Report No. CDOT-DTD-R-2000-8

Guidelines for Selection of Rehabilitation Strategies for Asphalt Pavement

Bud A. Brakey, P.E

August 2000

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CDOT-DTD-R-2000-8		

4. Title and Subtitle	5. Report Date
Guidelines for Selection of Rehabilitation Strategies for Asphalt Pavement	August 2000
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Bud A. Brakey, P.E.	CDOT-DTD-R-2000-8

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Bud A. Brakey, P.E. Geotechnical Engineering 2540 E. Floyed Ave. Englewood, CO 80110	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Colorado Department of Transportation 4201 E. Arkansas Ave. Denver, Colorado 80222	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Included in this report are detailed guidelines and decision tables for selecting rehabilitation strategies for asphalt pavements. The author proposes that following the guidelines will reasonably assure the *functional lives* of rehabilitated asphalt pavements will at least equil their *design lives*. Recommended rehabilitation strategies are based on degree and type of existing distress and the traffic level. The most pervasive distress, and the most difficult to correct, was found to be transverse cracking. Appendix A summarizes the original research study plan findings. Appendix B reports on a satellite study by the author where 21 flexible pavement projects were analyzed using CDOT Pavement Management System condition data. PMS pavement distress categories and indexes, were compared, before and after rehabilitation. The PMS study results significantly contributed to the development of the decision tables.

17. Key Words	18. Distribution Statement
Pavement distress, rehabilitation strategy, design life, functional life, PMS, Pavement condition index, transverse cracking, cracking index.	No restrictions. This document is available to the public through: National Technical Information Service. 5825 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		65	

Guidelines for Selection of Rehabilitation Strategies for Asphalt Pavement

by

Bud A. Brakey, P.E.

Report No. CDOT-DTD-R-2000-8

Prepared for
Colorado Department of Transportation
Research Branch

August 2000

Colorado Department of Transportation
Research Branch
4201 E. Arkansas Ave.
Denver, CO 80222
(303) 757-9506

EXECUTIVE SUMMARY

The research report is presented in three sections. The first section is the Guidelines for Selection of Rehabilitation Strategies for Asphalt Pavements. The second is Appendix A that explains the reasons for this study and reports the results of the original research Study Plan. The third is Appendix B that reports on a satellite study added during the progress of the Study.

The Guide

Because a percentage of asphalt pavement overlays in Colorado have not reached their design life, better guidelines for selecting rehabilitation strategies are needed to reasonably assure the functional lives of rehabilitated pavements are equal to their design lives. The main purpose of this Guide is to provide such information to the designers and decision makers.

Design life is defined as the service life of a pavement without the loss of load-carrying capability from fatigue damage. Functional life is defined as the service life without the development of excessive distress that adversely affects the highway user. Examples of the types of distress that affect each of the two service lives are given.

Seven categories of distress are tabulated as the ones most likely requiring selection of a rehabilitation strategy from among several options. The rehabilitation strategies are divided into two major classes, wearing surfaces and subsidiary treatments.

The selected wearing surfaces are hot bituminous pavement overlays (major, medium, or thin thickness), stone matrix asphalt overlays, micro-surfacing and grind/micro-mill. The selected subsidiary treatments are divided into major, moderate, minor and basic (all related to level of effort and cost). A detailed outline of conditions for use, advantages and constraints is provided for each category of wearing surface and subsidiary treatment.

The documentation used to development the two decision tables, FL- I and FL-2 (pg. 21 and 22) are provided along with examples for using the tables. Table FL-1, for high traffic, shows that the typical functional lives for medium to thin overlays are 7 and 5 years respectively.

The tables allow the user to select a wearing surface and subsidiary treatment combination related to traffic and distress that will provide the desired functional life (usually 10 years) for an overlay. It also allows the users to estimate the functional life of overlays designed only to meet design life criteria. The functional lives and estimated first costs of the strategies being considered can be used to perform life cycle cost analyses to aid in selecting the best strategy for the project.

Appendix A

This section presents an abbreviated outline of the research study for this Guide, which included (1) formal literature review of 21 references, (2) potential rehabilitation strategies to be included, (3) identifying distresses to be included in the decision tables, (4) selecting interviewees, (5) developing questionnaires and interviewing 23 people relative to specific and general rehabilitation strategies and (6) compiling the information gathered and using it to develop the Guidelines. Detailed tables are included that summarize the literature reviews and the personal interviews.

Significantly, none of the rehabilitation strategies investigated are new to CDOT. All have been tried to one degree or another. From the literature and by consensus of the interviewees, the most pervasive distress, and the most difficult to correct, was found to be transverse cracking.

Appendix B

At a Panel meeting during progress of the study, it was decided that an independent method of estimating functional life was needed. In order to relate the performance of the various rehabilitation strategies to existing distress, it was decided to use the CDOT network PMS pavement condition data in a satellite study.

The PMS data from 1991 through 1999 for two series of projects was used to plot RSL curves in order to estimate the functional lives of various strategies specific to category and degree of distress. Aschenbrener of CDOT reported the first series for nine overlay projects on 1-25 done in 1994. The second series was from the projects reported on by the interviewees as tabulated in Appendix A.

The analysis of the plotted post and pre-construction PMS data (for tables and figures, see pages B-8 to B-13) showed cracking for both series to be the most pervasive of the three distresses being measured for condition indexes, e.g., ride, ruts and cracking. OPI is calculated from the three values. To determine cracking condition index, five cracking distresses are measured: alligator, block, longitudinal, transverse and load-associated longitudinal. Of these, transverse was by far the most extensive and severe. The plotted data furnished information used to develop Tables FL- I and FL-2.

ACKNOWLEDGEMENTS

The author gives special thanks to the Research Study Panel members for their work in providing a valuable, comprehensive study plan. The Panel gave a sound basis for initiating the research for this project. Later, the members provided assistance in redirecting the effort as work progressed. And, finally, they are thanked for their advice on presenting the research results in a usable format. Members of the Panel were: Tim Aschenbrener (CDOT Staff Materials), Greg Lowery (CDOT Staff Materials), Dave Gonser (CDOT Region 2), Bernie Kuta (FHWA), Tom Peterson (CAPA), Scott Shuler (LaFarge Co), Richard Zamora (CDOT Staff Materials) and Donna Harmelink (CDOT Research, as Study Manager). Additionally, the author acknowledges the assistance and data provided by the many asphalt pavement technologists who were interviewed for this study.

GUIDELINES FOR SELECTION OF REHABILITATION
STRATEGIES for ASPHALT PAVEMENT

Contents

List of Tables

List of Figures

Abbreviations Used in This Report

AASHTO	American Association of State Highway and Transportation Officials	LCCA	Life Cycle Cost Analysis
CAPA	Colorado Asphalt Pavement Association	LTPP	Long-Term Performance Projects
CDOT	Colorado Department of Highways	NHS	National Highway System
CIPR	Cold-in-Place Recycling	Non-NHS	Non-National Highway System
DL	Design Life	OPI	Overall Pavement Index
ESAL	Equivalent Single Axle Load	PMS	Pavement Management System
FL	Functional Life	PR	Principal Researcher
HBP	Hot Bituminous Pavement	RSL	Remaining Service Life, at Condition Index Threshold = 50
HIPR	Hot-in-Place Recycling	SMA	Stone Matrix Asphalt
LALC	Load Associated Longitudinal Cracking	SP	SuperPave
		YFL	Years Functional Life

GUIDELINES FOR SELECTION OF REHABILITATION STRATEGIES for ASPHALT PAVEMENT

Bud A. Brakey

INTRODUCTION AND BACKGROUND

A sporadic but a persistent problem in Colorado has been that a percentage of asphalt overlays have not reached their design life. Better guidelines need to be available for the pavement designers and decision makers for the selection of rehabilitation strategies that produce functional lives equal to design lives. When the rehabilitation strategy efforts are properly related to the type and degree of distress, the functional lives of asphalt overlays will have a higher likelihood of reaching their design lives.

One example of the above stated problem is a major asphalt overlay project on 1-25 in the Denver area that was completed in July of 1997. The mix and thickness designs fully met state-of-the-art procedures. But, by March of 1998, load associated longitudinal cracks appeared in the wheel tracks. The cracks were low to medium severities, and in some instances, were high severities. This was totally unexpected and helped initiate the study for development of this Rehabilitation Strategies Guide.

CONCEPT OF EVALUATING DESIGN AND FUNCTIONAL LIVES SEPARATELY

Design Life, Definition and Deficiency Examples

Design Life is the expected years of service a pavement will provide without a significant loss of load carrying capabilities caused by fatigue damage. During the DL, usually 10 years for rehabilitated pavements, the surface is expected to adequately accommodate the estimated total equivalent single axle load applications (ESALs) for the period. Examples of structural inadequacies from traffic loading are fatigue cracking, distortion, and disintegration caused by inadequate pavement thickness (e.g., the **designed** serviceability loss is reached before the end of the design period). Distresses initially related to materials, climate, or construction can be intensified by traffic to the point where they adversely affect load-carrying capacity. The CDOT structural design of a flexible pavement overlay is based on component analysis or nondestructive testing (by deflection measurement), or a combination of both. The required thickness of overlays and subsidiary treatments for a project are determined from a series of formulas with a number of variables. Complete details on thickness design for a given "life" can be found in CDOT's Pavement Design Manual[(1)]. During design, the overlay thickness and treatment strategies selected are those expected to reduce traffic loading damage caused by future ESALs over the design life.

The CDOT Traffic Analysis Unit will furnish future design ESALs for a proposed project upon request. The design ESALs are used with the AASHTO flexible pavement design equation, as characterized in the DARWin computer program, supplemented by CDOT adopted criteria, to determine the required design structural number (SN). By referenced formulas, overlay thicknesses and subsidiary treatments are selected that satisfy the SN. There is no confirmed, rational method of accurately estimating the structural number of the existing pavement layers (except by back-calculating from deflection measurements). Mostly, designers rely on tables, charts and experience.

Functional Life, Definition and Deficiency Examples

Functional Life is defined as the years of service a pavement will provide without the development of excessive distresses that adversely affects the highway user. Examples of functional deficiencies are poor surface friction, rutting, and excessive surface distortion. Currently, in Colorado, rutting and poor friction are not major problems. Excessive surface distortion (e.g., poor ride) by the most recent Network PMS data is primarily related to cracking, transverse being the most pervasive of the categories. Where fatigue cracking is not dominant, such distress is considered to be functional.

The CDOT overlay design procedure does not directly consider future overlay damage that will result from existing cracking distresses, except for load associated (alligator) cracking. The true functional or structural contributions of most subsidiary treatments can only be estimated from experience and empirical relationships. Indirectly, if other types of cracking have weakened the existing structure, nondestructive testing may pick this up, thus showing a greater thickness of overlay is required. Unfortunately, just putting on a thicker overlay is not usually the most cost-effective way of correcting distresses caused by transverse and reflective cracking.

Reports by others which were evaluated by the author[1], as well as studies done by the author in connection with the development of this Guide, clearly show that the most pervasive flexible pavement distress is transverse cracking. For medium to low traffic situations (characterized by the non-National Highway System), the functional life of an overlay may frequently equal or exceed its design life. For heavier traffic roads, (such as the National Highway System) the functional life is sometimes considerably less than the design life. This Guide offers guidelines for selecting strategies that will allow the functional life of a rehabilitated pavement to be at least equal to the design life. Further along in this Guide, Tables FL-1 and FL-2 are presented, along with examples for their use. For pavements designed to increase their functional life in accordance with these procedures, there may be a reduced life cycle cost, which could compensate for the greater first cost.

PURPOSE OF GUIDE

The Guide is to be used to provide guidance to pavement designers and decision makers on the importance of selecting better rehabilitation strategies and to properly address existing distresses prior to overlay. The Guide provides a reasonable estimate of the functional life (FL) of the selected rehabilitation strategy combinations to be used with life cycle cost analyses to better compare options. For example, if the level of funding is low or inadequate, a short functional life and a higher life cycle cost will result. If the level of funding is sufficient, a longer functional life and a lower life cycle cost will result. With this information provided by the pavement designer, the decision makers will be better informed about their decisions regarding rehabilitation strategies.

Another benefit will be the education of new engineers performing pavement design duties. Additionally, experiences tabulated in Appendix A will be shared around the state. Where strategies have been successful in some Regions, other Regions will benefit by the cited experiences.

PAVEMENT DISTRESSES AND SELECTION OF TREATMENT STRATEGIES

Pavement Distress Categories Used in FL Tables

The study detailed in Appendix B uses before and after PMS data and as-built information to study the relationship of rehabilitation effort to subsequent performance. The study indicates the most critical pavement distress is transverse cracking. In Appendix A, the answers to the Interview Questions, Part II, have been summarized. Questions 3 and 4 are related to the most frequent distresses in the respondent's area and the most difficult distresses to deal with. The answers clearly show that severe cracking, especially transverse cracking, is the defect of greatest concern. From the PMS study and the interview answers, Category 1 in Table 1, below, has been established. It addresses severe general cracking as well as transverse cracking.

---

[1] See Development and Use of Functional Life Tables preceding Tables FL-1 and FL-2, and Appendixes A and B.

The other six categories in Table 1 are composite categories from Appendix B, Table B-1 of the Design Manual. Listed in the Design Manual are 17 distresses, with Appendix B page references which describe the distresses and their severity levels.

The seven categories in Table 1 below are listed in approximately the frequency of occurrence. Only one category should be selected as the **predominant** distress for each linear representation. It should be used for selecting the rehabilitation strategy combination (level of effort) from the FL Tables. Probably 95%, or more, of the distresses requiring correction at the project level are included in Table 1 and the FL Tables. Often there are several distresses present to one degree or another. However, the design is usually based on the one selected as predominant. The final treatment strategy needs to be evaluated to assure the less dominant distresses are also satisfactorily corrected.

The consolidation of distress categories for the FL Tables is a matter of practical application. Cracking categories No. 2 and 3 are each a combination of two distresses (as shown) and are listed separately in the Design Manual, but combined here because the causes and treatments are similar. For each category, load associated cracking is treated as a single defect in the Design Manual, while the Network PMS uses the two categories shown below for No. 4. Of the many pavement distresses, the seven categories in the Table 1 are most applicable to life cycle cost analysis (LCCA) when comparing one rehabilitation strategy to another. That is, for each of the categories, more than a single strategy could be considered for corrective action. When one of them is the predominant project distress, the region pavement designer will use the Functional Life Tables (FL 1 or 2) to aid in strategy selections. Of course, these are *not* the only pavement distresses that might need correction. They are, however, the primary ones involved in comparing and analyzing rehabilitation strategies.

Table 1
PREDOMINANT FLEXIBLE PAVEMENT DISTRESSES ADDRESSED IN THIS GUIDE

No.	DISTRESSES LISTED in Tables FL-1 and FL-2 (Medium & High Severity)	Line 1, by PMS, 2-7 by Project and/or Network PMS Evaluation	PRIMARY CAUSE OF DISTRESS: Traffic/Load or Climate/Materials
1	Lesser RSL Value of Cracking Condition or Transverse Crack Index	Only from Network PMS Condition Survey	Climate/Materials
If both of the two above distress RSLs are >3.0, then use the predominant of the below list.		DESCRIPTION: Pg No. In Design Manual Appendix B	
2	Transverse & Reflective Cracking	B-9, B12	Climate/Materials
3	Block Cracking & Joint Separation	B-6, B-11	Climate/Materials/Construction
4	Load Associated Cracking (Alligator & Load Associated Longitudinal [LAC])	B-4	Traffic/Load
5	Rutting (Non-Plastic)	B-17	Traffic/Load
6	Raveling & Weathering	B-16	Climate/Materials
7	Bleeding	B-5	Climate/Materials

Other distresses discussed in Appendix B of the Design Manual and not listed above are: corrugation, depressions, lane/shoulder drop-off, patch deterioration, polished aggregate, potholes,

plastic rutting (part of B-17), slippage cracking and stripping. Additional distresses occurring occasionally that need correction are roughness, frost heaves, swelling soil heaves and those caused by poor drainage. Nearly all of these additional distresses occur only rarely, and do not lend themselves to typical LCCA. In these cases, normally there is only one acceptable correction strategy for each distress. The selected treatment will be based on experience, judgement, and information found in other CDOT manuals and directives. Headquarters and region specialists will also help solve these uncommon problems.

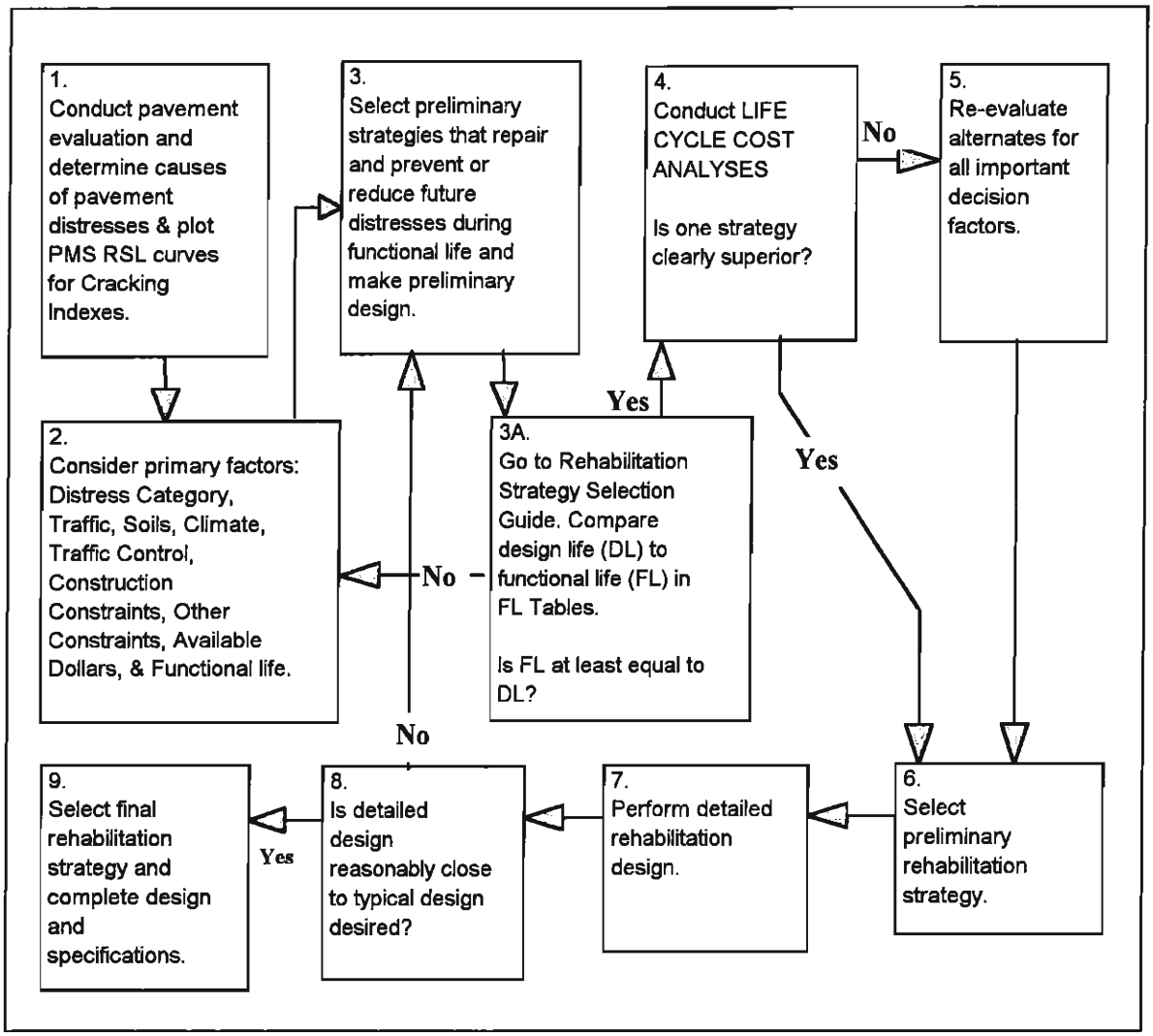


Figure 1 Rehabilitation Strategy Selection Procedure

OVERVIEW OF THE REHABILITATION STRATEGY SELECTION PROCESS

It is important that an evaluation of the existing pavement be conducted at the project level to identify functional and structural deficiencies, and to select the most appropriate rehabilitation strategies for correction of those deficiencies. Figure 1 is a flow chart of the selection and design process. The Design Manual sets forth the procedures to be used in designing structural overlays and subsidiary treatments for rehabilitation projects. This guide is intended to supplement the process and not supersede it.

CANDIDATE REHABILITATION STRATEGIES: CONDITIONS FOR USE, ADVANTAGES, AND CONSTRAINTS.

Much, but not all, of the information in the following section can be found various locations in the Design Manual. The order and detail presented here complement the rehabilitation treatment selection procedure. For evaluation purposes, the various rehabilitation strategies have been divided into two major classes: wearing surfaces and subsidiary treatments.

WEARING SURFACES, GENERAL.

In the FL tables, Wearing Surfaces heads the first column in each. Listed are three thicknesses of overlays for HBP, SMA and micro-surfacing. Though not technically a new wearing surface, grinding/micro-milling is listed as an acceptable restoration technique for the existing surface.

