately in the following sections of this report.

Description and Input Variables

Pavement types. A listing of the pavement types is shown in Table 1. The list includes ten pavement types and ranges from continuously reinforced concrete (EP-1) to thin surfaced flexible base (EP-10). These descriptions are intended to cover a range of existing pavement types which compose the existing state maintained highway network. These descriptions are based on the current cross section of a pavement structure - not the original construction alone. The Pavement Evaluation System, which calculates score and funding strategy, has been implemented only for pavement types EP-4 through EP-10. Efforts are underway to extend this system to handle rigid pavements, EP-1 through EP-3. In 1984, condition data on rigid pavements will be collected for the first time and a pavement score calculation procedure has been defined. However, as of yet, no funding strategy procedure exists, and additional work is needed in this area.

Funding strategies. A description of the currently considered funding strategies and their equivalent maintenance and rehabilitation strategies are shown in Table 2. A total of five funding strategies are used ranging from the equivalent of seal coat maintenance (R-1) to a 7 1/2 in. thick asphalt concrete overlay (R-5). These funding strategies were selected from a listing originally prepared by J. L. Brown (1).

Visual defect evaluation form for flexible pavements. The form shown in Table 3 was jointly developed by the SDHPT and TTI for the 1984 data collection effort. The pavement rating procedure is

TABLE 1. Listing of Pavement Types

Pavement Type	Description
EP-1	Continuously reinforced concrete pavement
EP-2	Jointed reinforced concrete pavement
EP-3	Jointed plain concrete pavement
EP-4	Thick asphaltic concrete pavement (greater than 5 1/2" of hot-mixed asphaltic layers)
EP-5	Intermediate thickness asphaltic concrete pavement (2 1/2" to 5 1/2" of hot-mixed asphaltic layers)
EP-6	Thin surfaced flexible base pavement (hot-mixed asphaltic layers less than 2 1/2" thick)
EP-7	Composite pavement (concrete pavement which has received an asphalt overlay)
EP-8	Overlaid and/or widened old concrete pavement
EP-9	Overlaid and/or widened old flexible pavement
EP-10	Thin surfaced flexible base pavement (surface treatment - seal coat combinations)

TABLE 2. Listing of Funding Strategies

Funding Strategy	Description of Equivalent Maintenance or Rehabilitation	
	Hot Mix Pavement	Surface Treated Pavement
R-1	Seal coat, or fog seal, or extensive patching plus seal	Seal Coat
R-2	1" ACP overlay, or seal plus level-up	Partial reconstruction
R-3	2 1/2" ACP overlay	Full reconstruction, reworking and adding additional base and surfacing
R-4	4" ACP overlay or rotomill plus thin overlay	Not applicable
R-5	7 1/2" ACP overlay or reconstruction	Not applicable

State Department of Highways
and Public Transportation
FORM 1624 (Replaces Form 1505)

TABLE 3.

FLEXIBLE PAVEMENT EVALUATION

6-84

SYSTEM - ID & CARD - ID: M M S (1 2 3) E 1 (4 5)

DISTRICT NO. (6 7)

RATERS: (8–29) (30–51)

DATE: MONTH (52 53) DAY (54 55) YEAR (56 57)

PAVEMENT CONDITIONS

COMMENTS / NOTES

NOTE: Zero should be inserted in appropriate pavement condition column if no visual defect is noted.

LOCATION

SYSTEM ID	CARD - ID	COUNTY NO.	FOREMAN NO.	HIGHWAY NO. PRE. / NO. / SUF.	FROM MILEPOST	FROM ± DISPLACEMENT	TO MILEPOST	TO ± DISPLACEMENT	LANE	RUTTING (1/2"-1" = 1, >1" = 2; % Area: 1 - 25, 26 - 50, > 50)	PATCHING (% Area: 1 - 10, 11 - 50, > 50)	FAILURES (No. per LN./MI.: 1 - 5, 6 - 10, > 10)	BLOCK CRACKING (% Area: 1 - 10, 11 - 50, > 50)	ALLIGATOR CRACKING (% Area: 1 - 10, 11 - 50, > 50)	LONGITUDINAL CRACKING (Lin. Ft. per Sta./Ln.: 10 - 99, 100 - 200, > 200)	TRANSVERSE CRACKING (No. per Sta: 1 - 4, 5 - 10, > 10)	COMMENT CODE	SPEED LIMIT	PAVEMENT TYPE	COMMENTS / NOTES
M M S	E 2																			
M M S	E 2																			
M M S	E 2																			
M M S	E 2																			
M M S	E 2																			
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M M S	E 2																			
1 2 3	4 5	6 7 8	9 10	11 12 13 14 15 16 17	18 19 20	21 22 23	24 25 26	27 28 29	30	31 32 33	34 35 36	37 38 39	40 41 42	43 44 45	46 47 48	49 50 51	52 53	54 55	56 57	58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

Pavement Types

Code	Description
1	Continuously Reinforced Concrete Pavement
2	Jointed Reinforced Concrete Pavement
3	Jointed Plain Concrete Pavement
4	Thick Asphaltic Concrete Pavement (greater than 5 1/2")
5	Intermediate Thickness Asphaltic Concrete Pavement (2 1/2" to 5 1/2")
6	Thin Surfaced Flexible Base Pavement (less than 2 1/2")
7	Composite Pavement (Asphalt Surfaced Concrete Pavement)
8	Overlaid and/or Widened Old Concrete Pavement
9	Overlaid and/or Widened Old Flexible Pavement
10	Thin Surfaced Flexible Base Pavement (Surface Treatment-Seal Coat Combination)

Comment Codes

Code	Description
01	Concrete Pavement with Asphaltic Level-up
10	Encroachment
11	Automobile Encroachment
12	Agricultural Encroachment
13	Advertisement Encroachment
20	Signal
21	Improper Operating Signal
22	Improper Operating Flashing Signal
30	Geometrics
31	Improper Speed Signing of Curve
32	Improper Striping of No Passing Zone
40	Roadside Hazard
41	Dangerous Sign Support
42	Dangerous Tree
43	Dangerous Slope
50	Bridge
51	Narrow Bridge
52	Damaged Bridge Railing
53	Damaged Bridge Superstructures
60	Pest Control

described in detail in the Department's Raters Manual (3). This form is a composite of the original visual condition survey procedure developed in Study 151 (2) and the new utility concepts. The data collected with this form is used to calculate the visual defect utility which is a component of the current pavement score (PSC). This score will be further discussed in the next subsection.

Additional inputs required for calculating the current PS (PSC). Table 4 shows the additional inputs necessary to calculate the current PS (PSC) for each highway segment. The inputs which would be included in this table would fall into the categories used in Tables 5, 6, 7, and 8.

To calculate the PSC for a highway segment these inputs and the appropriate utility curves are required. The proposed overall pavement score equation is as follows:

$$PSC = [(AVU)^{a_1} (SIU)^{a_2} (SKU)^{a_3} (RMCU)^{a_4}]^{1/FC} \quad (1)$$

where

PSC = Pavement Evaluation System score which represents the current condition of a highway segment.

AVU = Adjusted visual defect utility.

SIU = Serviceability index utility.

SKU = Skid number utility

RMCU = Routine maintenance cost utility.

a_1, a_2, a_3, a_4 = Weighting factors.

$a_1 = \frac{1}{(ADTF)(KEF)}$ and $a_2 = a_3 = a_4 = 1$

TABLE 4. Additional Inputs Required to Calculate Pavement Score

1. Highway Functional Class
2. ADT/Lane
3. 18-kip Equivalent Single Axles in Design Lane
4. Rainfall (in./year)
5. Freeze-Thaw Factors (cycles/year)

Inputs 4 and 5 are available on a county basis. For each section a county number is input, these environmental factors are obtained via a table look-up.

TABLE 5. Rainfall Factors

Rainfall (in./yr.)	Rainfall Factor (RF)
20 or less	1.00
21 - 40	0.97
greater than 40	0.94

TABLE 6. Freeze-Thaw Factors

Freeze Cycles (cycles/year)	Freeze-Thaw Factors (FF)
10 or less	1.000
11 - 30	0.973
31 - 50	0.967
greater than 50	0.960

TABLE 7. Average Daily Traffic Factors (ADTF)

ADT/Lane	Average Daily Traffic Factors
300 or less	1.00
301 - 750	0.96
751 - 2000	0.92
2001 - 7500	0.88
7501 - 25,000	0.84
greater than 25,000	0.80

TABLE 8. 18-kip Equivalent Axle Load Factors (KEF)

18-kip EAL	18-kip EAL Factors
less than 6×10^6	1.00
$6 \times 10^6 - 12 \times 10^6$	0.95
greater than 12×10^6	0.90

ADTF = Average daily traffic factor.

KEF = 18-kip equivalent axle loading factor.

FC = Functional Class weighting factor.

