DEVELOPMENT AND IMPLEMENTATION OF PAVEMENT CONDITION INDICES FOR THE VIRGINIA DEPARTMENT OF TRANSPORTATION

PHASE I

FLEXIBLE PAVEMENTS

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ABSTRACT

This report documents work done by the Virginia Department of Transportation (VDOT) over the past 5 years to develop pavement condition indices compatible with Virginia conditions. The work began with attempting to choose indices that would be similar in "look and feel" to a Virginia index used to quantify windshield data since the early 1980s and called a Distress Maintenance Rating (DMR)[1]. The DMR was used principally in the establishment of needs lists on a "worst first basis". In turn, that list was used in the development of resurfacing schedules.

The purpose of the study was to develop pavement condition indices suited to the management of Virginia pavements. Included were indices to describe load and non-load related distresses and pavement longitudinal and cross-slope information including rutting and ride quality. Pavement types to be included in index development were flexible (asphalt), rigid (concrete), and composite (a combination of asphalt and concrete). The present document addresses the development and use of flexible pavement indices only. These indices have received by far the most attention of VDOT staff as over 90% of the system is comprised of flexible pavements. Indices used to define the conditions of jointed and continuously reinforced concrete pavements are the subjects of a second document under preparation.

A guiding principle of the index development effort was to arrive at indices that would be acceptable to VDOT users of the pavement management system. This meant the indices needed to describe critical pavement condition features in such a way that field personnel would understand what those indices tell them about the condition of their pavements. Further, those personnel need to be comfortable with the use of those indices in planning pavement maintenance and rehabilitation activities on a project basis. At the same time, central office pavement management personnel needed to be able to use the indices to describe network as well as project pavement conditions and to use those indices in optimization and other studies directed at the best use of available funds. Because of the need to consider maintenance and rehabilitation options separately for distresses relating to wheel loads and those related to weathering the decision was made early that two indices would be required. These were labeled the Load Related Distress Rating (LDR) and the Non-Load Related Distress Rating (NDR).

The general approach to index development was to borrow from existing work to the extent practical and to modifying existing approaches to gain the look, feel, and acceptability mentioned above. In addition to the previous DMR work in Virginia, a major resource was the PAVER work done by the Corps of Engineers[2]. A first cut at index development was to use the PAVER curves of deduct values relating to each level of each distress where applicable. Then, to the extent possible threshold values used with the old DMR system and built into a VDOT HMAC maintenance and rehabilitation decision tree were used to modify the PAVER values. Next, equations of best fit were derived for the modified values. These equations are used in developing the deduct values for each level of each distress. Finally, after field trials, use of the deduct equations in VDOT pavement management software, and sensitivity analysis other modifications were made to ensure that deduct values and the resulting indices met the test of reasonableness.

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INTRODUCTION

HISTORICAL OVERVIEW OF PAVEMENT MANAGEMENT IN VIRGINIA

Formal pavement management in the Virginia Department of Transportation began in the late 1970s as documented in the first research report spelling out the need for a pavement management system[3]. Clearly, pavements had been managed before formal pavement management came into common use. That earlier management however had been largely informal and budget rather than needs driven.

As a part of the earlier pavement management process, a flexible pavement (HMAC) windshield pavement condition rating procedure had been developed and used for the allocation of funds among the districts and down to the county level. The rating procedure also was used for priority programming of the primary and interstate resurfacing schedules. The process, however, did not address long range project or network needs and had no optimization module. A basic element of the rating procedure was a condition index called the distress maintenance rating (DMR)[1]. The DMR was a deduct based index where a perfect pavement was assigned a value of 100. The DMR included only various pavement surface distresses as parameters. The major distresses considered were cracking, raveling, pushing, rutting, flushing, and patching with cracking and patching given the most severe deduct weights. The DMR included no measure of pavement ride quality such that a very subjective ride quality rating was used as a tie-breaker between pavement sections having otherwise similar characteristics. An example DMR pavement rating worksheet is given in Appendix A. Note on that worksheet that pavement surface distresses are evaluated on the basis of both frequency of occurrence and the severity of the distress. Note further that rating factors of from 0 to 9 depend upon the frequency of occurrence classified as none, rare (less than 10%), occasional (10 to 40%), and frequent (over 40%). The percentages relate to the percentage of the pavement (or wheel path in the case of alligator cracking) effected. The rating factor is multiplied by a distress weighting factor (reflecting the fact that different distresses are considered to be of different importance) to arrive at the deduct points for a given distress.

The DMR based system was used from the early 1980s until the early 1990s when it was deemed too dangerous to have personnel conduct windshield surveys and that automated pavement condition data collection would be desirable. Further, in the absence

of a well-defined quality control process on data collection some users lacked confidence in the DMR approach, especially as a funds allocation tool.

At about the same time as moving to automated data collection, the department had a consultant evaluate the existing pavement management effort and recommend the changes necessary to implement a full system with optimization capabilities[4]. While a discussion of this effort is beyond the scope of the present report, many of the issues raised have been addressed in the topics described below.

PAVEMENT MANAGEMENT DEVELOPMENTS IN THE 1990S

VDOT Pavement Condition Parameters Committee

A small committee comprised of pavement management data users was formed to provide advice to pavement management program (PMP) developers on what parameters were of most value to them and how those parameters might be used to best advantage. In view of their role the group was named the "Parameters Committee". The group met numerous times and provided input to the development of data collection contract documents, to pavement maintenance and rehabilitation decision trees, and to the development, evaluation, and initial implementation of the pavement condition index work described herein.

Automated Data Collection

In the mid-1990s VDOT began to collect pavement distress data through the use of videotaped images. To make use of data collected from those tapes VDOT also made interim use of the pavement condition index (PCI) defined and used by the U.S. Army Corps of Engineers[2]. After several trial years, the PCI was deemed too general for Virginia conditions so that a VDOT specific method, the major subject of this report, was considered necessary.

For the first three years videotape distress data was collected there were no standards for distress data collection and reduction such that procedures tended to change each year. The result was that there was no stable basis for the development of pavement performance curves and for other long-range data uses.

To overcome some of the problems associated with the absence of standards, in 1997 pavement management staff undertook the development of a manual "A Guide to Evaluating Pavement Distress Through the Use of Video Images" [5]. The manual provided general distress evaluation rules as well as detailed procedures for the rating of asphalt concrete pavements, overlays of jointed PCC pavements, jointed PCC pavements and continuously reinforced concrete pavements (CRCP). Procedures spelled out in the

manual were applied to data collected in 1998 and became a part of contract documents for the data collected in 1999. It is notable that the VDOT manual was developed in response to recognized fundamental differences in the evaluation of pavements through the use of imaging rather than through direct pavement observation by trained observers. Those fundamental differences relate to the fact that not all distresses are readily captured on or discerned from images and that it is very difficult to evaluate levels of distress severity from images. The VDOT distress evaluation manual is believed to be one of the first of it type to be developed.

New PM Software

Also in 1995 a contract was awarded to develop new pavement management software for the department. This personal computer based software is to replace old mainframe software in use for many years within the department.

The software has the capability of single year project prioritization, multi-year work planning, funding optimization studies, and feedback analysis. The software offers many new analysis capabilities and a departure from the single year and "worst first" approach to programming pavement maintenance and rehabilitation. During 1999 the software underwent user testing and VDOT personnel received preliminary training in its use.

Full use of that software clearly requires the development and implementation of meaningful and reliable measures of pavement condition and the availability of data collected in accordance with the applicable standards.