The most common wearing surfaces are overlays. When done as stand-alone techniques (only basic subsidiary treatments), they tend to be the lowest first cost method of rehabilitation. When functional life and increased maintenance are considered in life cycle cost analyses, this will probably not be true. Conditions under which HBP or SMA overlays would not be feasible without subsidiary treatment, beyond basic patching/leveling and crack sealing include the following:

- High to medium severity transverse cracking is extensive which will cause reflection cracking in the overlay and shorten its functional life; in this case subsidiary treatments from minor to major should be considered relative to the degree and extent of distress.
- High load associated cracking is extensive such that subsidiary treatments from moderate to major should be considered.
- Where there is limited allowance for raising the pavement surface elevation, e.g., overhead clearance, matching gutters, no room for shoulder slope steepening, etc.
- Where excessive surface rutting (usually plastic) indicates the existing materials are so unstable that severe rutting is likely to be repeated without removal and replacement of the weak material.
- Stripping in the existing asphaltic concrete surface dictates that it should be removed and replaced.
- An existing stabilized base shows signs of serious deterioration and would require an inordinate amount of repair to provide uniform support for the overlay.
- An existing granular base is contaminated, or otherwise unsatisfactory, requiring the entire pavement structure to be rebuilt.

In the FL tables, overlays have been subdivided by thickness as major, medium or thin. Major overlays are defined as greater than 4 inches and less than 6 inches. Medium overlays are greater than 2 inches and ≤ 4 inches. Thin overlays are defined as 2 inches. These definitions are similar to the Department PMS definitions. The thin definition is consistent with the Pavement Design Manual (which limits the minimum thickness of an overlay to 2 inches). Thinner than two-inch overlays are not addressed in this guide, although the network PMS defines thin as less than 2 inches. The PMS defines medium as greater than 2, up to 4 inches, and thick as 4 to 6 inches. Greater than 6 inches is categorized as reconstruction. The PMS is designed to provide information for federal aid contracts, state contracts and preventive maintenance. Such maintenance may be by contract or by state forces.

HBP Overlays (2 to 6 inches); and Stone Matrix Asphalt Overlays (1.5 to 2 inches) with Compatible Subsidiary Strategies

- Descriptions:
  - HBP (hot mix) asphalt pavement *overlays* will normally consist of Grading S in the lower

layers. Surface layers can be either Grading S or Grading SX. Grading SX, which has a one-half inch maximum size aggregate, can be used where layers are very thin or where the pavement must taper into an existing pavement. The lift thicknesses for all gradings should be a minimum of twice the maximum aggregate size. The bitumen may or may not be polymer-modified, depending on the climate, traffic and importance of the layer or project.

- Stone matrix asphalt (SMA) is a gap-graded, highly stable, hot-mixed material containing more filler and bitumen than HBP. The aggregates require special characteristics and the bitumen is usually polymer-modified. Nominal maximum size aggregates range from 3/8 inch to 3/4 inch. SMA has shown high levels of rut resistance and durability. It also delays the reflection of low to medium severity cracks up to two years, compared with HBP surfaces using non-modified asphalts. SMA is recommended as a wearing course for high traffic pavements and in other critical circumstances. SMA has been successfully placed in layers as thin as one inch, however, thicknesses of 1.5 to 2.5 inches are recommended.

- Compatible Subsidiary Strategies:
  - Cold mill
  - Cold-in-place recycling (minimum 2-inches OL required)
  - Hot-in-place recycling
  - Fabric interlayer (minimum 2-inches OL required)
  - Basic preparation (patch/level & seal cracks)

- Distresses Applicable for Treating:
  - All distresses, with or without subsidiary treatments as indicated in Tables FL 1 or FL 2 (except those calling for micro-surfacing or grind/micro-mill)

- Constructability Advantages:
  - Can be done one lane at a time
  - Overlay phase can be in cool to hot weather
  - Overnight lane closure not required

- Constraints and Disadvantages:
  - Stand -alone overlays probably won't prevent, or substantially reduce, reflection cracking
  - Vertical clearance, without milling may be of concern

- Performance:
  - Usually the lowest first cost method of significantly increasing structural capacity
  - SuperPave mixtures made with 98% reliability PG asphalts have high probability of slowing onset of most distresses
  - SMA overlays will slow rate of reflection cracking and most other deterioration
  - When considering conservation of materials and protection of the environment, overlays in combination with certain subsidiary strategies, are usually better than rebuilding

- Climate Constraints
  - When CDOT standard specifications are followed, not sensitive to climate variables

Micro-Surfacing

- Description:
  - Micro-surfacing is a cold-mixed paving material composed of a polymer modified asphalt emulsion, 100% crushed aggregate, mineral filler, water, and field control additives. It is applied as a slurry at a thickness of 0.4 to 0.5 inches. This thin surface treatment improves friction and durability of a pavement surface. The functional condition is improved, but not the structural condition (load carrying capacity) of a roadway.

- Compatible Subsidiary Strategies:
  - Basic preparation (patch/level & seal cracks)
  - Hot-in-place recycle (heater scarify)
  - Ruts pre-filled with micro-surfacing

- Distresses Applicable for Treating:
  - Low to medium severity NP ruts (if over 0.5 inches, should be pre-filled)
  - Raveling or dry surfaces (assure that existing surface is moisture resistant)
  - Low severity cracking of all types (some spotty, medium severity areas may be included)
  - Low to medium bleeding

- Constructability Advantages:
  - Can be done rapidly, and generally opened to traffic within one hour
  - Time requiring traffic control is minimal
  - Does not significantly raise pavement surface elevation
  - Manholes and other surface utilities are not significantly affected
  - Can be feathered out without edge raveling

- Constraints and Disadvantages:
  - Must be done in warm weather
  - High quality aggregates, sometimes not locally available, required
  - Number of contractors with capabilities are limited which reduces competitive bidding

- Performance:
  - Economical method of sealing and restoring friction to the surface where structural capacity increase is not of concern
  - Additional micro-surfacing layers, or structural layers can be placed later
  - It is particularly suitable as a functional treatment for high volume & urban roads

- Climate Constraints:
  - Very cool (high mountains), not recommended due to potential curing and rain problems
  - Cool (lower mountains and foothills), use with caution
  - Moderate (plains and west) and hot (SE and west), use with normal precautions

Grind/Micro-mill

- Compatible Subsidiary Strategies:
  - None, except that any patching and crack sealing required (for cracked surfaces) should be done while pavement surface is being restored.

- Distresses Applicable for Treating (where analysis shows structural capacity is adequate for expected life):

- Medium ruts, plastic or from consolidation
- Roughness caused from all types cracking

- Constructability Advantages:
  - Can be done rapidly with minimal traffic control

- Constraints and Disadvantages:
  - Can only be done where surface utilities and appurtenances are not in conflict
  - Reduces structural capacity of pavement (not critical for asphalt over PCCP)
  - Lateral drainage needs to be provided for

- Performance:
  - Economical method of removing ruts and/or restoring ride characteristics
  - For full flexible structures, structural analysis needs to be made in order to estimate functional life after grind/milling.

- Climate Constraints:
  - All climates, use with normal precautions

SUBSIDIARY TREATMENTS CONDITIONS FOR USE, GENERAL

Subsidiary treatments are defined as those intended to be covered by a wearing surface. In the FL Tables, the treatments are broken into four categories: Major, Moderate, Minor and Basic. The grouping is mostly in accordance with the level of resistance to future reflective cracking. The grouping also indicates the level of construction effort and is generally related to first cost. The four categories appear in the second column in the FL Tables, and are repeated for each overlay and SMA block. Micro-surfacing and micro-mill have two choices and one choice respectively.

The four subsidiary categories (the first three include any applicable Basic treatments) are defined as follows:

- **Major:** (1) Cold-in-place recycle, 4 inches or greater or (2) Cold mill & replace lost SN, >3 inches. (*The SN replacement thickness is to be added to the original wearing surface thickness for all depths of cold mill and replace).*
- **Moderate:** (1) Cold mill & replace lost SN, >1.5 inches to 3 inches, (2) hot-in-place recycling >1.5 inches, or (3) fill non-plastic ruts (>0.5 inches to 1.5 inches) with micro surfacing.
- **Minor:** (1) Cold mill & replace lost SN, 0.75 inches to 1.5 inches, (2) hot-in-place recycle >0.75 inches to 1.5 inches, (3) fabric interlayer (4) or fill non-plastic ruts (<0.5 inches) with micro surfacing.
- **Basic:** Includes, but is not limited to, patching isolated weak areas, leveling up to 0.75 inches average by milling or HBP, and crack filling, as appropriate for the subsidiary treatment selected.

Following are descriptions and conditions for use of the specific subsidiary treatments in the order of their first appearance in the above four categories:

Cold Mill (basic to major)

- Description:

- Cold milling means removing the top portion of the existing pavement by use of a rotary drum milling head, either by "down cutting" or "up cutting", removing the millings (usually they become the property of the contractor) and thoroughly cleaning the milled surface. Major milling (>3 inches) may be done to remove very unsatisfactory material and to accomplish major grade control. Moderate milling (>1.5 to 3.0 inches) may be done to remove moderately unsatisfactory material and/or to accomplish moderate grade control. Minor milling (>0.75 to 1.5 inches) is done usually to uniform the surface and/or to match appurtenances as well as to remove thin layers of unsatisfactory materials. Basic milling (up to 0.75 inches average) is often done to uniform the surface and/or to match appurtenances. Normally, no structural consideration is given to milling for leveling purposes.

- Compatible Wearing Surfaces:
  - All thicknesses of HBP and SMA (provided that structural and functional requirements are met)
  - Micro-surfacing can be used as a short term (3 to 6 years) surface over smoothly cut, thin milled surfaces where structural characteristics are not critical
- Distresses Applicable for Treating:
  - All of the distresses shown in the FL Tables at all degrees of severity and all extents can be corrected by milling, up to total removal and replacement (which then becomes reconstruction). This does not mean that major distresses corrected by deep milling will always be the most cost effective. Other rehabilitation subsidiary strategies should be compared, as well as reconstruction.

- Constructability Advantages:
  - Milling leaves a roughened surface that provides an excellent bond with the overlay.
  - Milling machines with automatic grade control restore both longitudinal grade and transverse grade, thus improving the smoothness of the final overlay
  - Milling eliminates the need for leveling courses and therefore the problems associated with compacting material of varying width and thickness is eliminated
  - Oxidized, weathered material is removed from the top portion, thereby increasing the exchange ratio (e.g., the entire existing pavement might have a SC of 0.25 assigned, but the portion to be milled is deemed to have a SC of 0.15) with the new replacement materials. If this condition is uniform and the designer considers it important in the cost analysis, it may be taken into account when conducting comparative cost analyses with other strategies. Be careful and investigate thoroughly; the existing pavement at the bottom may be worse than at the surface.
  - By thinning the existing pavement and thickening the overlay, increased protection from crack reflection is accomplished

- Constraints and Disadvantages:
  - Part of the existing structural number is removed. Additional structural overlay thickness must be included to account for the removed material
  - Milling depth must uniformly leave a thick enough asphalt pavement layer to support construction and public traffic or other steps must be taken to protect any weakened sections from weather and construction traffic loadings
  - Millings must be used or disposed of

- Performance:
  - With the wearing surface, restores friction, ride, and cross slope. (Restoring ride & cross slope by milling requires less new hot mix material than by using HBP)
  - Removes old distressed pavement and replaces it with new material; this is a functional benefit (yielding increased life), but a structural number loss, requiring increased OL thickness (meaning greater first cost). All this is in relation to milling depth. Analyze carefully. Thin milling will require crack maintenance early in life.

- Climate Constraints.
  - Not in itself sensitive to environmental conditions

Cold-in-Place Recycling (CIPR) (nominal 4-inch depth)

- Description:
  - This is a technique in which the existing pavement is reused by crushing and mixing it in place without the use of heat. Normally, only the asphalt-bound materials are treated, to a minimum depth of 4 inches. Although where the existing bound pavement thickness is less than 4 inches, with special considerations, precautions and proper design, some untreated base aggregates could be added. The steps in CIPR are (1) prepare existing surface (remove and replace defective materials), (2) cold mill to design depth, (3) add recycling agents (usually asphalt emulsion and rarely, lime or additional aggregates), (4) mixing (depending on the complexity of the contractor's methods, milling, sizing, adding materials and mixing may be all in one operation by use of a recycling train), (5) aeration of excess liquids (the **need** for this should be avoided by planning and scheduling, as it reduces cost effectiveness; however **if there are excess liquids present** which are not removed, **poor performance is almost guaranteed**), (6) laydown and (7) compaction.

- Compatible Wearing Surfaces (2" minimum thickness required):
  - Thin to thick overlays (HBP)
  - SMA alone or in combination with HBP intermediate layers

- Distresses Applicable for Treating:
  - Medium to high severity cracking of all types (treating low severity cracking is usually not cost-effective)
  - Infrequent settlements
  - Infrequent overlay patches
  - Raveling (must be high to justify unless medium to high cracking is present)
  - Low severity bleeding
  - Rutting from consolidation (not recommended to correct medium to high plastic rutting without special study and design)

- Constructability Advantages:
  - Can be done one lane at a time
  - Overnight lane closures not required
  - No leveling required

- Constraints & Disadvantages:
  - Manholes, surface and sub-surface utilities need to be addressed

- Must be done full width or a trench (a bath tub) effect could cause moisture to become entrapped leading to low support strength and early failure
- **Adequate substrata support is required to carry the heavy recycling train**
- Cannot be done satisfactorily in cool/and or wet weather
- Cold-in-place recycled material must cure **thoroughly** before overlaying (use of quick lime in the mix may expedite curing/strengthening of the constructed layer in marginal situations, but this is costly)
- For traffic control, should not use where there is >5000 ADT/lane
- Must mill off excessive crack sealing and/or patching
- Previously placed fabric interlayer may cause problems
- Not recommended for 10-yr ESALs >3,000,000 without overlays ≥4 inches

- Performance (with adequate structurally designed wearing surface):
  - Restores ride, friction and cross slope
  - Recycled layer adds structural capacity (where existing surface SC is less than 0.25)
  - Eliminates reflection cracking
  - Eliminates all existing pavement distress to depth treated
  - Early maintenance may be required **(especially if not thoroughly cured and compacted)**

- Climate Constraints:
  - Very cool (high mountains), do not use due to potential curing and rain problems
  - Cool (lower mountains and foothills), use prudently, then **deduct 1 to 2 yrs** from FL table
  - Moderate (plains and west) and hot (SE and west), use with normal precautions

Hot-in-Place Recycling (HIPR)

- Description:
  - The method consists of heating and softening the existing asphalt surface, then scarifying or milling to the specified depth. Described below are the three subcategories (all may have recycling agents added to improve the surface)
  - Heater repave (scarify 0.75 to 1.00-inch plus, with simultaneous 1.00-inch plus hot overlay), if total thickness is ≥1.5 up to 3 inches, consider as **moderate subsidiary**
  - Heater remix (heat & scarify, pick up and mix in a pugmill with hot aggregate and/or hot asphalt mix) if total thickness is ≥1.5 up to 3 inches, consider as **moderate subsidiary**
  - Heater scarify (typically a thin wearing surface is done separately), consider as **minor subsidiary**

Note that heater scarifying is the most common option. With this method, it is preferable to place hot wearing surfaces while the scarified and rolled surface is still warm to hot.

- Compatible Wearing Surfaces:
  - Thin to thick Overlays (HBP)
  - SMAs alone or with HBP intermediate layers
  - Micro-surfacing (likely surface for heater scarified only)

- Distresses Applicable for Treating:
  - Low to medium severity cracking (all types)
  - Infrequent high severity cracking (all types, high fatigue cracking should be corrected first)
  - Infrequent or no overlay patching
  - Low to medium severity raveling (if high severity, may use heater remix)

- Low severity non-plastic rutting
- Low severity bleeding

- Constructability Advantages:
  - Can be done one lane at a time.
  - Overnight lane closures not required
  - No leveling required

- Constraints and Disadvantages:
  - Manholes and other surface utilities need to be accounted for
  - Smoke emissions may prohibit use in some areas
  - Traffic control may be a problem in some urban areas
  - Careful calendar scheduling required, should be done in warm or hot weather (to achieve economics and acceptable results, method is more critical than simply overlaying)
  - **Pavements with non-uniform characteristics may yield unpredictable results**

- Performance:
  - Restores ride, friction and cross slope (mostly from overlay)
  - Recycled layer adds structural capacity
  - Destroys upper surface cracking pattern
  - Retards initiation of reflection cracking from one to two years (depending upon treatment thickness and degree and type of existing cracking)
  - Maintenance may be required early in life

- Climate Constraints:
  - Very cool (high mountains), use with caution, then deduct 1 from FL tables
  - Cool to Hot climates, use with normal precautions

Micro-Surfacing for Ruts

- Description:
  - See micro-surfacing under wearing surfaces. The same material is used for rut filling. Ruts can be filled in reasonably stable pavements. When surfaced with micro-surfacing, it is a two-step process. First, a scratch course is applied with the screed set to make contact with the high points of the surface, followed by the application of a final surface. For ruts deeper than 0.5 inches, a special V-shaped rut box is used over each rut for the scratch lift.

- Compatible Wearing Surfaces:
  - Micro-surfacing, for expected YFLs up to 6.
  - HBP or SMA. (Consider use over pre-filled ruts on an experimental basis). Object would be to have a more cost-effective and better performing strategy than filling ruts with a hot mixed leveling course

- Distresses Applicable for Treating:
  - Low to high severity non-plastic ruts (up to 3" deep if placed in maximum 3/4" lifts)
  - Low severity, low plasticity ruts if overlaid with HBP or SMA

- Constructability Advantages:
  - Can be done rapidly, generally opened to traffic within one hour

- Time requiring traffic control is minimal
- Depending on quantity, project scheduling, availability, etc., may be more cost-effective and give better performance than using hot leveling courses

- Constraints and Disadvantages:
  - Must be done in warm weather
  - High quality aggregates required, sometimes not locally available
  - Number of contractors with capabilities are limited which reduces competitive bidding

- Performance:
  - Will be more dense and stable than a thinly applied hot mix scratch course, providing better performance of the hot mix overlays
  - With a micro surface top layer, is particularly suitable as a functional treatment for high volume & urban roads

- Climate Constraints:
  - Very cool (high mountains), not recommended due to potential curing and rain problems.
  - Cool (lower mountains and foothills), use prudently, then **deduct 1** from FL table values
  - Moderate and hot climates, use with normal precautions

Fabric Interlayer (Paving Geotextile)

- Description :
  - CDOT specifications refer to this material as a paving geotextile. Industry commonly refers to the system as a fabric interlayer. The fabric is a non-woven geotextile, conforming to (section 712), and applied per (section 420) of CDOT specifications. It is installed over a hot sprayed asphalt cement binder layer on the old pavement. Pre-treatment of the old surface may include leveling course, heater scarifying or cold milling. Purposes are to reduce reflection of low to medium cracking and perhaps impart moisture resistance to the existing pavement.

- Compatible Wearing Surfaces (minimum thickness of 2" required):
  - Thin to thick Overlays (HBP)
  - SMAs alone or with HBP intermediate layers

- Distresses Applicable for Treating
  - Low to medium severity cracking (all types except transverse, both reflection and temperature)
  - Low severity transverse cracking (as above)

- Constructability Advantages:
  - Can be applied rapidly in cool to hot weather a few hundred feet ahead of paving operation
  - For smaller, narrower cracks, crack pre-sealing is not required

- Constraints and Disadvantages:
  - Traffic (except for overlay mixture haulers) must be kept off fabric.
  - Thickness and temperature of overlay at time of compaction must be adequate to assure bonding
  - Active transverse and reflection cracks are not prevented from recurring in the overlay

- Wide cracks (+ 0.25") must have pretreatment
- All structurally weak (severely distressed) areas must be corrected (true for other systems, also)
- Structural strength of the system is not significantly enhanced (only indirectly over long time by possibly reducing moisture intrusion into the subgrade)

- Performance:
  - Retards reflection cracking by 1 to 2 years of all but transverse and other very wide cracks
  - Provides moisture protection to lower pavement layers (investigate carefully, some researchers report pavement distress in moisture susceptible layers due to "trapped" moisture. This is not widely reported in the literature, however, nor at all by Colorado personnel)
  - Long range, may provide more uniform (stable) moisture in subgrade layers, reducing early spring damage

- Climate Constraints:
  - Very cool (high mountains), apply only in warm weather
  - Cool to hot climates, use with normal precautions

Basic Preparation

- Description:
  - The most common subsidiary treatment is "basic preparation" which in this guide may include patching all severely distressed areas, sealing cracks and (if required) leveling by thin cold milling or a hot mix leveling course. How much distress should be repaired before a wearing surface is placed? The amount of pre-surfacing repair needed is a cost versus performance function. If patching required is too extensive, then deeper cold mill and fill, CIPR or reconstruction may be required. It may be more cost and performance effective if the patching can be done by maintenance forces ahead of the contract. Crack sealing should be only to top of cracks (no Band-Aid type sealing).

- Compatible Wearing Surfaces:
  - Thin to thick Overlays (HBP)
  - SMAs alone or with HBP intermediate layers
  - Micro-surfacing (only over low severity cracking, see FL tables for other distresses)

- Distresses Applicable for Treating
  - All low severity cracking categories with occasional medium severity areas
  - Non plastic rutting of all severities (with leveling as required)
  - Low to medium severity raveled surfaces
  - Low bleeding with some medium if not extensive (spot mill & fill may be required)

- Constructability Advantages:
  - Where hot mix asphalt is available ahead of paving, it is economical to patch on contract
  - Weather (cool temperatures and rainfall) not a problem
  - No over night lane closures required
  - Can be done one lane at a time
  - Common techniques used make competitive bidding attractive

- Constraints and Disadvantages of Overlays with Basic Only:
  - Overhead clearance may be of concern
  - Increased shoulder elevation may require steepening slopes or lengthening cross structures
  - Extra work required at bridge approaches
  - Patching, leveling & rut filling costs could possibly be better spent to mill or in-place recycle
  - Existing cracking patterns remain to reflect through new surface

- Performance of Combinations with Basic:
  - Restores ride, friction and cross slope (mostly from overlay and leveling)
  - Overlay adds structural capacity without loss of existing structure
  - Crack maintenance required early in life

- Climate Constraints.
  - All climates, use normal precautions.