Functional Class	Factor
1	0.80
2	0.80
3	0.80
4	0.90
5	0.95
6	1.00

$$AVU = (U_{rutting})^{b_1} (U_{patching})^{b_2} (U_{failures})^{b_3} (U_{block\ cracking})^{b_4} (U_{alligator\ cracking})^{b_5} (U_{longitudinal\ cracking})^{b_6} (U_{transverse\ cracking})^{b_7}$$

The utility inputs required to compute the AVU can be obtained from utility curves developed by SDHPT personnel. Equations which approximate these curves are as follows:

Rutting

1/2" - 1"

$$U_{rutting} = 1 - 1.020\ e^{-19.840(1/x)} \quad (3)$$

> 1"

$$U_{rutting} = 1 - 0.778\ e^{-16.392(1/x)} \quad (4)$$

where x = percent of area (wheelpath)

Patching

$$U_{patching} = 1 - 0.461\ e^{-10.277(1/x)} \quad (5)$$

where x = percent of area (total surface)

Failures

$$U_{failures} = 1 - 1.492\ e^{-6.204(1/x)} \quad (6)$$

where x = number of failures per mile

Block Cracking

$$U_{block\ cracking} = 1 - 0.4995\ e^{-9.900(1/x)} \quad (7)$$

where x = percent of area (total surface)

Alligator Cracking

$$U_{alligator\ cracking} = 1 - 0.549\ e^{-8.135(1/x)} \quad (8)$$

where x = percent of area (wheelpath)

Longitudinal Cracking

$$U_{longitudinal\ cracking} = 1 - 1.000\ e^{-191.20(1/x)} \quad (9)$$

where x = lin. ft. per lane per station

Transverse Cracking

$$U_{transverse\ cracking} = 1 - 0.741\ e^{-8.892(1/x)} \quad (10)$$

where x = number per station

For all equations listed above, the utility is 1.0 when x is zero. The b coefficients are tentatively determined by the following relationships with Rainfall Factor (RF) and Freeze-Thaw Factor (FF):

b_1 = 1/RF, rutting

b_2 = 1/(RF)(FF), patching

b_3 = 1/(RF)(FF), failures

b_4 = 1/(RF)(FF), block cracking

b_5 = 1/(RF)(FF), alligator cracking

b_6 = 1/(RF)(FF), longitudinal cracking

b_7 = 1/(RF)(FF), transverse cracking

The Rainfall Factor and Freeze-Thaw Factor can be obtained from Tables 5 and 6. For each distress type, there are only three possible non-zero values of x in the above equation (see inspection form in Table 3). To simplify programming, the possible utility values have been tabulated, the current values for flexible and composite pavements are shown in Tables 9 and 10, respectively.

Now that the required equations and table look-up values have been identified for visual distress, the procedures for determining the SIU, SKU, and RMCU will be discussed.

Serviceability Index

There are three curves available for use and these curves are a function of a factor defined by multiplying the ADT/Lane by the SPEED for each highway segment. The ADT/Lane is the Average Daily Traffic for the highway segment and SPEED is the posted speed limit for the highway segment.

TABLE 9. Utility Values for Flexible Pavement Distresses

Distress Type	Area Covered by Distress		
	Small (100)*	Moderate (010)	Extensive (001)
Rutting < 1"	0.931	0.810	0.760
Rutting > 1"	0.800	0.600	0.400
Patching	0.940	0.725	0.550
Failures	0.811	0.313	0.198
Block Cracking	0.930	0.700	0.508
Alligator Cracking	0.890	0.685	0.400
Longitudinal Cracking	0.970	0.720	0.616
Transverse Cracking	0.979	0.774	0.696

*The values in parenthesis indicate how the area of distress would be coded on the inspection form (Table 3), for example for alligator cracking a (100) would indicate 1-10% of area covered, (010) would indicate 10-50%, and (001) would indicate > 50%.

TABLE 10. Utility Values for Composite Pavement Distresses

Distress Type	Area Covered by Distress		
	Small (100)*	Moderate (010)	Extensive (001)
Rutting < 1"	0.941	0.846	0.826
Rutting > 1"	0.840	0.737	0.721
Patching	1.000	0.825	0.745
Failures	0.811	0.313	0.198
Block Cracking	0.980	0.818	0.720
Alligator Cracking	1.000	0.795	0.641
Longitudinal Cracking	0.970	0.842	0.800
Transverse Cracking	0.983	0.849	0.801

*The values in parenthesis indicate how the area of distress would be coded on the inspection form (Table 3).

Curve A: (ADT)(SPEED) < 27,500

SIU = 1.0	if $2.5 \le SI \le 5.0$
SIU = $1.0 - 0.10 \left(\frac{2.5 - SI}{0.5}\right)$	if $2.0 \le SI < 2.5$
SIU = $-0.2666 + 0.58333$ (SI)	if $0.8 \le SI < 2.0$
SIU = $0.20 \left(\frac{SI}{0.8}\right)^2$	if $0 \le SI < 0.8$
SUY = 0	if $SI < 0$

where

SIU = Serviceability Index Utility

SI = Serviceability Index (obtained by use of the Mays Ride Meter)

Curve B: 27,500 < (ADT)(SPEED) < 165,000

SIU = 1.0	if $3.0 \le SI \le 5.0$
SIU = $1.0 - 0.10 \left(\frac{3.0 - SI}{0.5}\right)$	if $2.5 \le SI < 3.0$
SIU = $-0.5583 + 0.58333$ (SI)	if $1.3 \le SI < 2.5$
SIU = $0.20 \left(\frac{SI}{1.3}\right)^2$	if $0 \le SI < 1.3$
SIU = 0	if $SI < 0$

Curve C: (ADT)(SPEED) > 165,000

SIU = 1.0	if $3.5 \le SI \le 5.0$
SIU = $1.0 - 0.10 \left(\frac{3.5 - SI}{0.5}\right)$	if $3.0 \le SI < 3.5$
SIU = $-0.85 + 0.58333$ (SI)	if $1.8 \le SI < 3.0$
SIU = $0.20 \left(\frac{SI}{1.8}\right)^2$	if $0 \le SI < 1.8$
SIU = 0	if $SI < 0$

Skid Number

There are three curves available for use and these curves are a function of a factor defined by multiplying the ADT/Lane by the Rainfall for each highway segment.

Curve A: (ADT/Lane)(Rainfall) > 350,000

$SKU = 1.0$	if $50 \leq SN < 75$
$SKU = 1.0 - 0.20 \left(\frac{50 - SN}{11}\right)^2$	if $39 \leq SN < 75$
$SKU = -1.4286 + 0.05714\ (SN)$	if $28.5 \leq SN < 39$
$SKU = 0.20 \left(\frac{SN}{28.5}\right)^2$	if $0 \leq SN < 28.5$
$SKU = 0$	if $SN < 0$

where

SKU = Skid Number Utility

SN = Skid Number (obtained by use of Texas SDHPT Skid Meter)

Curve B: 40,000 < (ADT/Lane)(Rainfall) < 350,000

$SKU = 1.0$	if $50 \leq SN \leq 75$
$SKU = 1.0 - 0.20 \left(\frac{50 - SN}{17.5}\right)^2$	if $32.5 \leq SN < 50$
$SKU = -1.05714 + 0.05714\ (SN)$	if $22 \leq SN < 32.5$
$SKU = 0.20 \left(\frac{SN}{22}\right)^2$	if $0 \leq SN < 22$
$SKU = 0$	if $SN < 0$

Curve C: (ADT/Lane)(Rainfall) < 40,000

$$SKU = 1.0 \qquad \text{if } 50 \leq SN \leq 75$$

$$SKU = 1.0 - 0.20 \left(\frac{50 - SN}{22.5}\right)^2 \qquad \text{if } 27.5 \leq SN < 50$$

$$SKU = -0.7714 + 0.05714\,(SN) \qquad \text{if } 17 \leq SN < 27.5$$

$$SKU = 0.20 \left(\frac{SN}{17}\right)^2 \qquad \text{if } 0 \leq SN < 17$$

$$SKU = 0 \qquad \text{if } SN < 0$$

Routine Maintenance Costs

There are three curves available for use and these curves are a function of the pavement type. The pavement type can be found in Table 3.

Pavement Type EP-10 (Surface Treatment)

$$RMCU = 1.0 \qquad \text{if } \$0 \leq RMC < \$1400$$

$$RMCU = 1.0 - 0.13 \left(\frac{RMC-1400}{700}\right)^2 \qquad \text{if } \$1400 \leq RMC < \$2100$$

$$RMCU = 2.697 - (8.7 \times 10^{-4})(RMC) \qquad \text{if } \$2100 \leq RMC < \$3100$$

$$RMCU = 0 \qquad \text{if } \$3100 \leq RMC$$

where

RMCU = Routine Maintenance Cost Utility

RMC = Routine Maintenance Cost per Lane-Mile

Pavement Types EP-4, EP-5, EP-6, EP-7, EP-8, and EP-9
(Asphalt Concrete Surfaced Pavement)

$$RMCU = 1.0 \qquad \text{if } \$0 \le RMC < \$2000$$

$$RMCU = 1.0 - 0.26 \left(\frac{RMC-2000}{1800}\right) \qquad \text{if } \$2000 \le RMC < \$3800$$

$$RMCU = 2.146 - (3.7 \times 10^{-4})(RMC) \qquad \text{if } \$3800 \le RMC < \$5800$$

$$RMCU = 0 \qquad \text{if } \$5800 \le RMC$$

Implementation of Pavement Score Approach

The described pavement score calculation procedure has been implemented within the SDHPT Pavement Evaluation System. However, in the current (1984) system the Skid Number Utility and Routine Maintenance Cost Utility are not used, the current pavement score is a function only of visual distress and serviceability index, with appropriate weightings being applied for traffic and environmental factors.