PURPOSE AND SCOPE

The purpose of the study was to develop pavement condition indices suited to the management of Virginia pavements. Included were indices to describe load and non-load related distresses and pavement longitudinal and cross-slope information including rutting and ride quality. Pavement types to be included in index development were flexible (asphalt), rigid (concrete), and composite (a combination of asphalt and concrete).   The present document addresses the development and use of flexible pavement indices only. These indices have received by far the most attention of VDOT staff as over 90% of the system is comprised of flexible pavements. Indices used to define the conditions of jointed and continuously reinforced concrete pavements are the subjects of a second document under preparation.

A guiding principle of the index development effort was to arrive at indices that would be acceptable to VDOT users of the pavement management system. This meant the indices needed to describe critical pavement condition features in such a way that field personnel would understand what those indices tell them about the condition of their pavements. Further, those personnel need to be comfortable with the use of those indices

in planning pavement maintenance and rehabilitation activities on a project basis. At the same time, central office pavement management personnel needed to be able to use the indices to describe network as well as project pavement conditions and to use those indices in optimization and other studies directed at the best use of available funds.

ADDITIONAL BACKGROUND

PAVEMENT CONDITION INDEX OVERVIEW

Pavement condition indices typically provide aggregated measures of several related pavement features. Typical indices assign a rating of 100 to pavements having no discernable distress or other characteristics that detract from engineering or user perception of pavement condition or functionality. Deducts from the perfect score typically relate to the type and degree of a given feature and to how extensively it occurs. Because several features are combined in an index, a good measure of overall pavement condition may result although extreme values of some features may be masked.

Two major classes of pavement condition parameters are represented by indices. These are pavement surface distress parameters and parameters relating to pavement longitudinal or transverse profile. The first typically are visually evaluated, from direct observation or from pavement images, while a vehicle passing over the pavement measures the second. Such vehicles are instrumented to provide a known plane of reference and to measure deviations of the pavement surface from that plane. Measurements are typically through the use of high speed ultrasonic or laser based transducers, which send a signal from the plane of reference to the pavement surface and measure the rebound of that signal from the surface. The time required for the signal to travel to the pavement surface and back is directly related to the distance between the reference plane and the surface.

Highway agencies use both types of indices in the priority programming of pavement activities and in multi-year planning of those activities as well as in the analysis of funding optimization through the definition of network and project level pavement performance curves.

NEED FOR VIRGINIA SPECIFIC INDICES

The early VDOT approach was but a first step toward "true" pavement management because the DMR considered only surface distress and was not related to the various distress causes or to the consequences of those distresses and their causes in making pavement management decisions.   For example, one may wish to address distresses related to wheel loads differently from those caused by weathering. Further, it is recognized by most pavement management systems that addressing the worst pavement first often is not the best use of available funds. It may at times be much more

cost effective to repair a pavement in relatively good condition because that repair may prolong the "remaining life" of the pavement far beyond the life expected if the same pavement was permitted to continue to deteriorate.

Fortunately, proper design and use of several different indices of pavement condition permit the pavement manager to identify those pavements that could benefit from early treatment. At the same time, those indices can indicate those pavements where deferred maintenance will not be overly detrimental or costly.

INTERNATIONAL ROUGHNESS INDEX

The standard measure of ride quality for VDOT is the International Roughness Index (IRI) also used by the Federal Highway Administration in the nationwide monitoring of the Highway Performance Monitoring System (HPMS) used in the distribution of Federal Highway Funds to the states[6]. Roughness as defined by ASTM Designation E867 is "The deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality." While an important measure of pavement condition, the IRI is one of several condition indicators not within the scope of the present report.

PAVEMENT CONDITION REPORTS

The pavement condition indices described herein form the basis for two reports of interstate and primary pavement condition in Virginia. For the first, in 1998[7] indices were determined from pavement condition data captured on videotapes and manually reduced following the procedures given in reference (5). The second report in 2002 [8] used windshield data structured and collected in a manner consistent with the requirements of reference (5). The Department found it necessary to resort to windshield surveys in 2000-2002 due to the absence of automated data caused by contractual problems.

INDEX DEVELOPMENT PROCEDURE

IDENTIFICATION OF CRITICAL DISTRESSES

One of the first steps in developing new indices was to identify the pavement condition factors that enter into maintenance and rehabilitation decisions. With input from the VDOT pavement management parameters committee it was concluded that there are three major classes of distress leading to most maintenance and rehabilitation decisions. These are cracking and other surface distress related to loads on the pavement, cracking and other surface distress related to environmental effects on the pavement

surface, and the roughness (or smoothness) of the pavement surface. By definition, with the exception of patching, distresses designated as load related do not occur in the absence of wheel-loads applied to the pavement. Distresses designated as load related typically occur in the wheel paths while distresses relating to environmental factors may occur anywhere on the pavement surface.

The flexible pavement distresses deemed critical by the parameters committee are given in Table 1. These distresses are described in detail in *A Guide To Evaluating Pavement Distress Through the Use of Video Images*[5]. In addition to the distresses, the committee agreed that pavement roughness or ride quality was a critical pavement condition parameter.

Table 1 – Flexible Pavement Distresses

LOAD RELATED DISTRESSES		NON-LOAD RELATED DISTRESSES	
Distress	**Description**	**Distress**	**Description**
Alligator Cracking	- One longitudinal crack in the wheel path, **or** - Interconnected cracks having a chicken wire or "alligator hide pattern"	Bleeding	- Excess asphalt cement, **or** - Surface appears shiny or glassy
Delaminations	Areas of pavement surface missing due to the loss of adhesion between the surface and underlying layers.	Block Cracking	A pattern dividing pavement into approximately rectangular pieces of less than or equal to 6 feet by 6 feet.
Patching	- Areas of pavement replaced, **or** - Areas of pavement covered with new material	Linear Cracking	Longitudinal cracks outside the wheel paths or transverse cracks.
Potholes	Bowl shaped holes in the pavement surface, usually extending through more than one pavement layer.	Reflection Cracking	Relatively straight Transverse cracks directly over joints and cracks in underlying PCC pavement
Rutting	Longitudinal depressions of the pavement surface in the wheelpaths.		

INDEX DEFINITIONS

A total of three new indices have been defined. These are listed below while the components of each are summarized in Table 2:

1. The load related distress index - **LDR,** is a deduct based index having a value of 100 when the pavement being evaluated has no discernible load related distress. Deduct points are assigned for each distress given in Table 2. The magnitude of deduct is related to the distress type as well as the severity and frequency of occurrence of that distress. As discussed later, some distresses are more detrimental to pavement performance than others and are, therefore, weighted more heavily.

2. The non-load related distress index – **NDR,** is defined similarly to the LDR except the distresses assigned to the index are non-load related.

3. The combined condition index – **CCI,** is defined as the lowest of the LDR or NDR and is used as a "one measure" indicator of overall pavement condition.

Table 2- Index Components

INDEX	COMPONENTS
LDR	Alligator cracking, patching, potholes, delaminations, rutting
NDR	Block cracking, patching and longitudinal cracking out of wheel path, transverse cracking, reflection cracking, bleeding
CCI	The lowest of the LDR or NDR

DEVELOPMENT OF DEDUCT VALUES

<u>**Alligator Cracking Used as Example**</u>

Others have shown that the degree to which a given pavement distress is detrimental to pavement performance is a function of both the extent and the severity of that distress [1][2]. Distress deduct values are related to that detrimental effect and typically are non-linear, i.e., there is not a one-to-one correspondence between distress frequency and severity and the deduct values assigned for the distress. An example is given in Figure 1 where the PAVER deduct curves for alligator cracking are displayed [2]. Note that a log horizontal scale is used in this figure. Values on the horizontal axis are distress density in terms of the percentage of pavement area affected. This figure will be used as an example of how the shapes of PAVER curves were used as the basis for VDOT deduct curves for alligator cracking. Deduct curves for other load and non-load related distresses were developed in a similar manner.