DEVELOPMENT AND USE OF FUNCTIONAL LIFE TABLES (FL-1 and FL-2)

The Functional Life Tables are the most important part of this guide. The development and use are described below.

Development, Substantiation and Sources of Data

Year 2000 Report on 32 Projects by Goldbaum

For life cycle cost analysis purposes, pavement lives were defined in a study reported by Goldbaum[2] in 2000 on 32 Colorado asphalt projects. The projects were reconstructed mostly in the early to mid-1980s. Seventeen projects on the National Highway System (NHS) received their first rehabilitation at 8.6 years average age. Their average PMS Overall Pavement Index (OPI) at rehabilitation was 72. Fifteen non-NHS projects had their first rehabilitation at an average age of 11.1 years (average OPI was 78). There was a considerable scatter in the plotted data. All projects were 20-year designs. During the period of construction for most of these projects, CDOT was experiencing many problems with pavement performance (some rutting and then brittleness as asphalt content was reduced). The problems were related to design, specifications, construction, and rapid growth in traffic, among other things. Goldbaum[2] reported the average age of the new or reconstructed pavements, and not of the overlays (apparently, none of the overlays had reached the end of their life).

The average overlay thickness for all 32 projects was *1.30* inches. The thickest seven overlays were 2.0-inch. All the rest were 1.5 inches or less, with 16 being 1.0 inches; such thicknesses are considered preventive maintenance, or functional overlays. Goldbaum[2] shows OPI performance curves for the first 4 to 7 years of the overlay lives. One for the average indexes for NHS overlays and one for the average indexes for non-NHS overlays. Again, there is a lot of scatter in Goldbaum's plotted data, indicating a probable range in life from about five to 15 or more years. By extending Goldbaum's two average curves to their intersection with the threshold index value of 50, the OPI projected functional lives are 7.5 and 8.5 years. These values closely agree with the YFLs by OPI curves as shown in Tables FL-1 and Fl-2 for thin overlays with basic or minor subsidiary treatments.

Only one of the NHS original pavements and three of the non-NHS pavements were constructed after 1989. Beginning in the late 1980s, a number of positive changes occurred in pavement design and

construction procedures in Colorado (and nationally). CDOT continued a series of progressive improvements in mix design and construction techniques, especially in the early nineties. By the middle nineties, the present SuperPave (SP) hot-mix asphalt design procedure had been fully phased in. Also, quality control/quality acceptance specifications (QC/QA) had been fully implemented for field construction. Because of these and other positive changes, it is expected that new and reconstructed pavements built using SP and QC/QA criteria will have longer service lives than those cited by Goldbaum[2]. However, not enough information is currently available to verify such expectations.

Overlay History on Sections of I-25 in the Denver Metro Area

An unpublished tabulation by Region Six of past overlay projects on I-25 in the region was made for two sections. The data from C 470 to Colorado Blvd. shows the average 1.5-inch overlay lasted between five and 7 years. One project overlaid with three inches lasted 14 years. The data from West Sixth Avenue to I-70, shows that pre-1980 overlays, 1.5 to 2 inches thick, lasted about 10 years before rehabilitation. Since that time, several lengths with 2 to 3-inch overlays have lasted an average of seven years (5-9). All overlay sections received basic or minor subsidiary treatments. Except for the one 14-year life, these lives are within a year or two of those given in Table FL-1 for similar treatment and the assumed, predominant existing distresses.

Network PMS Data as Related to Pavement Distress and Rehabilitation Techniques

Appendix B contains information from the CDOT PMS condition summary on flexible pavements as related to pavement distress categories and severity, before and after receiving rehabilitation. One set of data is from nine rehabilitation projects constructed on I-25 in 1994. One set is for data gathered on nine projects evaluated in 2000 for this guide. Greater detail than given below is available in Appendix B.

Performance of Nine I-25 Projects Rehabilitated in 1994

The details of design, materials and construction on nine I-25 projects rehabilitated in 1994 were reported by Aschenbrener[3] in 1995. The locations ranged from MP 0.0 at the New Mexico border to MP 235 north of Denver. He noted the purpose of his report was to provide data for future long-term pavement performance studies. The performance of the projects was evaluated for this Guide, then summarized in Tables B-1 and B-2. The evaluation procedures are discussed in Appendix B.

Performance of Nine Projects from the Rehabilitation Study

Table A-2, Appendix A, summarizes the interviews done with engineers and managers relative to 27 projects chosen to represent a variety of rehabilitation examples. A careful review of the projects revealed there were nine CDOT projects that had been constructed long enough to provide one or more years of rehabilitation performance history. These nine projects were evaluated and summarized in Appendix B in Tables B-3 and B-4.

Table B-5 contains a summary of the post-construction (performance) data for both the above sets of projects. The table shows a distinct trend which is: the greater the combined thickness (level of effort) of overlay and subsidiary treatment, the longer will be the pavement's functional life, as might be presumed. Keep in mind, though, that all the projects tabulated were 10 year designs, except for two noted in the table. So theoretically, they all should have 10-year lives, regardless of the level of rehabilitative effort. But, obviously, they will not. Also, there is an indication that SP modified asphalt pavements are performing better than pavements with unmodified asphalts. The projected

YFLs from the 21 projects, both by OPI and by Cracking Indexes, were heavily relied on in developing Tables FL-1 and FL-2.

Network PMS Task Force and Survey of CDOT Managers

Finally, the FL Tables are constructed such that they are in general agreement (± 1 year) with the survey conducted by a PMS task group in late 1999 to obtain data for the Network PMS. Several levels of discipline in CDOT's field and front offices were polled as to how long specific levels and types of rehabilitation could be expected to last, or the YFL (RSL at time done).

There was a consensus as to YFL for the wearing surfaces as follows: Thick overlay, 10; medium overlay, 7; thin overlay, 5; SMA, 8; HIP recycle/minimum 2-inch OL, 8; CIP recycle/minimum 2-inch OL, 8; and Micro surface, 4. These values were focal points for developing the FL Tables. The consensus YFL values were assumed to be for existing pavements typically having medium to severe transverse cracking (RSL <0). Only Basic or Minor was assumed as the subsidiary treatment.

Details of Tables

The numbers within the individual cells of Tables FL-1 and FL-2 are estimates of the YFL at the intersection of rows, beginning at the chosen rehabilitation strategy combination, and the column under the predominant category and degree of distress in the existing pavement. The first two distress columns are for the most severe categories, the lower RSL of either Cracking Index or Transverse Cracking as plotted from the Network PMS data for the project (or representative sections). Regardless of any other predominant distress, if either of the two cracking categories RSLs are 3.0 to 0.0, use the first column. If either is less than 0.0, use the second column.

If both cracking category RSLs are above 3.0, then select the most appropriate under the next six major column headings. Low distress is not included as it is unlikely that a rehabilitation project would be established when the predominant distress is of low severity.

Table FL-1 for NHS roads was constructed initially, and the first two YFL columns filled by considering the information listed above, using rational spreads and steps. The second two columns were then filled using a rational spreads and steps related the previous column values. Finally all of the cells in Table FL-1 were filled using a similar approach. The term NA indicates "not applicable or "not recommended".

Next Table FL-2, for non-NHS roads, was filled with YFL values. Goldbaum's[2] study showed 2.6 years average difference in the lives of new pavements between non-NHS and NHS projects. Based on this, for the most part, the YFL values in the first two columns (under the two RSL cracking categories) were set at 2.0 YFLs higher than in Table FL-1. The exception was for micro-surfacing and grind/micro-mill, which were set just one YFL higher. The other YFL values in the remaining columns were set at 3.0 YFL higher than the NHS values. In many cells this gave unreasonably high numbers for a 10-year design. Consequently any numbers higher than 13 were removed and a sub-note added as to why. Essentially the same set of notes appears under each FL Table. They have been repeated for easier table use.

EXAMPLES FOR USING THE TABLES

Example for NHS, Given:
(1) Interstate Project IXX-1 in an Urban setting, the existing asphalt surface will receive a 10-year rehabilitation pavement design.
(2) A plot of the most recent existing pavement Network PMS condition data for the proposed project shows the RSL by Cracking Index is 0.0, by Transverse it is -2.5.
(3) The project distress evaluation indicates the predominant distress is low to medium transverse cracking with low, load-associated cracking.
(4) 10-yr ESALs are 5.8 million
(5) Conventional design by the Region calls for a 3-inch overlay using SP Grading S (98% reliability PG asphalt cement).
(6) Subsidiary treatment is to be Basic with average 0.5-inch cold milling for leveling.

- To check for treatment required for YFL = 10, enter into **Table FL-1**, the column under RSL <0.
- **Option 1:** Across from Medium Overlay, read that Subsidiary treatment for 10 YFL should be Major, even if allowing for use of modified AC. (Note: Since cold recycling is not an option due to urban setting & high traffic, cold milling 3 inches or greater is the only reasonable *rehabilitation* option for Medium overlay. Due to loss of $\pm$0.66 SN by milling 3 inches, result would likely be a total of $\pm$4.5 inches of HBP on the milled surface.)
- **Option 2:** Across from Major Overlay, read that minimum Subsidiary treatment for 10 YFL should be Minor for modified AC (add one year to table YFL). Choices are cold mill 0.75 to 1.5 inches and replace lost SN, or hot-in-place recycle 0.75 to 1.5 inches. (Due to loss of $\pm$0.22 SN by milling of say, 1.0 inches, result would likely be a total of $\pm$5.5 inches of HBP on the milled surface.)
- To check the YFL for the proposed conventional design, read on down under RSL <0 across from Medium Overlay, Basic treatment, and find the value of 5. Add one year for use of modified asphalt cement. The predicted YFL is 6.

Example for non-NHS, Given:
(1) Rural Secondary Project SXX-2. The existing asphalt surface will receive a 10-year rehabilitation pavement design.
(2) A plot of the most recent existing pavement Network PMS condition data for the proposed project shows the RSL by Cracking Index to be -0.4, by Transverse it is -8.0.
(3) The project distress evaluation indicates the predominant distress is medium to high alligator cracking with medium to high transverse cracking closely following in extent.
(4) 10-yr ESALs are 520,000
(5) Conventional design by the Region calls for a 2-inch unmodified asphalt overlay.
(6) Subsidiary treatment is to be minor, 1.25 total thickness of Heater Repave (0.5-inch heater scarify, with 0.75-inch SX overlay, in one operation).

- To check for treatment required for YFL = 10, enter into **Table FL-2,** the column under RSL <0.
- **Option 1:** Across from Thin Overlay, read that minimum Subsidiary treatment for 10 YFL should be Major. Choices are cold mill $\geq$3 inches and replace lost SN or cold-in-place recycle minimum 4 inches. (If milling is selected, due to loss of $\pm$0.66 SN, result would likely be a total of $\pm$3.5 inches of HBP on the milled surface.)

- **Option 2:** Select Medium Overlay, read that minimum Subsidiary treatment for 10 YFL should be Moderate. Choices are cold mill 1.5 to 3.0 inches or hot-in-place recycling >1.5 inches. (If milling, say 1.5 inches, is selected, due to loss of $\pm$0.33 SN, the result would likely be a total of $\pm$3.75 inches of HBP on the milled surface.)
- To check the YFL for the proposed conventional design, read on down under RSL <0 across from Thin Overlay and Minor treatment and find a predicted value of 7

ENGINEERING JUDGEMENT REQUIRED

In Tables FL-1 and FL-2, the thicknesses of wearing surfaces and subsidiary treatments, in many cases are presented in ranges, rather than specific values. This demands that engineering judgement be used in selecting the combination of rehabilitation treatments to be used. The object in using this Guide should be to select the best practical combination of thicknesses and treatment categories that will reasonably assure the construction of rehabilitated pavements with 10-year minimum functional lives. It is possible to subvert the intent by selecting the thinnest (or cheapest) of treatment categories and combinations that strictly meet the minimum values given. Such an approach may not fully accomplish the desired result of increasing pavement functional lives to better equal their design lives.

Where this Guide is followed for design, and the intent is to continue to do so, it is suggested when making LCCA for NHS highways that the rehabilitation cycle be set at 10 years rather than the 8 years as recommended by Goldbaum [2]. The increased first cost will tend to be offset by expected longer life of each cycle.

Goldbaum [2] already recommends using a 10-year cycle for non-NHS. In the few cases where increased first cost will occur by following this Guide, the improved 10-year design reliability will tend to offset this.

LIST of REFERENCES

Numbered References

(1) Pavement Design Manual, State of Colorado, Department of Transportation. October 1999.

(2) Report No. CDOT-R1-R-00-3, Life Cycle Cost Analysis, State -of-the-Practice, Colorado Department of Transportation, March 2000, by Jay Goldbaum.

(3) Report No. CDOT-DTD-R-95-14, A Documentation of Hot Mix Overlays on I-25 in 1994, Colorado Department of Transportation, June 1995, by Tim Aschenbrener.

Un-numbered References

See Table A-1, Appendix A, this report, for a specific list of publications formally reviewed for this study Listed below are additional pertinent publications reviewed or consulted while developing this report:

- Synthesis and Literature Review of Nonwoven Paving Fabrics Performance in Overlays, Transportation Research Record 1687, Paper No. 99-1380, by R.F. Carmichael III and Mark L. Marienfeld. 1999.
- Report No. 3042, The Design of a Long Life HMA Pavement for the Southeast Corridor Project, Denver, Colorado. Prepared for Colorado Asphalt Pavement Assoc. by Harold Von Quintas and Brian Killingsworth, Fubro-BRE, Inc., 8240 Mopac, Ste #220, Austin, Texas, 78759. Apr. 2000.

Table FL 1 **NHS (High Traffic) YEARS FUNCTIONAL LIFE (YFL)**

REHABILITATION STRATEGIES		10-YR DESIGN YFL [1] WHEN EXISTING DISTRESSES BELOW ARE TREATED BY THE INDICATED REHABILITATION STRATEGIES												
WEARING SURFACE HBP overlay YFLs are for neat asphalts, 50% reliability.	SUBSIDIARY TREATMENTS [2] May be used with selected wearing surface. Basic is included in Major-Minor.	YFL by **Cracking Index** [3] if existing **Transverse** or **Crack Index** has an:		YFL expected by **OPI** plot for the identified predominate existing distress.[4] End parentheses are Design Manual pgs. The two degrees of severity include the subjective extent. Low level not included as it is unlikely to be treated.										
				Transv (Temp/ Refl) Cracking (B9, 12)		Long. or Block Cracking (B6, 11)		Load Assoc (Alig or Long) Cracking (B4)		NP Rutting (B17) If plastic, see note 5		Raveling or Weathering (B16)		Bleeding (B5)
		RSL 3-0	RSL <0	Med	High	Med	High	Med	High	Med	High	Med	High	No Degree
MAJOR OVERLAY >4 to 6", 5" used. If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	12	12	14	14	14	14	14	14	14	14	14	14	NA
	Moderate	11	10	13	12	14	13	14	13	13	12	14	13	NA
	Minor	10	9	12	11	13	12	13	12	12	11	13	12	NA
	Basic Only	9	8	11	10	12	11	12	11	11	10	NA	NA	NA
MEDIUM OVERLAY >2 to 4", 3" used. If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	10	10	12	12	12	12	12	12	12	12	12	12	NA
	Moderate	9	8	11	10	12	11	12	11	11	10	12	11	NA
	Minor	8	7	10	9	11	10	11	10	10	9	11	10	NA
	Basic Only	7	6	9	8	10	9	10	9	9	8	10	NA	NA
THIN OVERLAY (2" HBP) If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	8	8	10	10	10	10	10	10	10	10	10	10	NA
	Moderate	7	6	9	8	10	9	10	9	9	8	10	9	NA
	Minor	6	5	8	7	9	8	9	8	8	7	9	NA	8
	Basic Only	5	4	7	6	8	7	8	7	7	6	NA	NA	NA
SMA (1.5 - 2") If over CIPR, must be ≥2"	Major	10	10	12	12	12	12	12	12	12	12	12	12	NA
	Moderate	9	8	11	10	12	11	12	11	11	10	12	11	NA
	Minor	8	7	10	9	11	10	11	10	10	8	11	10	10
	Basic Only	7	6	9	8	10	9	10	9	9	8	NA	NA	NA
MICRO SURFACING	Basic/Minor	4	3	5	4	5	4	5	4	5	4	6	5	NA
	Micro Surf in filled ruts	4	3	5	4	5	4	5	4	5	4	NA	NA	NA
GRIND/MICRO-MILL	Basic (applicable)	1	1	5	5	NA	NA	NA	NA	5	5	NA	NA	NA

Table Notes: (Columns are alternately shaded for easier reading)
Hatched cells represent 1999 PMS survey consensus values, +/- 1 year.

1. Years Functional Life (YFL) is defined as the life predicted by the CDOT Network PMS at time of construction, at this time it is synonymous with RSL.
2. Defined as any applicable treatment (see Conditions for Use) to the existing pavement prior to placing new HBP or other wearing surfaces. The four categories (the first three include **Basic**) are defined as follows:
- **Major:** (1) Cold-in-place recycle, 4" or greater or (2) Cold mill >3"(and replace lost SN). **(In this table, the SN replacement thickness is to be added to original Wearing Surface thickness)**
- **Moderate:** (1) Cold mill >1.5"to 3" (& replace lost SN), (2) hot-in-place recycling >1.5", or (3) fill non-plastic ruts (>0.5" to 1.5") with micro surfacing.
- **Minor:** (1) Cold mill >0.75" - 1.5" (& replace lost SN), (2) hot-in-place recycle 0.75" - 1.5", (3) fabric interlayer (4) or fill non-plastic ruts (<0.5") with micro surf.
- **Basic:** Includes, but is not limited to, patching isolated weak areas, leveling up to 0.75" average by milling or HBP, or crack filling, as appropriate for the subsidiary treatment selected.

3. The YFL by Cracking index is listed first as it is critical to performance and affects Ride and OPI. If by the PMS condition plot, either the Transverse or Cracking RSL at time of design are as indicated, YFL by Cracking Index is as shown. Use these YFLs for Cracking regardless of whether Transverse cracking is predominate, or not.
4. The degrees of distress in the five categories below are to be arrived at subjectively by PMS data and/or project evaluation and include extent. The YFLs shown are those predicted from OPI by PMS.
5. For medium to severe plastic rutting, it is presumed that little cracking and no raveling is present. For these conditions, repair by milling and replacing in accordance with CDOT guidelines shall be done. The pavement is then presumed to be restored to its original design life.

Table FL 2 **Non-NHS (Low to Medium Traffic) YEARS FUNCTIONAL LIFE (YFL)**

REHABILITATION STRATEGIES		10-YR DESIGN YFL [1] WHEN EXISTING DISTRESSES BELOW ARE TREATED BY THE INDICATED REHABILITATION STRATEGIES												
WEARING SURFACE HBP overlay YFLs are for neat asphalts, 50% reliability.	SUBSIDIARY TREATMENTS [2] May be used with selected wearing surface. Basic is included in Major-Minor.	YFL by **Cracking Index** [3] if existing **Transverse** or **Crack Index** has an:		YFL by **OPI** plot for the identified predominate existing distress[4]. End parentheses are Design Manual pgs. The two degrees of severity include the subjective extent. Low level not included as it is unlikely to be treated.										
				Transv (Temp/ Refl) Cracking (B9, 12)		Long. or Block Cracking (B6, 11)		Load Assoc (Alig or Long) Cracking (B4)		NP Rutting (B17) If plastic, see note 5		Raveling or Weathering (B16)		Bleeding (B5)
		RSL 3-0	RSL <0	Med	High	Med	High	Med	High	Med	High	Med	High	No Degree
MAJOR OVERLAY >4 to 6", 5" used. If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	#	#	#	#	#	#	#	#	#	#	#	#	NA
	Moderate	13	12	#	#	#	#	#	#	#	#	#	#	NA
	Minor	12	11	#	#	#	#	#	#	#	#	#	#	NA
	Basic Only	11	10	#	13	#	#	#	#	#	13	NA	NA	NA
MEDIUM OVERLAY >2 to 4", 3" used. If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	12	12	#	#	#	#	#	#	#	#	#	#	NA
	Moderate	11	10	#	13	#	#	#	#	#	13	#	#	NA
	Minor	10	9	13	12	#	13	#	13	13	12	#	13	NA
	Basic Only	9	8	12	11	13	12	13	12	12	11	13	NA	NA
THIN OVERLAY (2" HBP) If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	10	10	#	#	#	#	#	#	#	#	#	#	NA
	Moderate	9	8	13	12	13	12	#	13	13	12	#	13	NA
	Minor	8	7	11	10	12	11	13	12	12	11	13	12	8
	Basic Only	7	6	10	9	11	10	12	11	11	10	12	NA	NA
SMA (1.5 - 2") If over CIPR, must be ≥2"	Major	12	12	#	#	#	#	#	#	#	#	#	#	NA
	Moderate	11	10	#	13	#	#	#	#	#	13	#	#	NA
	Minor	10	9	13	12	#	13	#	13	13	12	#	13	10
	Basic Only	9	8	12	11	13	12	13	12	12	11	13	NA	NA
MICRO SURFACING	Basic/Minor	5	4	6	5	6	5	6	5	6	5	7	6	NA
	Micro Surf in filled ruts	5	4	6	5	6	5	6	5	6	5	NA	NA	NA
GRIND/MICRO-MILL	Minor	2	2	6	6	NA	NA	NA	NA	6	6	NA	NA	NA

 # YFLs for these cells were 14, or higher, removed as unlikely combinations for 10-yr design.

Table Notes: (Columns are alternately shaded for easier reading)

1. Years Functional Life (YFL) is defined as the life predicted by the CDOT Network PMS at time of construction, at this time it is synonymous with RSL.
2. Defined as any applicable treatment (see Conditions for Use) to the existing pavement prior to placing new HBP or other wearing surfaces. The four categories (the first three include **Basic**) are defined as follows:
   - **Major:** (1) Cold-in-place recycle, 4" or greater or (2) Cold mill >3"(and replace lost SN). **(In this table, the SN replacement thickness is to be added to original Wearing Surface thickness)**
   - **Moderate:** (1) Cold mill >1.5"to 3" (& replace lost SN), (2) hot-in-place recycling >1.5", or (3) fill non-plastic ruts (>0.5" to 1.5") with micro surfacing.
   - **Minor:** (1) Cold mill >0.75" - 1.5" (& replace lost SN), (2) hot-in-place recycle 0.75" 1.5", (3) fabric interlayer (4) or fill non-plastic ruts (<0.5") with micro surf.
   - **Basic**: Includes, but is not limited to, patching isolated weak areas, leveling up to 0.75" average by milling or HBP, or crack filling, as appropriate for the subsidiary treatment selected.
3. The YFL by Cracking index is listed first as it is critical to performance and affects Ride and OPI. If by the PMS condition plot, either the Transverse or Cracking RSL at time of design are as indicated, YFL by Cracking Index is as shown. Use these YFLs for Cracking regardless of whether Transverse cracking is predominate, or not.
4. The degrees of distress in the five categories below are to be arrived at subjectively by PMS data and/or project evaluation and include extent. The YFLs shown are those predicted from OPI by PMS.
5. For medium to severe plastic rutting, it is presumed that little cracking and no raveling is present. For these conditions, repair by milling and replacing in accordance with CDOT guidelines shall be done. The pavement is then presumed to be restored to its original design life.