Skid data were collected in the initial implementation efforts of the Pavement Evaluation System from 1978 to 1980. However, it has not been collected for PES in recent years because:

1) It was costly to collect in network level evaluations.

2) The skid values were having an overriding effect on the pavement score calculation.

3) Skid numbers are related to pavement safety, whereas distress and mays ride are related to the pavement's structural condition. A separated system for safety would be more appropriate.

4) Skid number itself is not a good predictor of accident potential. Work in Texas is currently underway to improve the Wet Weather Safety Index (3), which has been shown to be a much better indicator of accident potential.

The Routine Maintenance Cost data collected by the SDHPT is not a suitable format for use with this system.

Equivalent costs for funding strategies. Table 11 is a listing of the five separate funding strategies and their associated costs (statewide average) in terms of dollars per lane foot per mile (a one foot wide strip a mile long). It is recognized that these costs should vary somewhat from district to district. Thus, these costs must be developed for each of the twenty-five districts within the state. It should be noted that these costs currently exclude any consideration of traffic handling costs. Future updates of these values may take these costs into consideration.

Determination of final attributes as a function of current attributes. An important component of this system is the ability to estimate what the Final Pavement Score (PSF) will be for a given highway segment after some type of maintenance or rehabilitation is applied. To aid in this task, Tables 12 and 13 were developed.

Table 12 provides a method of determining the final utility value for each distress (after maintenance) for a highway segment given the initial utility values (before maintenance). For example, an R-1 treatment (seal coat) will have no effect on deep rutting, and hence the after treatment utility value will be the same as the before treatment value. The values given in this table indicate how effective a particular strategy is at remedying a particular distress

TABLE 11. The Equivalent Statewide Average Cost for Each PES Funding Strategy

Funding Strategy	Equivalent Cost ($/foot-mile)
R-1	214
R-2	925
R-3	2000
R-4	3550
R-5	7000

TABLE 12. Gain in PES Components for the Various Funding Strategies

Distress	Maximum % Recovery of Utility Score following various funding strategies				
	R-1	R-2	R-3	R-4	R-5
Rutting < 1"	33	100	100	100	100
Rutting > 1"	0	70	100	100	100
Patching	75	100	100	100	100
Failures	25	62	75	87	100
Block Cracking	60	80	100	100	100
Alligator Cracking	60	80	100	100	100
Longitudinal Cracking	60	80	100	100	100
Transverse Cracking	75	100	100	100	100

type.

Table 13 provides a method of determining the final serviceability index and skid number following each of the rehabilitation strategies. The data used to generate this table were obtained from actual condition and performance information available in District 21 and the Texas Flexible Pavement Data Base (recently developed in Study 284).

Two kinds of maintenance for which fairly extensive information was available were seal coats (R-1) and thin asphalt concrete overlays (R-2). Linear regression equations were fitted through some of the figures to provide for the "best" estimates of how the "before" maintenance condition of a highway segment affects the "after" condition. Table 14 further shows the average before and after maintenance conditions for seal coats and thin asphalt concrete overlays. This table shows that placement of a seal coat does not necessarily result in a perfect Pavement Score of 100 or any improvement in SI. As a contrast, thin asphalt concrete overlays show substantial improvements in both PSC and SI. Skid number data for both maintenance strategies are also shown but are considered to be somewhat unreliable due to the small number of data points available. For all funding strategies greater than R-2, the serviceability index values were assumed to be constant regardless of the initial condition prior to maintenance or rehabilitation. There were small amounts of data available which indicated the expected AVU should approach unity and the serviceability index should range between 4.3 to 4.7. Thus, for serviceability index, an average value of 4.5 was chosen.

Minimum acceptable PS (PSM). The values for PSM shown in Table

TABLE 13. Determination of the Final Serviceability Index and Skid Number as a Function Current Serviceability Index and Skid Number

Attribute	Current Attribute Measure (before Maint/Rehab.)	Final Values following Funding Strategy				
		R-1	R-2	R-3	R-4	R-5
Serviceability	0.0 - 1.0	SI Current + 0.2	4.3	4.5	4.5	4.5
	1.0 - 2.0	SI Current + 0.2	4.3	4.5	4.5	4.5
	2.1 - 3.0	SI Current + 0.1	4.3	4.5	4.5	4.5
	3.1 - 4.0	SI Current	4.3	4.5	4.5	4.5
	4.1 - 5.0	SI Current	4.3	4.5	4.5	4.5
Skid Number (SN)	0 - 10	45	45	45	45	45
	11 - 20	45	45	45	45	45
	21 - 30	45	45	45	45	45
	31 - 40	45	45	45	45	45
	41 - 50	45	45	45	45	45
	> 50	45	45	45	45	45

TABLE 14. Mean and Standard Deviations for Before and After Maintenance for Three Data Types

Maintenance Strategy	Data Type	Before or After Condition	Mean	Standard Deviation
Seal Coat (R-1)	PSC	Before	67.5	20.1
		After	89.7	8.2
	SI	Before	3.2	0.8
		After	3.2	0.8
	SN	Before	35.6	7.9
		After	40.7	9.1
Thin Asphalt Concrete Overlay (1" - 1 1/2") (R-2)	PSC	Before	62.5	13.1
		After	95.4	5.6
	SI	Before	3.6	0.3
		After	4.3	0.3
	SN	Before	32.6	3.0
		After	34.0	9.0

15 are listed for four highway functional classifications. The definitions for these highway functional classification types were obtained from DFHR Research Report 124-1F and are as follows:

Highway Functional Classification Definitions as Used in This Example: (CFHR Report 124-1F)

1. Principal Arterial:

   (a) Interstate System

   (b) Other principal arterials

   These facilities provide continuous and connected routes to all large urban areas and corridor movements with trip length and travel characteristics which are of statewide or interstate interest.

2. Minor Arterial:

   This system connects cities and other traffic generators and provides for relatively high speeds over long distances. It is spaced to provide arterials to all developed areas.

3. Major Collector:

   Provide service to intercounty travel corridors and connect county traffic generators with cities, towns, or higher classified routes.

4. Minor Collector:

   Collect traffic from local roads and provide service to smaller communities.

The PSM values contained in the table are estimated. Further use of the system will no doubt require that these values be refined, but use of the values shown have appeared to be reasonable in an example

TABLE 15. Minimum Acceptable PES (PSM)

Highway Functional Classification	F.C. No.	Minimum Acceptable PSM
Principal Arterial (IH and Urban Freeway)	1, 2	0.50
Minor Arterial (US and SH)	3, 4	0.45
Major Collector (FM)	5	0.40
Minor Collector (FM)	6	0.30

problem run with actual field data from District 17.

Traffic factors required for calculating TMIN and DS. Table 16 shows the traffic factors which are used to determine the final values of TMIN (Minimum Allowable time between treatments) and DS (Deterioration Slope) for each highway segment. These factors should be a function of highway functional classification, percent trucks, and AADT. Currently, the traffic factors have been developed with available data for only two AADT levels and the four functional classifications. Available data precluded use of percent trucks at this time. These factors were developed from pavement survival data available from District 21 and the Texas Flexible Pavement Data Base. This survival data will subsequently be discussed in more detail in the following sections.

Minimum allowable time to next maintenance or rehabilitation. Table 17 shows how the minimum allowable time to next maintenance or rehabilitation should be organized. These times should be a function of highway functional classification and traffic factor. The table considers only the first factor and a simple equation incorporates the traffic factor. The initial allowable time from the table and the traffic factor can be related as follows:

$$TMIN = (TMINI)(TF) \tag{11}$$

where

TMIN = the minimum allowable time (years) to the next application of a maintenance or rehabilitation funding strategy following the application of the maintenance

TABLE 16. Traffic Factors Required for Calculating TMIN and DS (TF)

AADT	% Trucks	Principal Arterial, (1, 2)	Minor Arterial, (3, 4)	Major Collector, (5)	Minor Collector, (6)
HIGH Arterial: AADT $\geq$ 10,000 Collector: AADT $\geq$ 2,000	High	1.40	1.40	1.40	1.40
	Low	1.10	1.10	1.00	1.00
LOW Arterial: AADT < 10,000 Collector: AADT < 2,000	High	1.20	1.20	1.20	1.20
	Low	1.00	1.00	1.00	1.00

Column heading: Highway Functional Classification

TABLE 17. Recommended Minimum Allowable Time (TMINI) Until Next M&R Application

Functional Class	TMINI (years)
1	9
2	7
3	7
4	5
5	3
6	3

or rehabilitation strategy currently being considered.

