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16. Abstract

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The study indicated that the RAMS-D01 program has great potential for assisting the Districts in allocating its resources. However, in this study there was only limited agreement between the projects recommended by RAMS and those selected by the District staff. This was found to be due to the following two reasons. First, the needs of the District were greatly in excess of funds available. An estimate of the overall District need for M&R work was $35 million; however, the District's allocation was only $12.6 million. Therefore, the District had a large mileage of pavements in substandard condition and only 35% of the funds available to address that need. The second reason was that the District concentrated its M&R selections on the higher volume roads, whereas RAMS selected both high and low volume projects. This selection was based on its objective function which calculates benefit caused by improving pavement condition independent of the traffic served. This indicated the need to expand the RAMS objective function, and therefore a traffic factor was introduced in later runs.

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RAMS-D01 AS A DECISION ANALYSIS TOOL

by

Emmanuel Fernando
John Fowler
Tom Scullion

Research Report 0930-3

Research Study Number 2-18-88-930

Study Title "District Level Pavement Management System"

Conducted for

Texas State Department of Highways and
Public Transportation

by

Texas Transportation Institute

August, 1988

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

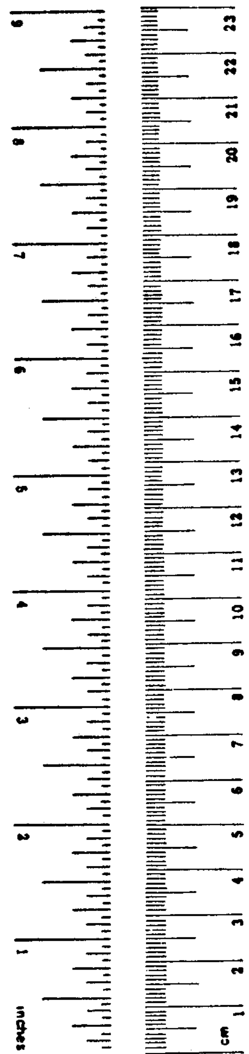
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

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

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements

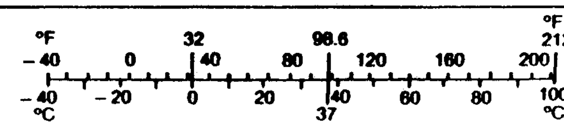


APPROXIMATE CONVERSIONS TO SI UNITS

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
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
		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

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

ABSTRACT

The RAMS series of programs were developed to assist the Texas SDHPT with its PMS activities. This report describes the evaluation of the RAMS-District Optimization Program in selecting projects to maximize network benefit. The trial involved using the system to analyze the decisions made by a specific Texas District in 1985 to allocate its maintenance and rehabilitation (M&R) funds. The decisions made by the District staff were compared with those recommended by the optimization scheme.

The study indicated that the RAMS-D01 program has great potential for assisting the Districts in allocating its resources. However, in this study there was only limited agreement between the projects recommended by RAMS and those selected by the District staff. This was found to be due to the following two reasons. First, the needs of the District were greatly in excess of funds available. An estimate of the overall District need for M&R work was $35 million; however, the District's allocation was only $12.6 million. Therefore, the District had a large mileage of pavements in substandard condition and only 35% of the funds available to address that need. The second reason was that the District concentrated its M&R selections on the higher volume roads, whereas RAMS selected both high and low volume projects. This selection was based on its objective function which calculates benefit caused by improving pavement condition independent of the traffic served. This indicated the need to expand the RAMS objective function, and therefore a traffic factor was introduced in later runs.

DISCLAIMER

This report is not intended to constitute a standard, specification, or regulation, and does not necessarily represent the views or policies of the Federal Highway Administration or the Texas State Department of Highways and Public Transportation.

PREFACE

Project 930 "District Level PMS" was initiated in September 1987 to provide continuation in the Department's ongoing Pavement Management effort. Other reports in this study include:

Report 930-1 "Pavement Management, Where Do We Go From Here" presents a plan on how the Texas SDHPT can proceed with its PMS efforts to meet both Federal and Departmental requirements. The departmental requirements were identified by interviews with the Administration, senior engineers and the staff of six Districts. Also a questionnaire was completed by all 24 Districts.

Report 930-2 "Micro-PES Release 1.0, User's Manual" presents a users manual for a microcomputer system developed for the Texas SDHPT for analyzing the annual Pavement Evaluation System pavement condition data. Analysis tools include a procedure to make one-year Maintenance and Rehabilitation (M&R) estimates, the RAMS-District Optimization Program, and a procedure for estimating routine maintenance requirements.

Table of Contents

Section 1

Introduction

In the early 1980's the Texas Department of Highways and Public Transportation implemented its network level Pavement Evaluation System (PES). Initially, only a small portion of the state's road segments were inspected. Since then the sample size has increased considerably and in recent years every mile of Interstate pavement has been inspected annually. However, in general, the main user of the PES data has been the Austin office in its efforts to track network condition and estimate overall funding requirements. The District offices are generally not users of the information generated, despite the fact that they expend considerable effort to collect the data.

In an attempt to address this problem, Study 930 was initiated in September 1987. The aim of the project was to develop and implement applications at the District level. It was acknowledged that the PES database was an excellent source of current pavement condition data that could be used by the Districts to assist with the maintenance and rehabilitation (M&R) operations. Study 930 was therefore focused on building a "user-friendly" microcomputer package that could readily be used within the District offices. The result of this study was the development of MICRO-PES system (release 1.0).

MICRO-PES currently contains four application programs. These include a) a program to extract a user-selected set of road segments from the master PES database called the 'Create a Subset File' program (the file created by this program is used on the other three programs), b) a program that uses a series of decision trees to assist in determining "first-cut" estimates of network M&R needs, c) a program that selects the "optimum" set of M&R strategies to perform on the road segments within a given budget level, and d) a program that estimates the amount and cost of routine maintenance required on any particular set of road segments. More information on the MICRO-PES system can be found in the MICRO-PES Release 1.0 User's Manual [1]*.

The purpose of this report is to show how the third program mentioned above (RAMS District Optimization Program or RAMS-D01) can be used to assist the District engineer in determining the "best" use of allocated M&R funds. The utility of this program is illustrated by performing a

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* Numbers in brackets denote references cited.

case study on the decisions made in the Lufkin District (District 11) in 1985 relative to the selection of M&R projects. This particular District and time period were chosen because complete PES data for District 11 was readily available for 1985 and 1986. The 1986 data was needed to analyze the effect of the decisions that were made in 1985 and implemented in 1986. District 11 was also a good choice because most of the road segments in this District are flexible pavements. RAMS-DO1 is currently set up to handle only flexible pavements.

The funds allocated to District 11 in 1985 were not sufficient to allow the proper M&R activity to be performed on each and every deficient road segment. Therefore, the problem that District 11 was faced with in 1985 was to find what M&R strategies should be applied to which road segments to make the "best" use of the allocated funds.

RAMS-DO1 is a 0-1 linear program that selects the "best" set of road segments and strategies based on a given budget level. The "best" set is the one that maximizes the total "benefits" derived from the application of M&R strategies to road segments. The "benefit" for a particular road segment/M&R strategy combination is a function of the area of the road segment and a weighted measure of how the strategy performs in eliminating existing distresses over the next several years (the number of years is a user supplied input--usually 10 years). This program is documented in TTI Research Report 207-3 [2] and an overview of it can be found in Appendix A.

Table 1 shows the projects selected by the District engineers for Polk County and the strategies selected by RAMS-DO1 for each PES road segment within these projects. Table 2 shows the additional road segments selected by RAMS-DO1. It is obvious that the choices are not identical. The differences between the two selections and some of the reasons for these differences will be discussed in Section 3.

It should be pointed out that RAMS-DO1 is not meant to replace the District engineer in determining how to allocate M&R funds. The purpose of the program is simply to assist in the selection process. There will always be factors that affect the final decisions that are not incorporated into RAMS-DO1. The program will, however, give the District engineer a good idea of some of the road segments that should be seriously considered for M&R activities.

TABLE 1
COMPARISON OF PROJECTS SELECTED BY DISTRICT AND BY RAMS-D01

PROJECT (MILES)	STRATEGY SELECTED BY DISTRICT	PES SEGMENTS FROM	TO	STRATEGY SELECTED BY RAMS-D01
FM0062 (6.01-9.76)	RECONSTRUCTION	006+00	008+00	NONE
		008+00	008+18	NONE
FM0350 (0.00-5.03)	RECONSTRUCTION	000-01	002+00	LIGHT DUTY RECONSTR.
		002+00	004+00	NONE
		004+00	006+00	LIGHT DUTY RECONSTR.
FM3126 (4.39-5.90)	RECONSTRUCTION	004+00	006+00	NONE
LP0090 (1.73-3.86)	HEAVY OVERLAY	000+07	002+09	THIN OVERLAY
		002+09	004+06	NONE
US0059 (8.76-9.89)	HEAVY OVERLAY	008+04	008+19	THIN OVERLAY
US0059 (9.89-19.09)	THIN OVERLAY	008+19	012+00	NONE
		012+00	014+00	NONE
		014+00	016+00	NONE
		016+00	018+00	SEAL COAT
		018+00	020+00	NONE
US0059 (35.71-37.69)	THIN OVERLAY	034+00	036+00	NONE
		036+00	038+09	NONE
US0190 (0.00-0.11)	HEAVY OVERLAY	000+00	002+00	NONE
US0190 (16.34-16.94)	HEAVY OVERLAY	014+15	018+00	SEAL COAT
US0287 (1.00-10.57)	SEAL COAT	000+00	002+00	NONE
		002+00	004+00	NONE
		004+00	006+00	NONE
		006+00	008+00	NONE
		008+00	010+00	NONE

TABLE 2
ADDITIONAL SEGMENTS SELECTED BY RAMS-D01

HIGHWAY NUMBER	FROM	TO	LANE	STRATEGY
FM0350	006+00	008+00	L	L.D. RECONSTRUCTION
FM0350	008+00	010+00	L	L.D. RECONSTRUCTION
FM0350	010+00	012+00	L	L.D. RECONSTRUCTION
FM0350	016+00	018+00	L	THIN OVERLAY
FM0350	018+00	020+00	L	MOD. OVERLAY
FM0350	022+00	024+00	R	L.D. RECONSTRUCTION
FM0942	004+00	006+00	R	L.D. RECONSTRUCTION
FM0942	006+00	006+19	R	L.D. RECONSTRUCTION
FM0942	018+00	020+00	L	L.D. RECONSTRUCTION
FM0942	030+00	032+00	L	L.D. RECONSTRUCTION
FM1745	002+00	004+00	L	L.D. RECONSTRUCTION
FM3126	002+00	004+00	R	L.D. RECONSTRUCTION
FM3126	006+00	008+00	R	L.D. RECONSTRUCTION
FM3152	004+00	006+06	R	L.D. RECONSTRUCTION
PR0065	000+00	000+08	R	L.D. RECONSTRUCTION
SH0146	002+00	004+00	L	SEAL COAT
US0059	000+00	002+00	R	SEAL COAT
US0059	000+00	002+00	L	SEAL COAT
US0059	002+00	004+00	R	SEAL COAT
US0059	004+00	006+00	R	SEAL COAT
US0059	022+11	026+00	S	THIN OVERLAY
US0190	010+14	014+00	R	SEAL COAT

Section 2
Data Collection and Reduction

This case study was primarily based upon information derived from a list of pavement related projects for Fiscal Year 1986 for District 11 as supplied by Mr. Bryan Stampley of D-18 of the Texas State Department of Highways and Public Transportation (SDHPT). The first step in analyzing this data was to determine for each project the RAMS-D01 M&R strategy that most closely resembled the "Type of Work" as specified in the SDHPT projects list. Table 3 lists the M&R strategies currently available in RAMS-D01.