GUIDELINES FOR SELECTION OF REHABILITATION STRATEGIES for ASPHALT PAVEMENT

APPENDIX A

Contents

List of Tables

APPENDIX A

RESEARCH STUDY PLAN

An abbreviated outline of the Research Study Plan for developing the Guidelines for Selection of Rehabilitation Strategies for Asphalt Pavement is presented below.

Research Study Panel

The Research Study Panel, convened in the spring of 1999, consisted of the following:

Tim Aschenbrener, CDOT Staff Materials
Greg Lowery, CDOT Staff Materials
Dave Gonser, CDOT Region 2
Bernie Kuta, FHWA
Tom Peterson, CAPA
Scott Shuler, LaFarge Co.
Richard Zamora, CDOT Staff Materials and
Donna Harmelink, CDOT Research, as Study Manager

Work Plan

(1) Literature Review: The Study Panel compiled 14 references for publications and literature from several States and various other sources for the principal researcher (PR) to review. The PR located several additional literature references which were added to the list, making a total of 21 references that were formally reviewed. Table A-1 lists the references and summarizes the reviews. Each report is listed in order of its importance, or contribution to the study. Several other publications were consulted by the PR; they appear in a separate reference list.

Had the panel had a clearer idea of the direction this research would take, perhaps more references would have been located preliminarily having a closer relationship to the study. By the time the true direction was known, allotted funding and time did not permit additional formal literature searches and reviews. The direction taken was to estimate field performance of rehabilitated pavements as characterized by network PMS condition indexes over several years. This data was then compared with the category and degree of distress in the existing surface and the rehabilitation strategy used. Appendix B described the limited but valuable work done along this line.

Only the first two publications listed, the Department's new **Pavement Design Manual, October 1999**, and the **Distress Identification Manual for the Long-Term Pavement Performance Project**, SHRP-P-338, 1993, were of much value to the study. The next 10 were of some value. The main contribution of the literature was the development of a clear understanding of the current flexible pavement design procedures in Colorado and how flexible pavement distresses in many agencies are categorized and tabulated. From the literature, it is obvious that transverse (and reflected transverse) cracking is one of the most pervasive and difficult problems to correct. The only sure methods of correcting this distress are removal (deep cold milling) or reconstruction. Other treatments, depending on the amount of effort and cost, can delay onset of reflected transverse cracking by one to perhaps three years.

Publication #6, **LTPP Rehabilitation Performance Trends**, summarizes the **Performance Trends for SPS-5, Rehabilitation of Asphalt Concrete Pavements.** One significant finding, based on project observations in the several participating states, was that with overlay thicknesses of two and five inches, non-load-associated cracking was appearing after only three years in both thicknesses.

Ruts and load-associated cracks have a low redevelopment rate in both thicknesses. This finding agrees substantially with the CDOT Pavement Management condition index Study reported in Appendix B.

(2) Rehabilitation Strategies: The Panel had identified eight rehabilitation strategies to be considered. The PR was to confirm these and investigate to determine if others should be added. Tables FL-1 and FL-2 in the Guide list the strategies chosen, six wearing surfaces (including three HBP thickness categories) and five subsidiary strategies (cold milling, hot-in-place recycling and rut filling each have more than one level of effort). It should be noted that none of the final strategies are new to CDOT. All have been used to one degree or another. Some are frequently used. The literature search revealed no methods of rehabiltation that CDOT was not aware of. Each strategy, and its conditions for use, is described in detail in the Guide.

(3) Pavement Distresses: The Panel had identified nine flexible pavement distresses to be considered. Five of these are used at the project evaluation level and at the Network PMS level. The other four are used only at the project level. The PR was to confirm these and investigate to determine if others should be added or if any should be dropped. The only one listed by the panel not included in the decision tables was stripping (it being a specific distress with only one reasonable treatment). It is addressed in the Guide text, however. Tables FL-1 and FL-2 list the distresses and levels of severity chosen. In the first two columns of each table, the two combined cracking distresses and severity levels come only from the PMS ratings. These columns are used unless the distresses are less severe than the threshold values noted. If not that severe, selection is then made from six other distresses or combinations (each with two severities) as tabulated. One category and one severity are selected as predominant for each representation on the project. Low severity was not included as it is unlikely that rehabilitation will be scheduled for this level as the predominant distress. See the Guide for more details.

(4) Selection of Interviewees: The Panel included a list of experts (mostly CDOT) and their areas of expertise (rehabilitation strategies, usually on specific projects) for the PR to interview, using a question format as discussed under No 5, below. The PR was free to change the list with Panel approval. Essentially, the list was followed as offered.

(5) Interviews (and development of question list): Direction was given by the panel as to the questions to be included when interviewing. Approval was required before use. Using the Panel suggestions as a base, a two-part questionnaire was developed by the PR.

> **The Questionnaire, Part I** was project specific; the questions are summarized as follows: Project identity, Location, & Climate? Condition of existing pavement (OPI)? Existing distress type & severity? Existing structural section? Rehabilitation strategy used (including materials & layer details)? Why was this strategy chosen? Was reconstruction an option? *Was underground or surface drainage improvement done?* Design life and ESALS? *Expected failure mode? Was LCCA done?* What were traffic disruptions? Was the project rural or urban? What constraints affected the strategy selection? *Did local maintenance personnel contribute to rehabilitation decision?* Problems during construction? Any materials or work not in substantial compliance? Time frame of critical construction? Negative effects of weather? At present, is the pavement performing as expected? (See comments below on the four italicized questions). A copy of the detailed questionnaire is available on request.

The interview results have been summarized in Table A-2. Interviews involved 23 people relative to 17 specific rehabilitation projects. Four people were asked general questions about specific strategies. Nine of the 17 specific projects were chosen for PMS condition evaluations, before and after construction, as related to preconstructing distress, strategy and predicted YFL. The description blocks for the nine projects are outlined in bold in Table A-2. See Appendix B for the details of the PMS study.

Four questions were not summarized in Table A-2. (1) *Question was asked if surface or groundwater drainage was improved.* For these projects, all answers were "NO." (2) *Question was asked as to expected failure mode.* Answer: In most cases, respondents expected failure from non load associated cracking, predominantly from transverse; exception was for CIP recycling where the expected failure mode was by fatigue cracking. (3) *Question was asked if life-cycle-cost analyses (LCCA) had been done to compare multiple strategies on these specific projects.* Answer: According to respondents, LCCA studies had been done only in Region 5, then to justify cold recycling with 20-year overlays. (4) *Question asked about local maintenance forces' contribution to the rehabilitation* ***decision.*** Answer: Generally, maintenance forces were not involved in the *selection* of specific rehabilitation strategies; however, maintenance forces were frequently involved in various phases of planning and field reviews for most projects

Questionnaire, Part II, General. The questions and summarized answers follow Table A-2. Note the answers to Question 3, regarding the most common distresses, and Question 4 regarding distresses most difficult to correct. Transverse cracks, thermal cracks, and cracking in general were most frequently mentioned. Based on these answers, and (2) in the above paragraph, selecting rehabilitation strategies that stop or significantly slow the onset of reflected transverse cracks should be of the highest CDOT priority.

(6) Compile Information from the Literature Review and from the Study Research, Then Submit a Final Report (Guide): The Guide, in the first part of this publication, fills the requirements as outlined above and in the Study Plan.

STUDY PLAN SUMMARY

There was much in the literature about thickness design and prioritizing maintenance and rehabilitation. Several reports and manuals contained details on how to do the various treatments. These details were not the main focus of the investigation, so they were of little benefit. In the literature, it was generally accepted that transverse cracking is an extremely difficult distress to correct and that breaking up the existing crack pattern is the only reasonably sure treatment. If the crack pattern is not substantially disrupted, it is sure to repeat. It is only a matter of time. The literature *was* helpful toward writing the Guide section, **"Candidate Rehabilitation Strategies: Conditions for Use, Advantages, and Constraints."**

The interviews, conducted mostly with CDOT field personnel at the management level, were very valuable in establishing and verifying the general direction of this report. The people were knowledgeable and helpful.

Appendix B reports on a relatively small satellite study for the Guide that was not originally included in the Study Plan. The summary and conclusions from that study are included in the report and are referred to in the Guide.

Table A-1

SUMMARY OF LITERATURE/PUBLICATIONS REVIEWED				
NAMES of PUBLICATION and SUMMARY OF CONTENTS	**Size, Pages**	**SUMMARY of RELEVANT PARTS or CHAPTERS**	**Degree of Influence**	**REFERENCES Parts Used or That Influenced This Guide**
Colo. Department of Transportation (CDOT). *Pavement Design Manual.* **October 1999.** *Presented are CDOT's methods and guidelines for designing and rehabilitating pavements, including asphalt (flexible) pavements, rigid (PCCP pavements), and composite structures.*	101 in the text, plus 64 app-ended	*It is very relevant, particularly the parts relative to flexible pavement rehabilitation. It modifies the 1993 AASHTO guide by removing data derivations and parts inapplicable to CDOT's working practice. Incorporated are the many CDOT policies and procedures that are based on experience and current practice in Colorado. The result is a comprehensive document that, although complex, is much easier to read and follow than the AASHTO guide. It addresses CDOT's needs and was referenced extensively for this Guide.*	Very much #1	*Section 5.3.1, ...Rehabilitation Alternatives; it is particularly valuable, as is all of 5.6 related to asphalt surfaces and pertinent parts of the three appendices were referenced.*
Distress Identification Manual for the Long-Term Pavement Performance Project (LTPP). Strategic Highway Research Program, SHRP-P-338, National Research Council. 1993. *This manual was developed especially for the LTTP program. It provides a common language for describing cracks, potholes, rutting, spalling and other pavement distresses.*	147	*As a "distress dictionary," the manual will improve inter- and intra-agency communication and lead to more uniform evaluations of pavement distress and performance. Most relevant to this Guide is Section 1, Distresses with Asphalt Concrete Surfaces. It is important that detailed, project-level, distress surveys be made using an established, common measuring procedure. For uniformity, it is particularly necessary when using this Guide as a tool to aid in selecting the rehabilitation strategy. There are 15 distresses listed for asphalt surfaced pavements, while CDOT has chosen to use seven for inclusion in the decision chart in this Guide. (See Tables FL-1 & 2 for correlation).*	Much #2	*This Guide has been developed with the intent that this LTPP manual will be the standard for measuring similarly identified distresses at the Project level. For each distress, there is a measuring diagram. Three levels of severity are identified with color photos examples.*
Techniques for Pavement Rehabilitation. National Highway Institute Course # 13108, rev. August 1998. *The manual, in 5 Blocks, each with several modules, is primarily for training and includes updated rehabilitation technology for both flexible and rigid pavements. Included are project evaluation, construction procedures and selection of the most appropriate treatments at the project level. The final block is on evaluating alternate strategies.*	Each mod-ule has its own pg #s, total pgs =100s	**Block 2** *emphasizes the need for, and how to make a thorough project-level evaluation of the existing pavement. A good reference, but CDOT's new Design Manual is adequate for most applications.* **Block 3, Module 3-11,** *identifying feasible flexible pavement rehabilitation alternatives, was valuable a reference for this* ***Guide****. Block 5 is about selection of preferred alternatives. Its emphasis is life cycle cost analyses. CDOT's Design manual adequately covers this. The effects of local traffic, climate and estimated life of each treatment strategy is not directly addressed. This remains an Agency problem, e.g., the reason for development of this* ***Guide****.*	Some #3	*This NHI course served as a review and reference while this Guide was being developed. No direct information was found which would indicate how long pavements really last that have been structurally designed by AASHTO* (CDOT) *procedures.*

Table A-1

SUMMARY OF LITERATURE/PUBLICATIONS REVIEWED				
NAMES of PUBLICATION and SUMMARY OF CONTENTS	**Size, Pages**	**SUMMARY of RELEVANT PARTS or CHAPTERS**	**Degree of Influence - #**	**REFERENCES Parts Used or That Influenced This Guide**
Colo. Department of Transportation (CDOT). *Guidelines for Rehabilitation with Overlays.* July 1992. *An abbreviated version of some pertinent parts of Chapter 5, Part III (without the Tables and Figures), of the* **1986 AASHTO GUIDE for DESIGN of PAVEMENT STRUCTURES.** *The 1993 version is described below.*	16	*The manual is relevant, but outdated. Part III of the 1986 (and the 1993) AASHTO is the Pavement Design Procedures for Rehabilitation of Existing Pavements. The CDOT condensation served as a reference for this Guide. It presents methods and guidelines for designing and rehabilitating pavements, including asphalt concrete, portland cement concrete, and composite structures with overlays.*	Some #4	*It served as a valuable reference when initiating this project. No direct references have been made to the 1992 Guidelines which have been incorporated into the new Design Manual*
Pavement Rehabilitation Manual, Vol II: Treatment Selection, Materials Bureau, N Y State Dept of Transportation, Rev. 1993. *It is used in conjunction with Vol. I, (#19, below) to select pavement treatment alternatives and develop life cycle costs for the collected distresses. Included are treatment strategies for preventive maintenance, corrective maintenance, rehabilitation, and reconstruction for rigid, flexible and composite pavements.*	163 plus 3 appe-ndices.	*This manual is well organized with strategies for specific distresses and constraints listed for the conditions indicated at left. The Section on flexible pavements lists three corrective maintenance strategies for a variable list of five distresses. This is followed by seven rehabilitation strategies for a variable list of five distresses. For both, corrective maintenance and rehabilitation, constructability advantages and disadvantages, performance characteristics, expected failure modes, and expected service lives are listed. The expected service lives are a constant* ***8 Yrs*** *for each maintenance treatment and a constant* ***15 Yrs*** *for each rehabilitation strategy. For a project, treatment strategy and thickness is selected based on degree of distress from a visual survey. OL thicknesses are not determined by nondestructive deflection testing.*	Some #5	*New York has the policy of selecting treatment strategy & OL thickness to provide a constant service life for all projects. CDOT varies treatment strategies and, thicknesses, including OL, for combinations that give each project a unique service life. CDOT has more than 30 strategy combinations, compared to 7 for NY.*
Rehabilitation Performance Trends: ***Early Observations From Long-Term Pavement Performance (LTPP) Specific Pavement Studies (SPS).*** Jan.1998. *This report documents the early observations from the LTPP SPS conducted as part of the LTPP Program Data Insight conducted to identify initial findings from the test sections established for this program.*	51 text, total = 245	**Chap. 3. Performance Comparisons.** ***Performance Trends for SPS-5, Rehab. of Asphalt Conc Pavements (AC).*** *Overlay (OL) thicknesses were 2 & 5". Non load-associated cracking is appearing after only three years in both 2 & 5"OL. Ruts and load-associated cracks have a low redevelopment rate in both 2 & 5".* ***Performance Trends for SPS-6, Rehab. of Jointed Concrete Pavements (JCP)*** *For JCP overlaid with 4" AC, reflection cracks developed at joints in 1-2 yrs. However, ride quality is much better compared to that prior to overlay.*	Some #6	*Table 8. Summary of apparent effects of various parameters on performance of SPS-5 projects.* *Table 9. Summary of apparent effects of various parameters on performance of SPS-6 projects.* *And various text conclusions. See Guide text for references.*

Table A-1

SUMMARY OF LITERATURE/PUBLICATIONS REVIEWED				
NAMES of PUBLICATION and SUMMARY OF CONTENTS	**Size, Pages**	**SUMMARY of RELEVANT PARTS or CHAPTERS**	**Degree of Influence**	**REFERENCES Parts Used or That Influenced This Guide**
The Asphalt Handbook, Asphalt Institute Manual Series No.4 (MS-4), Chapter 9. Asphalt in Pavement Maintenance and Rehabilitation. *Chap. 9 deals with pavement maintenance and rehabilitation for all types of pavement structures.*	Ch. 9, 64 of text & figs.	**Sect. 9.1 Planning for Improvement/Pavement Management:** *Introduces some very basic PMS concepts including a simple chart (tree), Fig. 9.1, as a guide for engineering maintenance and rehabilitation decisions. Included is Table 9.1, Alternatives in Pavement Maintenance and Rehabilitation where 14 asphalt distresses are listed with Causes, Maintenance, Rehab. and Reconstruction.* **Sect. 9.4 Asphalt in Pavement Rehabilitation:** *Includes a guide (Fig. 9.42) for priority of overlays and functional versus structural overlays.*	Some #7	*Fig. 9.1, Fig. 9.42 and Table 9.1 used as references. Also the subsection on correcting surface (functional) deficiencies was referred to.*
Pavement Distress and Selection of Rehabilitation Alternatives - Michigan Practice from HRR 1629, 1998, Baladi, G.Y., et al. *The Michigan DOT (MDOT) practice regarding the preservation, rehabilitation, and preventive maintenance actions for rigid, flexible, and composite pavements is discussed. For each type, the causes of distresses and the MDOT fix alternatives are presented. Examples of selection of maintenance and rehab alternatives are shown.*	11 text and Figs	*Most of this technical paper has some relevance to this Guide. Out of the 11 pages, there are only about three pages of text. There are 13 Tables. Since PCCP pavements are included, as well as maintenance and reconstruction, information relative to flexible rehabilitation has to be gleaned.* *The tabular presentation is unique and has furnished ideas for this Guide. Many of the triggered actions are presented in code, with code keys furnished. This reduces table and column size, but makes it difficult to understand until familiarity with the codes is gained.* *The flexible distresses, causes, and fix methods were valuable references and influenced this Guide.*	Some #8	*The list of flexible distresses and causes table was a good reference. The "fix," or rehabilitation strategies are keyed to their cold, wet climate, and not particularly applicable to Colorado's climate.*
AASHTO Guide for Design of Pavement Structures. Published by AASHTO in 1993. *This guide presents methods and guidelines for designing and rehabilitating pavements, including asphalt (flexible) pavements, rigid (pccp pavements), and composite structures. It is widely used by the member States and other agencies. There are four major Parts with Chapter divisions in each.*	322 text, plus appendix	**Part III Pavement Design Procedures for Rehabilitation of Existing Pavements, and Appendix K, Typical Pavement Distress Type-Severity Descriptions.** **Part III:** *Presented is the comprehensive framework of methods for selecting major rehabilitation strategies for specific projects. The strategies encompass not only structural overlay procedures, but other rehabilitation methods as well.* **Appendix K:** *Contains general descriptions of the major types of distress that may be encountered in pavements with descriptions of three levels of severity associated with each distress.*	Some #9	*Few references, since CDOT's 1999 Design Manual has condensed the pertinent parts as added to their Manual. For the most part, references are to CDOT's Design Manual*