To develop the VDOT curves, the shapes of the PAVER curves were used for all three severity levels. The rationale was that the shape of PAVER curves would be a

reasonable approximation of the shape of an alligator cracking curve on a scale other than the pavement condition index (PCI) used in PAVER. On the other hand, the deduct values were derived through consideration of the DMR deducts VDOT personnel had become accustomed to using (Appendix A). In this case, the rationale was that VDOT personnel would more readily accept and use indices seeming similar to the DMR values they had been using.
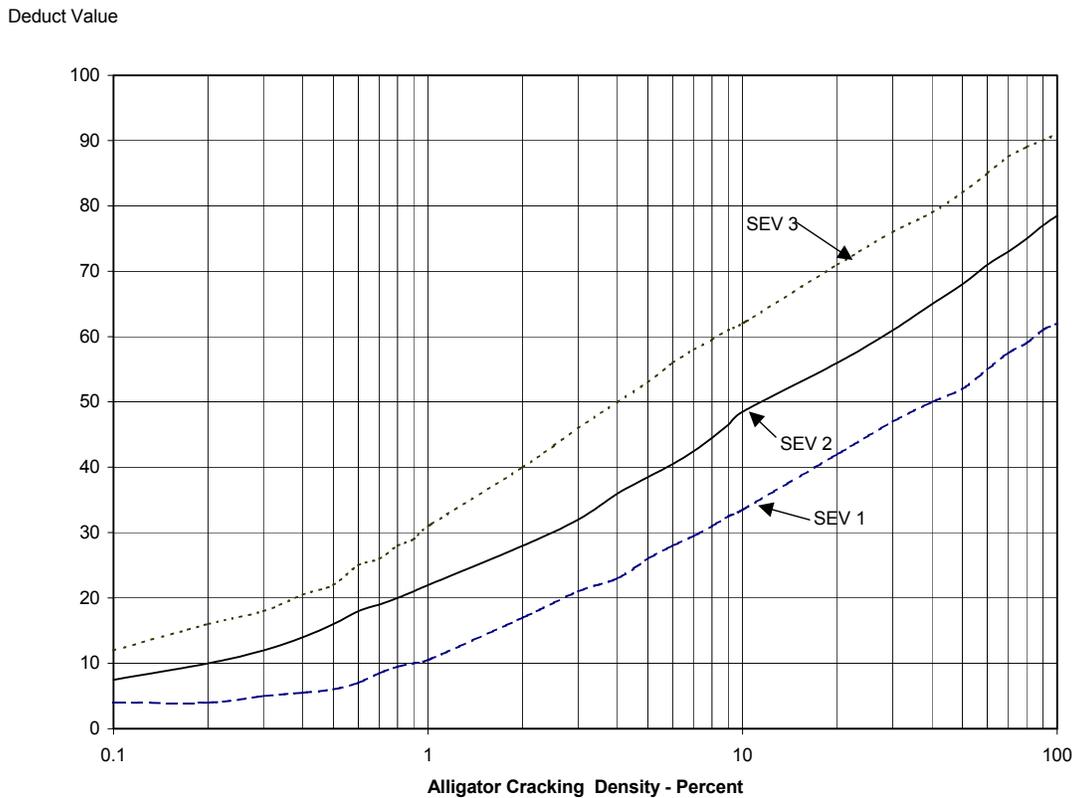
Deduct Value

Figure 1. PAVER Alligator Cracking Deduct Curves[2]

The adjustment of alligator cracking PAVER values to a VDOT scale are given as VDOT1 (Version 1) in Table 3 and are plotted graphically in Figure 2. The values have been adjusted to accommodate draft VDOT decision trees (Appendix B) for the various levels and extents of distress and to make a deduct of about 50 points a "threshold". Therefore, 15% of severity 3 is assigned 50 deduct points, as is 40% of severity 1. The curve for severity 2 was placed approximately between the curves for severities 1 and 3. Then, all curves were made to fit the shape of the PAVER curves accordingly. Unlike the PAVER curves given in Figure 1, the VDOT1 curves are plotted using an arithmetic

distress density scale. That scale permits the user to better visualize the impacts of small changes in distress density on the deduct values.

For alligator cracking, calculations are the wheel-path area of each severity level in the section expressed as a percentage of the total wheel-path area in the section. VDOT defines the wheel path as two 3.5 ft. wide strips separated by 3.5 ft. with lane edge widths depending upon total lane width.

Deduct Value

$y = 9.2856Ln(x) + 24.428$
$R^2 = 0.994$

Sev. 3

$y = 9.4184Ln(x) + 19.073$
$R^2 = 0.9845$

Sev. 2

Sev. 1

$y = 9.5511Ln(x) + 13.719$
$R^2 = 0.967$

Alligator Cracking Density - Percent
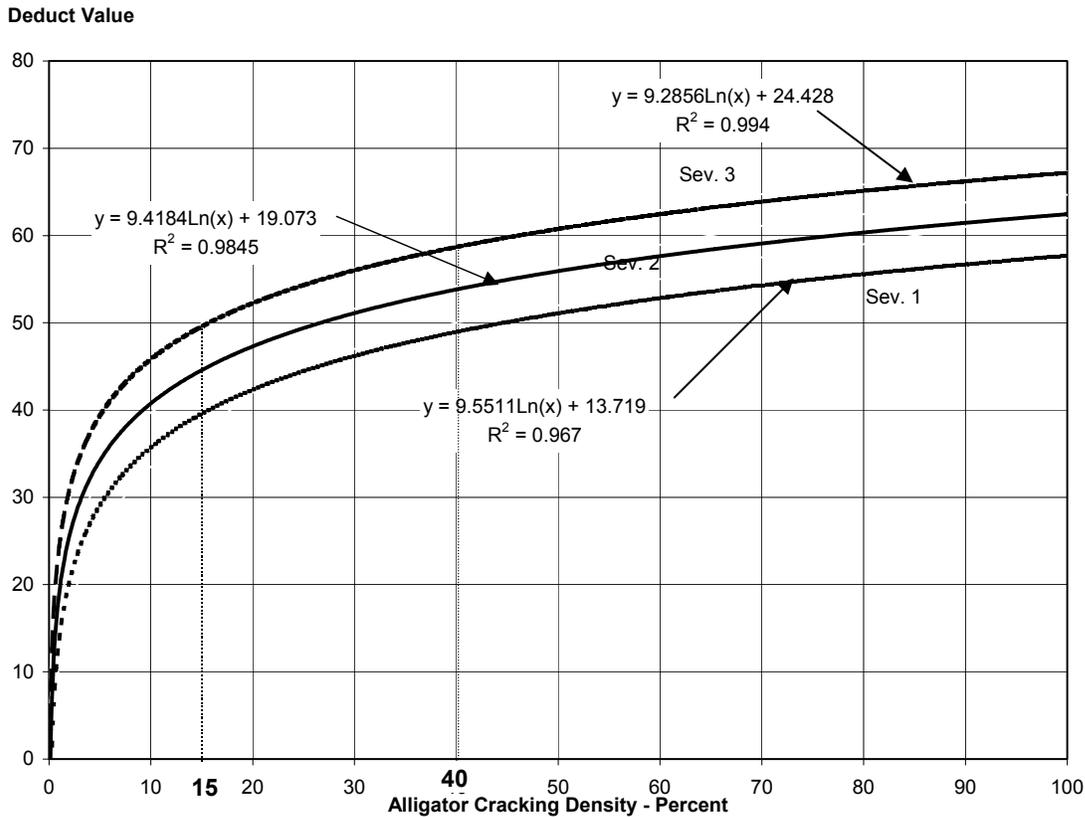
Figure 2. Version 1- VDOT Alligator Cracking Deduct Curves