A few of the project descriptions in the SDHPT list were identical to the names of the RAMS-D01 strategies. (e.g., Seal Coat'). Most of the other descriptions were in some way different from the RAMS-D01 strategy names. For some of these it was quite easy to determine which RAMS-D01 strategy was most appropriate (e.g., 'Rotomill, Seal & Overlay' in the SDHPT list was interpreted to be equivalent to a 'Heavy Overlay' in RAMS-D01). For others, it was not quite so easy and required some judgement to be made by the researchers (e.g.,'Resurface' in the SDHPT list became a 'Thin Overlay' in RAMS-D01). Finally, some of the SDHPT descriptions were not close to any of the RAMS-D01 strategies (e.g.,'Clear Trees and Underbrush') and were therefore not included in the study. Of the 64 projects in the SDHPT list, 45 were determined to be close enough to a RAMS-D01 strategy to be included in the analysis.

TABLE 3
RAMS-D01 M&R STRATEGIES

STRATEGY	MEANING
FOG SEAL	AS STATED
SEAL COAT	AS STATED
OGPMS	OPEN-GRADED PLANT MIX SEAL
THIN OVERLAY	LESS THAN 2" ASPHALT CONCRETE
MODERATE OVERLAY	2"-3" ASPHALT CONCRETE
THICK OVERLAY	3"-6" ASPHALT CONCRETE
LIGHT DUTY RECONSTRUCTION	STRENGTHEN BASE & SURFACE TREATMENT
HEAVY DUTY RECONSTRUCTION	FULL RECONSTRUCTION

The next step was to determine the average cost per mile-foot for each of the M&R strategies. This was done by dividing the cost for each project of a given strategy by the product of the length (in miles) and the width (in feet) of the road segments in the project and then averaging these values. For all strategies, except for Thin Overlay, an increase of between 110% and 120% was calculated over the default cost values that were recommended in the original RAMS-D01 package. The increase for Thin Overlay was higher, but it was felt that some of the projects classified as Thin Overlay might have really been a Moderate Overlay or Base Rework and Thin Overlay. Therefore, in an effort to be consistent, the average cost per mile-foot for each of the strategies including thin overlays was set equal to the previous RAMS-D01 value times 2.15 (i.e., a 115% increase). This increase is very close to the overall inflation increase in the years since the original RAMS-D01 work was developed (1978). Obviously, more work needs to be done to get more precise estimates of the unit costs for the various strategies. Table 4 shows the unit cost values used in this case study.

TABLE 4
UNIT COST FOR RAMS-D01 M&R STRATEGIES

STRATEGY	COST PER MILE-FOOT
FOG SEAL	$ 120.00
SEAL COAT	$ 460.00
OGPMS	$ 2040.00
THIN OVERLAY	$ 1990.00
MODERATE OVERLAY	$ 4300.00
THICK OVERLAY	$ 7630.00
LIGHT DUTY RECONSTRUCTION	$ 4000.00
HEAVY DUTY RECONSTRUCTION	$ 5590.00

The next step was to determine the amount of money used for the projects in each of the 9 counties in District 11. These values beçame the budget levels used in the RAMS-D01 runs. This was done so that the decisions made by RAMS-D01 could be compared to the ones made by the District. Table 5 gives the amounts determined for each county. It was necessary to run the program by county because of the limitation on the number of highway segments that can be accomodated in the microcomputer version of RAMS-D01. Currently, the number of highways segments that can be analyzed in any given run is 125. Future versions of the program will handle larger data sets.

TABLE 5
COUNTY EXPENDITURES FOR PROJECTS

COUNTY NUMBER	COUNTY NAME	EXPENDITURES (IN DOLLARS)
3	ANGELINA	3,191,000.00
114	HOUSTON	670,000.00
174	NACOGDOCHES	406,000.00
187	POLK	3,810,000.00
202	SABINE	181,000.00
203	SAN AUGUSTINE	202,000.00
204	SAN JACINTO	204,000.00
210	SHELBY	1,147,000.00
228	TRINITY	2,776,000.00
TOTAL DISTRICT FISCAL YEAR 1986 ALLOCATION		12,587,000.00

In order to estimate the funds actually needed by the counties for M&R activities, the fourth program of MICRO-PES was run for District 11. This program consists of a set of SDHPT decision tables which relate pavement type, traffic level and distress types to the appropriate rehabilitation strategy (1). The results of that run for flexible pavements are shown in Table 6. Note that the estimated costs in Table 6 are broken down into "URBAN" and "RURAL" categories. Therefore to get the total requirements for a county, the "TOTAL" numbers from the 2 categories must be added together. Taking the District as a whole, it is clear that not enough funds were allocated to District 11 to solve all of the problems with flexible pavements. In fact, the $12,587,000 is only about one-third of the $35,086,764 ($16,933,169 + $18,153,595) needed, as estimated by MICRO-PES.

TABLE 6
FUNDS NEEDED FOR M&R ACTIVITIES

SUMMARY OF URBAN FLEXIBLE PAVEMENT REHABILITATION COST PER COUNTY

COUNTY	3 in. Overlay	6 in. Overlay	Part. Reconstruct.	Reconstruct.	Total
Angelina	2,201,079.	1,002,376.	331,056.	256,714.	3,791,225.
Houston	579,090.	517,595.	182,952.	0.	1,279,637.
Nacogdoches	880,365.	814,779.	49,833.	197,472.	1,942,449.
Polk	2,673,266.	1,329,897.	284,360.	197,472.	4,484,995.
Sabine	180,966.	0.	69,696.	0.	250,662.
San Augustine	113,271.	0.	0.	0.	113,271.
San Jacinto	536,865.	968,324.	0.	0.	1,505,189.
Shelby	1,306,304.	1,472,917.	0.	0.	2,779,221.
Trinity	147,454.	321,949.	317,117.	0.	786,520.
TOTALS	8,618,660.	6,427,837.	1,235,014.	651,658.	16,933.169.

TABLE 6
FUNDS NEEDED FOR M&R ACTIVITIES (Continued)

SUMMARY OF RURAL FLEXIBLE PAVEMENT REHABILITATION COST PER COUNTY

COUNTY	3 in. Overlay	6 in. Overlay	Part. Reconstruct.	Reconstruct.	Total
Angelina	1,026,433.	374,351.	988,986.	0.	2,389,770.
Houston	1,546,365.	693,243.	619,598.	0.	2,859,206.
Nacogdoches	654,248.	0.	453,953.	116,160.	1,224,361.
Polk	1,490,039.	684,577.	867,715.	1,403,213.	4,445,544.
Sabine	0.	0.	315,955.	0.	315,955.
San Augustine	86,655.	0.	297,370.	0.	384,025.
San Jacinto	866,554.	363,953.	1,209,923.	598,244.	3,038,654.
Shelby	853,555.	0.	785,242	0.	1,638,797.
Trinity	996,537.	0.	413,530.	447,216.	1,857,283.
TOTALS	7,520,386.	2,116,124.	5,952,272.	2,564,813.	18,153,595.

A result of the inadequate funding for District 11 was a drop in pavement condition between 1985 and 1986. In fact, Table 7 indicates that the average pavement score for 4 of the 6 distress types included in the PES data base were worse in 1986 than they were in 1985. The scores for the first 5 distress types that were used in determining the averages shown in Table 7 are derived from the PES rater's manual (3) according to the conversions shown in Table 8. For example, if a road segment was given a PES rating of 001 for rutting, for the purposes of Table 7 it had a rating of 5. The conversion values of Table 8 are also used by RAMS-D01 as a procedure for weighting the different distress types. It should be noted here that the PSI value is also converted to a scale between 0 and 50. This conversation is as follows:

If the PSI value is less than 2.4, it is converted to 0.0;
If the PSI value is greater then 4.7, it is converted to 50.0;
Otherwise the conversion is found by:

$$50.0 * (-EXP(-((2.84/PSI)^{**}10.0))).$$

In the next section, the decisions made by the District are compared to the decisions provided by RAMS-D01. The 1986 average pavement condition scores in Table 7 are compared to the values that would have resulted from implementing the RAMS-D01 decisions. As a final step in preparing to make the RAMS-D01 runs, it was necessary to create a file of pavement sections to be included in the analysis. Sections with no distress were excluded from the analysis. It was decided to only include those road segments with a pavement score below 80 in this file. This was done to reduce the size of the county PES files because of the limitation on the number of sections that can be handled by the micro-computer version of RAMS DO-1. A pavement score of 80 was selected as the cut-off score because, in the judgement of the researchers, it is unlikely that road segments with a pavement score of 80 or greater would require any M&R activity.

TABLE 7
AVERAGE PAVEMENT CONDITION SCORES BY DISTRESS TYPE

YEAR	RUTTING	ALLIG. CRK.	LONG. CRK.	TRANS. CRK.	FAILURES PER MILE	PSI (RAW)	PSI (CONVERTED)
1985	11.50	22.97	23.36	18.40	38.29	2.68	16.73
1986	11.16	21.99	23.58	18.53	37.21	2.52	13.08
MAX*	15.00	25.00	25.00	20.00	40.00	5.00	50.00

* The MAX value represents no distress present; therefore decreases in values represent worsening conditions.

TABLE 8
CONVERSION OF PES DISTRESS RATINGS (3)

AREA	NONE	LOW	MED	HIGH	LOW	MED	HIGH
PES RATING	000	100	010	001	200	020	002*
DISTRESS TYPE							
RUTTING	15	10	8	5	5	3	0
ALLIG. CRK.	25	15	10	5	-	-	-
LONG. CRK.	25	18	13	10	-	-	-
TRANS. CRK.	20	13	10	5	-	-	-
FAILURES/MILE	40	20	10	0	-	-	-

* Two severity levels are used for rutting 0.5 to 1.0 inch and >1 inch; only a single severity level is specified for the other distresses.

Section 3

RAMS-D01 Runs

Using the 1985 PES data for District 11, several runs of the RAMS-D01 program were made to generate, for each county within the District, an alternative list of projects along with the recommended maintenance or rehabilitation treatments. The maintenance and rehabilitation projects selected by the program were subsequently compared to those from the District to evaluate the degree by which RAMS-D01 matches the 1985 District selections. It was found that the results did not agree very well with the District selections. There were discrepancies in the projects selected and in the maintenance or rehabilitation treatments that were to be made.

A plausible explanation for these discrepancies may be obtained when one examines how projects are defined by the Districts. In current practice, a project can be an agglomeration of more than one PES segment along a particular route or a subset of a PES segment. Many of the 1985 District 11 projects, for example, were more than 2 miles long (the usual PES segment length) and consisted of more than 1 PES segment. However, the current version of RAMS-D01 works with the individual highway segments that are found in the PES data base and provides an optimized list of 'projects' which are really individual PES segments. These individual segments may not necessarily combine to form the projects selected by a particular county as was the case for this study. Consequently, one of the research needs identified concerns the improvement of RAMS-D01 to enable the user to specify projects so that the optimization will be made based on a specified pool of projects rather than on two-mile road segments. These projects may be individual PES segments or a combination of such segments. This will be discussed in more detail in Section 4.