TMINI = same as TMIN except unadjusted for traffic (Table 17).

TF = traffic factor for the highway segment being considered (Table 16).

<u>Time of constant level of service</u>. The constant level of service as measured by PSC is shown in Table 18 for five funding strategies and ten pavement type conditions. These data were developed from pavement survival times obtained from District 21 and the Texas Flexible Pavement Data Base.

Figures 3 through 9 show how this survival information was developed. For various highway segments the PSC values were calculated over the period of time in which visual condition, serviceability index and skid number data were available. These data were calculated for various funding strategy and pavement type combinations and plotted versus the age (years) a funding strategy has survived. Although the data scatter shown in these figures is significant, median values were selected to represent constant level of service (TC) values which are considered to be reasonable. In a like manner, deterioration slopes were determined.

<u>Funding strategy deterioration slopes</u>. Table 19 shows the initial deterioration slopes (DSI) for five funding strategies and ten pavement types. A simple equation is used to determine the final deterioration slope (DS) as a function of traffic and climatic factors. This equation is as follows:

$$DS = (DSI)(TF)(CF)(SF) \tag{12}$$

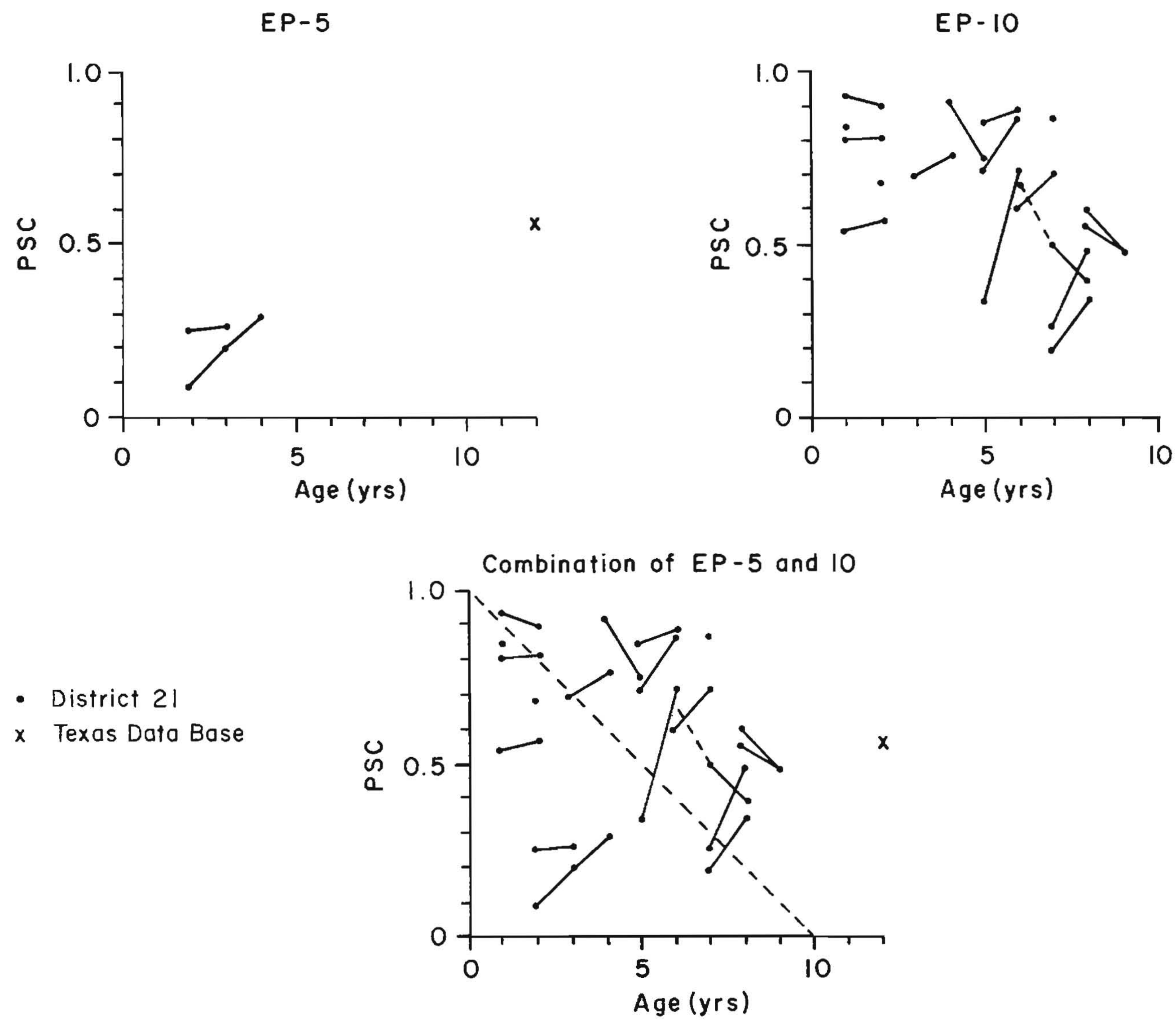


FIGURE 3. Determination of PES Constant Level of Service and Deterioration Slopes for Funding Strategy R-1 (AADT < 2000) for Pavement Types EP-5 and 10.

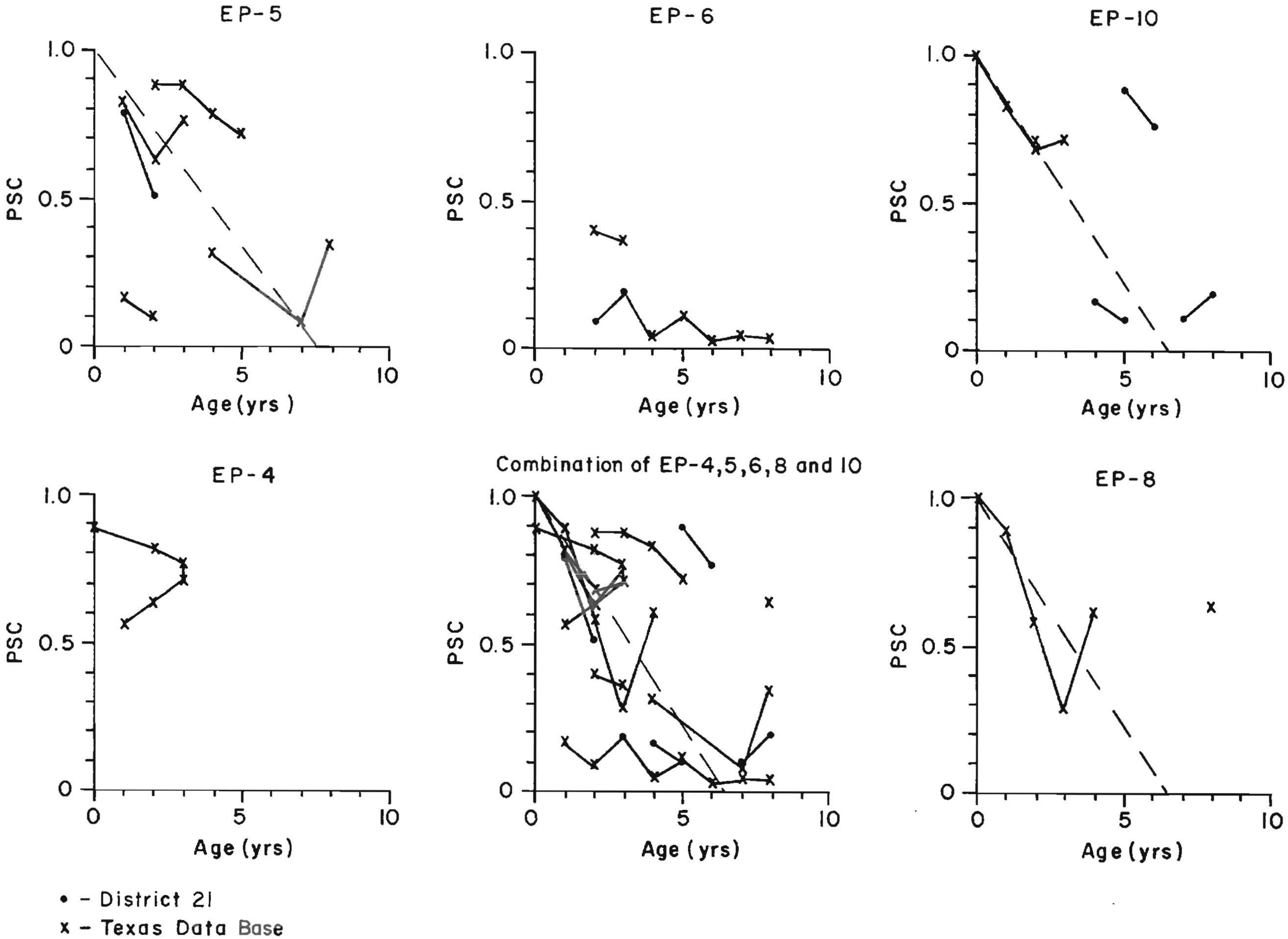


FIGURE 4. Determination of PES Constant Level of Service and Deterioration Slopes for Funding Strategy R-1 (AADT $\geq$ 2000) for Pavement Types EP-4, 5, 6, 8, and 10.