Table 3. PAVER and Version 1 VDOT Deduct Points for Alligator Cracking

Density	Low Severity		Medium Severity		High Severity	
	PAVER	VDOT1	PAVER	VDOT1	PAVER	VDOT1
0.1	4.0	4.0	7.5	6.4	12.0	8.9
0.2	4.0	4.0	10.0	7.9	16.0	11.8
0.3	5.0	5.0	12.0	9.2	18.0	13.3
0.4	5.5	5.5	14.0	10.3	20.5	15.2
0.5	6.0	6.0	16.0	11.1	22.0	16.3
0.6	7.0	7.0	18.0	12.8	25.0	18.5
0.7	8.5	8.5	19.0	13.9	26.0	19.2
0.8	9.5	9.5	20.0	15.1	28.0	20.7
0.9	10.0	10.0	21.0	15.7	29.0	21.5
1	10.5	10.5	22.0	16.7	31.0	22.9
2	17.0	17.0	28.0	23.3	40.0	29.6
3	21.0	21.0	32.0	27.5	46.0	34.0
4	23.0	23.0	36.0	30.0	50.0	37.0
5	26.0	26.0	38.5	32.6	53.0	39.2
6	28.0	28.0	40.5	34.7	56.0	41.4
7	29.5	29.5	42.5	36.2	58.0	42.9
8	31.0	31.0	44.5	37.5	59.5	44.0
9	32.5	32.5	46.5	38.8	61.0	45.1
10	33.5	33.5	48.5	39.7	62.0	45.9
15	37.5	37.5	51.0	43.7	67.5	**50.0**
20	42.0	42.0	56.0	47.3	71.0	52.5
30	47.0	47.0	61.0	51.6	76.0	56.2
40	50.0	**50.0**	65.0	54.2	79.0	58.5
50	52.0	52.0	68.0	56.3	82.0	60.7
60	55.0	55.0	71.0	59.0	85.0	62.9
70	57.5	57.5	73.0	61.1	87.5	64.8
80	59.0	59.0	75.0	62.4	89.0	65.9
90	61.0	61.0	77.0	63.8	90.0	66.6
100	62.0	62.0	78.5	63.8	91.0	67.3

Deduct Adjustment After Committee Review

Parameters committee and other reviews of initial deduct values and equations resulted in modest adjustments to most curves. Adjustments provided for somewhat reduced distress deduct values for small quantities of distress. The result, for alligator cracking, was a set of curves approximately parallel to the original but not as steep in the

low distress density region. Still the VDOT decision tree critical distress densities were maintained insofar as possible. These curves are given in Figure 3 "Version 2 VDOT Alligator Cracking Deduct Curves". Best-fit equations describing the deduct curves serve the purpose of "feeding" the pavement management software undergoing implementation within VDOT. That software requires algorithms to facilitate the use of pavement condition data in the various analysis packages provided.

Details of the alligator cracking and other deduct equations are given in Appendix E. Other instructions given there include those concerning limiting values assigned to various distress deducts to keep single distresses from totally dominating index values. An example is the maximum deduct of 64 for medium severity alligator cracking. Limits such as these were assigned through discussion with the parameters committee and, like most of the index work, are subject to revision as experience is gained with index use. An approach such as that used in PAVER, where distresses are aggregated and a pooled index applied, was rejected as not being capable of easy visualization by index users.
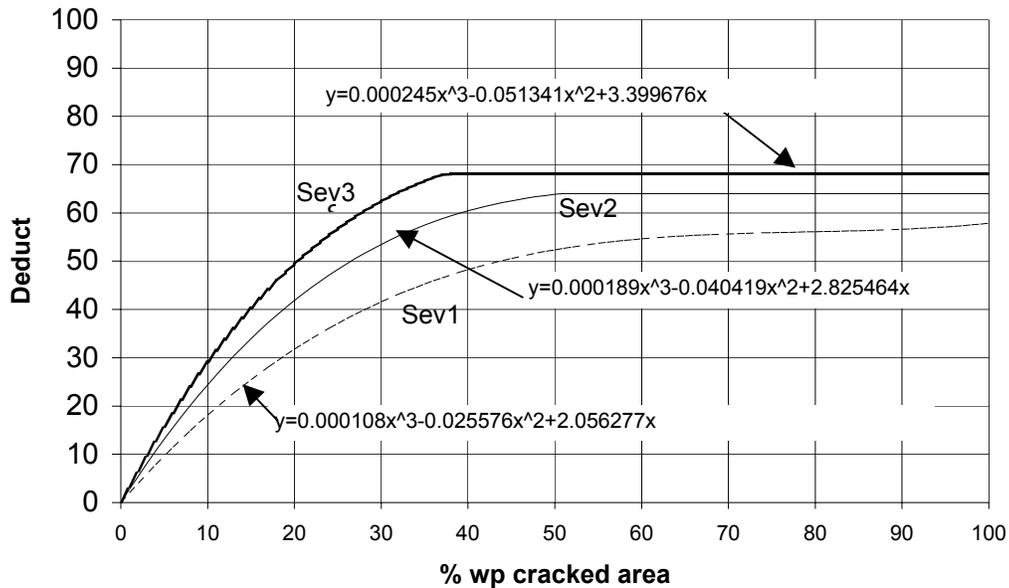
Figure 3. Version 2 VDOT Alligator Cracking Deduct Curves

Distresses Other Than Alligator Cracking

Appendix C contains brief commentaries on the development of adjusted equations similar to those for alligator cracking for all other pavement distresses used in index calculations. Other instructions, such as length and area computations, needed to make use of the equations in reaching index values also are given in the appendix. Also addressed in Appendix C is the separation of indices into load and non-load related factors

Finally, it will be noted in that appendix that there have been some liberties taken with the application of derived equations. One of these is the use of the high severity level alligator cracking deduct equation for two other distresses, potholes and delaminations. This step was taken due to the relative infrequency of occurrence of the latter two distresses making it undesirable to expend the resources to develop and validate separate equations. These distresses are grouped into a category designated "other LDR distresses". Similarly, bleeding and block cracking are combined to form a category called "other NDR distresses".

The full set of HMAC condition index models is given in Appendix E.

SIGNIFICANCE AND USE OF THE NEW INDICES

PILOT STUDY OF INDICE USE

In June 1998 a pilot study was conducted to evaluate the reasonableness and usefulness of the new indices. The pilot involved a team consisting of eight district personnel with pavement management as their primary responsibility and one pavement management consultant. The team evaluated some 70 sections of roadway in various states of distress. All sections had been rated from videotape images by a pavement data collection contractor who applied the procedures given in reference (5). All new indices had been developed for all sections rated and the evaluation team was asked to assess those indices to determine their applicability to the management of each section.

The evaluation consisted of a review by teams of three people of each section selected in advance for the study. Instructions and a work sheet used by the evaluation teams are given in Appendix D. Note that reviewers were asked to subjectively evaluate

the quality of the index data delivered by a data collection and analysis contractor as taken from videotapes of each section. Note that they were also asked to evaluate roughness data not included in the present study. For the purposes of the present report the most important elements of the evaluation involved the assessment of the reasonableness of the LDR and NDR indices. The responses to those questions are given in Table D1 of Appendix D as the rightmost two columns under each group of evaluators. Note at the bottom of that table the overall assessments range from 84 to 88 percent agreement on the LDR and 91 to 93 percent on the NDR. Agreement refers to the percentage of the sites in which raters placed a yes (Y) in the reasonableness column for each index.

As a result of other feedback gained from the pilot study the following provides a brief discussion of the practical implications of the various pavement condition indices and how they may be applied in a typical pavement management decision making process.