In addition to evaluating the agreement between the RAMS-D01 and District 11 lists of projects, a comparison of pavement condition ratings for projects selected by RAMS-D01, with the ratings for projects selected by the District, was also made. Table 9 provides a side-by-side comparison of average distress ratings for RAMS-D01 and 1985 District 11 projects. In most instances, the average distress ratings for projects selected by RAMS-D01 were lower than those for the District selections. This indicates that the sections selected by the program were, on the average, in a poorer condition than those selected by the District. This

TABLE 9

COMPARISONS OF AVERAGE DISTRESS RATINGS FOR PROJECTS SELECTED BY RAMS-DO1 WITH PROJECTS SELECTED BY DISTRICT 11 (PRE-TREATMENT RATINGS)

COUNTY	RUTTING (0-15)*	ALLIGATOR CRACKING (0-25)	LONGITUDINAL CRACKING (0-25)	TRANSVERSE CRACKING (0-20)	FAILURES (0-40)	PSI (0-5)	PES PAVEMENT SCORE (0-100)
1. ANGELINA							
a. DISTRICT 11	8.81	23.10	20.52	14.05	38.06	3.35	62.57
b. RAMS-DO1	11.03	17.97	17.38	13.50	34.69	3.08	43.25
2. HOUSTON							
a. DISTRICT 11	12.08	22.08	22.25	15.08	40.00	2.94	68.50
b. RAMS-DO1	11.43	18.57	18.29	11.57	40.00	2.77	51.71
3. NACOGDOCHES							
a. DISTRICT 11	9.78	21.67	21.33	14.33	37.78	2.59	67.78
b. RAMS-DO1	13.33	21.67	16.67	12.17	36.67	3.15	54.00
4. POLK							
a. DISTRICT 11	12.40	21.10	20.20	16.30	36.10	3.20	66.45
b. RAMS-DO1	7.75	13.04	17.14	14.75	27.50	2.26	29.54

* Numbers inside parentheses show the range in scores possible for each distress category.

TABLE 9

COMPARISONS OF AVERAGE DISTRESS RATINGS FOR PROJECTS SELECTED BY RAMS-DO1 WITH PROJECTS SELECTED BY DISTRICT 11 (PRE-TREATMENT RATINGS - CONTINUED)

COUNTY	RUTTING (0-15)*	ALLIGATOR CRACKING (0-25)	LONGITUDINAL CRACKING (0-25)	TRANSVERSE CRACKING (0-20)	FAILURES (0-40)	PSI (0-5)	PES PAVEMENT SCORE (0-100)
5. SABINE							
a. DISTRICT 11	10.27	21.36	25.00	20.00	40.00	2.45	75.91
b. RAMS-DO1	15.00	10.00	25.00	20.00	40.00	2.50	65.00
6. SAN AUGUSTINE							
a. DISTRICT 11	14.29	25.00	24.00	18.57	40.00	2.94	81.29
b. RAMS-DO1	10.00	15.00	18.00	20.00	40.00	2.20	54.00
7. SAN JACINTO							
a. DISTRICT 11	12.14	23.57	25.00	20.00	37.14	2.04	66.86
b. RAMS-DO1	12.00	16.25	13.00	12.25	40.00	3.53	52.25
8. SHELBY							
a. DISTRICT 11	10.00	25.00	22.00	17.57	40.00	3.06	80.43
b. RAMS-DO1	10.30	18.00	18.20	12.60	34.00	2.63	56.40
9. TRINITY							
a. DISTRICT 11	11.25	20.83	22.67	19.42	40.00	2.74	69.42
b. RAMS-DO1	9.64	20.20	20.60	16.44	36.00	2.30	51.16

* Number inside parentheses show the range in scores possible for each distress category.

is evident in Figure 1 which shows the cumulative distributions of pavement scores for each group of projects (i.e., RAMS-D01 and District 11). A pavement score is an aggregate rating that reflects the overall condition of a pavement section and is a function of the visual distress and roughness. From Figure 1, it is readily apparent that the pavement scores for the RAMS-D01 group of projects were generally lower than those for the District.

It is of interest to estimate what the average pavement condition scores would have been in 1986 had the RAMS-D01 selections been implemented. Table 10 compares the 1985 average pavement condition scores with the 1986 averages, after implementation of the District 11 group of projects, and also with estimates of the averages that would have been obtained had the RAMS-D01 group of projects been implemented. In the latter case, average pavement condition scores were estimated assuming that the distress ratings for projects selected by the District remained at the levels that they were in 1985. In addition, for those projects selected by RAMS-D01, the after-treatment scores predicted by the program were used in calculating the average pavement condition scores.

TABLE 10
COMPARISON OF AVERAGE PAVEMENT CONDITION SCORES

DISTRESS	AVERAGE RATINGS		
	1985	1986 - DISTRICT 11	1986 - RAMS-D01
RUTTING	11.50	11.16	11.43
ALLIGATOR CRK.	22.97	21.99	22.37
LONGITUD. CRK.	23.36	23.58	23.84
TRANSVERSE CRK.	18.40	18.53	18.75
FAILURES/MILE	38.29	37.21	37.69
PSI	2.68	2.52	2.55

Table 10 indicates that even if, in 1986, the RAMS-D01 selections had been implemented, the average pavement condition scores for 4 of the 6 distress types (i.e., rutting, alligator cracking, failures/mile, and PSI)

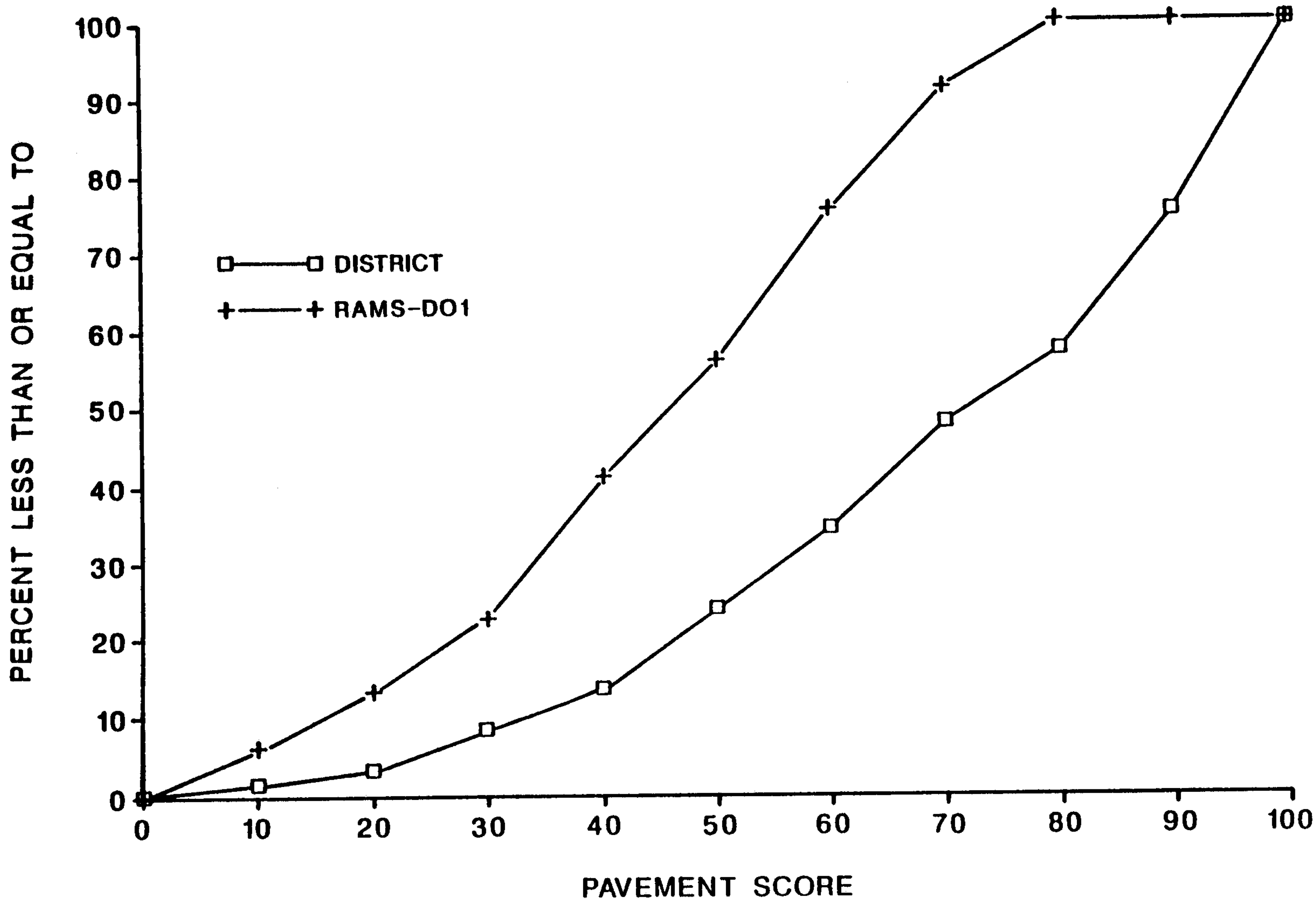

Figure 1. Cumulative Distributions of Pavement Scores for District 11 Projects and RAMS-D01 Projects.

would have been predicted to decline from the 1985 values. This is evident from Figures 2 to 5 which show the cumulative distributions for these distress types. The results shown in the figures are consistent with what actually occured in the District in 1986, and indicate that there probably was not enough money allocated to District 11 to improve the overall condition of its highways. As presented previously, the District only got about one-third of the $35,086,764 it needed for M&R projects. However, Table 10 also indicates that the reductions in average pavement condition scores are predicted to be less had the RAMS-D01 group of projects been implemented. This may be due to the fact that projects selected by RAMS-D01 were generally in a poorer condition than those selected by the District. Consequently, one would expect that, had such projects been repaired, the average pavement condition scores would have been higher than they were in 1986.

There could be a number of reasons as to why some roads, which were in a poorer condition than those which made the 1985 District list of projects, were not selected. One possible reason is by inadvertent omission. This can easily occur when one is faced with the situation of allocating a limited amount of resources among a host of different alternatives. It is, of course, in these situations that a program like RAMS-D01 can be most useful. By having the capability to consider a significant number of pavement sections in the development of a work schedule for a particular fiscal year, a highway engineer can have a more cost-effective allocation of the limited funds available.

It should be emphasized however that RAMS-D01 is only a decision analysis tool, and it was never intended to dictate the decisions for the highway engineer. There can be other considerations which play a significant role in the selection of projects that RAMS-D01 cannot presently account for. These include political considerations, project readiness, and the effects of traffic and the environment. In an effort to evaluate whether traffic played an important role in the selection of projects within the District, Figures 6 and 7 were prepared, which show the distributions of Average Daily Traffic (ADT) and 18-kip ESALs for the RAMS-D01 and District 11 groups of projects. Figures 6 and 7 indicate that the District selections had somewhat higher traffic levels.