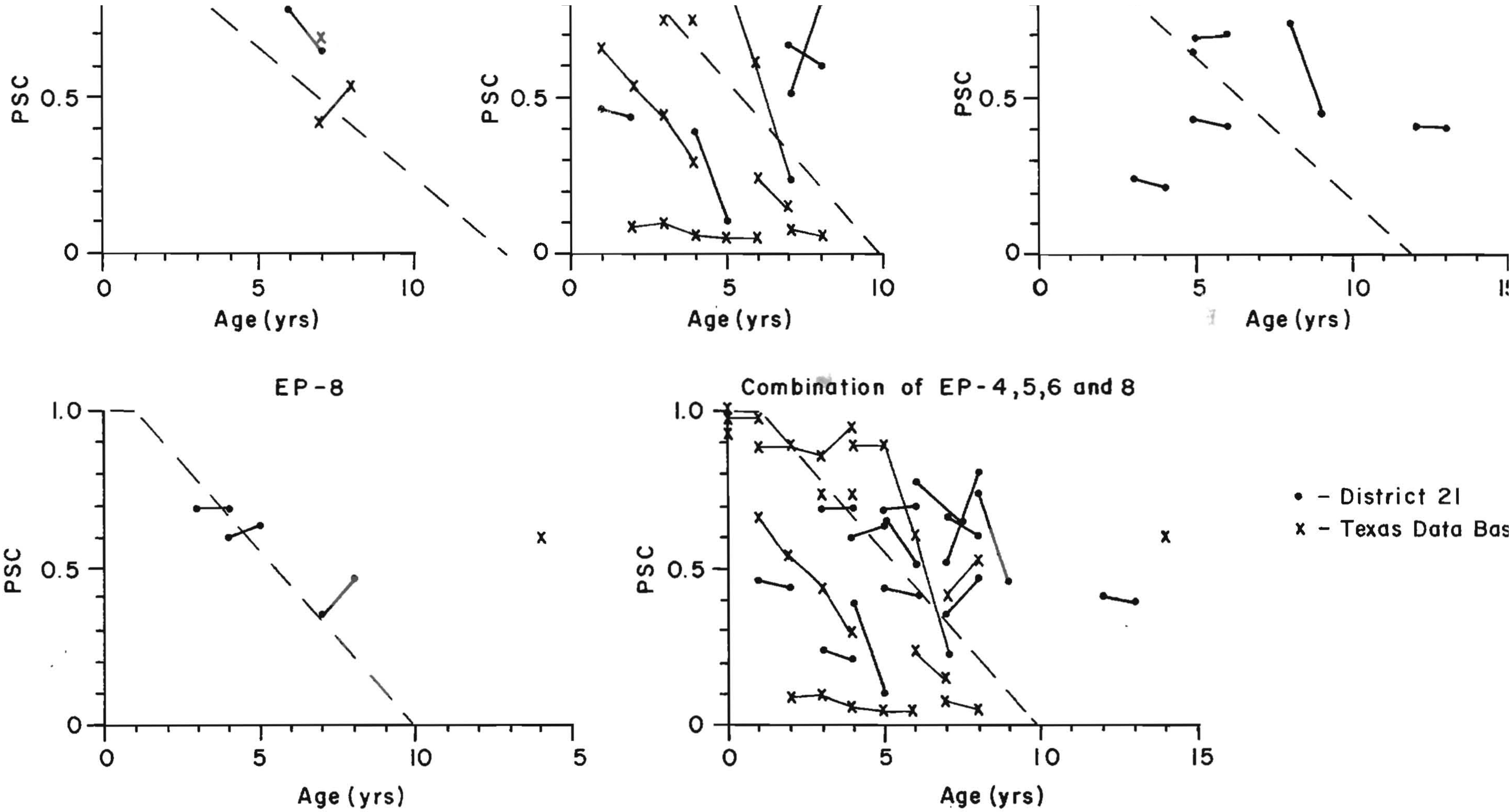


FIGURE 5. Determination of PES Constant Level of Service and Deterioration Slopes for Funding Strategies R-2 and R-3 (AADT < 10,000) for Pavement Types EP-4, 5, 6, and 8.

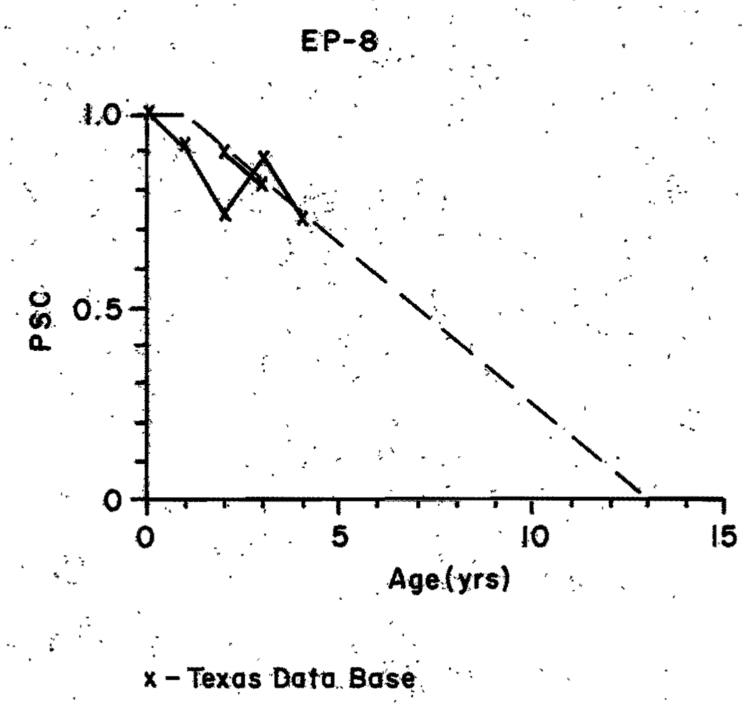


FIGURE 6. Determination of PES Constant Level of Service and Deterioration Slopes for Funding Strategy R-4 (AADT < 10,000) for Pavement Type EP-8