Table A-1

SUMMARY OF LITERATURE/PUBLICATIONS REVIEWED				
NAMES of PUBLICATION and SUMMARY OF CONTENTS	Size-Pages	**SUMMARY of RELEVANT PARTS or CHAPTERS**	Degree of Influence -	**REFERENCES Parts Used or That Influenced This Guide**
Calif. Depart. of Transportation (CalDot). Proposed Preventative Maintenance Strategies, Internal letter by R.N. Doty to J.R. Cropper, 1986. *Attachments are related to preventive paintenance showing several maintenance strategy trees (never used) that could serve as models for CDOT Rehab. Strategies.*	9	*A series of hand-drawn flow diagrams, one diagram for each of seven asphalt pavement distresses are shown. Four climates, 3 traffic levels, and 3 surface conditions are shown with codes for 1-8 different alternate strategies listed under each of the 36 branches. Although never used by CalDot, the trees served as a an idea model in developing this Guide.*	Some #10	*All seven trees were considered, but not used directly.*
Federal Funding for Preventive Maintenance - Implications to State & Local Highway Agencies. Purdue Univ. Term Paper by Tom Peterson. 1994. *This paper explains the complex Regulations and legislation involved in the federal funding of the 3R/4R program. Graphs, charts and tables serve to enhance understanding of the topic.*	11 plus ref. And attch.	*It is an excellent paper explaining the FHWA regulations regarding federal aid funding for preventive by SHAs on the federal aid system. Traditionally, PREVENTIVE maintenance has not been eligible for federal aid. Under this program, if an SHA has a pavement management system which shows treatments are cost-effective and have an expected service life of five years, they can become eligible for Federal aid. Though not directly applicable to selection of rehabilitation strategies, it is very relevant to researchers and practitioners working with rehabilitation of pavements.*	Some #11	*None of the information in this paper has been included in this Guide, however, it is included here for reference as having some relevance.*
Pavement Recycling Guidelines for State and Local Governments FHWA-SA-98-42. By Prithvi S. Kandhal and Rajib B. Mallick. *Included in this report is information regarding hot-in-place and cold-in-place recycling. It is a "participant's" reference book for a series of 2-day workshops.*	Approx 100	*Covered are all aspects of asphalt pavement recycling, including hot & cold, as well as in-place & central plant strategies. Economics, environmental issues, energy conservation, mix design, structural design, specifications and results of surveys (from states and agencies) are included. For this Guide, the primary interest is in cold and hot in-place recycling strategies; however the entire report is valuable and should be a readily available reference for decision makers seriously considering either of the two strategies. Comprehensive reference lists are found at the end of each chapter.*	Some #12	*The following Chapters had some influence on this Guide: Chap 3 on Strategies; 9, 10 & 11 on Hot-in-Place techniques; 13, 14 & 15 on Cold Recycling; and Appendix B (NM specification for cold-in-place recycling.*
Colo. Department of Transportation (CDOT). ***Guidelines for Surface Treatment.*** **July 1994.** *These guidelines address crack filling, joint resealing, seal coats and thin asphalt overlays, essentially preventive maintenance.*	18	*The focus of this manual is primarily preventive maintenance. However; Chapter 3, Asphalt Overlays, provides a good description of structural and functional overlays and the conditions where each might be considered.*	A little #13	*Probably the most valuable portion are the five conditions where an asphalt overlay would not be feasible (of any thickness).*

Table A-1

SUMMARY OF LITERATURE/PUBLICATIONS REVIEWED				
NAMES of PUBLICATION and SUMMARY OF CONTENTS	**Size, Pages**	**SUMMARY of RELEVANT PARTS or CHAPTERS**	**Degree of Influence**	**REFERENCES Parts Used or That Influenced This Guide**
Calif. Depart. of Transportation (CalDot). ***Highway Design Manual, Topic 611, Pavement Structural Section Rehabilitation.*** **July 1995.** *Topic 611 briefly describes their PMS, details asphalt pavement failure types and describes rehabilitation strategies (most of which is maintenance or reconstruction). Overlays, hot and cold recycling are briefly discussed.*	22 of text	*According to 611.2, Pavement Management System (described only briefly), most of CalDOT's procedures for selection of rehabilitation strategies are included in their PMS. This includes analyzing the extent and severity of pavement distress, identifying potential repair strategies and alternatives. PMS develops a statewide list based on triggering factors and a decision tree. In 611.6, the list of asphalt pavement failure types is comprehensive and differs little from other literature. In 611.9 overlays and hot and cold recycling are addressed briefly. Also, a few general guidelines for pavement rehabilitation strategies and possible constraints are presented.*	A little #14	*Some of the guidelines and constraints in 611.9 provided some assistance in* developing this Guide.
Michigan Dept. Of Transportation (MDOT). Highway Preventive Maintenance Program, Guidelines, presumed as 1998. *This guide is a simplistic, easy to understand document, limited to preventive maintenance as defined by MDOT.* *Very little of the detail desired by CDOT is included.*	21	*It includes seven asphalt pavement treatment strategies, three of which are described in this Guide. Approximately 1-1/2 pages of text describes each, its purpose, limitations, expected life, cost, etc. The three flexible pavement strategies are: Non-structural HBP overlay (1-1/2"), Surface milling and 1-1/2" of overlay, and micro-surfacing. The described details of each of the three were compared to similar ones in this Guide, and influenced it in minor ways. In addition to the asphalt treatment strategies, seven are listed for rigid pavements.*	Very little #15	*See the column second at left.*
Michigan Dept. Of Transportation (MDOT). Savings From Preventive Maintenance (no date, estimated as 1997). *This is a 5-page report by L. Galehouse, MDOT, that documents the significant savings experienced over a 5-year period by largely following the outlined policies.*	5	*The report had no direct influence on this Guide. It does, however, confirm similar findings to those of others, e.g., one dollar spent on preventive maintenance (early in the pavement life cycle) will return as much as 11 dollars spent for rehabilitation and reconstruction where the pavement is nearing the* ***end*** *of its service life, or a cost advantage of eleven to one.*	Very little #16	*See the column second at left.*

Table A-1

SUMMARY OF LITERATURE/PUBLICATIONS REVIEWED				
NAMES of PUBLICATION and SUMMARY OF CONTENTS	**Size, Pages**	**SUMMARY of RELEVANT PARTS or CHAPTERS**	**Degree of Influence**	**REFERENCES Parts Used or That Influenced This Guide**
Benefits of Pavement Maintenance - An Update. By Hicks, Jackson and Moulthrop. Presented at the Western Pavement Maintenance Forum, Jan. 1998 *This paper describes causes of pavement deterioration, preservation techniques, and the importance of timely maintenance on reducing costs to agencies and users.*	28	*The paper addresses techniques which can be used to better manage the investment in the current highway system. According to the authors, it was designed specifically for fiscal decision makers; hence the content was non technical. (Note: It was a meeting hand-out that accompanied an oral presentation with visual aides. Although interesting, it has little practical value to this project. CDOT already is in the process of adopting similar policies.)*	Very little #17	*See the column second at left.*
How to Select Pavement Rehab Strategies. By D. Morian and G. Cumberledge. Better Roads, June 98. *This article is a very abbreviated, non-technical statement about properly evaluating existing distressed pavements and selecting the correct rehabilitation strategies.*	2	*The article addresses concepts discussed in detail in the 1999 CDOT Pavement Design Manual. It has a feel-good tone, and there is nothing included that would be in conflict with CDOT policies. However, no guidelines are included for selecting the right rehabilitation strategies for any given distress, or as to how life spans of the various strategies compare.*	Very little #18	*See the column second at left.*
Pavement Rehabilitation Manual, Vol I: Pavement Evaluation Manual. Materials Bureau, N Y State Dept of Transportation, Rev. 1992. *This Volume contains uniform procedures for determining the condition of pavement and shoulders. It includes standard forms and examples for collecting the data. This manual is complimented by Vol. II described above.*	*70, incl. Appe-ndices*	*Part 1, of the NY two-volume set, it presents information for identifying, collecting and reporting pavement distresses. Its function is similar to that of the LTPP Distress Identification Manual (described above). If we didn't have the latter, it would be particularly valuable to CDOT. However, the LTPP manual is more recent, the photos are in color and it being nationally recognized, is more appropriate for CDOT use. This is especially so, since we did not directly adopt Vol. II, but instead used its concepts to assist in developing this Guide. Some of the forms and reporting formats could be valuable references for CDOT personnel at the Region level.*	*Very little* *#19*	*See the column second at left.*

Table A-1

SUMMARY OF LITERATURE/PUBLICATIONS REVIEWED				
NAMES of PUBLICATION and SUMMARY OF CONTENTS	**Size-Pages**	**SUMMARY of RELEVANT PARTS or CHAPTERS**	**Degree of Influence -**	**REFERENCES Parts Used or That Influenced This Guide**
Pavement Policy Manual. Pennsylvania Department of Transportation. 1996. *This manual establishes PennDOT's policies, guidelines, and procedures for the maintenance, construction, restoration, rehabilitation, resurfacing, and reconstruction of pavement structures.*	About 100	*This manual does not addresses specific pavement distresses and the selection of rehabilitation strategies. According to Section 1.2, PennDOT uses a pavement management program called STAMPP to survey their highway system, collect distress tabulations and recommend treatment strategies. The design personnel apparently begin with this information. Any changes must be documented, but no guidelines for treatments of specific distresses are included.*	None #20	*See the column second at left.*
Flexible Structural Design and Rehabilitation. Nevada Department of Transportation, Jan. 1996. This is Chap. Six of NDOT's Design Manual. It is very abbreviated in comparison to CDOT"s version, described above.	22	*Only some very general statements about rehabilitation are included, with little technical data or guidelines included. The designer is pretty well left to follow his own judgment in designing and selecting rehabilitation strategies for distressed pavements. The entire Chapter is 22 pages long, and the section on rehabilitation of asphalt pavements is one page in length.*	None #21	*See the column second at left.*

Table A-2

SUMMARY OF QUESTIONNAIRE, PART I: INTERVIEWS

Rehabilitation Strategy (The projects reported here are not necessarily representative for CDOT)	Brief Description of Rehab. Strategy, Year Constructed (Note: Bold outline indicates projects used in PMS study, Appendix B)	Subsidiary Treatment or Wearing Surface	Design Yrs and ESALs	(Est) OPI & Condition Description	Predominant Distress When Treated	Rural or Urban	Constraints, Problems, Precautions, Warnings, Comments	Performance To-Date
Wearing Surfaces with Subsidiary Strategy as Indicated (See Appn. B for PMS study on projects outlined in BOLD)								
Thick Overlay (>4 to 6") Two CDOT projects Two people interviewed	(1) In Region 6. HBP Grade "C" over 8" PCCP, leveling + two 2" courses. Done in 1988.	Normal pre-treatment	10 yrs, 2 to 4 million ESALs	Est. at 65, fair.	Rutted from wear, faulted PCCP	Urban	Existing soil support & moisture needed for all overlay strategies. Should locate & use as-built soil profile	Very good, some reflection cracks, not a maintenance problem
	(2) In Reg. 6, 2.5 mile overlay of 4.25" with HBP Grad. C on portions of US 285, E & W of C 340. Existing 5+" over 11"base. Done in 1994..	Milled 0.7", placed paving fabric.	10 yrs, 1.34 million ESALs.	OPI = 60, good to fair condition.	Low to Med severity non-load cracking, low rutting.	Rural	No problems on construction. The Grading C designed by Texas Gyratory is not performing as well as would be expected of SP	Good in uphill lanes, 5 yrs RSL. Fair in down hill lanes, 2 yrs RSL.
Medium Overlay (>2 to 4")? One CDOT project One person interviewed (Many medium overlays are routinely done in all Regions, this project was selective.)	(1) 3" SuperPave Grading S on existing 12" AC. Prev. OL 11 & 13 yrs old. Located on I 25 in Reg 6, 120th Ave - SH 7, done in 1997.	Cold milled aver of 0.5" in driving lanes	10 yrs. ESALs = 7.8 million	OPI 57, 1.5 yrs RSL. Crack Index 54.. By PMS, LALC Indx = 77, Trnsv = 0	Per Reg, Low LALC, 70% extent/ SC = 0.30. With Crk Indx of 54, maybe 0.20?	Urban	Well designed SP mix, treatment and/or OL thickness not adequate to prevent severe reflective cracks . OL needed was maybe 6" with 3" mill?	In '99, 10 yrs RSL for ride, only 3 yrs RSL by LALC! Poor Performance!
Thin Overlay (≤2") One CDOT project One person interviewed	HBP Grade "CX", over AC, 1.0 to 1.5 " overlay on 35-miles of 2-lane, in 1992 on US 666 NW of Cortez.	Minimal pre-treatment	4--6 yrs, 200 to 400 thousand	Est @ 50-60, fair to poor.	Fatigue with misc. cracking.	Rural	Today, project would be classed as machine patching or a maintenance overlay	Per Region, equal or better than predicted.

Table A-2

SUMMARY OF QUESTIONNAIRE, PART I: INTERVIEWS

Rehabilitation Strategy (The projects reported here are not necessarily representative for CDOT)	Brief Description of Rehab. Strategy, Year Constructed (Note: Bold outline indicates projects used in PMS study, Appendix B)	Subsidiary Treatment or Wearing Surface	Design Yrs and ESALs	(Est) OPI & Condition Description	Predominant Distress When Treated	Rural or Urban	Constraints, Problems, Precautions, Warnings, Comments	Performance To-Date
Stone Matrix Asphalt (SMA) Two CDOT projects Three people interviewed	(1) Reg 4 Demo Proj, 2" SMA (3 different mix designs) used on several sections over 2-2.5 " Grade "C" HBP on SH 119, Longmont - Boulder, in 1994; 11,000 tonnes placed.	Minimal preparation prior to lower lift placement .	10 yrs, 807,000 ESALs	Est. @ 60, fair to poor. Est 2 yrs remaining life.	60% load associated cracking; some transv. cracking.	Mostly rural	At first, difficult to achieve compaction; with mix adjustments and roller pattern changes it was OK, minor drain-down of bitumen.	In '98 no significant rutting any sections, low cracking; good performance
	(2) In Reg 3, Gypsum-Eagle on I 25, 8 mi of 4-lane. Exist sect 2 ft SB, 4" ABC, 5" AC & 0.75" PMSC. Top 1" milled off and 1.5' of SMA placed. It was 3/8" nom size, 3% limestone filler with PG 76-28. Done in 1996.	Only prep was the cold milling to remove Plant Mix Seal and level the surface.	10 yrs, 4 million ESALs	1995 OPI was 55, 1 yr RSL, fair to poor condition	Wear ruts in PMSC. Med to high block cracking, cracking index = 37. No structural distress.	Rural	Some compaction problems (see above notes). WB lanes lean on asphalt with higher voids, EB lanes better. Surface very smooth. SMA surf may be more cost effective than SP.	WB lanes expected to meet design life, EB lanes expected to exceed deign life.
Micro-Surfacing Two people interviewed	(1) Reg 1 placed treatment on driving lanes only (+ 1 ft onto shoulder) in 1998 on I 70 in Eastern Colo. Selected because reconstruction scheduled within 5 years	Minimal pre-treatment	Est. @ 5-10 yrs. ESALs not used for design. Est. 10-yr @ 5 million±	OPI was 76. Est 3 yrs RSL.	Low longitudinal. & transverse cracking.	Rural	Generally no problems. One day emulsion setting was faulty. Applied material removed & replaced. Treat medium & severe cracks before applying micro- surfacing.	Performing as expected.
Grind/Micro-Mill Two CDOT projects Two people interviewed	(1) In 1996, micro-milled 1.5" to remove ruts in 12 yr old 5.5" overlay of 5-mile section of PCCP on I 25, S of SH 119 in Reg 4.	NA	Est RSL was 0 yrs. Est 10-yr ESALs , 8 million.	OPI 66 Rut Index = 49. Condition poor	Rutting, 0.75 to 1.0 inches in depth.	Rural	OL age now 16 yrs old. N of SH 119 . 3-mi section is fair. South, new ruts are 0.5". Can be milled again.	Milled section performing as expected
	(2) Reg 1 Micro-milled to remove a 3/4" PMSC in 1990 .	No subsidiary treatment	No design yrs, preventive maint.	OPI 80+/-	Shoving of PMSC, some stripping in AC	Rural	Only 1-yr old. Done to prevent futher stripping of the underlying AC.	Performing as expected.
	(3) Reg 1 Diamond Ground project in 1989 to remove faulting on PCCP.	No subsidiary treatment	Est 5-10 yr life. EASLs not used, a maint. proj.	OPI = 70+/-	Mod to severe faulting.	Rurasl	No problems encountered	Performing better than expected.

Table A-2

SUMMARY OF QUESTIONNAIRE, PART I: INTERVIEWS

Rehabilitation Strategy (The projects reported here are not necessarily representative for CDOT)	Brief Description of Rehab. Strategy, Year Constructed (Note: Bold outline indicates projects used in PMS study, Appendix B)	Subsidiary Treatment or Wearing Surface	Design Yrs and ESALs	(Est) OPI & Condition Description	Predominant Distress When Treated	Rural or Urban	Constraints, Problems, Precautions, Warnings, Comments	Performance To-Date
Subsidiary Strategies with Wearing Surface as Indicated								
Cold Mill (Aver. 1" rural, usually more in Urban areas with grade control constraints) One general One person interviewed	(1) Reg 6 uses strategy (mill/fill) frequently . Typical, mill 1.5" & fill 2.0". Mill & fill depths depend on existing soil modulus and effective SN by FWD.	Super-Pave Grading S or SMA overlay.	Usually 10-yr design. ESALS vary from 500,000 to several million	OPI is typically 50-65, in fair to poor condition.	Non-load & load associated cracking, & rutting.	Urban, no C & G	Used where surface elevation must be maintained and there is severe distress. Judgement supplements structural design by formula.	Past performance has been as predicted. SP use is slowing OPI reduction.
Hot-in-Place Recycle (Heater Scarify) Four CDOT projects Note: 3 & 4 combined bid. Three people interviewed (This strategy has been used on many projects in most of the Regions, interviews were selective)	(1) Reg 6, Denver Metro, on W. 6th Ave, from Approx. Union. To Colfax. Heater Scarified 1" followed by overlay. Some sections were milled to below rut bottoms and overlaid without heater scarifying. Done in 1996. Moderate climate.	Existing was 6-8" HBP over 16-20" ABC. Overlay on HS was 2" of HBP Grading C.	10-yr design, 2.5 million ESALs	OPI = 60. RSL =1.6 Fair to poor condition.	Cracking index was 38, rut index 30; ruts 0.5".	Urban	Reconstruction not considered because of lack of funds. No constrains due to grade control, gutter matching, or otherwise. Reg 6 was unfamiliar with process, it went well, however.	After 3 yrs, by PMS, OPI is 90 and projected RSL is 15+. Trnsv Crack Index = 56
	(3) Reg 1, I 70, El Rancho-Morrison Exit. Existing was 8" HBP on 4" ABC. Heater Scarified 1" followed by overlay. Done in 1999. Cool dry climate.	Overlay 2" SuperPave Grading S/ AC-20R	10-yr design, 5.5 million ESALs	OPI was 73, RSL 2 yrs, fair condition.	Med to high long. cracks in WP, ruts in center ln, low transv. cracking.	Rural	Heater scarify chosen to help seal cracks. 2" overlaid as design minimum. Section only slightly structurally deficient. A few minor construction problems, no constraints..	Performing as expected, too early to plot trends. To perform well, new cracks must be sealed regularly.
	(4) Reg 1, US 6, I 70 to Golden. Existing was 3.5" HBP on 4" ABC. Heater Scarified 1" followed by overlay. Done in 1999. Cool dry climate.	Overlay 2" SuperPave Grading S/ AC-20R	10-yr design, 2.2 million ESALs	OPI was 66, RSL 0 yrs, fair condition.	Medium longitudinal, block, & transverse cracks , med. raveling & some allig. cracking	Rural	Heater scarify chosen to help seal cracks. 2" overlaid as design minimum. Section only slightly structurally deficient. A few minor construction problems, no constraints..	Performing as expected. To perform well, new cracks must be sealed regularly.

Table A-2

SUMMARY OF QUESTIONNAIRE, PART I: INTERVIEWS

Rehabilitation Strategy (The projects reported here are not necessarily representative for CDOT)	Brief Description of Rehab. Strategy, Year Constructed (Note: Bold outline indicates projects used in PMS study, Appendix B)	Subsidiary Treatment or Wearing Surface	Design Yrs and ESALs	(Est) OPI & Condition Description	Predominant Distress When Treated	Rural or Urban	Constraints, Problems, Precautions, Warnings, Comments	Performance To-Date
Hot-in-Place Recycle (Heater Re-Mix) Two CDOT projects Two people interviewed	(1) In Reg 2, US 50 W of Mc Culloch. Hot climate. WB lane only, 9.4 mi. Exist 8"AC over 8" ABC. Top 2" Heater-Remixed /50 lb/ SY of Grad'g "S" SP (58-28), 1999.	Two 2" OL lifts with Grading "S" SP (64-22).	20-yrs. 2.8 million ESALS.	OPI = 74. Condition fair.	80-100% Med severe non-load assoc. cracking, low alligator crks.	Rural, prin artery	Selected to eliminate reflective cracking.	Performing as expected
	(2) In Reg 5, Del Norte-Center Jct. Heater Re-Mixed 2", including addition of 5-10% Grading CX and small % of rejuvinating agent. Done in 1996.	Existing pave. 2-3" HBP over 6"ABC. Re-mix topped with 2"HBP Grading CX	10-yrs. ESALS are 445,000	Est. OPI = 60. Condition fair to poor.	Med to high transverse cracks, med. alligator & block cracking	Rural	Selected to eliminate reflective cracking. Maintenance forces corrected several base failures in advance. Judged best strategy for available funds.	Performing better than expected. By all PMS indexes, YFL =15+.
Hot-in-Place Recycle (Heater Re-Pave) Two CDOT projects Two people interviewed	(1) On SH 119 in Reg 4. Approx. 1" heater- scarified then overlaid with 0.5-0.75" of Grading EX in one operation followed later with a 1.75-2.25" overlay of Grading C. Done in 1995.	Overlaid with Grading C per column at left.	10-yrs, est. ESALS of 800,000	OPI = 30 RSL = -1.6. Trnsv Crack index = -5.0. Poor condition	Alligator cracking, high severity.	Urban	Traffic handling was considered potential problem, didn't affect decision. No problems or constraints. Very smooth, won award.	Performing as expected. YFL by OPI = 15+. YFL by Trnsv Crack = 9.8
	(2) On SH 45, I 25 to Ark. River in Reg 2. Exist 4" AC (over 8"ABC) was heater-scarified 1" and overlaid with 1.5" SP (64-22) in single pass in summer of 1999.	Surface is SuperPave C & G section, milled at gutter.	10 yrs, ESALs of 519,000	OPI = 74. Condition fair to poor.	Alligator cracks, 100% M-H severity other cracks 60%, M to H	Very Urban, prin. artery/ C&G	Traffic a problem, but doing work in one pass caused less traffic delay. Reconstruction not considered.	New, expected to have more than design life with programed maintenance.