LDR

The LDR is an indication of pavement condition from the perspective of damage due to wheel loads applied to the pavement. A pavement with an LDR of 100 has no discernable load related distress. As a pavement wears and begins to show load related (wheel path) distress, the LDR begins to decrease. Unless a pavement is significantly under designed for the loads it carries the LDR will decrease very slowly for a fairly long period of time (usually 40 to 50 percent of the pavement's life) then will begin to decline rapidly as the pavement becomes "fatigued". Ideally, major maintenance such as a structural overlay would be applied just before the rapid decline in LDR begins.

A pavement that is under designed or one that experiences a sudden significant increase in heavy axle loadings may be subject to early rapid decline in LDR. In any event of very rapid change in LDR, a thorough analysis of the pavement is desirable. This can take the form of coring and materials testing, FWD tests, traffic analysis, or some combination of these actions to try to determine the cause of poor pavement performance. Failure to correct the cause of the rapid change in pavement condition may lead to a repeat of the same behavior if simply an overlay is applied.

NDR

Non-load related distresses can occur anywhere on the pavement surface and at any time. Some of these distresses are related to temperature and moisture changes in the pavement over time while some are related to other climate related issues such as oxidation of asphalt concrete, etc. Wheel loads can aggravate some non-load distresses (e.g., reflection cracking) although not directly the cause of those distresses.

Non-load related distresses typically do not affect the whole pavement structure (i.e., they are often superficial) and are much more likely to be treatable by less drastic actions than load related. Slurry seals, chip seals, and very thin overlays often will work well on non-load related distresses. Composite pavements, however, may require thick overlays, milling and replacement, or even reconstruction to overcome the wide reflection cracks sometimes occurring.

CCI

The combined condition index (CCI) is defined as the lower of the LDR or NDR and is used as a "one measure" indicator of overall pavement condition. The CCI should be used as only a gross indicator of pavement condition as the appropriate corrective action for a low CCI will depend on the cause of the reduced value. For that reason, the CCI may be appropriate as a priority programming tool, but is less useful for optimization purposes.

Also, it is important to note that all condition indices are computed on the basis of 1/10-mile segments while they often are summarized and reported on the basis of homogeneous sections. For this reason, it is not unusual for a homogeneous section CCI to seem much harsher than any of the other indices for the same section would indicate. This is especially true where there is a wide variation in indices through a homogeneous section because the computation of CCI will use the lowest index (LDR or NDR) for each 1/10-mile segment and average those low values over the full homogeneous section.

ACKNOWLEDGEMENTS

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APPENDIX A - DISTRESS MAINTENANCE RATING
(DMR)

VDOT
ASPHALTIC CONCRETE
PAVEMENT RATING

Date_____

District _____ County_____ Route_____

From:_____ M.P._____ EBL/NBL (circle)

To:_____ M.P._____ WBL/SBL (one)

(1)	(2)	(3)	(4)	(5)	(6)
Distress Type	Frequency (Circle One)	Severity (Circle One)	Rating Factor (0 to 9)		
Long. or Alligator Cracking	N R O F	NS S VS	_____	x 2.4=	_____
Rutting	N R O F	NS S VS	_____	x 1.0=	_____
Pushing	N R O F	NS S VS	_____	x 1.0=	_____
Ravelling	N R O F	NS S VS	_____	x 0.9=	_____
Flushing	N R O F	NS S VS	_____	x 1.0=	_____
Patching	N R O F	NS	_____	x 2.3=	_____

Sum =

DMR = 100 – sum of column 6 = 100 – _____ =

Ride Rating _____

Frequency of Distress		Not Severe (NS)	Rating Factor Severe (S)	Very Severe(VS)
None (N)	0%	0	0	0
Rare (R)	Less than 10%	1	2	3
Occasional (O)	10% – 40%	2	4	6
Frequent (F)	Over 40%	3	6	9

Ride Quality	Ride Rating
Very Rough	0.7
Rough	0.8
Slightly Rough	0.9
Average	1.0
Smooth	1.1

Distress Maintenance Rating (DMR) Worksheet

APPENDIX B-VDOT HMAC DECISION TREE (1998)

INITIAL DECISION TREE
for
BITUMINOUS CONCRETE PAVEMENTS
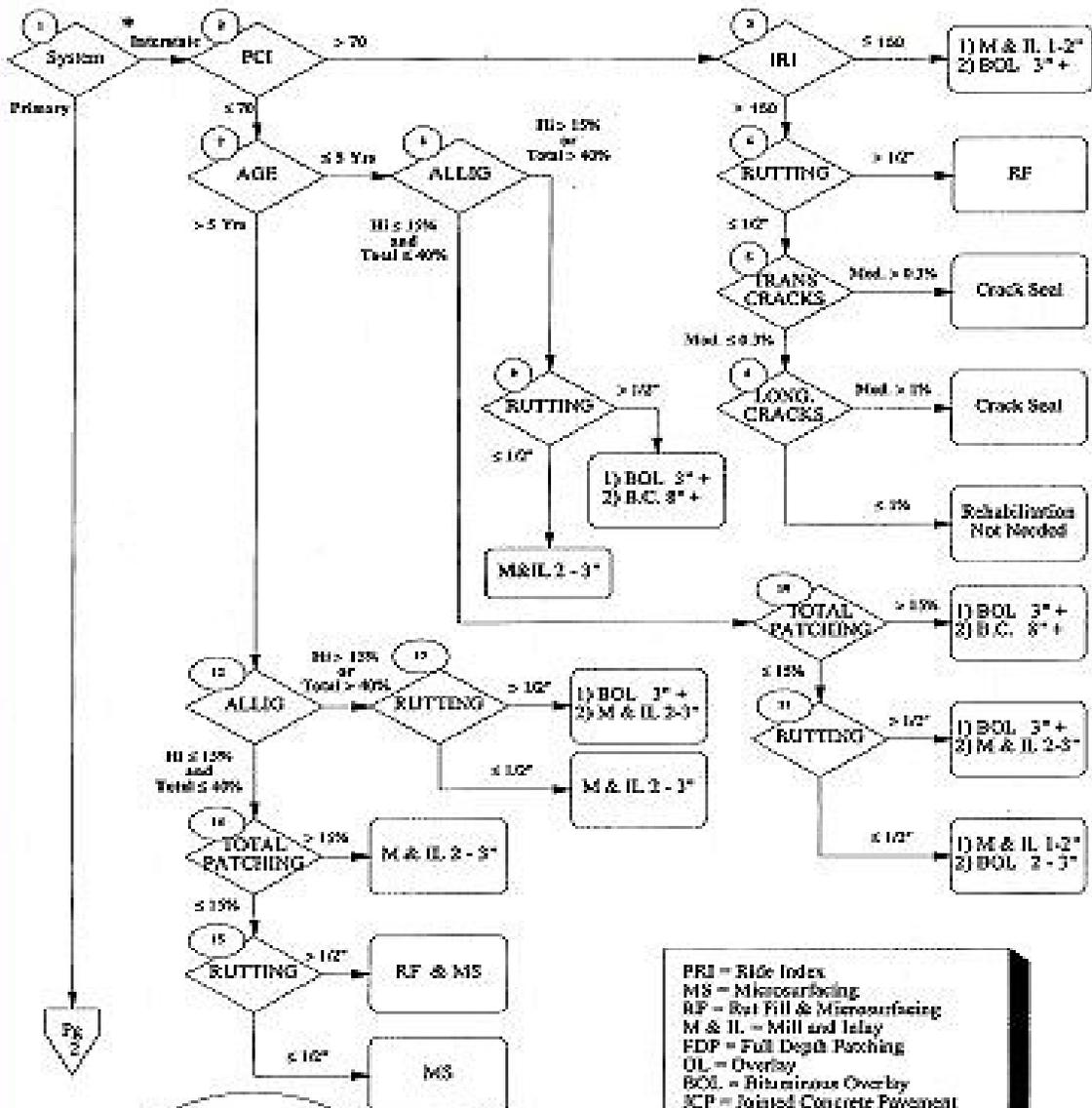
This decision tree was an initial attempt by a VDOT committee of experts to devise rules for when and what repairs should be carried out to Bituminous Surface Pavements. Information from this tree was used to design the new condition indices.