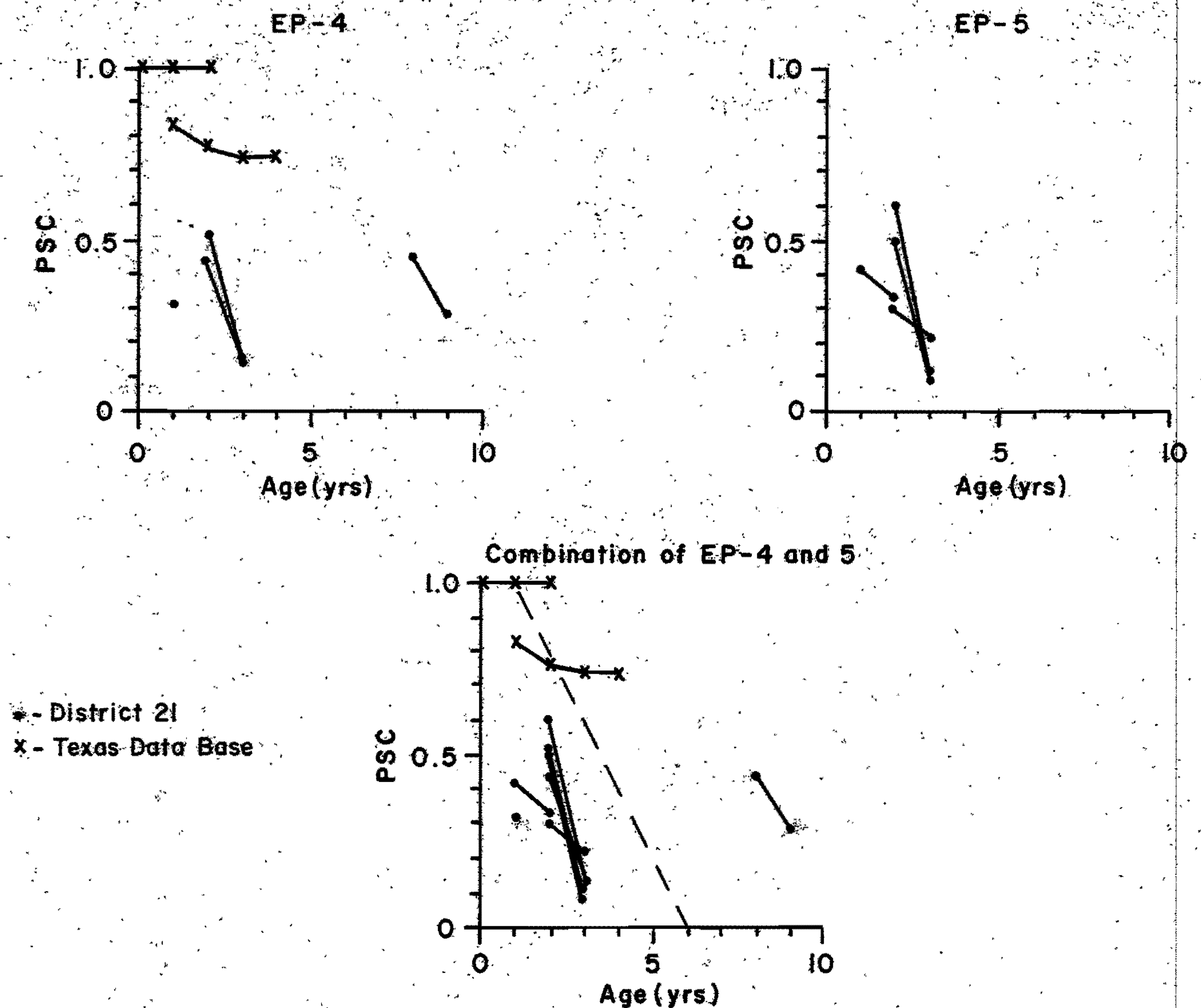


FIGURE 7. Determination of PES Constant Level of Service and Deterioration Slopes for Funding Strategies R-2 and R-3 (AADT ≥ 10,000) for Pavement Types EP-4 and 5

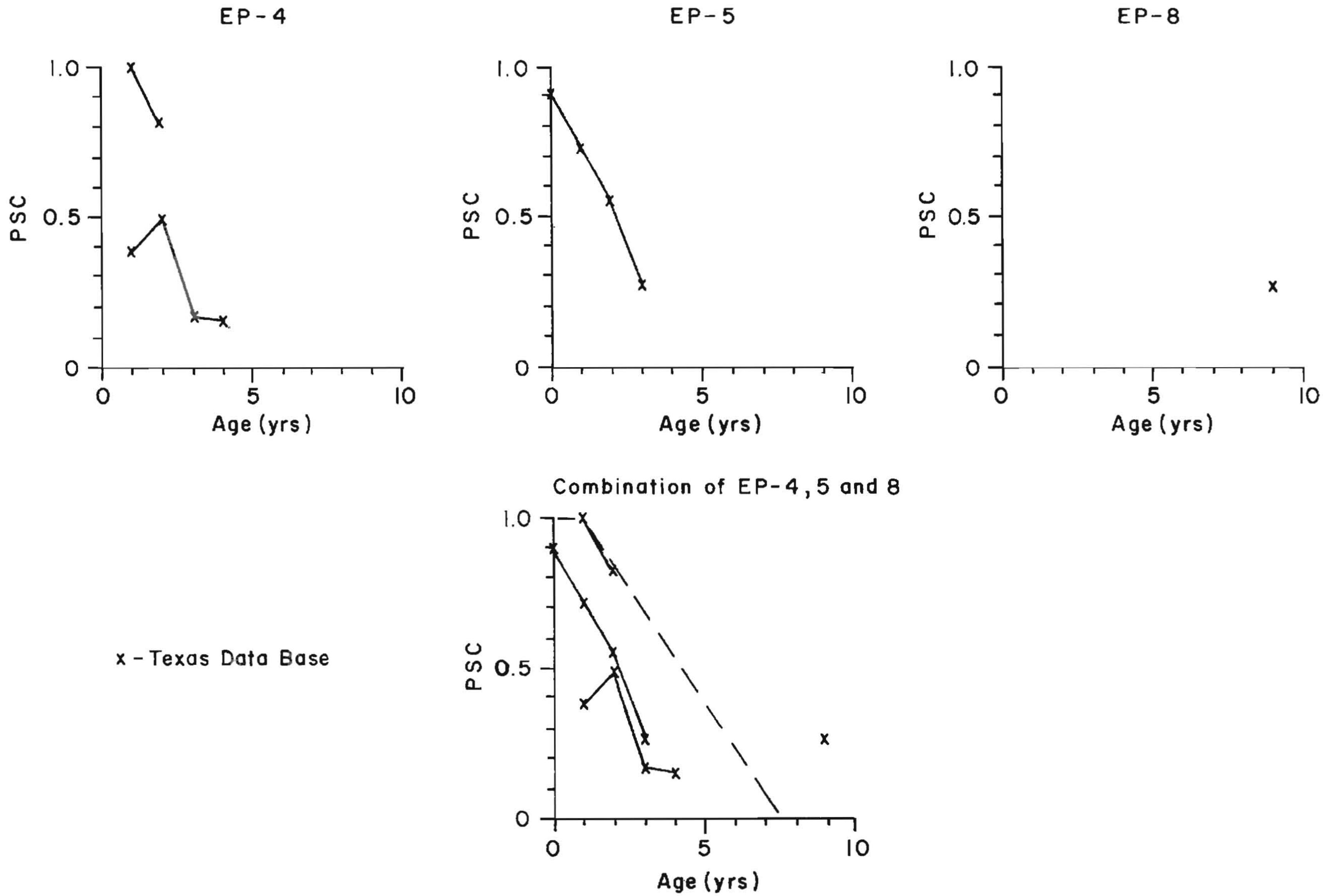
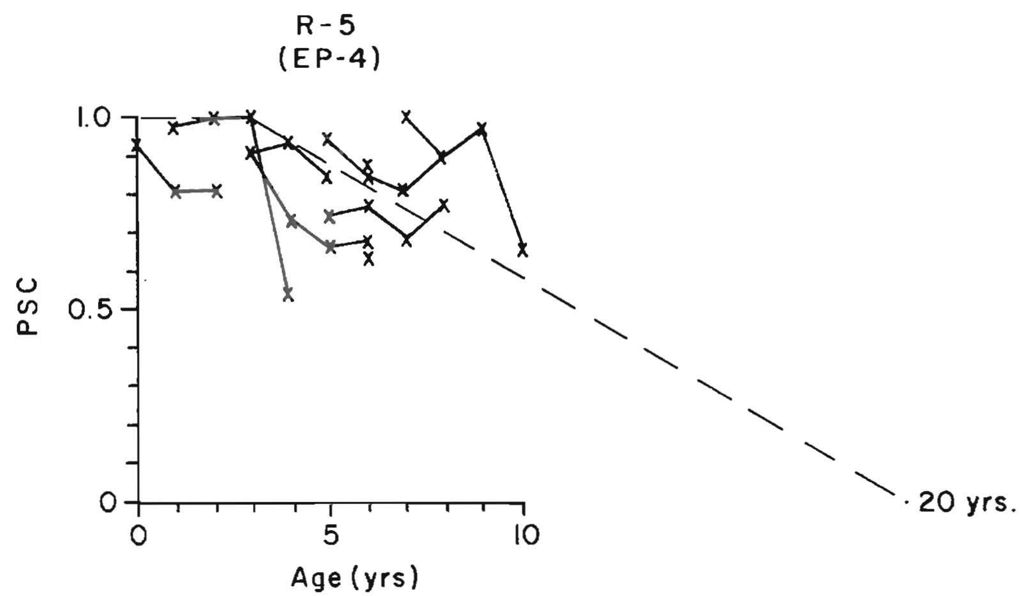


FIGURE 8. Determination of PES Constant Level of Service and Deterioration Slopes for Funding Strategy R-4 (AADT ≥ 10,000) for Pavement Types EP-4, 5, and 8



x - Texas Data Base

FIGURE 9. Determination of PES Constant Level of Service and Deterioration Slopes for Funding Strategy R-5 for Pavement Type EP-4

TABLE 18. Time of Constant Level of Service (TC for Six Funding Strategies and Nine Pavement Type Combinations (Units: Years)

Funding Strategies	Pavement Type (Table 1)						
	EP-4	EP-5	EP-6	EP-7	EP-8	EP-9	EP-10
R-1	0	0	0	0	0	0	0
R-2	1.5	1.5	1.5	1.5	1.5	1.5	1.5
R-3	2.5	2.5	2.5	2.5	2.5	2.5	2.5
R-4	5.0	5.0	5.0	5.0	5.0	5.0	5.0
R-5	7.5	7.5	7.5	7.5	7.5	7.5	7.5

TABLE 19. Funding Strategy Initial Deterioration Slope (DSI) (Units: PES/yr)

Funding Strategies	Pavement Type (Table 1)						
	EP-4	EP-5	EP-6	EP-7	EP-8	EP-9	EP-10
R-1	0.100	0.100	0.100	0.100	0.100	0.100	0.100
R-2	0.083	0.110	0.110	0.110	0.110	0.110	0.110
R-3	0.083	0.100	0.100	0.100	0.100	0.100	0.100
R-4	0.083	0.083	0.083	0.083	0.083	0.083	0.083
R-5	0.059	0.059	0.059	0.059	0.059	0.059	0.059

where

DS = deterioration slope of a funding strategy for a given pavement type after adjustment for traffic and climate conditions

DSI = initial deterioration slope obtained from Table 19

TF = traffic factor for the highway segment being considered (Table 16)

CF = climate factor (Table 20)

SF = soil factor (Table 21)

The deterioration slopes and appropriate traffic factors were determined from the data previously shown in Figures 3 through 9. Adequate amounts of data were available for pavement types EP-4, 5, 6, 8, and 10. The slopes for the remaining pavement types (EP-1, 2, 3, 7, and 9) were estimated since little or no data were available. This is an area which needs additional research. Additionally, the data shown in Figure 9 for funding strategy R-5 is approximate. It was difficult to find highway segments in the state which have received such heavy rehabilitation strategies (7.5 in. overlays). Therefore, performance and condition information collected in Study 207 for black base constructed pavements were used to approximate this funding strategy.