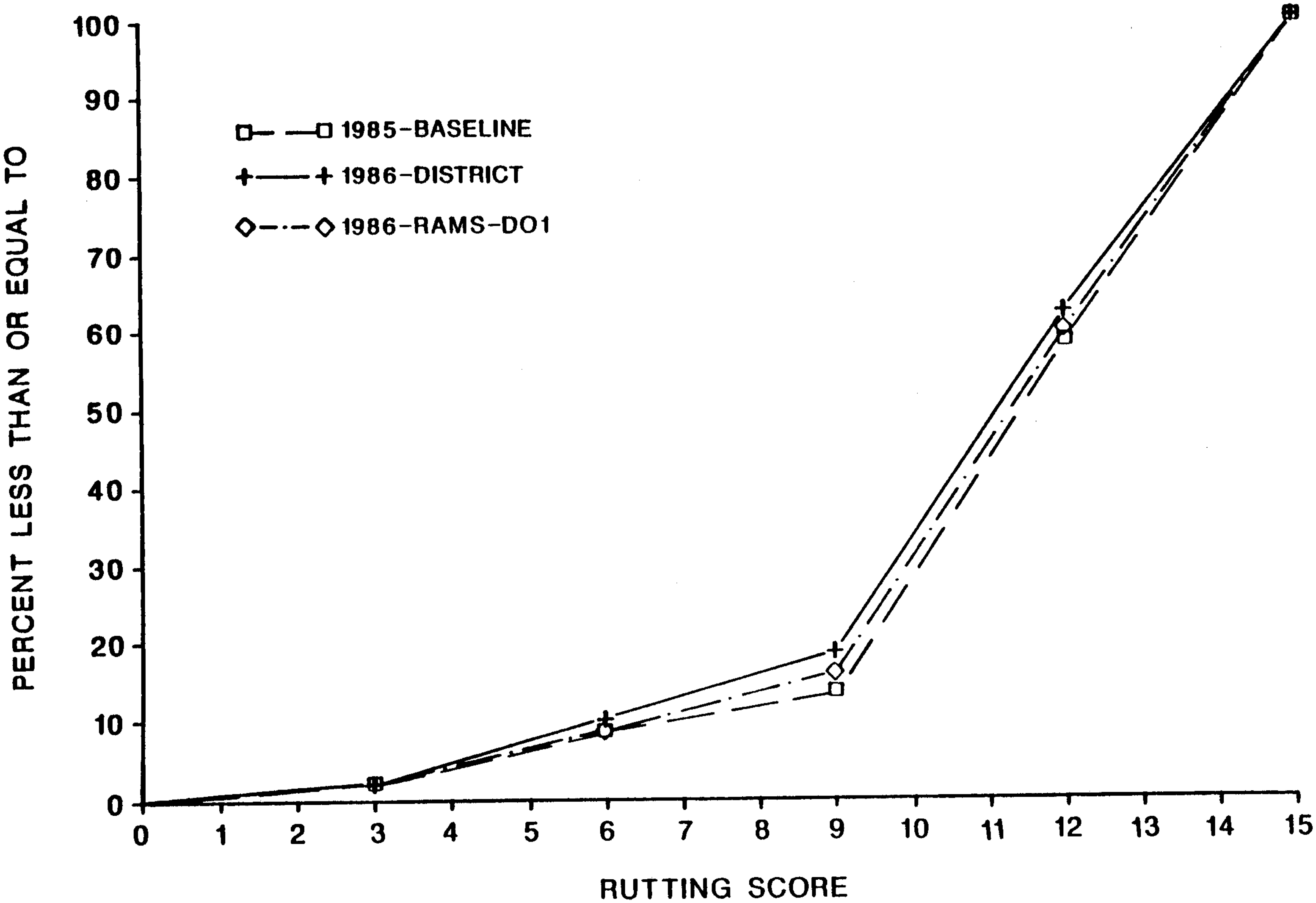

Figure 2. Cumulative Distributions of Rut Depth Scores.

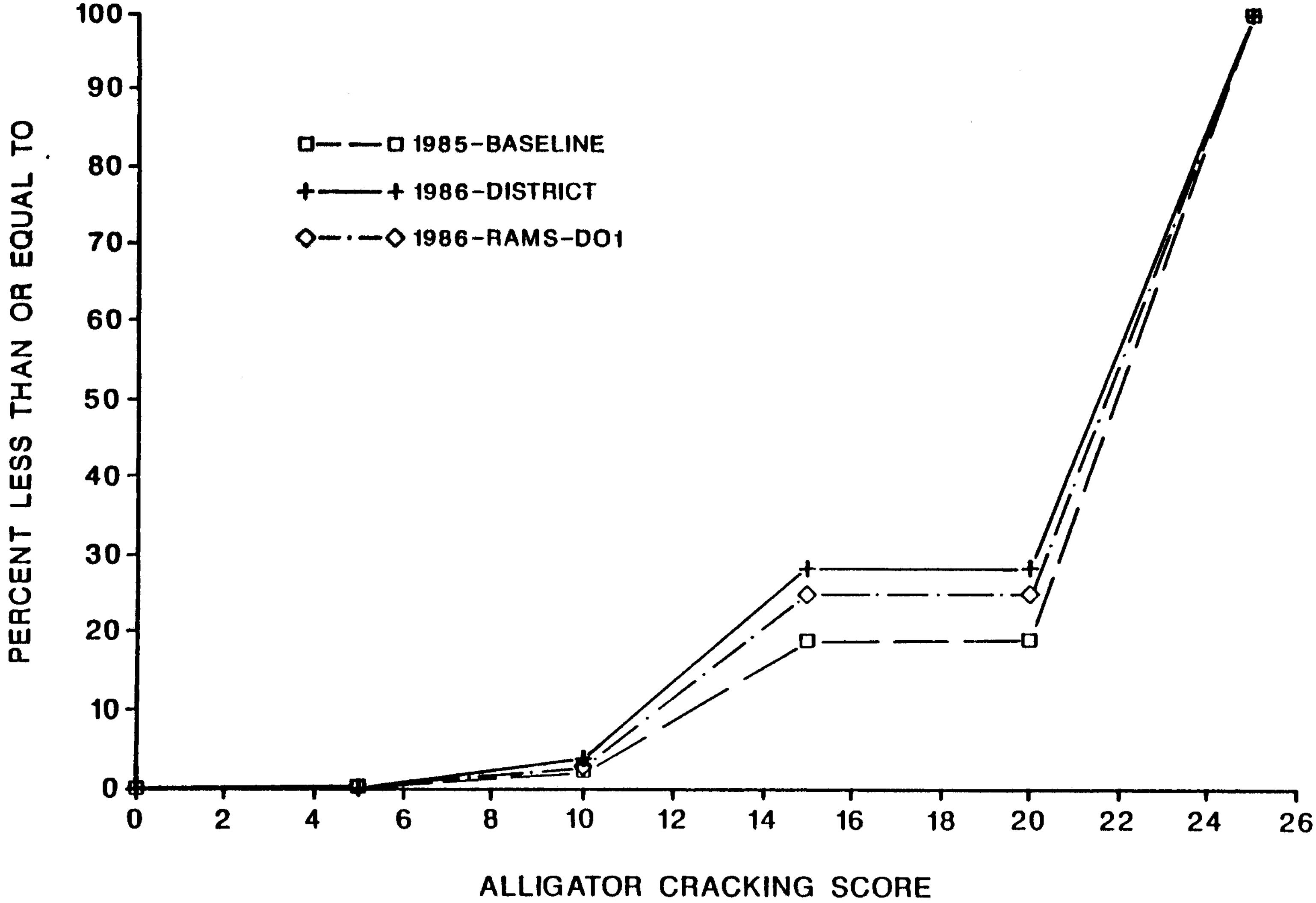

Figure 3. Cumulative Distributions of Ratings for Alligator Cracking.

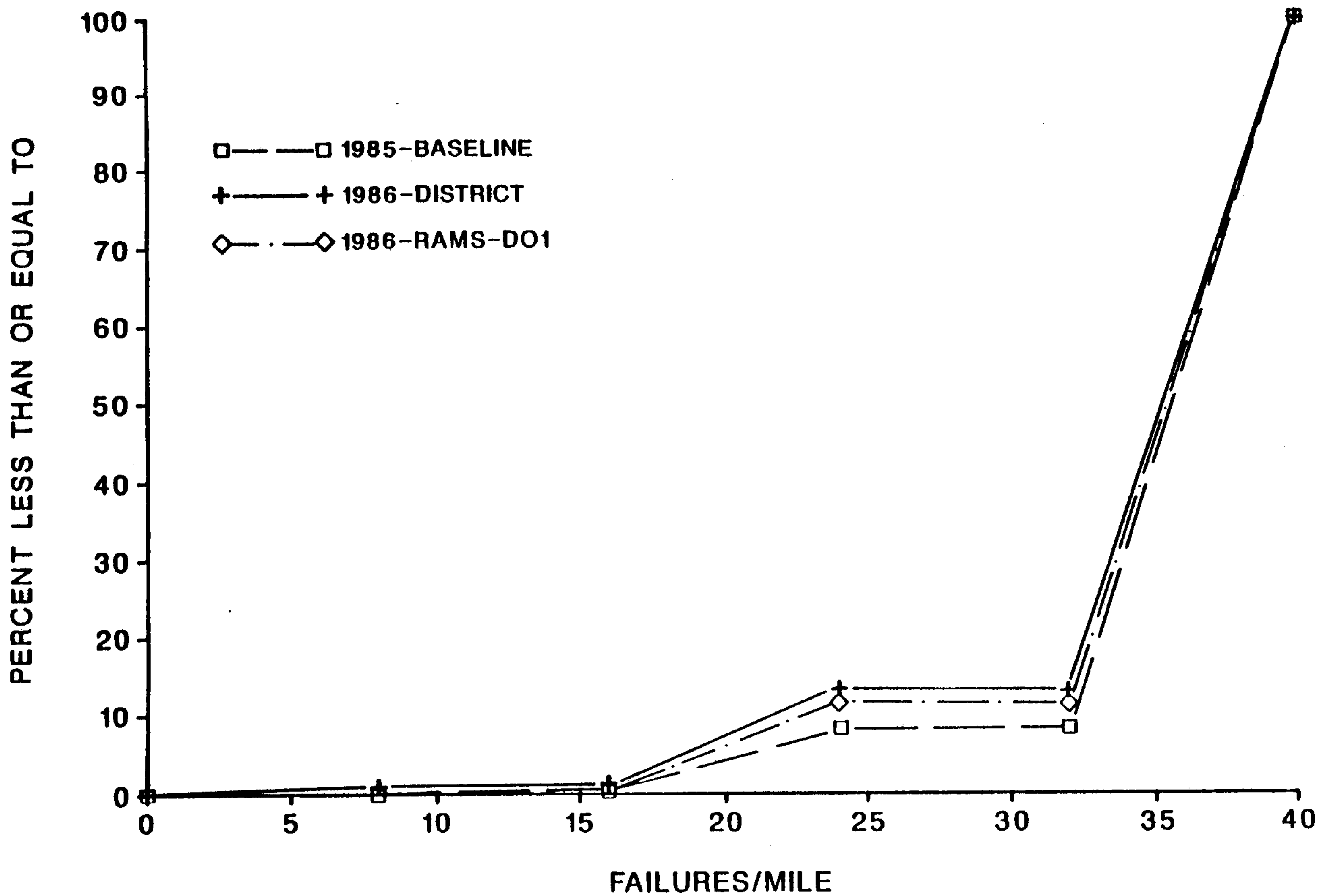

Figure 4. Cumulative Distributions for Failures per Mile.