Table A-2

SUMMARY OF QUESTIONNAIRE, PART I: INTERVIEWS

Rehabilitation Strategy (The projects reported here are not necessarily representative for CDOT)	Brief Description of Rehab. Strategy, Year Constructed (Note: Bold outline indicates projects used in PMS study, Appendix B)	Subaidiary Treatment or Wearing Surface	Design Yrs and ESALs	(Est) OPI & Condition Description	Predominant Distress When Treated	Rural or Urban	Constraints, Problems, Precautions, Warnings, Comments	Performance To-Date
Cold-in-Place Recycle Three CDOT and one NM project.	(1)In Reg 2, I 25, Ludlow - North, 12.6 mi of N-Bound only. Existing was 8" AC over 12" agg. Top 4" was cold recycled. Finished in 1999.	Overlaid with 4" of Grading S (AC-20R)	20 yrs. 5 million ESALs.	OPI = 76 Condition fair	Alligator cracking in the driving lanes, slight rutting	Rural. Cold recyc. Easier on rural project	Surface drainage improved, reconstruction not considered, budget restrictions. Previous adjacent projects successful. Had difficulty **ouring & compacting recycle.**	Not as expected. Long. cracks developing in WP, with slight rutting. Base needed Mr of 100,000
This strategy has been used on many projects in all Regions, except 6; not practical for highly urbanized locations. Interviews were selective, not necessarily representative of the state-of-the-art in CDOT	(2) In Reg 1, on SH 71 N & S of Limon in 1999. Existing: 5" Grading F over 6" Cl 7 ABC. Top 4" cold recycled using HFMS-2PS. Dry, cold climate.	Overlay, 2" Grading S (58-22) & topped with 2" Grading S (64-28)	10-yr, 500,000 ESALs	OPI = 69, 0 yrs RSL, Condition was poor	High severity cracking, load & non-load + roughness.	Rural	Selected to prevent reflective cracking. Reconstruction not considered. No traffic control problems. No significant construction problems, done in warm weather.	Performing as expected.
	(3) On I 25, South NM, cold milled 2" to remove extensive crack sealant; cold recycled 4"using HFE-150P and hot-lime slurry in 1997. Climate dry, no freeze.	Overlay: 2.5" SP (64-20); then 1.5" SMA (70-22).	10-yr design. ESALs are 3.3 million.	OPI of 60±. Condition fair to poor, 10" existing asph pave.	Extens, med. severity non-load cracks, med severity rutting.	Rural	Selected because it was most cost-effective. NM has extensive experience. See sub-note (5) for constraints and comments.	Performing well. Based on past experience, expected to = design life.
	(4) Cold recycling has been used on several projects in Region 5, including two south of Cortez.	With 3-4" HBP overlays., moving to SP bitumen	Designed for 20 yrs, ESALs are med to low.	Est. OPI usually close to 50 with surface poor condition.	Predominant distresses are cracking, (1)fatigue & (2) non-load.	Mostly rural	Biggest constraints curing moisture from mix & rain. Don't use in mountains. LCCAs shows it is cost-effective	Performing well with no reflective cracks
Fabric Interlayer One project, one general Two people interviewed	(1) In 1981, an experimental placement of 6 different fabrics was done on a project in Reg 6, SH 83, Iliff to Miss. Ave. The existing pavement was widened, the cracked old surface had various fabrics placed, then overlaid. Evaluated for 4 years.	First a leveling course, then fabric, then a 2' lift of HBP Grading E.	Design was 20-yr. ESALs not available, est. at 1.5 million±.	OPI not used at time; from descriptions, is estimated at 75. Fair condition.	Medium to high block, longitudinal & transverse cracking	Urban, no C & G	Several of the fabrics used are no longer available. Currently available fabrics easily placed. Not good for wide active transverse cracks or where there is extreme braking or acceleration.	Four fabrics slowed crack reflection compared to control. Cost could be recovered by 1-2 yrs added YFL.
	(2) Reg. 6 sometimes places fabric interlayer over severe load-associated cracks after milling. Not used to control block or transverse cracks.	Overlay per structure analysis, HBP or SMA.	Usually 10-yr design, fabric contributes 2-3 yrs life.	OPI is normally low, 50-60 where fabric is used.	Load associated cracking.	Urban	Must make final evaluation after milling and cleaning existing pavement	Experience shows this application can be cost effective.

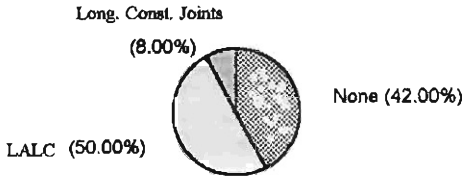
SUMMARY of QUESTIONNAIRE, PART II GENERAL

1. Listed below are the current distresses collected by the CDOT Pavement Management System for asphalt pavement:

a. Longitudinal cracking	d. Transverse cracking	g. Raveling
b. Alligator (Fatigue)	e. Rutting	h. % Patching
c. Block cracking	f. Bleeding	i. % Edge cracking

1A. Are there any additional distresses (such as longitudinal cracking in the wheel paths, reflection cracking at joints or roughness) that you collect, or believe ought to be collected, or used at the project level for design purposes? _____ If yes, please list them.

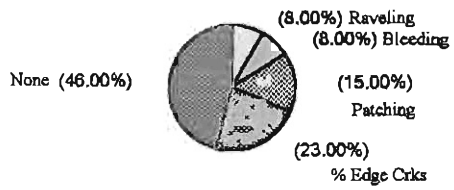
Distresses Needed at Proj. Level



Twelve people answered this question. Essentially, only load associated longitudinal cracking is believed necessary in addition to the PMS list above. (Note that LALC is now collected).

1B. Are there any of the above list you believe that are unnecessary at the project level? _____ If yes, please list them.

Distresses Not Needed at Project Level



Thirteen people answered this question. Six thought no change is needed. Two thought patching is unnecessary (one noted that patching itself is not a pavement distress). Three thought edge cracks did not need tabulating, and one each thought that raveling and bleeding did not need tabulating.

---

2. In your opinion, regardless of the predominant distress, are there certain rehabilitation strategies that are impractical to use because of environment (weather), traffic or other constraints. _____ If yes, please list them and the constraints.

Impractical strategies listed were: Chip seals in urban areas, cold milling into a fabric layer, micro-surfacing to fill plastic ruts, cold recycling (long list of constraints submitted by Regions 1, 5 & NM, but they all frequently use it; this points out need to thoroughly pre-evaluate its use), Regions 2 & 5 pointed out problems with hot-in-place recycling. A Roadway Design engineer suggested more investigation into HIPR is needed before accepting it as standard procedure, and that HIPR and CIPR should not be used on high volume roads. (See section, "Candidate Rehabilitation Strategies: Conditions for Use, Advantages, and Constraints." in this Guide which incorporates most constraints cited).

3. Please list the distresses most common in your areas of responsibility, and the respective rehabilitation strategies most often used for each. **(See summary below)**

Reg. 1	High cracking: 2" OL or CIPR/2" OL	Reg. 5	High Transverse Cracks: HIPR/2' OL, or CIPR/2 to 3" OL
Reg. 2	Mod. Crks: HIPR, High Crks: CIPR/OL Alligator Crks & Ruts: Mill	Reg. 6	Cracking general: Mill and fill.
Reg. 3	Trnsv Crks: Plain OL, Plastic Ruts: Mill	New Mex.	Cracking: CIPR/OL or HIPR/2" OL, Plastic Ruts: Mill/OL, Roughness: Level/Patch/OL
Reg. 4	High Transverse Cracks: CIPR, Ruts: Lrvel/OL, mill or fill		

4. Please list the most challenging, or difficult to correct, distresses within your experience. Considering your answers to No. 2, above, describe what you believe would be the most cost effective strategy for treating each. **(See summary below)**

Transverse cracks ---	8 responses	Cracking (general) --------	2 responses (Urban)
Longitudinal cracks ---	2 responses	Thermal crks, plastic ruts --	New Mexico

Region 1 noted that fabrics are not effective against transverse (thermal) cracks and that dollars and severity of distress are usually deciding factors in strategy selected. Another respondent noted that patching severely distressed areas should be a part of all strategies and that crack sealing just before overlaying can cause problems on thin overlays.

---

5. Note any concerns or general comments you may have.

Comments are listed below in order received:

- **Traffic volume (ESALS) more of a factor than most people realize.**
- **In urban rehabilitation, needing the overlay to match (about 1/2" above) gutter pans is one of biggest challenges (and still get the structural strength required).**
- **For distresses related to subgrade failures, having maintenance forces do corrective work in advance is most-cost effective.**
- **More than one respondent mentioned several of the following about hot-in-place recycling: Watch out for excessive crack sealant. Don't crack seal within a year prior to contract. Be sure you have enough voids in the recycled mixture to allow for addition of additives. Watch for extensive and variable patching and spot overlays ... may need to cold mill the surface, or use another strategy. Don't do in cold or rainy weather. Can't use in environmentally sensitive areas (such as Vail).**
- **Many respondents mentioned concerns and constraints related to cold-in-place recycling. These have mostly been incorporated into the "Candidate Rehabilitation Strategies: Conditions for Use, Advantages, and Constraints." part of the Guide.**

GUIDELINES FOR SELECTION OF REHABILITATION STRATEGIES for ASPHALT PAVEMENT

APPENDIX B

Study: Years Functional Life for Rehabilitated Asphalt Pavement, Based on Pavement Management System Condition Data as Related to Existing Distress and Treatment Strategy

Contents

Tables

Figures

APPENDIX B

Years of Functional Life for Rehabilitated Asphalt Pavement, Based on Pavement Management System Condition Data as Related to Existing Distress and Treatment Strategy (PMS Functional Life Study)

Background

In the fall of 1999, a study for CDOT, "Guidelines for Selection of Strategies for Rehabilitation of Asphalt Pavements" was initiated. The principal researcher (PR) contracted to develop a guide manual. At a meeting of the Study Panel in February 2000, the PR presented and discussed a partially completed, preliminary draft of the Guide.

The PR presented decision tables for estimating years of life for various rehabilitation strategies. They were developed by extending the CDOT flexible pavement design procedures. This premise was not what the panel had in mind. They wanted an entirely independent method of estimating the functional lives of the various rehabilitation strategies when applied to pavements, specific to the existing distress categories, degree and extent. This required additional research.

PMS FUNCTIONAL LIFE STUDY

In order to develop some data on which to base such a decision table, CDOT made available to the PR their network PMS condition data for the years, 1991-1999. This included a computer program that calculates average condition indexes for any selected mile-length on the State Highway System for any given year. Each direction, of a milage representation for a given year, is calculated separately.

The study being reported herein is a satellite study to the primary study as described in the Guide and Appendix A. Two sources of rehabilitated pavement data were used to accumulate the rehabilitation part of the data. They are (1), from nine Interstate projects overlaid in 1994 and (2), from nine of the interview projects listed in Table A-2.

NINE I-25 PROJECTS

The first source is from a report by Tim Aschenbrener[3] on nine contracts for overlaying sections of I-25 in 1994. The report purpose was to provide HMA and rehabilitation information on the projects for correlation to long-term performance five to 15 years in the future. The location ranged from MP 0.0 at the New Mexico border to MP 235 north of Denver. The PR broke these into 12 sections and the PMS condition data were calculated for the years prior to and after construction. Two sections were 20-year designs; the rest were 10-year designs. The 12 sections are represented by Tables 1 and 2 which summarize data from 48 graphs. Figures B-1 through B-4, for Series E of this group, are typical for the graphs, although not all plot this precisely. The graphs for all series are on file at the CDOT Research offices, as are the Excel computer files for all the data and graphs.

The preconstruction 1991-1993 PMS indexes, and post construction 1995-1999 indexes for the sections were calculated using the CDOT 1991-1999 Condition Data and their Index Calculator computer program. From the calculated indexes for the 12 sections, graphs were plotted to determine remaining service lives (RSL) and average condition indexes as of 1993 and years functional life YFL and average indexes as of 1999. The average indexes are from the *plotted* trend lines, and not the calculated averages.

Table B-1 summarizes the pre- and post-construction condition indexes from plotted data. Mean slope values for each project are tabulated for Crack Index and OPI, then averaged as shown. Mean Slope is the mean deterioration slope, e.g., reduction in index points per year at, or near the time the trend line crosses the 50 threshold value. Based on typical deterioration curves (for this study) of preconstruction distresses, we can be sure that any nearly flat curves for post-construction distresses will not continue to be so. Sooner, or later they will turn downward and probably cross the 50 threshold line with slopes similar to the mean deterioration slopes.

Table B-2 summarizes the pre- and post-construction cracking distress indexes. Series A and D, designed for 20-year ESALs are not averaged with the other 10, but are tabulated and averaged separately. Note that an RSL of 10 was used as the maximum value for pre-construction where deterioration curves were nearly flat. A YFL of 15 was the maximum value used for post-construction. These values were used to calculate averages.

Preconstruction Evaluation

The preconstruction averages for projects with 20-year designs are not especially different from those with 10-year designs; the averages for all are used in the following discussion. For Condition Indexes, in every series, the Crack Index was equal to or lower than either Ride or Rut. The average Index/RSL of the three distresses are in this order, lowest to highest: **Crack 30/-1.2, Ride 58/1 and Rut 76/6.6, with the OPI at 61/2.0.** Figure B-9 depicts the relative RSLs. OPI is a calculated index representing a composite of the other three. Typically, CDOT projects seem to be rehabilitated when they have RSLs of between 1.0 and 4.0 by OPI and less than 0.0 by Cracking Index.

Because cracking was the predominant distress from the Condition Indexes, the individual cracking categories were analyzed to determine which types of cracking were the most frequent and severe. To find the predominant preconstruction cracking distress, go to Table B-2. Transverse cracking was predominant, except in two series where block cracking just barely predominant. In every section, Transverse RSL was less than zero. The average cracking category Index/RSLs are in this order, lowest index to highest: **Transverse 7/-2.2, Longitudinal 62/5.1, Block 66/4.9, LALC 71/4.6 and Alligator 78/5.3.** Figure B-10 shows the relative RSLs. By far, transverse cracking was the predominant cracking distress, with an average RSL of -2.2. Each of the other four distresses are close to their average RSL of 5.0.

Post-construction Evaluation, 10-Year Design

For post-construction **Condition Indexes**, in every section , the Crack Index was equal to or lower than either Ride or Rut. The average Index/YFLs are in this order, lowest to highest: **Crack 70/8.0, Ride 84/14.2 and Rut 93/15.0, with the OPI at 85/14.3.** See Figure B-9 for YFL plots. For all values, except Crack, the average numbers are not especially significant because of the maximum value of 15 used for nearly flat trend curves.

Again, since cracking was the only critical index, the individual cracking categories were analyzed to determine which types of cracking were the most frequent and severe. To find the predominant post-construction cracking distress, go to Table B-2. In all but two sections transverse cracking was predominant. In those two, Longitudinal cracking was predominant, but not by much. The average cracking category Index/YFLs are in this order, lowest index to highest: **Transverse 60/6.2, Longitudinal 75/9.7, LALC 78/10.5, Alligator 97/15.0, and Block 100/15.0.** See Figure B-10 for

YFL plots. The order of cracking distresses are essentially the same as for preconstruction, except that block cracking has moved into last place.

At the one-half design life point, the predicted average YFL by OPI for the 10 sections is 14.3 (greater, actually, because YFLs were cut off at 15). Only two sections are less than 15 YFL (12.0 and 11.0). It appears that all will easily meet the 10-year design criteria if OPI is the measuring tool. However, the predicted average YFL by the Cracking Index is 8.0 and by Transverse cracking it is 6.2. Sections B and K have low LALC indexes/YFLs, averaging 56/5.8. At this time, it is predicted that due to severe cracking distress, four or more of the 10-year DL series will need some type of rehabilitation before they reach age 10.

Pre- and Post-construction Evaluation, 20-Year Design

The average preconstruction condition and cracking indexes for the two 20-year designs are not significantly different from those for the 10-year designs. See the discussion above for 10-year designs.

The two post-construction 20-year designs deserve to be looked at separately. Series A had a minimum of 2 inches of milling plus an overlay thickness ranging in thickness from 4.0 to 6.5 inches. Presumably, severely distressed areas received special attention in order to bring the entire project up to 20-year design standards. All three condition indexes show YFLs of 20+, so of course, the YFL by OPI is 20+. Transverse cracking is the only significant post-construction cracking distress. It has a YFL of 12.5. Based on PMS data, this project should easily exceed the 8.6 average reported by Goldbaum [2] and maybe make 12 to 15 years before it needs **more** than routine maintenance.

Series D consisted of 4-inches CIP recycling with a 2-inch modified AC overlay. The Ride and Rut Indexes show 20+ YFL. The Crack Index/YFL is 76/9.0. This is not bad if for 10-year, but maybe low for expected 20-year performance. Table B-2 shows that the predominant cracking distresses are Longitudinal, Transverse and LALC, with RSLs of 7.2, 8.7 and 6.0, respectively. The support value (strength) of the CIP recycled material may not be adequate. Although the project appears to be performing well by 1999 PMS data, the projected LALC deterioration curve indicates that early major maintenance may be required.

NINE PROJECTS FROM ORIGINAL REHABILITATION STUDY

The second source of data is from the original Guide Study Plan. Appendix A, Table A-2 is a summary of 27 projects which are characterized from interviews with involved engineers, mostly from CDOT. The summary provides detailed information on their design and rehabilitation strategy, their construction, and subjective performance. An evaluation showed that nine of these were relevant and had been constructed long enough to have one or more years of post-construction PMS data available. Under the project description column the selected project blocks are outlined in bold. These nine were used to develop data similar to that from the I-25 projects built in 1994. The nine projects are represented by Tables 3 and 4 which summarize data from 36 graphs. Figures B-5 through B-8 for Series 1 of this group are typical for the graphs, although not all plot this precisely. The graphs for all series are on file at the CDOT Research offices, as are the Excel computer files for all the data and graphs.

The preconstruction PMS indexes, using 1991 to the last year for which data was available before

construction, were calculated using the CDOT 1991-1999 Condition Data and the Index Calculator. The post-construction indexes were calculated using all available years' post-construction PMS data for the projects. From the calculated indexes for the 9 projects, graphs were plotted to estimate RSL and average indices at time of rehabilitation. The post-construction graphs were used to estimate YFL. The average Indexes are from the *plotted* trend curves, and not from calculated averages.

Table B-3 summarizes the pre- and post-construction plotted Condition Index data. Table B-4 summarizes the pre- and post-construction Cracking Distress Indexes. Series 5 and 6, which were micro-surfaced and micro-milled, respectively , were not averaged with the other seven post-construction projects. Note that an RSL of 10 was used as the maximum value for pre-construction where deterioration curves were nearly flat. A YFL of 15 was the maximum value used for post-construction. These values were used to calculate averages.

Pre-construction Evaluation

For pre-construction Condition Indexes, on five of the projects, the Crack Index was the predominant distress. For the other four, Rut was predominant. The average Index/RSL are in this order, lowest to highest: **Crack 46/-0.2, Rut 53/0.3 and Ride 62/1.3, with the OPI at 58/1.3.** See Figure B-9 for RSL plot. As noted for the I-25 projects, typically, CDOT projects seem to be rehabilitated when they have RSLs of between 1.0 and 4.0 by OPI and less than 0.0 by Cracking Index. One significant difference between these averages and the I-25 averages is that the average I-25 Rut RSL was 6.6 compared to 0.3.

As for the I-25 projects, the individual cracking categories were analyzed to determine which types of cracking were the most frequent and severe. To find the predominant preconstruction cracking distress, go to Table B-4. In every section transverse cracking was predominant and all Transverse RSL values were less than zero. The average cracking category Index/RSLs are in this order, lowest index to highest: **Transverse 19/-3.5, Longitudinal 72/5.5, Block 77/6.5, LALC 80/7.3 and Alligator 84/7.9.** See Figure B-10 for RSL plots. By far, transverse cracking was the predominant cracking distress and a little lower than on the I-25 projects. The other four distresses were a little less severe than they were on the I-25 projects. Of interest is that the order of severity is exactly the same as for I-25.

Post-construction Evaluation, Seven 10-Year Designs

For post-construction **Condition Indexes**, the Crack Index was equal to or lower than either Ride or Rut for five projects. Rut was the lowest on Series 1, while Series 8 had essentially flat trend lines for all distresses. The average Index/YFLs are in this order, lowest to highest: **Crack 82/10.7, Rut 88/13.8, and Ride 87/14.1 with the OPI at 85/14.4.** See Figure B-9 for YFL plots. These categories are in the same order of severity as the I-25 distresses, and about the same order of magnitude, except that Cracking YSL is 2.7 higher than the I-25 value.

The individual cracking categories were analyzed to determine which types of cracking were the most frequent and severe. To find the predominant post-construction cracking distress, go to Table B-4. In all but two sections transverse cracking was predominant. In those two, longitudinal cracking was predominant for one and LALC for the other, but not by much in either case. The average cracking category Index/YFLs are in this order, lowest index to highest: **Transverse 74/6.9, LALC 91/10.2, Longitudinal 90/11.3, Block 99/14.7, and Alligator 99/15.0.** See Figure B-10 for YFL plots.

Again, transverse is the lowest of the group. The order of the next three distresses is different from pre-construction, but alligator cracking is still the least severe.