Climate factors. The climate factors shown in Table 20 have all been set to unity. As additional research is accomplished in subsequent studies, the climatic effects on pavement deterioration rates will be further examined and developed. Currently, it is expected that these factors can be made a function of freeze-thaw

TABLE 20. Climate Factors (CF)

Freeze-thaw cycles (cycles/yr)	Rainfall (in./yr)		
	> 20	21-40	< 40
> 10	1.0	1.0	1.0
11 - 30	1.0	1.0	1.0
31 - 50	1.0	1.0	1.0
< 20	1.0	1.0	1.0

Freeze-thaw cycles can be obtained from Table 2B

Rainfall cycles can be obtained from Table 2B

TABLE 21. Soil Factors

Plasticity Index	Rainfall (in./yr)		
	< 20	21-40	> 40
< 20	1.00	1.00	1.00
20 - 40	1.02	1.07	1.05
> 40	1.05	1.15	1.10

cycles and rainfall.

Soil factors. The soil factors shown in Table 21 range between 1.00 for non-expansive soil to 1.15 for a highly expansive soil in a climate with moderate rainfall. The soil factor increases the slope of the PES deterioration curve to account for the effect of expansive clays. These clays are known to be most active in the central Texas area where annual wetting and drying cycles are common.

Calculation of final PS (PSF). For a given highway type and funding strategy the PESF is a function of the final (after maintenance) AVU, SI, and SN. The final AVU (AVUF) is calculated from the values given in Table 12 and the SI and SN values are selected from Table 13. Then the appropriate utility equation for SI and SN is used to convert these two attributes to utilities. A simple multiplication of the final AVU, SI utility, and SN utility results in the PSF as follows:

$$PSF = [(AVUF)^{a_1} (SIUF)^{a_2} (SKUF)^{a_3} (RMCUF)^{a_4}]^{1/FC} \qquad (13)$$

where

AVUF = final AVU after maintenance or rehabilitation

SIUF = final serviceability index utility after maintenance or rehabilitation

SKUF = final skid number utility after maintenance or rehabilitation

RMCUF = final routine maintenance cost utility after maintenance or rehabilitation

a_1, a_2, a_3, a_4, and FC are as defined in Equation 1.

Currently, the routine maintenance cost utility and skid number utility are set at 1.0 and, as such, do not affect the calculated value of PSF.

Calculation of TMAX. To calculate the time a given maintenance or rehabilitation funding strategy will last after it is applied to a highway segment, the PSF, PSM, TC, and DS must be known. They are related by the following equation:

$$TMAX = TC + \frac{PSF - PSM}{DS} \qquad (14)$$

where

TMAX = the time a given maintenance or rehabilitation funding strategy will last to a minimum PES (PSM)

TC = time of constant service for a given maintenance or rehabilitation funding strategy obtained from Table 18

PSF = the final PES after a maintenance or rehabilitation funding strategy is applied

PSM = the minimum PES obtained from Table 15

DS = deterioration slope obtained from Table 19 and adjusted for traffic, climate, and soil factors (Tables 16, 20, and 21, respectively).

Calculation of Reinspection Data

For those sections whose current pavement score is above the minimum values (PSM), a reinspection date is calculated. This date is obtained by calculating when the current pavement score will reach PSM by using the deterioration rates shown in Table 19. In the current calculation procedure the maximum time before reinspection is set at three years.

MAINTENANCE AND REHABILITATION SYSTEM -
STATE COST ESTIMATING PROGRAM

Example Problem

To illustrate the calculation procedure, the data from a single 2-mile highway section will be processed. The location information is shown below.

Highway:	FM 487
Milepost:	MP 10-12
District:	17
County:	166 (Milam County)
Functional Class:	5 (Collector)
Pavement Type:	10 (Surface Treated Pavement)
ADT/Lane:	360
18-kip ESAL (20 years):	0.8 million

The pavement was evaluated, and the following distresses were found.

Distress	Area Covered	As coded on Inspection Form (Table 3)
Severe Rutting	1 - 25%	200
Patching	0	000
Failures	6 per lane mile	010
Block Cracking	0	000
Alligator Cracking	1 - 10%	100
Longitudinal Cracking	0	000
Transverse Cracking	0	000

The mean Mays Ride value on this section was measured to be 2.4.

Pavement Score Calculation Procedure

Within the Pavement Evaluation System, the following scores are calculated.

1. Unweighted Visual Utility Score (UVU)

   where

   $$UVU = (U_{rutting}) \times (U_{patching}) \times (U_{failures}) \times (U_{block\ cracking}) \times (U_{alligator\ cracking}) \times (U_{longitudinal\ cracking}) \times (U_{transverse\ cracking})$$

2. Adjusted Visual Utility Score (AVU)

   where

   $$AVU = (U_{rutting})^{b_1} \times (U_{patching})^{b_2} \times (U_{failures})^{b_3} \times (U_{block\ cracking})^{b_4} \times (U_{alligator\ cracking})^{b_5} \times (U_{longitudinal\ cracking})^{b_6} \times (U_{transverse\ cracking})^{b_7}$$

   where the b values are environmental weighting factors dependent upon rainfall and freeze-thaw cycles. The values of b are defined in the main body of the report and the environmental factors are obtained from Tables 5 and 6.

3. Weighted Visual Utility Score (WVU)

   where

   $$WVU = AVU^{a_1}$$

   where a_1 is a traffic associated weighting factor, as defined in the main body of the report.

4. Pavement Score (PSC)

   where

   $$PSC = [(AVU)^{a_1} \times (SIU)^{a_2} \times (SKU)^{a_3} \times (RMC)^{a_4}]^{1/FC}$$

where SKU (Skid Utility) and RMC (Routine Maintenance Cost Utility) are both set to 1.0. a_2, a_3, and a_4 are set to 1.0 and FC is a factor based on functional class.

For the data presented above for FM487 the following scores are calculated.

$$UVU = (0.800) \times (1.00) \times (0.313) \times (1.00) \times (0.89) \times (1.00) \times (1.00) = 0.22$$

the individual utility values being obtained from Table 9.

The rainfall and freeze-thaw values for this county are 33 in./yr and 11 cycles/yr, respectively, therefore from Table 5, RF = 0.97 and Table 6, FF = 0.973.

therefore

$$AVU = (0.800)^{1.03} \times (1.00)^{1.06} \times (0.313)^{1.06} \times (1.00)^{1.06} \times (0.890)^{1.06} \times (1.00)^{1.06} \times (1.00)^{1.06} = 0.20$$

From Tables 7 and 8

$$a_1 = \frac{1}{ADTF \times EALT} = \frac{1}{0.96 \times 1.0}$$

$$= 1.042$$

$$WVU = (0.20)^{1.042}$$

$$= 0.187$$

From the SIUC equation for an ADT x Speed = 19250

$$SIUC = 1.0 - 0.1 \times \left(\frac{2.5 - 2.3}{0.5}\right)^2$$

$$= 0.984$$

$$PSC = (0.187 \times 0.984 \times 1.00 \times 1.00)^{1/0.95}$$

$$= 0.169$$

When these value are presented in the PES outputs, the scores are rounded and multiplied by 100. For this section of FM 487, the following scores would be reported.

UVU = 22

AVU = 20

WVU = 19

PSC = 17

Calculating the Appropriate Funding Level

The current pavement score for this section is 0.17. This is below the minimum acceptable of 0.35 (Table 15), therefore a rehabilitation funding level would be calculated.

The first step in calculating the funding level is to determine the final pavement score after each funding strategy (R-1, R-2, or R-3 for surface treated pavements).

Calculating final AVU for Strategy R-1: for each distress utility value the final utility value is determined using the following equation.

$$U_{final} = U_{initial} + (1-U_{initial}) \times G$$

where G is the % gain factor obtained from Table 12 where U_{final} has a maximum value of 1.0.

The calculation of final AVU for strategy R-1 on FM 487 is shown below.