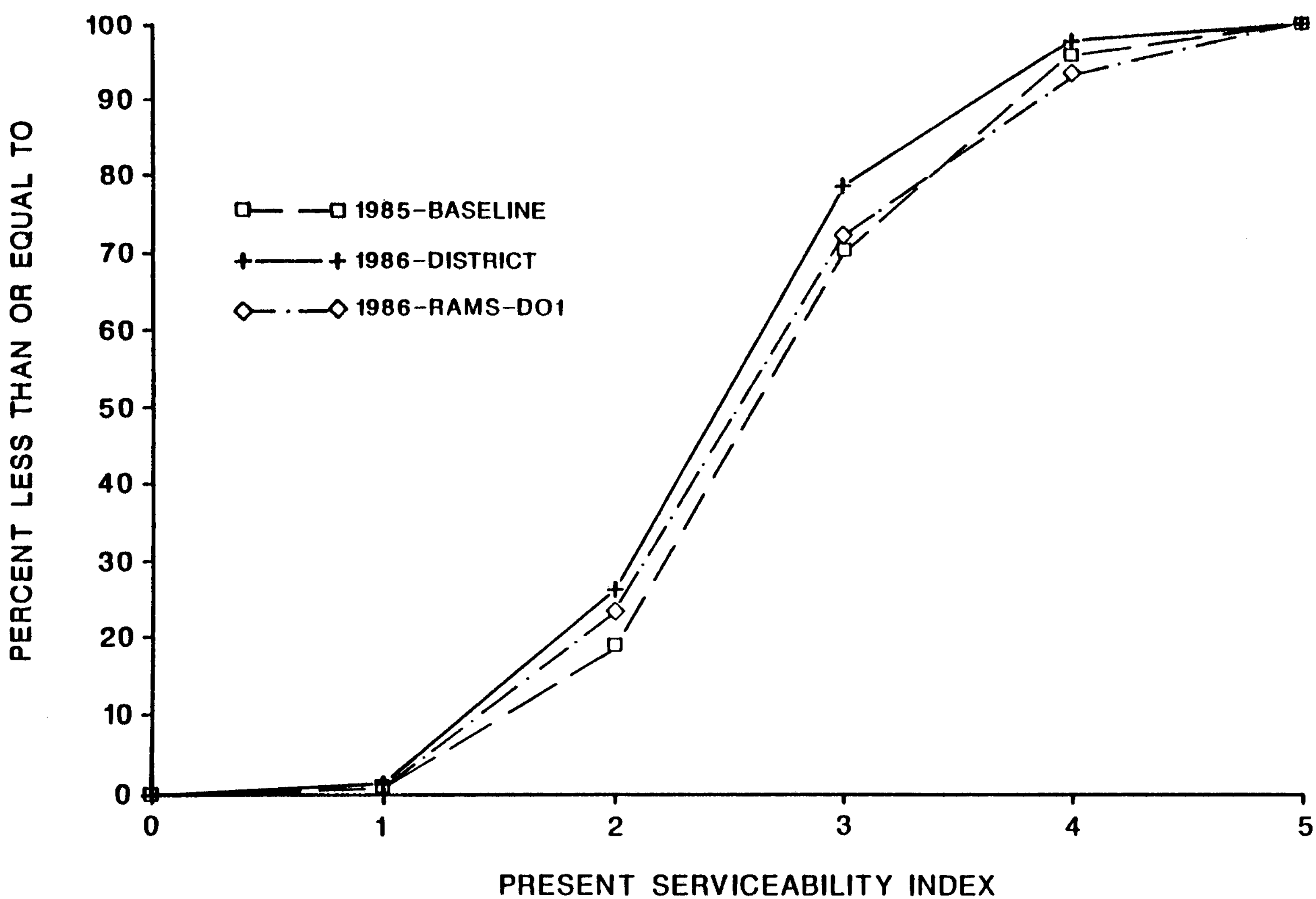

Figure 5. Cumulative Distributions for Present Serviceability Index.

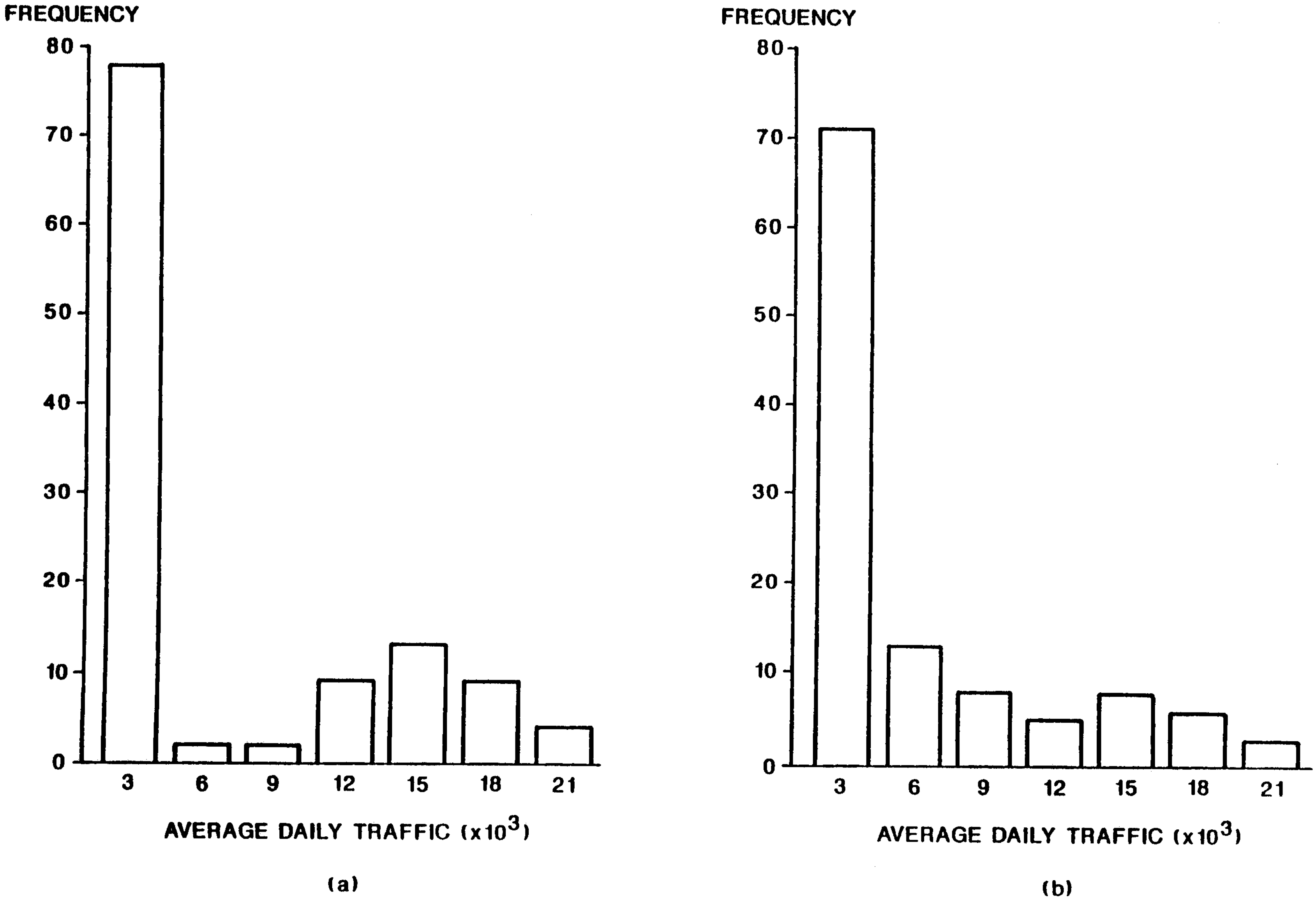

Figure 6. Distributions of Average Daily Traffic for a) District 11 Projects and b) RAMS-D01 Projects.

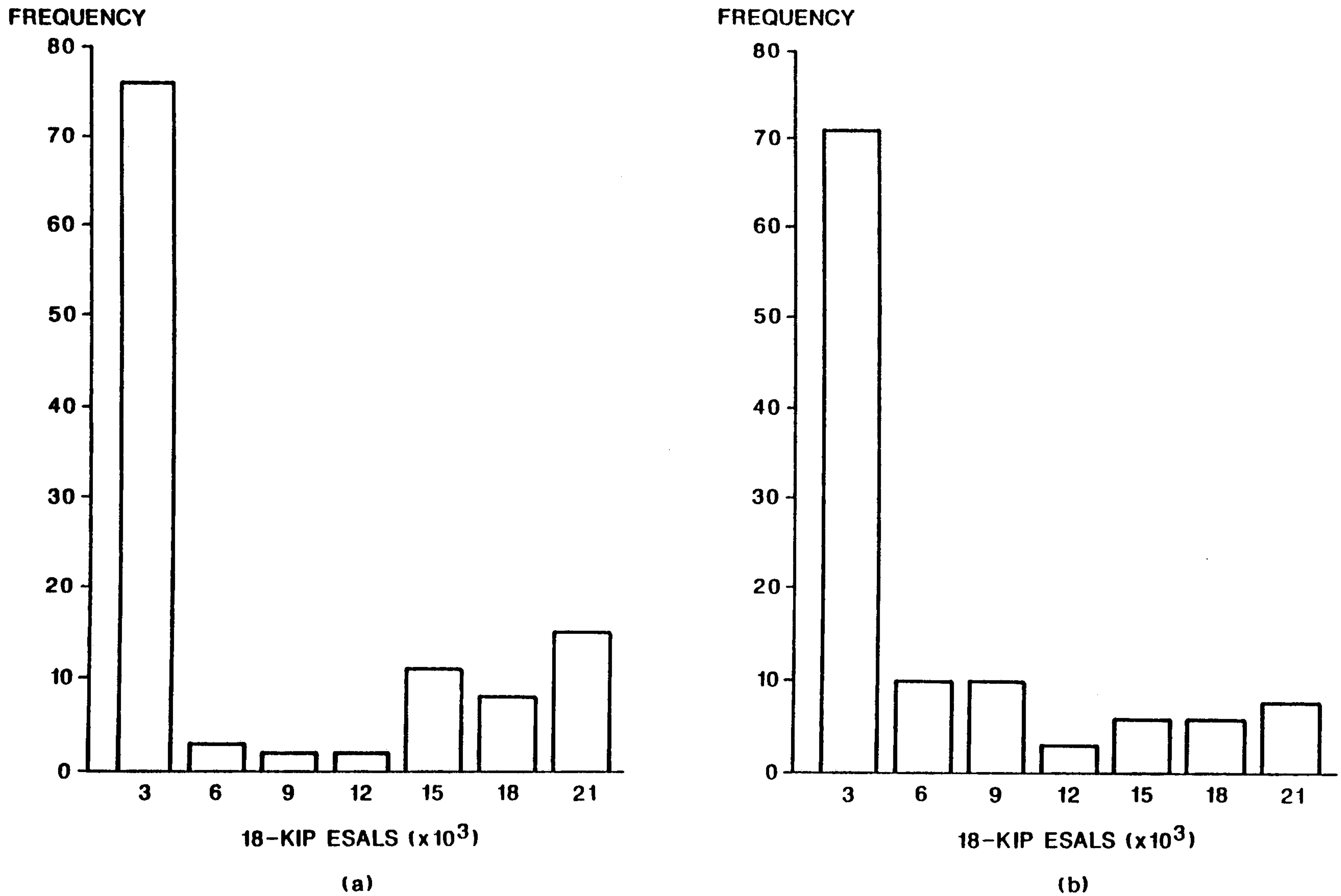

Figure 7. Distributions of 18-kip ESALS for a) District 11 Projects and b) RAMS-D01 Projects.

There are more observations at higher ADT's and 18-kip ESALs for the District selections than there are for the RAMS-D01 group of projects. In fact, the means of the ADT and 18-kip ESALs for the District projects were 6046 and 6802, respectively, compared to 3396 and 3607 for the RAMS-D01 selections. This would indicate that traffic was an important factor in the District selection of projects. The results obtained therefore point to the need for increasing the weighting given to traffic in the RAMS-D01 optimization algorithm. This task would involve generation of survivor curves for different traffic levels and development of a scheme for weighting the RAMS-D01 objective function depending on traffic. Currently, there is a scheme by which a user can specify adjustment factors to account for the influence of traffic level on the survivor curves. Adjustment factors greater than 1.0 can be used to shift the survivor curves to reflect the influence of heavier traffic loadings. However, this feature of the program is not used at the present time. The relationship between level of traffic loading and traffic adjustment factor needs to be further evaluated.

In order to illustrate the effect of this factor on the optimal list of projects generated by RAMS-D01, a series of runs were made wherein a traffic weighting factor equal to LOG_{10} (ADT) was applied to the objective function. This evaluation was conducted using the PES data for Angelina, Polk and Trinity counties. The results from this evaluation are presented in Table 11. As may be expected, the effect of a traffic weighting factor is to favor the selection of projects with higher traffic levels as reflected in the upward shift of the means for ADT and 18-kip ESALs. In addition, application of a weighting factor can lead to selection of projects with higher condition ratings over projects with lower ratings but with much less traffic. This is evident in the upward shift of the mean pavement scores for Angelina and Polk counties as the objective function is weighted for traffic level. The effect of traffic as illustrated in Table 11 can also help to explain why the District group of projects had higher mean condition ratings than those for the RAMS-D01 group. Consequently, consideration of traffic in the optimization process is a research item that needs to be addressed in order to simulate more realistically how decisions are made on maintenance and rehabilitation projects.