APPENDIX C – DEVELOPMENT OF OTHER DEDUCT EQUATIONS

APPENDIX C – OTHER DEDUCT EQUATIONS

LOAD RELATED DISTRESSES

While alligator cracking is the major load related distress seen on Virginia pavements several other occur frequently and are also the source of major deduct values in the rating system used. These are discussed briefly below.

Rut Depth

Figure C1-Rut Depth Deducts, Version 1 and 2
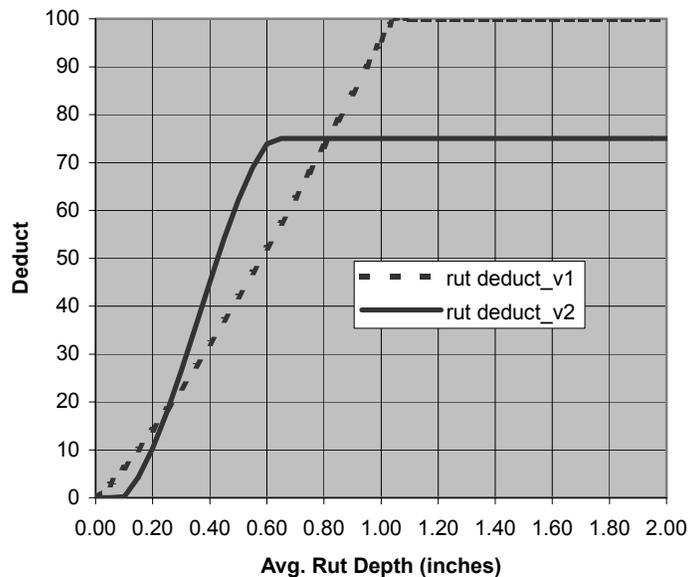
For version2 (final): (Equation 5 of Appendix E – All equation numbers referred to in this appendix are number assigned in Appendix E)

Equation 5

if RUT_AVG > 0.65 then RUT_AVG = 0.65

$$RUT\_DED = -634.132091 * RUT\_AVG^3 + 686.305766 * RUT\_AVG^2 - 60.384474 * RUT\_AVG$$

if RUT_DED > 75 then RUT_DED = 75

if RUT_DED < 0 then RUT_DED = 0

Where RUT_DED = LDR deduct due to rutting, and RUT_AVG is the average rut depth for the pavement section being evaluated. Average is defined as the average of deepest of the two wheel path ruts.

Rut Deduct Development Notes:

Note that rutting is a measured value determined from 5 or more lasers measuring transverse pavement profile. The paver deduct curves for rutting were tried in the Virginia methodology and found to be overly burdensome to use as a density of rutting at various severities was required. Instead, a deduct curve relating to average rutting (the average rut from two wheel paths at a given location) was developed (version 1 above) based on the judgments of the team members. It was then revised into version 2 (final) after field review. A threshold (50% deduct) was set an average rut depth of 0.40 in. Further, an average rut depth ceiling of 0.65 in. and a minimum of 0 in. were established. Finally, a maximum rut depth deduct of 75 was established.

Patching – Wheel Path

Figure C2 - Patching Deducts -September 2002

y=0.0002*x^3-0.0419*x^2+2.6117*x

if x+>50, y=50
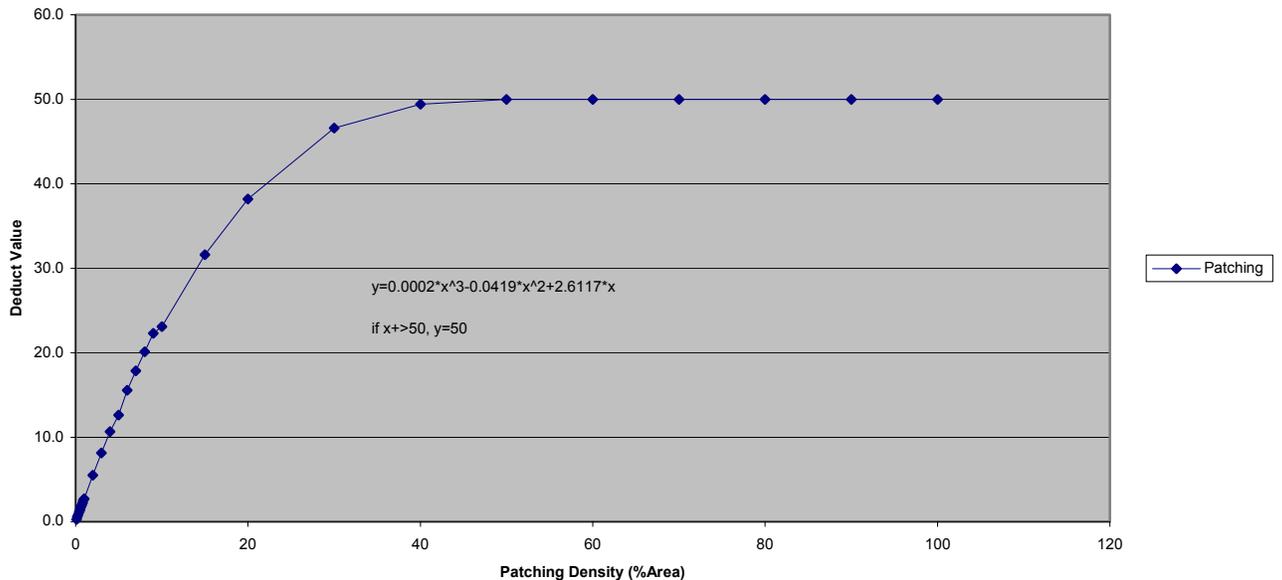
Wheel Path Patching Deduct Notes:

To develop the initial patching deduct curve (not shown), the medium severity PAVER data were used to form the shape. Then, the 15% patching from the initial VDOT decision tree (Appendix B) was used as a threshold and assigned a 50% deduct. Other deduct values were proportioned from the 15/50 to follow the PAVER curve shape. Density calculations were the area of patching in the section as a percentage of the total area of the section.

Upon review of earlier data, it was decided by the pavement management staff that the above deducts were excessive as patched pavements rated lower than the same pavements prior to patching and with conditions warranting patching. Figure C2 reflects the adjustment that was made in September 2002. The major adjustment was to assign a maximum patching deduct of 50 points for 50% patching then to rework the earlier deducts to fit the curve for medium severity alligator cracking. The staff had concluded that patching deduct should be no more severe than the distress repaired and medium severity alligator deduct seemed a reasonable choice.   The resulting equation, from Figure C2 with changes in terminology to fit the VDOT data delivery format (Equation 8, Appendix E) is:

Equation 8

$$PAT\_WP\_DED = 0.0002* PAT\_WP^3 - 0.0419* PAT\_WP^2 + 2.6117* PAT\_WP$$

$$\text{if } PAT\_WP => 50 \text{ then } PAT\_WP\_DED = 50.$$

Where PAT_WP_DED is the deduct for wheel path patching and PAT_WP is the wheel path patching as a percentage of total pavement area.

Note that the wheel path patching deduct is a component of the LDR while that outside the wheel path is an NDR component. Both are handled in the same way except for the area computations.

Other Load Related Distresses

As mentioned earlier, load related distresses other than alligator cracking, rutting, and patching were found to occur so infrequently they are all grouped together and treated as one distress having a deduct equivalent to high severity alligator cracking. The distresses treated in this manner are potholes, delaminations, and high severity alligator cracking.