The predicted average YFL by OPI for the seven sections is 14.4 (more, actually, because YFLs were cut off at 15). Only one project shows less than 15 YFL (10.5). It appears that all will easily meet the 10-year design criteria if OPI is the measuring tool. However, the predicted average YFL by the Cracking Index is 8.7 and by Transverse Cracking it is 6.9. Series 2 has a low LALC index/YFL of 3.0. At this time, it is predicted that due to cracking distress, at least three of the seven projects will need some type of rehabilitation before they reach age 10.

SUMMARY AND COMMENTS

Table 5 is a summary of the information obtained by evaluating the 21 sets of data found in Tables 1 through 4. The YFL years shown in Tables FL 1 and FL 2, Years Functional Life for National Highway System and Non-National Highway System State Highways were highly influenced by the data from these 21 projects.

For several series the Index Calculator program was unable to calculate indexes for the year 1995. There was some sort of incompatibility with the computer, the program or raw data. This may have affected the slopes or shapes of some of the post-construction deterioration curves.

The following comments, not necessarily in order of importance, summarize the study:

1. Except for the I-25 sections north and south of the EL Paso County line, the primary and secondary direction data for each condition index were averaged. In the case of the El Paso Co. line north and south series, where substantially different structural sections existed and different treatments were done, the two directions were analyzed separately. For all series, the two directions could have been averaged and analyzed separately, but that would have required more than the time allotted for this study. If they had been analyzed separately, it is not believed the trends of the deterioration curves, and the general conclusions, would have been substantially different.

2. The calculated indexes were highly variable from year to year and in many cases, appeared to be illogical. For example, take Series 7, Post-construction Condition Indexes. The 1999 indexes were all in the 90s, while three of indexes for the previous two years showed distinct downward trends (84, 80, and 63), and the other, Ride, showed a somewhat downward trend of 90. It is estimated that all four would have had YFLs between 10 and 3 if the 1999 points were not included, instead of 15+ as shown. Because of this variability, only general trends can be determined, some of these are probably incorrect.

3. With the tools (PMS computer programs) and limited number of projects, the 21 series analyzed barely scratched the surface. Not enough projects were studied to make these conclusions statistically representative of the entire State Highway System. It is recommended that a study similar to this be conducted on a much broader scale, with stratified random selections of highways and projects representing many conditions and rehabilitation treatment strategies.

4. On the I-25 projects, the preconstruction Cracking Condition Index was the lowest (least RSL) of the three distress indexes for every individual section, followed closely by ride. On the average,

rutting was the least problem. For the Rehabilitation Study projects, on preconstruction cracking was the lowest index on five of the projects and rutting on the other four.

5. For pre- and post-construction, the five crack categories' indexes were plotted and curves drawn in order to determine the primary sources of the cracking distress. On preconstruction for the I-25 sections (in all but two), transverse cracking had by far the lowest index (RSL) (see averages Table 2). And for the other two, block cracking was only slightly lower. On preconstruction for the Rehabilitation Study projects, in every case transverse cracking was the worst of the five, individually and average.

6. CDOT pavements are structurally designed to resist load-associated cracking and rutting. Interestingly, based on these 21 series, for preconstruction and rehabilitated post-construction, load associated cracking is not a significant problem, at least by PMS ratings. So CDOT designs are working. But the overlay design procedure does not prevent **non load-associated cracking**, particularly transverse, from recurring. Rutting was somewhat of a problem on the old surfaces, not much on the new. Ride seemed to be tied to transverse cracking on the old surfaces, but there is no correlation yet on the new surfaces.

7. On post-construction, the only significant problem area is the Cracking Index. The main contributor to that is transverse (15 sections), followed closely by longitudinal and LALC (three sections each). Block and alligator are not contributors.

8. Because of the high contribution of transverse cracking to the Cracking Index, (with apparent subsequent need for rehabilitation) these two categories are targeted as the headings for the first two columns in the YFL Tables FL 1 and 2. The designer (and Region) should look at these values first.

9. Without exception, (for the 17 10-year designs) all are predicted (as of 1999) to exceed a YFL of 10 by **OPI** plots. And the two 20-year designs will exceed 20 YFL by OPI. If there is concern about pavements not reaching their design lives, then the RSL by OPI (synonymous with YFL at time of construction), is not the correct Index for estimating functional life where **existing** transverse cracking is high.

10. Except for the first two columns, in Tables FL-1 and 2 the table YFL values are based on OPI indexes and plotted trends. These are believed to be realistic where the plotted RSL by Cracking Index or transverse cracks for the existing surface is not below 3.0. Even so, the designer or decision maker can to go with the YFL values by OPI if they choose. In most cases (where cracking is not severe), a YFL of 10 or more by OPI, will be reached by conventional design methods on the non-NHS. But this is not always the case for the NHS. Table FL-1 indicates additional treatment is required for many of the wearing surface-subsidiary treatment combinations if a YFL of 10 is desired, even by OPI plot.

Table B-1 PRE- & POST-CONSTRUCTION CONDITION INDEXES

PMS Data From 1991-99 on 9 Paving Projects (13 Sections) Constructed on I-25 in1994

				PRE-CONSTRUCTION							CONSTRUCTION & POST-CONSTRUCTION						
Series Ident.	File No.	LOCATION	B MP E MP	'94 Est.PMS Index/RSL Ride	Rut	Crack	OPI	Mean Slope* Crk In	OPI	Predom Crk RSL	Rehabilitation Treatment	Asph Type	'99 Est.PMS Index/Funct Life Ride	Rut	Crack	OPI	Predom Crk FL
A	00	New Mex Line - North	00.0	50	95	35	64			Trans	2" Grade "CX" Wearing Sur	AC-20R	84	97	95	90	Trans
		20-Yr ESALs 5.0 million	07.6	0.0	10.0	-1.5	1.5	-10.0	-9.3	-2.5	+ 2.0-4.5" Grd "C"+ 2" mill	AC-20	20.0	20.0	20.0	20.0	12.5
B	13	Tyrinidad Bypass	13.2	47	89	25	59			Block	2" Grade "C" Wearing Surf	AC-10	68	93	47	73	LALC
		10-Yr ESALs 1.3 million	15.6	-1.0	10.0	-1.0	3.0	-25.0	-3.0	-2.5	+4" Cold-in-place Recyc +	Emuls	10.0	15.0	4.5	12.0	6.5
C	58	Walsenburg - North	58.7	67	90	12	68			Trans	2" Grd "CX" Wearing Surf	AC-20P	92	96	64	90	Trans
		10-yr ESALs 2.4 million	65.9	3.0	10.0	-2.0	4.0	-19.0	-4.5	-2.3	+2" Heater Remix	AC-20?	15.0	15.0	6.0	15.0	5.0
D	70	Colo City Exit - N & S	70.0	48	77	26	48			Block	2" Grd "CX" Wear Surf +	AC-20P	86	98	76	88	Trans
		20-Yr ESALs 5.2 million	70.6	0.0	10.0	-1.5	0.0	-15.0	-6.5	-2.0	2" Grd "C", 4" Cold-IPR	AC-20	20.0	20.0	9.0	20.0	8.3
E	139	Woodman Rd - South	139.6	60	69	28	61			Trans	2" Grd "CX" Wear Surf +	AC-10	70	83	72	76	Trans
		10-Yr ESALs 6.5 million	148.0	1.0	2.0	-2.0	3.0	-11.0	-3.7	-2.0	1" Milling	NA	15.0	15.0	6.2	15.0	5.0
F	150	AF Acad. S Exit - North	150.4	68	48	46	62			Trans	2" Grd "CX" Wear Surf +	AC-20P	82	90	71	84	Trans
		10-yr ESALs 6.9 million	155.6	2.0	0.0	0.0	2.0	-9.0	-6.0	-2.0	1" Milling	NA	15.0	15.0	6.6	15.0	5.7
G	160N	NB, El Paso Co Line - S	159.9	56	50	15	52			Trans	2-1/2" Grd "C" Wear Surf +	AC-20P	89	96	82	90	Long
		10-Yr ESALs 6.3 million	163.4	1.5	0.0	-2.5	0.0	-14.0	-9.0	-2.3	2" Milling	NA	15.0	15.0	10.5	15.0	7.0
H	160S	SB, El Paso Co Line - S	159.9	63	88	15	60			Trans	2" + 2" Grd "C" Wear Surf	AC-20P	86	95	86	90	Trans
		10-Yr ESALs 6.3 million	163.4	1.5	10.0	-1.5	0.5	-21.9	-20.0	-2.3	4" Milling (*on exist PCCP*)	AC-20P	15.0	15.0	15.0	15.0	6.3
I	163N	NB, Monument Hill - N	163.4	35	64	15	50			Trans	2" Grade "C" Wearing Surf	AC-20P	89	98	83	89	Long
		10-Yr ESALs 6.3 million	167.4	-0.5	1.5	-2.0	0.0	-10.0	-10.0	-2.3	+ No other treatment	NA	15.0	15.0	10.5	15.0	7.0
J	163S	SB, Monument Hill - N	163.4	66	86	65	70			Trans	1" PMSC, Type "B"	AC-20P	94	97	83	93	Trans
		10-Yr ESALs 6.3 million	167.4	2.0	7.0	1.2	3.0	-12.5	-6.7	-2.4	(on exist *AC over PCCP*)	NA	15.0	15.0	10.6	15.0	4.0
K	216	US 36 - 84th Ave	216.6	66	80	20	66			Trans	2" Grd "C" Wear Surf +	AC-10	82	89	45	82	LALC
		10-Yr ESALs 9.6 million	218.7	1.5	9.0	-1.5	3.0	-20.0	-5.3	-1.8	1" Milling	NA	12.0	15.0	4.5	11.0	5.0
L	229	SH 7 - SH 52	229.1	66	78	50	70			Trans	2" Grd "C" Wear Surf +	AC-20	85	93	62	84	Trans
		10-Yr ESALs 5.8 million	235.1	3.6	10.0	0.0	3.6	-10.0	-2.2	-2.5	1" Milling	NA	15.0	15.0	6.0	15.0	6.0
		Averages, A & D		49	86	31	56				20-Year Design Averages		85	98	86	89	
		Averages, A & D		0.0	10.0	-1.8	0.8	-12.5	-7.9	-2.3	20-Year Design Averages		20.0	20.0	14.5	20.0	10.4
		Averages, all		58	76	30	61				10-Year Design Averages		84	93	70	85	
		Averages, all		1	6.6	-1.2	2.0	-14.8	-7.2	-2.2	10-Year Design Averages		14.2	15.0	8.0	14.3	5.9

Note: Where the value 10 appears for RSL in the pre-construction summary, it indicates the deterioration slope is so flat that an accurate estimate of the RSL is not practical, it is at least 10. This value used to calculate averages. In the post-construction summary, for very flat trend lines, the value 15 has been used for 10-yr designs and 20 for 20 yr designs.

* Mean Slope is mean deterioration slope, e.g., reduction in Index points/years at, or near the time the plot line crosses the 50 threshold value.

Note: Shaded columns represent predominant PMS distress (lowestRSL/FL).

Table B-2 PRE- & POST-CONSTRUCTION CRACKING INDEXES

PMS Data From 1991 - 99 on 9 Paving Projects (12 Sections) Constructed on I-25 in1994

		PRE-CONSTRUCTION					POST-CONSTRUCTION				
Series	File	'94 Est Cracking Index/Functional Life					'99 Est Cracking Index/Functional Life				
Ident.	No.	ALIG	BLCK	LONG	TRNS	LALC	ALIG	BLCK	LONG	TRNS	LALC
A	00	75	50	62	-5	95	100	100	100	82	95
		3.0	0.0	2.0	-2.5	10.0	20.0	20.0	20.0	12.5	20.0
B	13	80	-20	80	17	85	93	100	67	77	62
		10.0	-2.5	10.0	-2.0	10.0	15.0	15.0	7.0	7.0	6.5
C	58	77	67	55	0	75	100	100	60	20	76
		5.0	1.5	0.5	-2.3	3.5	15.0	15.0	5.3	4.0	6.2
D	70	66	0	62	44	56	98	100	83	77	80
		2.0	-2.0	3.0	-1.5	0.5	20.0	20.0	7.2	8.7	6.0
E	139	80	66	72	0	80	96	100	92	50	83
		7.0	1.6	6.0	-2.0	10.0	15.0	15.0	15.0	5.0	12.0
F	150	85	98	65	0	90	84	100	73	57	72
		8.0	10.0	2.0	-2.0	10.0	15.0	15.0	11.5	5.7	15.0
G	160N	85	90	66	13	50	100	100	66	75	88
		10.0	10.0	10.0	-2.3	0.0	15.0	15.0	7.0	9.0	14.0
H	160S	60	92	30	-10	81	100	100	72	62	100
		0.5	10.0	-1.5	-2.3	5.0	15.0	15.0	7.0	6.3	15.0
I	163N	85	92	66	12	50	100	100	36	76	88
		10.0	10.0	10.0	-2.3	0.0	15.0	15.0	7.0	9.5	12.0
J	163S	95	97	66	-5	50	100	100	77	57	93
		10.0	10.0	10.0	-2.4	0.0	15.0	15.0	7.5	4.0	15.0
K	216	75	20	70	20	62	98	99	92	68	50
		2.0	-1.5	7.0	-1.8	1.0	15.0	15.0	15.0	7.5	5.0
L	229	82	98	72	-10	90	96	100	80	60	69
		4.0	10.0	10.0	-2.5	10.0	15.0	15.0	15.0	4.0	4.7
20-Yr Dsgn Avg		71	25	62	20	76	99	100	92	80	88
20-Yr Dsgn Avg		2.5	-1.0	2.5	-2.0	5.3	20.0	20.0	13.6	10.6	13.0
10-Yr Dsgn Avg		80	70	64	4	71	97	100	75	60	78
10-Yr Dsgn Avg		6.7	5.9	6.4	-2.2	5.0	15.0	15.0	9.7	6.2	10.5
Average All		79	63	64	6	72					
Average All		6.0	4.8	5.8	-2.2	5.0					

Note: Shaded columns represent predominant PMS distress (lowest RSL/FL).

Table B-3 PRE- & POST-CONSTRUCTION CONDITION INDEXES

PMS Data From 1991- 99 on 9 Paving Projects in Rehab Study

			PRE-CONSTRUCTION							CONSTRUCTION & POST-CONSTRUCTION							
Series		B MP	At Constr. Est Index/RSL				Mean Slope*		Predom	When & Rehabilitation Type		Asph	'99 Est Index/Functional Life				Predom
No.	LOCATION	E MP	Ride	Rut	Crack	OPI	Crk In	OPI	Crk RSL	Year	Treatment Description	Type	Ride	Rut	Crack	OPI	Crk FL
1	SH 285, SH 8 - C 470, N	248.3	70	35	40	60			Trans	1994	2" Grade "C" Wearing Surf	AC-10	73	64	72	72	Trans
	10-Yr ESALs 1.34 million	250.0	2.4	0.5	-1.0	0.8	-10.0	-12.5	-1.8		2.25 Grd "C" + Fabric	AC-10	15.0	6.6	8.8	11.0	8.0
2	I 25, 120th Ave - SH 7	223.0	56	46	54	57			Trans	1997	3" Grd "S" SP Wearing Sur	PG76-28	90	96	57	90	LALC
	10-Yr ESALs 7.8 million	229.1	0.5	-1.0	1.5	1.5	-2.7	-4.7	-2.7		+ Aver. 0.5 Mill	NA	15.0	15.0	4	15.0	3.0
3	SH 119, Longmont - Bldr	49.0	67	57	25	57			Trans	1996	2" SMA Demo Wearng Surf	Multiple	88	92	77	88	Trans
	10-Yr ESALs 0.8 million	54.4	1.5	0.5	-2.7	0.6	-9.3	-11.7	-8.0		+ 2" - 2.5" Grad "C"	AC-10	15.0	15.0	12.5	15.0	4.0
4	I 70, Gypsum - Eagle	139.0	50	57	37	55			Trans	1996	1.5" SMA Wearing Surf +	PG76-28	86	88	87	90	Long
	10-yr ESALs 4.0 million	147.0	0.2	0.6	-1.5	0.8	-8.7	-8.3	-2.0		Aver 1" milling	NA	15.0	15.0	9.5	15.0	6.0
5	I 70, E Colo Near Bovina	372.0	68	65	83	76			Trans	1998	Micro-Surfacing driving	Emuls	85	100	82	90	Trans
	10-Yr ESALs + 4.0 millio	377.0	3.0	2.5	3.5	3.0	-9.4	-8.7	-1.5		lanes only + 1 ft on to shldr		3.5	15.0	9.5	5.5	2.5
6	I 25, SH 52 - SH 119	235.0	69	49	57	66			Trans	1996	Micro-milled 1.5" aver to	NA	88	73	65	76	Trns
	10-Yr ESALs 8.0 million	240.0	2.0	0.6	0.8	4.0	-8.8	-4.0	-0.5		remove ruts in 5"AC/PCC	NA	15.0	6.8	5.0	10.5	1.0
7	SH 6 in Denv, Union-Colfax	275.1	61.0	30.0	38	60.0			Trans	1996	2" Grade "S" Wearing Surf	AC-20R	88.0	83.0	92	91.0	Trans
	10-Yr ESALs 5.5 million	278.4	0.6	-2.0	-1.3	1.6	-9.2	-6.3	-4.4		1" Heater Scarify		15.0	15.0	15	15.0	4.0
8	SH 112, Del Norte- Cntr Jct	0.0	55	68	35	57			Trans	1996	2" Grd "CX" Wrng Surf + 2"	AC-10	39.0	98	98	96	Trans
	10-Yr ESALs 0.45 million	12.0	1.0	2.0	-0.5	1.0	-30.0	-7.0	-2.8		Heater Re-mix/10% "CX"		15	15.0	15	15.0	15.0
9	SH 119, Longmont - I 25	57.7	58	50	45	30			Trans	1995	2"+ Grade "C" Wear Surf +	AC-10	92	97	92	92	Trans
	10-Yr ESALs 0.52 millio	63.6	0.5	0.0	-0.4	-1.6	-12.5	-12.5	-8.0		+1" Hv Rapv (0.5" Gr "C")		9.0	15.0	9.8	15.0	7.0
Note: Series 5 & 6 not included in post-			62	53	46	58	-11.5	-8.2			Averages		87	88	82	88	
constr. aver. (not structurally designed)			1.3	0.3	-0.2	1.3			-3.5		Averages		14.1	13.8	10.7	14.4	6.7

* Mean Slope is mean deterioration slope, e.g., reduction in index points/years at, or near the time the plot line crosses the 50 threshold value.

Note: Shaded cells in both tables indicate predominate distress (lowest RSL/YFL).

Note: Where the value 10 appears for RSL in the pre-construction summary, it indicates the deterioration slope is so flat that an accurate estimate of the RSL is not practical, it is at least 10. This value used to calculate averages. In the post-construction summary, for very flat trend lines, the value 15 has been used (for the10-yr designs) and 10 for series 5 & 6 (which were not designed).

Table B-4 PRE- & POST-CONSTRUCTION CRACKING INDEXES

PMS Data From 1991- 99 on 9 Paving Projects (12 Sections) Constructed on I 25 in1994

	PRE-CONSTRUCTION						POST-CONSTRUCTION					
Series	Est Cracking Index/Yrs Functional Life						Constr.	'99 Est Crack Index/Yrs Functional Life				
No.	ALIG	BLCK	LONG	TRNS	LALC		Year	ALIG	BLCK	LONG	TRNS	LALC
1	76	86	67	34	59		1994	90	94	94	81	79
	8.0	10.0	2.6	-1.8	0.7			15.0	13.0	15.0	8.0	9.5
2	95	98	73	36	77		1997	100	100	100	100	100
	10.0	10.0	2.4	-2.7	10.0			15.0	15.0	12.5	4.0	3.0
3	77	47	66	0	77		1996	100	100	72	60	70
	4.5	-0.5	3.5	-8.0	5.5			15.0	15.0	5.0	4.0	4.4
4	87	80	81	36	88		1996	100	100	75	80	92
	10.0	10.0	10.0	-2.0	10.0			15.0	15.0	9.0	7.0	15.0
5	96	100	87	37	100		1998	100	100	90	79	81
	10.0	10.0	10.0	-1.5	10.0			10.0	10.0	6.0	2.5	2.5
6	100.0	98.0	92.0	20	97		1996	100	100	40	40	89
	10.0	10.0	10.0	-0.5	10.0			10.0	10.0	2.2	1.0	10.0
7	80	88	48	-20	54		1996	100	100	95	56	100
	8.0	10.0	-0.5	-4.4	0.3			15.0	15.0	15.0	3.5	15.0
8	73	54	57	32	83		1996	100	99	98	89	100
	4.5	0.4	1.3	-2.8	9.0			15.0	15.0	15.0	15.0	15.0
9	76	38	73	-5	82		1995	100	100	94	70	96
	6.0	-1.0	10.0	-8.0	10.0			15.0	15.0	10.4	7.0	9.6
Averages	84	77	72	19	80		Series 5 & 6 not included	99	99	90	74	91
Averages	7.9	6.5	5.5	-3.5	7.3		in post-constr.averages.	15.0	14.7	11.3	6.9	10.2

Table B-5 SUMMARY

BASED ON NETWORK PMS DATA, PRE-CONSTRUCTION RSL & POST-CONSTRUCTION YEARS FUNCTIONAL LIFE (YFL) FOR STUDY PROJECTS

REHABILITATION STRATEGY				EXISTING VARIABLES		
	STRATEGY COMBINATION			10-Yr Equiv. ESALS $\leq 3x10^6$	10-Yr Equiv. ESALs >3 Million	
	Asphalt Cement Character	Overlay or Other Thickness	Amount of Subsidiary Treatment	Pre-Construct. Crack Index RSL <0.0	Pre-Construction Crack/Rut Index RSL <2.5	AC over PCCP
				Estimated YFL/predominant **post-construction** distress/OPI YFL. Each listed under the predominant **pre-construction** distress.		
	Modified Asphalt Cement in Wearing Surface	Thick Overlay Surface	Major			7.0/Long/15+$_H$
			Moderate	#12.5/Trans/20+$_A$		
			Minor			
		Medium Overlay Surface	Major	#8.3/Trans/20+$_D$		
			Mod			
			Minor		3.0/LAI.C/12.5$_2$	
		Thin Overlay Surface	Major			
			Moderate	5.0/Trans/15+$_C$	4.0/Trans/15+$_7$	
			Minor		5.7/Trans/15+$_F$	
					7.0/Long/15+$_I$	
	Un-Modified Asphalt Cement in Wearing Surface	Thick Overlay Surface	Major			
			Moderate			
			Minor	6.6/Rut/ 10.5$_1$		
		Medium Overlay Surface	Major			
			Moderate	6.0/Trans/ 15+$_5$	7.0/Long/15+$_G$	
			Minor			
		Thin Overlay Surface	Major	4.5/CkInd/12.0$_B$		
			Moderate	15/Ride/ 15+$_8$		
			Minor		5.0/Trans/15+$_E$	
					4.5/CkInd/11.0$_K$	
					4.0/Trans/15+$_L$	
	SMA	2"	Minor	4.0/Trans/ 15+$_3$		
		1-1/2"	Moderate		6.0/Long/ 15+$_4$	
	PMSC, Type "B", 1"					4.0/Trans/15+$_J$
	Micro-Surfacing				2.5/Trans/ 5.5$_9$	
	Micro-Mill 1.5" Average To Remove Ruts					1.0/Trans/ 10.5$_6$

20-Yr design, 5.0 million ESALs, est. 2.3 million for 10-Yr count. ## 20-Yr design, 5.2 million ESALs, est 2.4 million 10-yr.