TABLE 11
COMPARISON OF MEAN TRAFFIC LEVELS AND PAVEMENT SCORES ON PROJECTS SELECTED TO SHOW EFFECT OF APPLYING A TRAFFIC WEIGHTING FACTOR ON THE RAMS-D01 OBJECTIVE FUNCTION

COUNTY	NO TRAFFIC WEIGHTING FACTOR APPLIED			TRAFFIC WEIGHTING FACTOR APPLIED		
	ADT	18-KIP ESALS	PAVEMENT SCORE	ADT	18-KIP ESALS	PAVEMENT SCORE
ANGELINA	8147	8904	43.25	9371	10,313	48.05
POLK	5638	6043	29.54	7039	7598	36.65
TRINITY	1704	1733	51.16	2217	2143	49.09

Another exercise that was conducted was to evaluate the effect of budget level on the "optimal" list of projects generated by RAMS-D01. One of the useful applications of this program is the development of a budget versus benefit profile. This capability for evaluating different budget levels should facilitate budget preparation, and help justify funding requests by the Districts in the State. In order to demonstrate this capability, a series of runs were made wherein the optimal list of projects for Angelina, Polk and Trinity counties was evaluated assuming a budget for each county twice that which was available in 1985. The benefits of a bigger budget are indicated in Table 12 which compares mean distress ratings predicted under two different budget levels. The mean distress ratings shown represent those that can be obtained immediately after implementation of the RAMS M&R strategy. As may be expected, a bigger budget level would enable the resident engineers to repair more miles of roadway and thus increase the average condition ratings or further improve the overall condition of their highways. Table 12 therefore shows the kinds of information highway engineers can obtain from RAMS-D01 to justify increased funding requests.

The next section discusses the conclusions of this case study and briefly discusses some areas for further research. The further research could lead to significant improvements in the performance of RAMS-D01.

TABLE 12

PREDICTED AVERAGE DISTRESS RATINGS AT 2 BUDGET LEVELS AFTER APPLICATION OF RAMS-D01 MAINTENANCE AND REHABILITATION STRATEGIES

DISTRESS	ANGELINA		POLK		TRINITY	
	AT 1985 BUDGET	AT TWICE 1985 BUDGET	AT 1985 BUDGET	AT TWICE 1985 BUDGET	AT 1985 BUDGET	AT TWICE 1985 BUDGET
RUTTING	10.94	11.49	11.29	12.16	11.26	12.24
ALLIGATOR CRACKING	22.32	23.29	21.51	22.63	22.32	23.48
LONGITUDINAL CRACKING	23.31	23.82	23.50	23.80	24.36	24.51
TRANVERSE CRACKING	17.88	18.50	18.80	18.96	19.51	19.51
FAILURES/MILE	39.33	39.38	34.09	35.63	36.36	37.98
PSI	2.74	2.79	2.48	2.49	2.32	2.36
NUMBER OF MILES REPAIRED	63.80	128.50	57.10	105.90	51.90	88.30

Section 4

Conclusions and Directions for Further Research

MICRO-PES is a decision analysis tool with promising potential and RAMS-D01 is an integral part of this package. RAMS-D01 is not meant to replace the decision maker, but is meant to assist him or her in determining the "best" combination of M&R activities and road segments. It can be used early in the decision making process to identify road segments that will obviously need to be worked on. It can also be used later in the decision-making process to help determine the appropriate M&R treatment for each of the road segments in a group subject to a given funding level.

While RAMS-D01 is a powerful tool as it is, there are several areas that should be researched in order to improve the existing capabilities. These areas include the generation of survivor curves for various climatic zones, consideration of the amount of traffic on each road segment in determining the "best" set of road segments, and a way to group road segments into projects and then use RAMS-D01 to find the "best" set of projects. A brief discussion of each of these research areas and several others is given below.

4.1 Survivor Curves for Various Climatic Zones

In the RAMS-D01 program, predictions of pavement performance are accomplished using survivor curves. A survivor curve shows the probability that a given pavement will not require additional maintenance or rehabilitation at a particular point in time. Survivor curves for various pavement distress types, and maintenance and rehabilitation activities, were determined from the collective judgement and experience of various Texas SDHPT engineers. The curves were subsequently built into the RAMS-D01 program.

It is recognized however, that the current set of survivor curves may not be applicable to all the Districts because of variations in environmental conditions around the state. Consequently, one suggested research activity is the development of survivor curves for different environmental regions in Texas. These regions or climatic zones are shown in Figure 8.

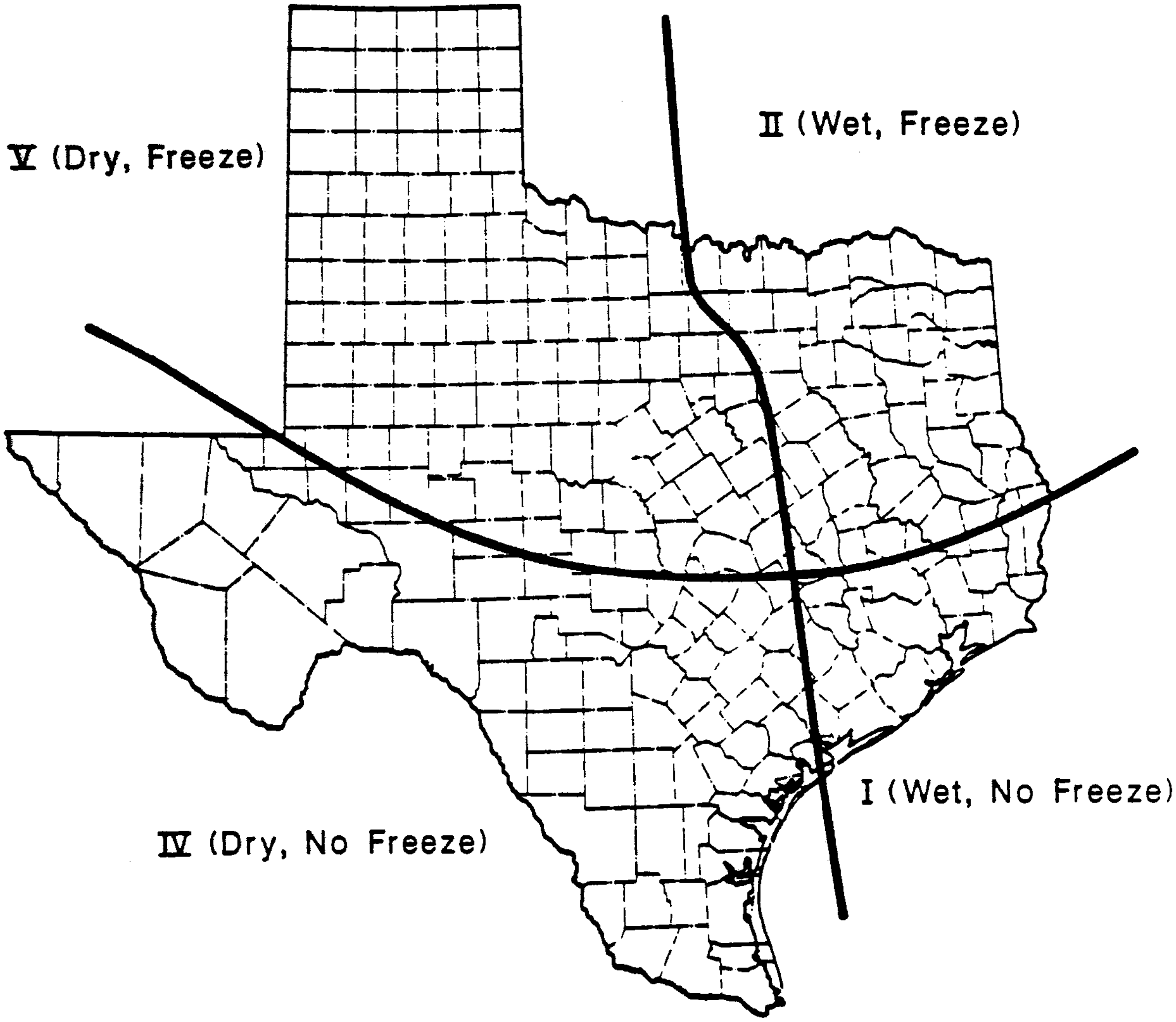

Figure 8. Environmental Regions in Texas.

In view of the lack of sufficient performance data to develop survivor curves for different distress types, and maintenance and rehabilitation activities, an approach based on the use of expert opinions is suggested for accomplishing this task. The basic premises of this approach are that a wealth of information can be obtained from the cumulative experience of highway engineers, and that this cumulative experience is just as useful as field data. A method, known as the Delphi technique, may be used to solicit expert opinions for the development of survivor curves. A brief discussion of this technique is given in Appendix B.

4.2 Effect of Traffic

RAMS-D01 currently gives an equal consideration to all road segments regardless of the amount of traffic on the individual segments. It seems logical to give highly traveled road segments more consideration because fixing one of these roads gives more "benefit" to more people. There are several ways that this could be accomplished. One possibility is by applying a weighting factor to the RAMS-D01 objective function. Section 3 illustrated the use of one proposed weighting factor (LOG_{10} ADT). The "best" weighting factor could be determined using the Delphi technique.

Another possible way to include the effect of traffic is to apply a weighting factor to the survivor curve, since pavement performance is influenced by the level of traffic loading. All other conditions being the same, a pavement section subjected to a greater number of 18-kip ESALs per day will deteriorate faster than one subjected to a lower number of 18-kip ESALs. As mentioned previously, the program can accept a user-supplied adjustment factor to shift the survivor curves to account for the influence of traffic loading. However, a procedure for selecting the appropriate adjustment factor for a given level of traffic loading needs to be developed.

A third possibility is to use weighting factors in both the survivor curve and the objective function. This would account for both the effect of traffic loading on the service life of the pavement section and the effect of traffic volume on user "benefits" that can be obtained.

4.3 Project Selection

A major weakness of the current implementation of MICRO-PES is that RAMS-D01 will only deal with PES data records. Most of the PES records are for two-mile road segments. Oftentimes the district engineer is considering a project that is made up of several of these two-mile segments or a project that is a subset of a two-mile segment. The answer to this problem is to modify the first MICRO-PES program (i.e., the Create a Subset File program) to allow the specification of individual projects. This will probably not be difficult to do for projects that are subsets of a two-mile segment. A PES data record can be split into two data records that are identical except for the beginning and ending mile posts. However, when two or more PES records are to be combined into a single project record, rules will have to be developed to assign distress ratings for the project if the PES records do not have identical ratings. In both of the cases above, the user will need to have a way to override the PES ratings.

4.4 Additional Research Areas

Another area that must be studied more closely is the average cost per mile-foot of each of the RAMS-D01 M&R activities (treatments). This can be done by collecting and analyzing data from already completed projects all over the state and systematically classifying them into one of the RAMS-D01 strategies. Another approach is to modify the RAMS-D01 treatments, survior curves, and costs to match SDHPT "typical" treatments.

The current implementation of RAMS-D01 also does not deal with rigid pavements. In order to include rigid pavements, several things must be done. First, M&R strategies appropriate for rigid pavements must be evaluated. Next, the cost per mile-foot for each of these strategies must be determined. Finally, survivor curves for each of the strategies must also be developed.

A final item that could be explored is whether the RAMS District Time Optimization (RAMS-DTO1) program should be incorporated into the MICRO-PES package. RAMS-DTO1 is similar to RAMS-DO1, except that it considers a multi-year planning horizon. Budget levels must be given for a user specified number of years, and the output tells which M&R activities should be performed in which years. This will help the Districts prepare their 2-5 year plans. Longer planning horizons (e.g., 10-20 years) may not be possible.

Probably the best way to determine the order in which the above mentioned research items should be explored is to let the Districts use the current version of MICRO-PES and get their feedback. TTI stands ready and willing to assist the Districts in the use of the package.

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Appendix A

Overview of RAMS-D01

Introduction

In many highway jurisdictions, maintenance and rehabilitation requirements exceed the resources available. Thus, highway engineers are faced with the problem of allocating limited resources among several competing alternatives--sections of roadways in need of maintenance or rehabilitation. The highway engineer is then confronted with the task of establishing a set of maintenance and rehabilitation activities that most effectively addresses the needs of the pavement network with the limited resources at his disposal.