Distress	$U_{initial}$	G from Table 12	U_{final} after R-1
Rutting	0.800	0	0.800
Patching	1.000	75	1.000
Failures	0.313	25	0.484
Block Cracking	1.000	60	1.000
Alligator Cracking	0.890	60	0.956
Longitudinal Cracking	1.000	60	1.000
Transverse Cracking	1.000	75	1.000

$$AVU_{final} = (0.800)^{1.03} \times (1.000)^{1.06} \times (0.484)^{1.06} \times (1.000)^{1.06}$$
$$(0.956)^{1.06} \times (1.000)^{1.06} \times (1.000)^{1.06}$$
$$= .351$$

Final PSI = 2.5 from Table 13

$SIU_{final} = 1.00$

$$PSF = ((.351)^{1.042} \times 1.00 \times 1.00 \times 1.00)^{1/0.95}$$
$$= 0.317$$

for strategy R-2

$$PSF = ((.664)^{1.042} \times 1.00 \times 1.00 \times 1.00)^{1/0.95}$$
$$= 0.639$$

for strategy R-3

$$PSF = ((.828)^{1.042} \times 1.00 \times 1.00 \times 1.00)^{1/0.95}$$
$$= 0.813$$

Calculation of T_{max} (time until next rehabilitation)

$$T_{max} = T_c + \frac{PSF - PSM}{DS}$$

PSM = 0.35 from Table 15

TC is obtained from Table 18

DS = (DSI)(TF)(CF)(SF)

DSI is obtained from Table 19

TF is obtained from Table 16

CF is obtained from Table 20

SF is obtained from Table 21

DS = 0.100 x 1.00 x 1.00 x 1.00 x 1.00 = 0.100

R-1 $$T_{max} = 0 + \frac{0.317 - 0.35}{0.100} = -0.3 \cong 0.0$$

R-2 $$T_{max} = 0 + \frac{0.639 - 0.35}{0.100} = 2.86 \text{ years}$$

R-3 $$T_{max} = 0 + \frac{0.813 - 0.35}{0.100} = 4.63 \text{ years}$$

Calculation of T_{min} (minimum allowable time)

$$T_{min} = T_{mini} \times TF$$

T_{mini} (from Table 17) = 3.0

TF (from Table 16) = 1.0

T_{min} = 3.0 x 1.0 = 3.0 years

Funding Strategy Selection

Select first strategy such that

$T_{max} > T_{min}$

R-1	$T_{max} = 0.0$	$T_{min} = 3.0$
R-2	$T_{max} = 2.86$	$T_{min} = 3.0$
R-3	$T_{max} = 4.63$	$T_{min} = 3.0$

Therefore, R-3 would be selected for this highway. For surface treated highways, this would be full reconstruction (rework existing pavement, bring in 2-4" of new base and resurface).

CONCLUSIONS AND RECOMMENDATIONS

The current Pavement Evaluation System has been designed to assist the Texas Department of Highways and Public Transportation in identifying rehabilitation projects and associated costs for flexible pavements at the network level. Since its initial implementation, the PES data have been used extensively by Central and District offices. Statistical summaries of state-wide and district-wide pavement conditions and funding requirements have been prepared. Each district has color-coded maps highlighting pavement deficiencies and the pavement score has become one of the factors in the allocation of rehabilitation funds for individual projects.

This current system is viewed as a first-level pavement management system. Efforts are now underway to improve and extend this system to meet more of the Department's pavement management requirements.

Below are listed recommendations as to how the current system could be improved and expanded.

IMPROVEMENTS TO EXISTING SYSTEM

1. Evaluation of Weighting Factors

The current system contains several weighting factors for variables such as area of distress, traffic level, and climatic conditions. There is a need to evaluate if these weights are correctly represented within PES. This can best be done by comparing the list of candidate rehabilitation projects as prepared by the Districts with their corresponding PES score, traffic level, etc. Statistical techniques such as discriminant analysis can be used to determine if adequate weighting is being given to each variable.

2. Needs for Structural Evaluation

Pavements which are structurally very weak but have recently received maintenance such as a thin overlay or seal coat could be rated very high within the existing PES. There is a need to determine the feasibility and desirability of including a structural parameter in the pavement score calculation.

3. Time of Inspection

Currently inspections are made in the Fall (September to December); however, it may be advantageous to move them to Spring (February to April) so that highways can be inspected in their worst condition.

4. Year to Year Comparisons

Some Districts have several ratings on the same section of pavement. Where possible, pavement deterioration rates should be calculated and included in the standard PES reports.

5. Safety

Inspecting pavements is extremely hazardous on high volume roadways, particularly in urban areas. High speed photographic surveys need to be investigated.

EXPANSION OF EXISTING SYSTEM

1. Budget and Time Optimization

The current PES system is based on one computer program from the RAMS (4) suite of programs. Other RAMS programs have the capability of:

a. calculating optimal combinations of projects given budgeting constraints, and

b. calculating optimal timing of rehabilitation projects by considering pavement deterioration rates and budgeting constraints.

These programs should be considered for inclusion within the future expanded pavement evaluation system.

2. Link to Project Level Pavement Management System

The department has a network level (PES) and a project level (FPS and RPS) pavement management system. However, there is an urgent need to tie these systems together so that more cost-effective pavement rehabilitation programs can be developed.

Specific areas of interest are:

a. Interpretation of PES outputs. The Department does a good job in training raters on how to input information into the system. However, more attention should be given to instructing the Districts on how to interpret and use the outputs. This training could take the form of a report or regional schools for the District personnel responsible for using pavement evaluation data in preparing pavement improvement programs.

b. Pavement Failure Analysis. PES identifies pavements in poor condition, it does not indicate the cause of the poor condition. Identification of this cause is fundamental to developing a pavement rehabilitation strategy.

Many techniques are available for identifying the causes of pavement deterioration and several TTI reports (5) have given guidelines. There is an urgent need to put this wealth of knowledge into practice. It is recommended that schools be developed to train District personnel in pavement failure analysis. The PES data would be used as a starting point; the need for detailed visual inspection, non-destructive and laboratory testing would be described by analysis of actual sections of highway.

The goal of these schools would be to provide a badly needed link between the departments network and project level pavement management activities.

3. Predicting Maintenance Requirements

The current PES only predicts needs once the pavement score has dropped to a level where rehabilitation (i.e. overlay) strategies are required. However, the system contains sufficient information on distress and traffic levels to make estimates of both routine and preventative maintenance type treatments. It is proposed that the current system be expanded to make these predictions and that a simple decision tree be used to determine the appropriate maintenance strategy.

4. Predicting Long Term Funding Requirements

The Texas SDHPT has since 1981 prepared an operational plan outlining the financial needs to adequately maintain and expand the highway system. A major portion of this cost estimate is in predicting maintenance and rehabilitation costs. The current operation plan uses a program called RENU (6) to make these predictions. The basic inputs to this program are simply the pavement age profiles and traffic volumes of the highways in the network. However, the current Pavement Evaluation System has considerable additional information concerning actual pavement condition as well as traffic level, pavement type, and environmental conditions of individual sections. Therefore, this is thought to be an excellent starting point for obtaining improved maintenance and rehabilitation cost estimates. Efforts should be undertaken to expand PES to make these predictions.

FUTURE DIRECTIONS

1. The Development of an Integrated Highway Management System

Funds can be allocated to improve a highway network for a variety of reasons. Typical examples are:

- poor pavement condition (maintenance or rehabilitation funds)
- high accident rates (safety improvement funds)

- congestion problems (capacity improvement funds)
- poor bridge condition (bridge improvement funds)

An integrated Highway Management System should provide essential information to the budgeting process. For example:

1. What funds are required to provide an adequate level of service? What will be the implication of a shortfall of funds?
2. How should the funds be allocated?
3. How can individual projects by prioritized?

The Pavement Evaluation System described in this report is intended to assist with the prioritization of rehabilitation funds. From the above discussion, PES is only one subsystem in a Highway Management System.

At the strategic planning level, the total funding needs should be addressed. Other subsystems need to be developed to assist with network and project level priorities for capacity, safety, and maintenance funds. For example, at the network level a simple capacity priority scheme could involve calculation of the number of hours per day a given section of highway exceeds a maximum capacity value (i.e. 2000 vehicles/lane/hour). Safety prioritization could be based on an inspection procedure such as that proposed in the Wet Weather Safety Index (3), or as is usually done on historic accident rates.

There is a need to expand the current PES into a Highway Management System. Administrators need timely, quality information in order to justify and allocate highway funds.

2. Organizational Implications of a Highway Management System

Traditionally PES (or PMS) have been developed by a single functional unit within a highway department, be it the maintenance, safety, or pavement design unit. The developed system, therefore, usually only addresses the needs of this single unit.

The Highway Management System as described above, crosses many functional boundaries. Therefore, the positioning within the organization of the group responsible for the management system is a difficult task. Many factors need to be considered, such as:

- communication channels to higher and lower levels within the Department
- resource allocation to the group
- visibility

An effective Highway Management System cannot be developed until these organizational issues are adequately resolved.

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