NON-LOAD RELATED DISTRESSES

Non-load related distresses make up the NDR parameter used in the Virginia rating system. These distresses are defined as those that may occur in the absence of an applied wheel load to the pavement and generally are considered to be environmental in origin.

The development of deduct values for the major non-load related distresses is discussed below.

Linear and Reflective Cracking

Linear cracking and reflective cracking are differentiated in Virginia as the latter occurs, by definition, when there is a jointed concrete pavement underlying the HMAC pavement under consideration. Yet, both distresses are related largely to the shrinkage of pavement components. For this reason, both linear and reflective cracking are deemed to have deduct curves of a similar nature and which can be quantified in a similar manner. However, linear cracking is considered to have only two severity levels (low and high) while reflective cracking has three (low, medium, and high). Linear cracking is comprised of both transverse and longitudinal shrinkage cracking while reflection cracking is considered only transverse.

Figure C3 is a graphical representation of both linear and reflective cracking deduct equations.

Figure C3 - VDOT LINEAR AND REFLECTION CRACK DEDUCT CURVES - REVISION 2
(Dec. 2001)
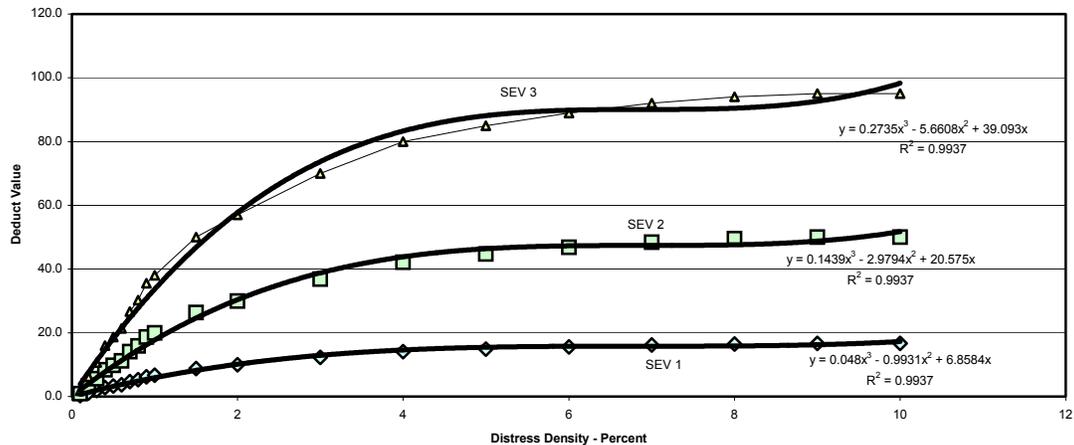
Linear and Reflection Crack Deduct Development Notes:

In the first draft (not shown) of deduct curves an effort was made to separate linear and reflective cracking as done in the PAVER procedure. However, due to strong similarities between the two sets of PAVER curves it was decided that the linear deducts could serve both purposes. Early curves followed the PAVER shapes with threshold points set from the old DMR procedure as expressed in the initial decision tree (Appendix B).

In practice, it was found that the PAVER curves were not suited to Virginia use so that major revisions were made. In late 2001 the pavement management staff, in consultation

with field personnel established the deduct curves given in Figure C3. These were set so that typical Virginia conditions would yield realistic deduct values. Starting points were 20, 50, and 85 deduct points for 10% density of low, medium, and high severity cracking, respectively. Then, the curves were shaped to the PAVER shape as near as possible. Note that for the purposes of distress density calculation every linear and reflective crack is considered to be of unit (1') width. Thus a 12' long crack in a pavement section 100' long by 12' wide would comprise a distress density of $((12*1)/(12*100))*100 = 1\%$.

Linear Cracking Equations

The linear cracking equations using coefficients from Figure C3 and the terminology of Appendix E are:

Low severity linear cracking deduct equation:

Equation 12

$$LIN1\_DED = 0.048 * LN1\_TOTP^3 - 0.993 * LN1\_TOTP^2 + 6.858 * LN1\_TOTP$$

$$\text{if } LIN1\_DED > 20 \text{ then } LIN1\_DED = 20$$

Where LIN1_DED is the deduct due to low severity linear cracking and LN1_TOTP is the low severity linear cracking as a percentage of the total pavement area.

High severity linear cracking deduct equation:

Equation 13

$$LIN2\_DED = 0.144 * LN2\_TOTP^3 - 2.979 * LN2\_TOTP^2 + 20.575 * LN2\_TOTP$$

$$\text{if } LIN2\_DED > 50 \text{ then } LIN2\_DED = 50$$

Where LIN2_DED is the deduct due to high severity linear cracking and LN2_TOTP is the high severity linear cracking as a percentage of the total pavement area.

Reflection Cracking Equations

Similarly, the equations for reflection cracking are:

Low severity reflective cracking deduct equation:

Equation 14

$$RF1\_DED = 0.048 * RF1\_TOTP^3 - 0.993 * RF1\_TOTP^2 + 6.858 * RF1\_TOTP$$

if $RF1\_DED > 20$ then $RF1\_DED = 20$

Where RF1_DED is the deduct due to low severity reflection cracking and RF1_TOTP is the low severity reflection cracking as a percentage of total pavement area.

Medium severity reflective cracking deduct equation:

Equation 15

$$RF2\_DED = 0.144 * RF2\_TOTP^3 - 2.979 * RF2\_TOTP^2 + 20.575 * RF2\_TOTP$$

if $RF2\_DED > 50$ then $RF2\_DED = 50$

Where RF2_DED is the deduct due to medium severity reflection cracking and RF2_TOTP is the medium severity reflection cracking as a percentage of total pavement area.

High severity reflective cracking deduct equation:

Equation 16

$$RF3\_DED = 0.274 * RF3\_TOTP^3 - 5.661 * RF3\_TOTP^2 + 39.093 * RF3\_TOTP$$

if $RF3\_DED > 85$ then $RF3\_DED = 85$

Where RF3_DED is the deduct due to high severity reflection cracking and RF3_TOTP is the high severity reflection cracking as a percentage of the total pavement area.

Patching

The contribution of patching to the NDR is directly related to the area of pavement outside the wheel path. That area is the complement of the area of the wheel path. Therefore, the deduct equation is:

Equation 17

$$PAT\_NWP\_DED = 0.0002 * PAT\_NWP^3 - 0.0419 * PAT\_NWP^2 + 2.6117 * PAT\_NWP$$

if $PAT\_NWP => 50$ then $PAT\_NWP\_DED = 50$.

Where PAT_NWP_DED is the deduct due to non-wheel path patching and PAT_NWP is the non-wheel path patching as a percentage of the pavement area.

Other Non-Load Related Distresses

The only other non-load related distresses deemed to be significant were bleeding and block cracking, both of which occur relatively infrequently on Virginia pavements. In the interest of keeping the process as simple as feasible both distresses are combined into one quantity for calculation purposes and the deduct curve given in Figure C4 applied. The area of the pavement effected by both distresses is expressed as a percentage of total pavement area to arrive at the distress density.