The Rehabilitation and Maintenance System (RAMS) is a set of computer programs developed at the Texas Transportation Institute for managing highways in the State of Texas. The RAMS package operates at two distinct levels: The District level and the State level. One of the programs for application at the District level is the RAMS District Optimization program [2], hereafter referred to as the RAMS-D01 program. RAMS-D01 was developed to aid District engineers in the selection of maintenance and rehabilitation activities that would make the best possible use of the resources available for a particular fiscal year. Categories of resources considered include materials, equipment, manpower and budget constraints.

Figure A-1 provides an overview of RAMS-D01. The program has been implemented on a microcomputer and is referred to as MICRO-RAMS-D01 in the figure. Program inputs include: 1) pavement section characteristics (i.e., pavement condition, section length, and width); 2) resource requirements and constraints (e.g., budget, materials, equipment, and manpower); 3) maintenance and rehabilitation strategies; 4) traffic and environmental conditions; 5) analysis period; 6) minimum rating requirements; and 7) pavement performance information. The input variables are those that are normally considered by a highway engineer during the decision process of allocating limited resources for preserving highways under his jurisdiction.

As may be inferred from Figure A-1, RAMS-D01 provides a highway engineer with an analytical tool for evaluating the effects of different budget levels, and for drawing a budget versus benefit profile. The effects of changes in unit costs for manpower, equipment and materials, or of different minimum rating requirements can also be evaluated.

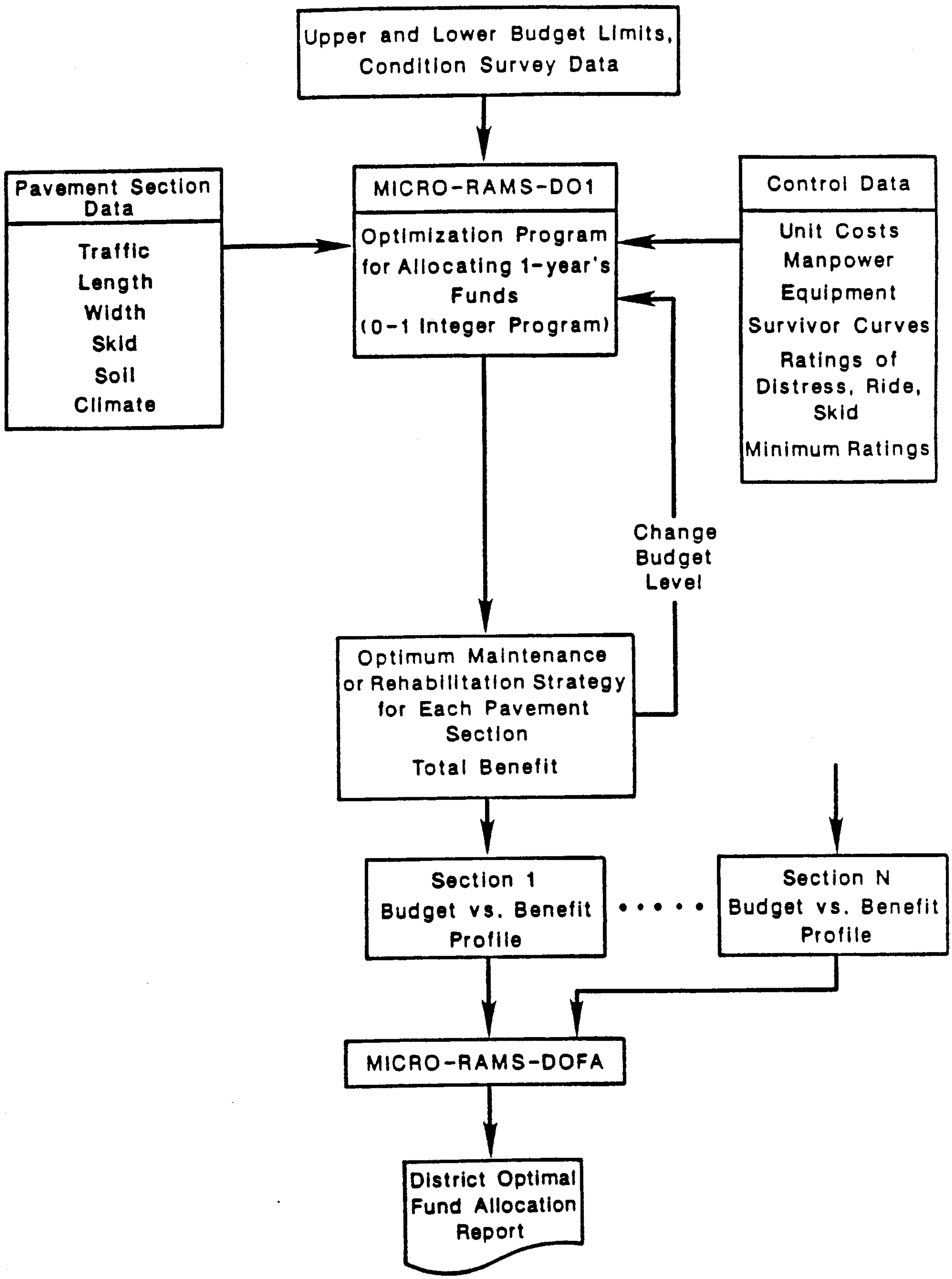

Figure A-1. Overview of Micro-RAMS-D01

This capability for evaluating different scenarios should facilitate budget preparation, and help justify funding requests by the Districts in the State. In addition, the rational allocation of State funds among the various Districts is encouraged. It is emphasized, however, that RAMS-D01 is only a decision analysis tool. The program is intended to help a highway engineer allocate funds judiciously, particularly when there is a host of competing alternatives to consider, which is usually the case in practice. RAMS-D01 was never intended to dictate the decisions for the highway engineer.

In the sections that follow, the essential features of the optimization program are discussed. Technical details on the objective function and optimization algorithm are presented elsewhere [2, 4, 5] and will not be repeated here. Only the important concepts underlying the program are explained with the purpose of providing the user with a general understanding of RAMS-D01.

The Resource Allocation Problem

In order to illustrate the problem of allocating limited resources among several competing alternatives, consider the hypothetical situation presented in Table A-1. The table shows nine different projects together with the resource requirements and profit associated with each project. For simplicity, only two resources, A and B, are considered. If the quantities available for resources A and B are sufficient to do all projects, then the resource allocation problem becomes trivial. The obvious decision would be to select all projects. However, this is not usually the case. Often, the resources available are limited. In the present example, the total requirements for resource A exceed the amount available by 10 units. Similarly, there is a deficit of 12 units for resource B. Obiously, therefore, not all projects can be selected, and the problem is to determine the set of projects that will yield the most profit while at the same time satisfying the resource constraints.

TABLE A-1
HYPOTHETICAL RESOURCE REQUIREMENTS AND PROFITS FOR VARIOUS PROJECTS

	Resource Requirements		
Project	A	B	Profit
1	3	5	150
2	8	3	300
3	2	7	200
4	5	8	600
5	3	1	150
6	7	6	700
7	5	7	400
8	6	8	650
9	9	5	700
TOTAL	48	50	
AVAILABLE	38	38	
EXCESS NEEDED	10	12	

Problems of this nature are best resolved in an operations research framework. An important element of this framework is the definition of the objective of the optimization process. In the preceding example, the objective was to maximize profits subject to the given resource constraints. Similarly, in the development of RAMS-D01, the objective was defined to be the maximization of the overall effectiveness of maintenance and rehabilitation activities, subject to resource constraints and mimimum requirements of pavement quality and service life [2].

An explanation of the concept of maintenance effectiveness is important to understand the optimization algorithm in RAMS-D01. What is to be optimized must be clearly defined. In many resource allocation problems, for example, profit is the controlling factor. Profit is usually defined as the difference between revenues and costs, where revenues are generated from the sale of products from a manufacturing process, and costs are incurred in the manufacture of the said products. For non-toll highways, where profit is not as important, the concept of maintenance effectiveness must be defined. In order to accomplish this, however, it is first necessary to have a basic understanding of the concept of pavement performance.

Pavement Performance

In order to design pavements, and to select appropriate remedial measures for maintaining or rehabilitating pavement structures, a model is required for predicting the trend in pavement condition over time or with increasing axle load applications. This trend in pavement condition defines the performance of a particular pavement structure over a given time period. The trend is influenced by several factors, such as (1) the materials the pavement is made of; (2) the thicknesses of the various pavement layers; (3) the traffic loads imposed on the pavement; (4) environmental variables; and (5) maintenance activities performed during the lifetime of the pavement structure. In addition, the trend is relative to a pavement condition indicator such as roughness, cracking or rutting. These pavement condition indicators are measures of the condition of a pavement section at a particular point in time. When considered individually and/or collectively, such indicators provide an estimate of the current overall adequacy of a particular roadway, and identify deficiencies which can lead to accelerated pavement deterioration with additional traffic.

For the RAMS-D01 program, prediction of pavement performance is accomplished using pavement survival curves. Figure A-2 shows a conceptual illustration of a survival curve which shows the probability that a given pavement will not require additional maintenance or rehabilitation at a particular point in time. If the probability of survival at some time t is denoted by R(t), the probability of failure is given by:

$$F(t) = 1 - R(t) \quad \text{(A-1)}$$

where,

$F(t)$ = probability of failure at time t

$R(t)$ = probability of survival at time t

In Figure A-2, for example, there is a 50 percent probability that a given pavement will require some form of treatment after approximately 6.5 years. Phrased another way, if there are 100 pavement sections, it can be predicted that 50 will require some form of maintenance or rehabilitation work after 6.5 years.

In the development of RAMS-D01, survival curves for various pavement distress types and maintenance and rehabilitation activities were determined from the collective judgement and experience of various Texas SDHPT personnel. It is pointed out that survival curves may vary from one highway jurisdiction to another. Differences in traffic and environmental conditions, and in design and construction practices, contribute to variations in pavement performance. Consequently, in the application of the RAMS-D01 program, pavement survival curves applicable to a particular locality should be established and used.