NOTES:

1. Subscript letters are Series identification from the twelve I -25 series' PMS condition data.
2. Shaded data cells represent projects from original Rehabilitation Study.
3. Subscript numbers are Series numbers from 9 projects from Rehabilitation Study PMS condition data.

THIN (2") HBP OVERLAY & THIN MILL (1") OVER FUNCTIONAL DISTRESS (High Transverse Cracks & Poor Ride)

Series Ident. E, I-25, Woodman Road - South, MP MILE 139.6 - 148.0

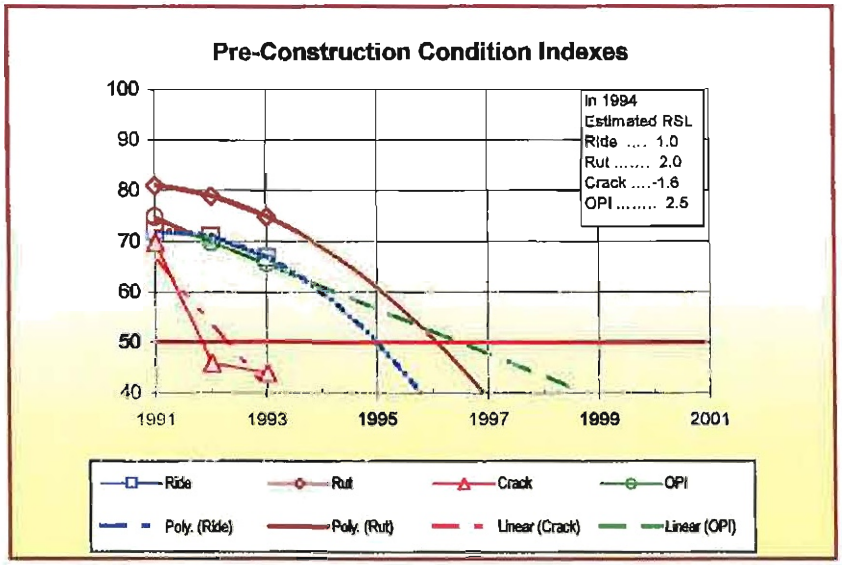


Figure B-1

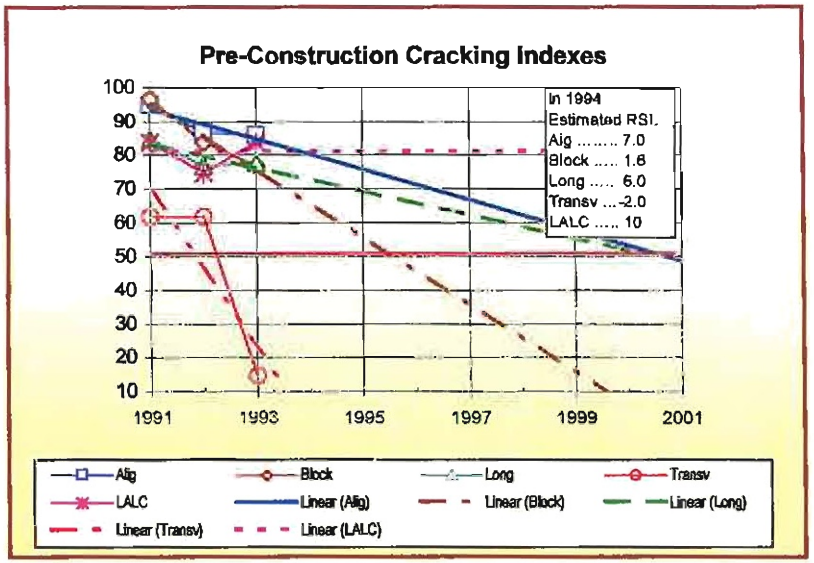


Figure B-2

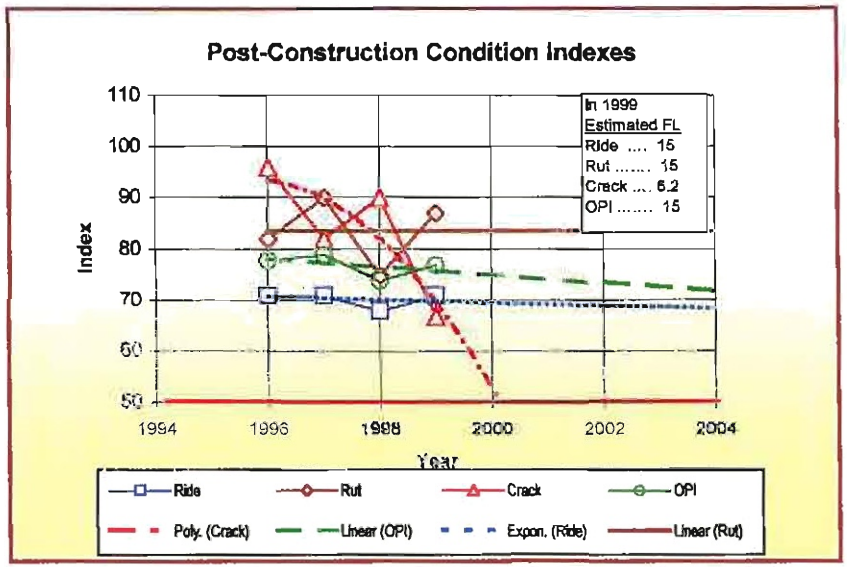


Figure B-3

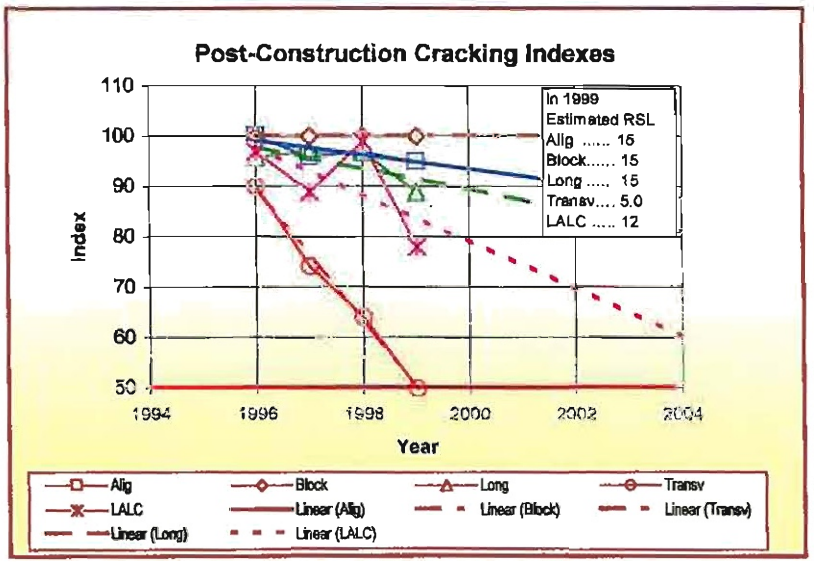


Figure B-4

4.25" Grade "C" OVERLAY + FABRIC OVER MOSTLY FUNCTIONAL DISTRESS (Med Ride/Med Ruts & HighTransverse/Med LALC Cracks)

Series Ident. No. 1, US 285, West of Denver, on Either Side of C 340, MP 248.3 -250.2

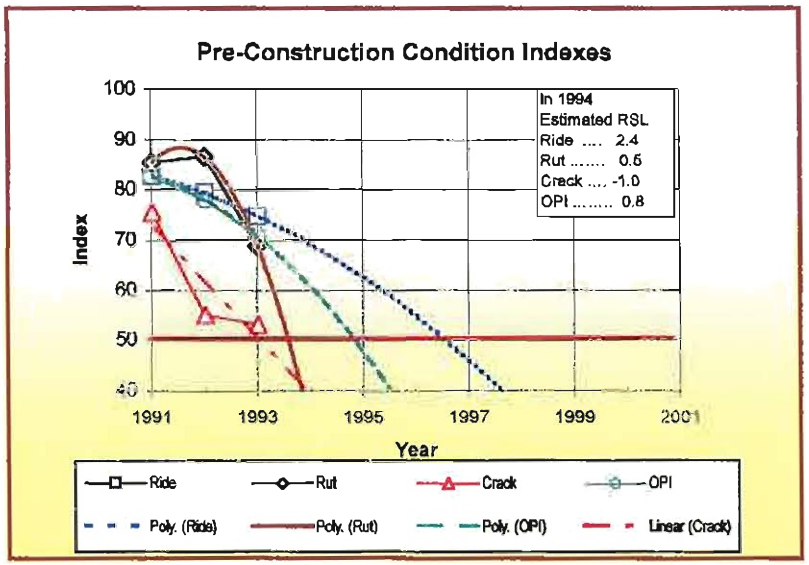


Figure A-5

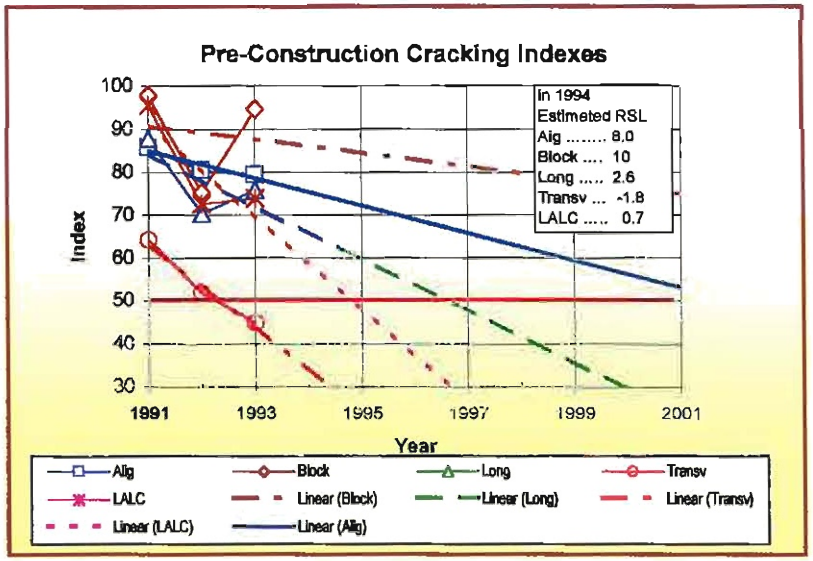


Figure A-6

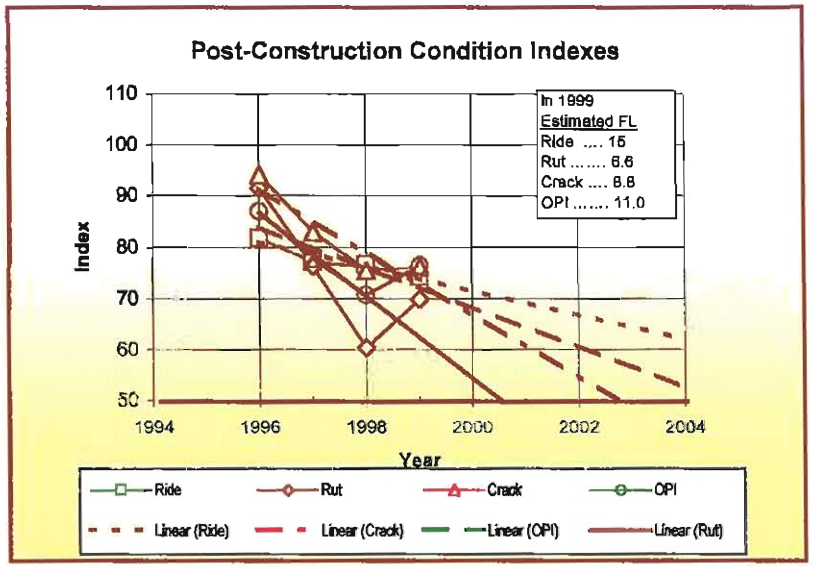


Figure A-7

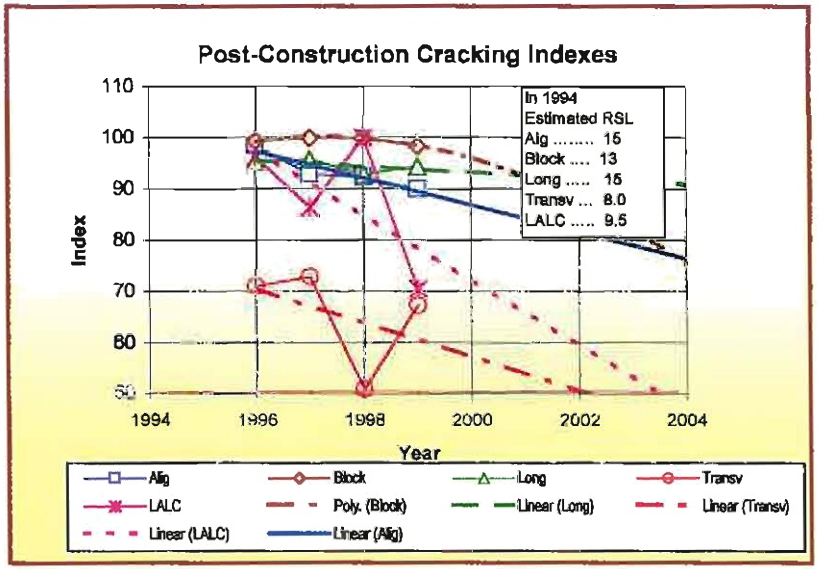


Figure A-8

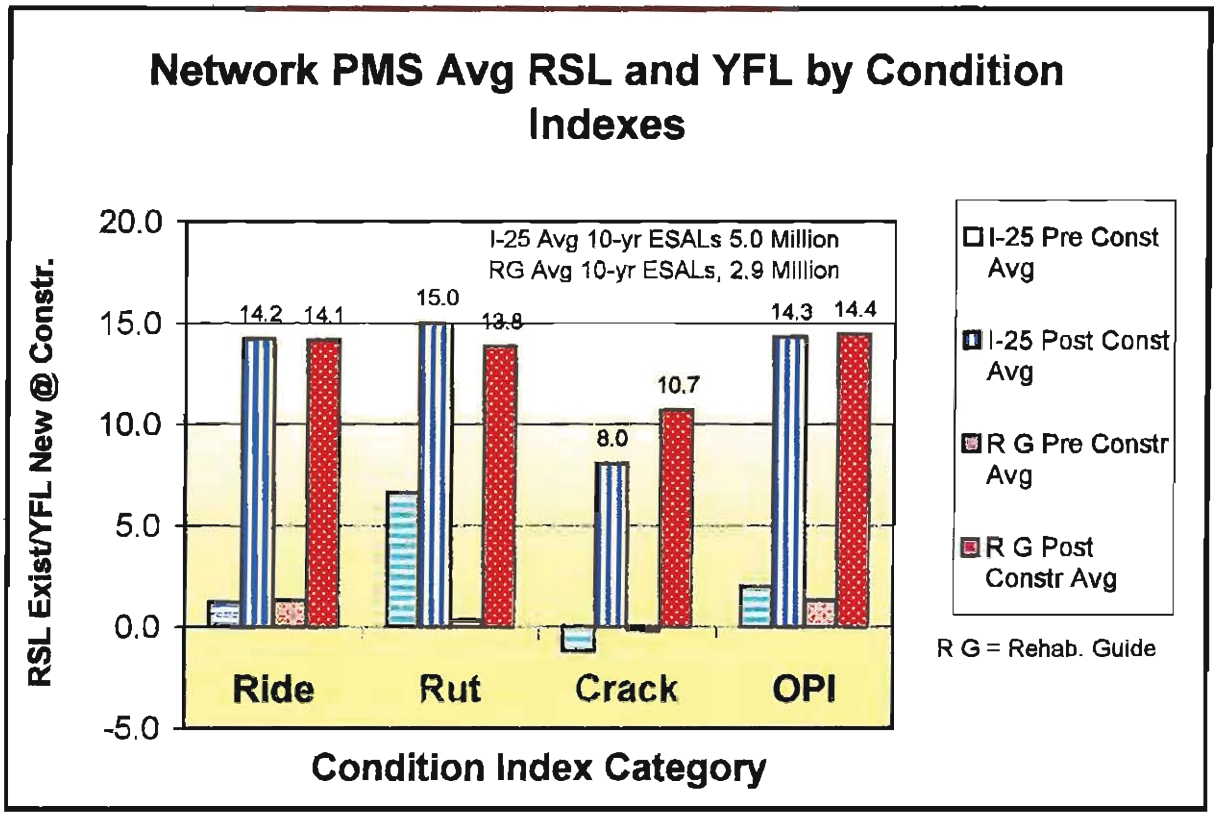


Figure B-9

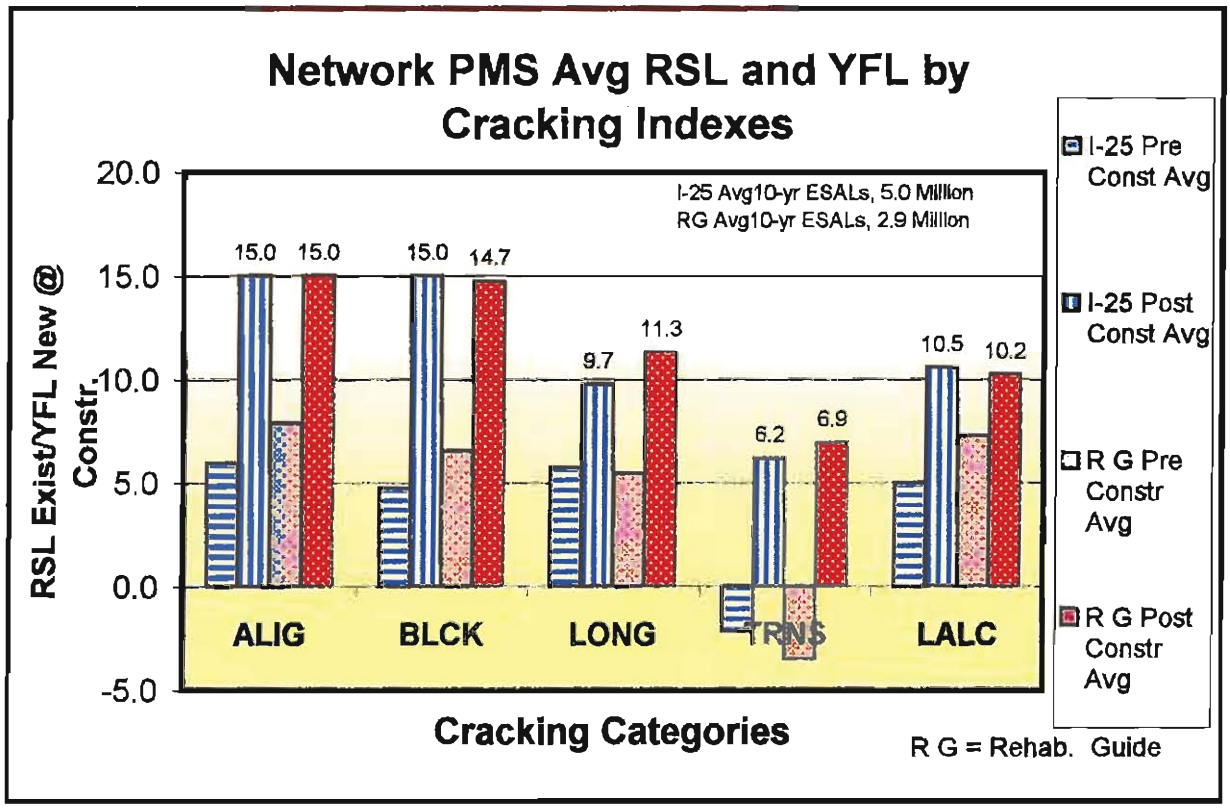


Figure B-10