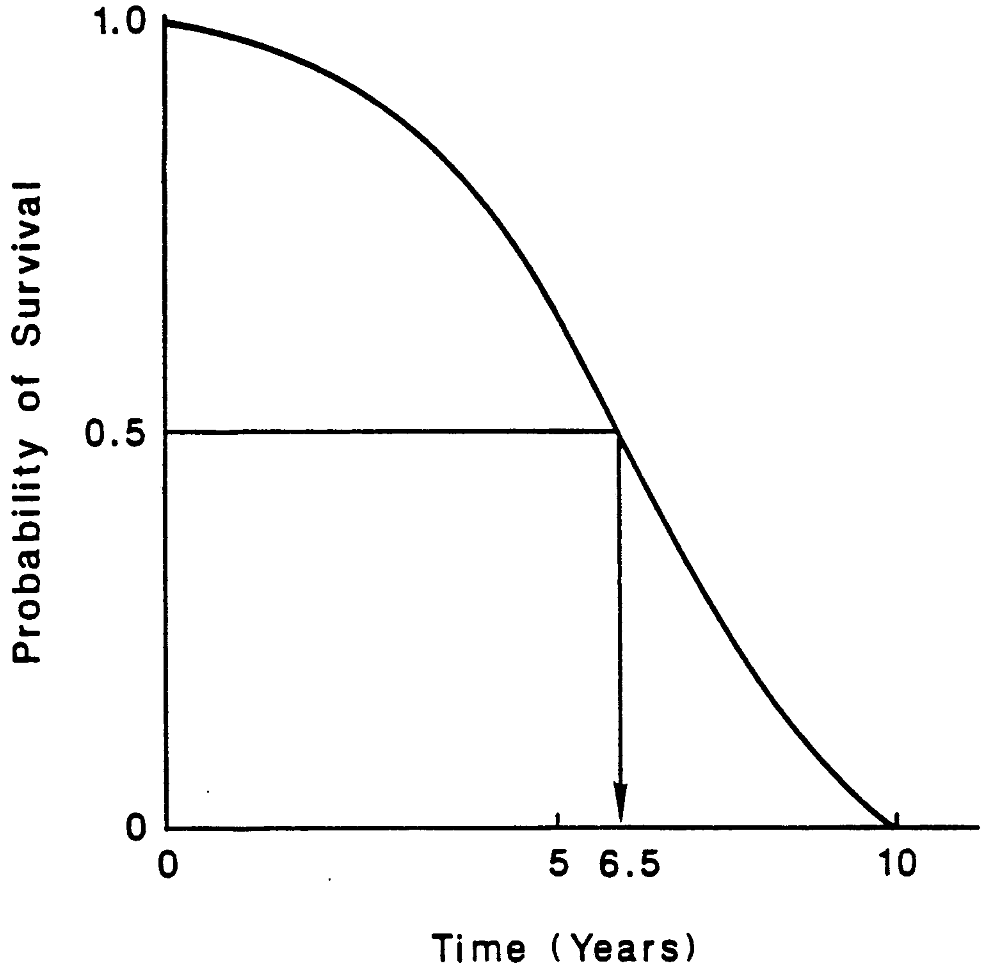

Figure A-2. Conceptual Illustration of a Survival Curve

Maintenance Effectiveness

Previously, it was indicated that the objective of the RAMS-D01 program is the maximization of the overall effectiveness of maintenance and rehabilitation activities. The concept of maintenance effectiveness is important to the understanding of what the program does. In order to explain maintenance effectiveness, it is necessary to refer back to the pavement survival curves discussed in the preceding section. As indicated previously, the survival curves are influenced by the types of maintenance or rehabilitation activities performed, and by the types of distresses considered. In the RAMS-D01 program, the survival curve for a particular maintenance or rehabilitation treatment and a given distress type is multiplied by a weighting factor that reflects the importance attached to the given distress type. This process merely transforms the ordinate scale of the survival curve. Instead of the ordinate values ranging from 0 to 1 as is shown in Figure A-2, the values will subsequently range from zero to the value of the weighting factor associated with a given distress type. Since the weighting factor is an upper limit, its value may be interpreted as the maximum rating that is possible for a given distress type. Table A-2 shows the maximum ratings established for different distresses. The values shown were established from the collective judgement of Texas SDHPT engineers.

TABLE A-2

MAXIMUM RATINGS FOR DIFFERENT DISTRESS TYPES [3]

DISTRESS TYPE	MAXIMUM RATING
Rutting	15
Alligator Cracking	25
Longitudinal Cracking	25
Transverse Cracking	20
Failures/Mile	40
Serviceability Index	50

When some form of treatment is applied to a particular pavement, the condition of the pavement will most likely improve, assuming that an appropriate treatment has been applied. Consequently, the condition rating of the pavement is expected to increase, the amount of increase being dependent on the type of distress considered and the maintenance or rehabilitation treatment applied. In the development of RAMS-D01, maximum gain-of-rating points were established using the collective judgement and experience of Texas SDHPT engineers. The maximum gain-of-rating reflects the maximum improvement that can be achieved when a given maintenance treatment is used to treat a specific distress. It should be clear that the maximum possible value for gain-of-rating for a distress type is the maximum rating for the distress type.

The gain-of-rating concept is illustrated in Figure A-3. Figure A-3(a) illustrates a situation where a given treatment significantly improves the rating of a given pavement relative to a certain distress but not enough to achieve the maximum rating associated with the given distress. Figure A-3(b) shows the opposite case where the treatment applied raises the condition rating to a level greater than the maximum rating associated with the given distress. Both of these situations are possible in practice.

Figure A-3 also illustrates the concept of maintenance effectiveness. The hatched area shown for each curve in the figure is a measure of the effectiveness of a particular maintenance activity in treating a given type of pavement distress. In Figure A-3(a), for example, the maintenance effectiveness of Treatment 1 on Distress Type A is quantified by the hatched area. Note that the calculation of the area starts at the point on the curve whose ordinate is the improved pavement condition rating after application of the maintenance treatment. This reflects the fact that the particular treatment did not raise the condition rating to the maximum level associated with the given distress. The maintenance effectiveness calculated is therefore only a fraction of the total area bounded by the curve and the horizontal line passing through the condition rating prior to treatment. In contrast, the maintenance effectiveness for the situation illustrated in Figure A-3(b) is calculated as the entire area bounded by the curve and the horizontal line through the current

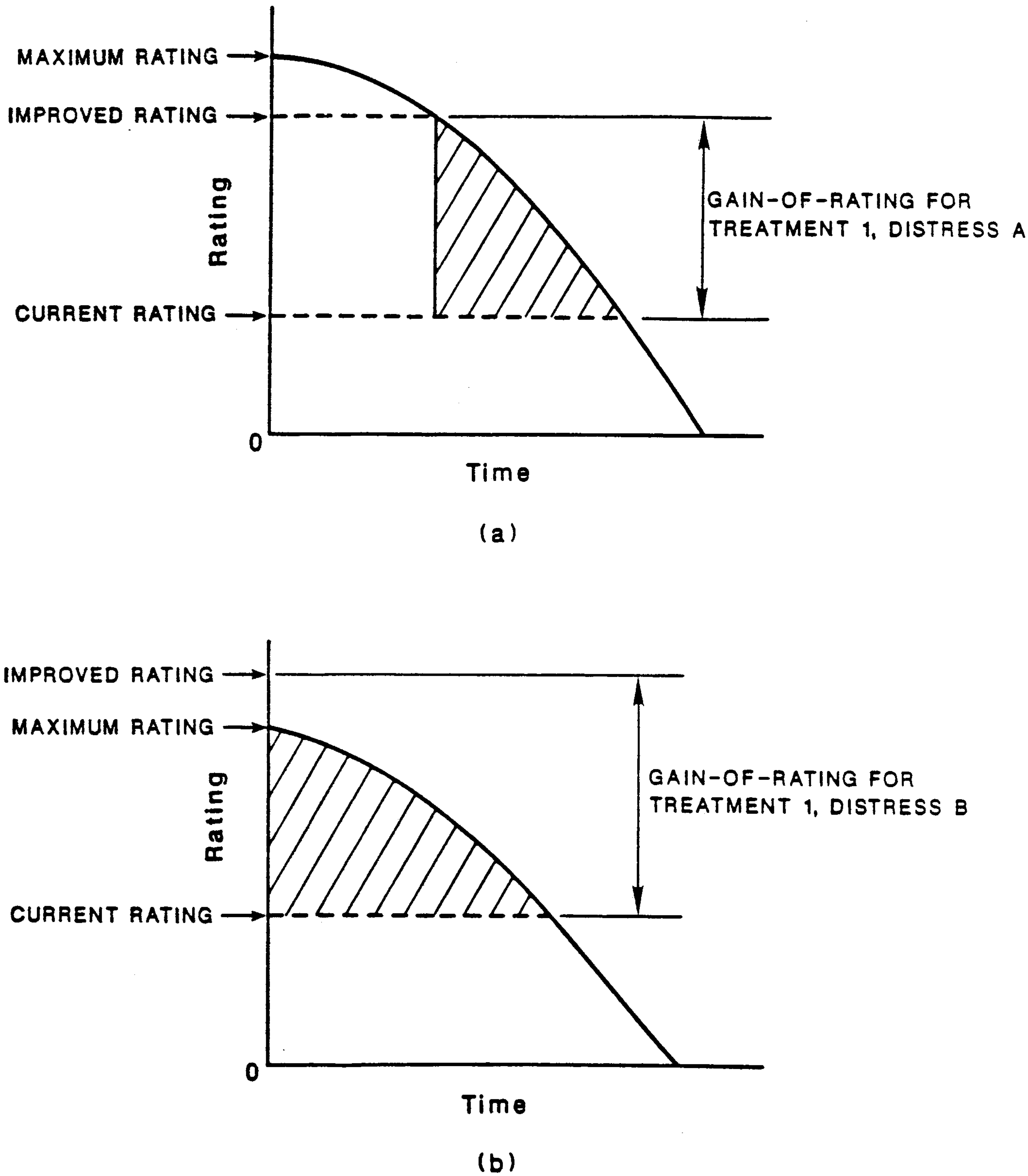

Figure A-3. Illustration of Maintenance Effectiveness condition rating. This is how the program calculates maintenance effectiveness when the improved condition rating exceeds the maximum rating associated with the given distress.

The area under the survival or performance curve is one component of the maintenance effectiveness calculated by the RAMS-D01 program. Essentially, the area provides a measure of the 'benefit' obtained due to the application of a particular maintenance or rehabilitation treatment. The larger the area under the curve, the greater the benefit.

However, another factor that should be considered is cost, since maintenance and rehabilitation activities that provide greater benefits usually require more of the limited resources available, in particular, the budget. Consequently, a ratio known as the effective gradient of maintenance effectiveness is evaluated in the RAMS-D01 optimization procedure.

For a given pavement, the total benefit attributable to a particular maintenance or rehabilitation strategy is calculated as the sum of the areas determined for the different distresses considered. This sum is multiplied by the pavement section area to account for this factor in the optimization process. Thus, the pavement area is like a weighting factor that is applied to the total benefit calculated. So, the larger the area of a road segment, the more total benefit it will have. This weighted benefit, divided by the sum of the resource requirements associated with a given treatment being applied to a particular pavement, is the effective gradient of maintenance effectiveness.

The effective gradient is essentially a benefit-cost ratio and is a controlling factor in the optimization process. Highway segments with high effective gradients are more likely to be selected for maintenance and rehabilitation treatments than those with lower effective gradients. This is only logical since a high effective gradient indicates a more efficient use of resources; i.e., more benefits are accrued per unit outlay of resources.

The details of the computational algorithm used to select optimum maintenance and rehabilitation activities are discussed elsewhere [2,5] and will not be repeated at length here. Essentially, the program uses an integer programming technique to maximize the overall benefit that may be achieved with the available resources. At each iteration, the program looks at the calculated effective gradients for the set of maintenance and rehabilitation (M&R) activities considered for each highway segment. The effective gradient is used to select the set of maintenance and rehabilitation activities considered at each step of the analysis. Iterations continue until a set of M&R activities is obtained that maximizes the overall maintenance effectiveness, and satisfies the given constraints.

Appendix B
The DELPHI Technique

The Delphi method attempts to achieve a consensus of opinion among a group of experts through cycles of intensive questioning interspersed with controlled opinion feedback. The technique avoids the direct confrontation of experts with one another, which is the traditional method of pooling individual opinions. In this way, some of the serious difficulties inherent in face-to-face interaction are circumvented, such as [6]:

1. The spurious influence of a high status individual on the group - here, the status of an individual, which is often unrelated to his expertise on the question at hand, is given undue consideration in a face-to-face discussion.

2. Ego commitment - after openly committing himself to a particular position, the individual is less likely to repond to facts and opinions advanced by other members of a face-to-face discussion group.

3. Group pressure for conformity - in a face-to-face situation, the individual encounters pressure to "jump on the bandwagon" and join the group.

Sucessive iterations of the Delphi process are made to achieve a group consensus. For the problem under consideration, a group of pavement experts may be asked to construct survivor curves for selected maintenance and rehabilitation activities, distress types and climatic zones. For a particular set of conditions, the group may be asked to draw curves or to establish points along a survivor curve by answering a series of questions, such as: "For the set of conditions considered, how many of 100 pavement sections do you think will require some form of maintenance or rehabilitation after 5 years?"

At each iteration of the Delphi process, survivor curves, representing the means of the opinions obtained during a previous cycle, are fed back to the participants who are invited to make changes in their curves in the light of the information presented. In addition to showing the mean survivor curves, the variation in the survivor curves obtained for a particular set of conditions may be presented. The final output of this process then is a set of survivor curves reflecting the group consensus.