Figure C4 -Total other distress (block cracking, bleeding) Deduct Curves

$$y= -000037*x^3 + 0.00168*x^2 + 0.696257*x$$

(Deduct vs. % pavement distressed area)
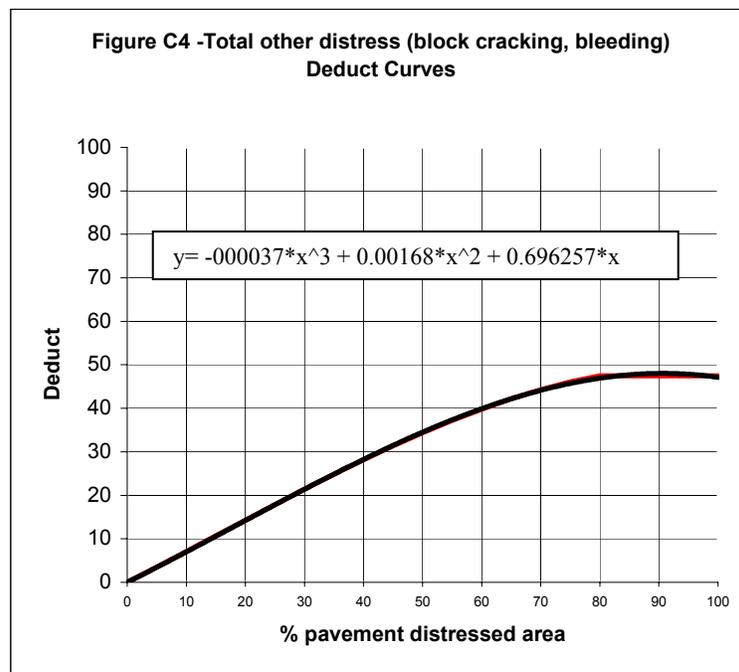
Block Cracking and Bleeding Development Notes:

The medium severity PAVER block cracking curve was used as a starting point. This was then reshaped in accord with the judgment of the development team and the best fit curve given above developed.

The deduct equation is:

Equation 18

Step 1

    if $OTHRNDR\_P > 80$ then $OTHRNDR\_P = 80$

Step 2

    $OTHRND\_DE = -0.000037 * OTHRNDR\_P^3 + 0.00168 * OTHRNDR\_P^2 + 0.696257 * OTHRNDR\_P$

Step 3

    if $OTHRND\_DE > 50$ then $OTHRND\_DE = 50$

Where $OTHRNDR\_P$ is the bleeding and block cracking combined as a percentage of pavement area and $OTHRNDR\_DE$ is the deduct due to bleeding and block cracking.

APPENDIX D

Pilot Study of Index Use

APPENDIX D - EVALUATION OF VDOT PAVEMENT MANAGEMENT DATA
AND RATING PROCEDURE
(Revised May 1998)

EXPLANATION AND INSTRUCTIONS

A. You are being asked to assist in evaluating the quality of the data delivered by the data collection and analysis contractor as taken from videotapes of the roadway. In this evaluation, a loop of roadway sections has been chosen and has been highlighted on the map provided. These sections have been chosen for the convenience of the exercise rather than on the basis of roadway condition. You will find a range of conditions.

B. You have received a listing and description of the sections you are asked to evaluate. The coordinator for the District you are working in has provided the information on the homogenous sections and will take the lead in evaluations while in his/her district.

C. You have also received distress/roughness graphs based on the 0.1-mile sections the contractor supplies. There will be one sheet per county for each route you are evaluating.

D. When you are ready to begin the evaluations you should travel in small groups (2 to 3 to a van). Using the distress/roughness graphs and the Worksheet provided, answer the first 6 questions for each homogeneous section you evaluate. Figure 1 of these instructions gives you an idea of what the 0 to 5 rating scale in Question 1 means. All evaluations should be a consensus of the people riding together.

E. As you evaluate a pavement section take a few minutes to look at the printout of the various Indexes (LDR, NDR, PRI, and CCI) for the section. Then, if your group has answered "Y" to <u>any part of Questions 4, 5, or 6 on the Worksheet,</u> proceed to answer Question No. 7. Remember that a pavement with any index below about 50 should be further evaluated for possible maintenance or rehabilitation.

F. Please be sure to answer every question as completely as you can, as every issue may be important in selling the future data to PMS users in VDOT.
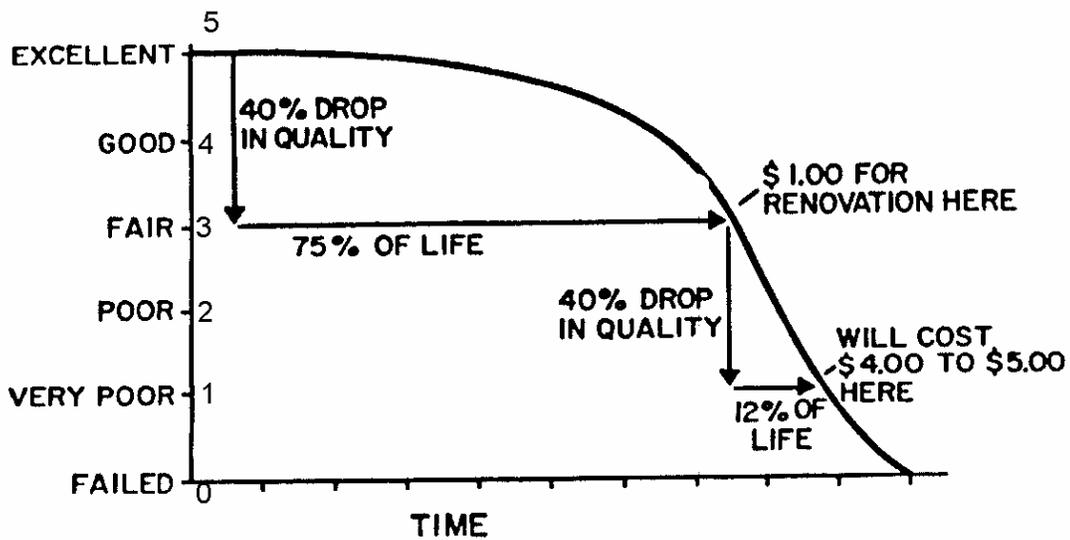
Figure 1. Typical pavement condition life cycle.

Description of Figure 1: Figure 1 is of a typical pavement performance curve based on a 0 to 5 scale. This kind of scale is used by some states and by the US Army Corps of Engineers to determine public perception of how well a road is serving its purpose. Typically, the public is concerned about how well a pavement rides and how it "looks" at normal traffic speeds. Highway employees look at pavement condition in a different way because they are concerned about cracking, etc. that they know will cause a problem if not addressed in a reasonable period of time. When you use this scale, don't even try to put yourself in the "shoes" of the public. Just rate the pavement on the basis of what you see and based on your own knowledge of pavements. You should note that a rating of 5 is a perfect pavement. Because of "as built" roughness very few brand new pavements rate over about 4.5, so keep that in mind as you assign your scores.

EVALUATION OF VDOT PAVEMENT MANAGEMENT DATA
AND RATING PROCEDURE
(Revised May 27, 1998)

Date _____   **Group**

Maintenance Jurisdiction_____ **Route No.** _____

Direction _____   **Begin MP** _____ **End MP**_____

1.   **Refer to the instructions on using a 0 to 5 scale in Pavement Evaluation and place an "X" at the point along the scale your group believes best characterizes this section of roadway.**

          | | | | | |

          0   1   2   3   4   5

              Failed   **Excellent**

2.   **What, if any, maintenance/rehabilitation treatment would you recommend for this road (based on what you see on the roadway? Please check a choice or explain "other treatment".**

      None Required _____   **Plant Mix Overlay_____**

      Chip Seal _____   **Mill & PM Overlay_____**

      Latex/Slurry Seal _____   **Patching _____**
      Crack Sealing _____

      Other (explain)

      _____

3.   **How long in years would you expect this pavement to perform satisfactorily without major maintenance or rehabilitation (i.e., overlay, mill and overlay, etc.)**

      __ **1-2 years**   __ **3-4 years**   __ **5 or more years**

4.   **Does the information given on the distress/roughness graph reasonably represent what you see on the roadway for this homogeneous section for each of the following categories? (Circle Y or N). Please comment when the answer is "N".**

      A.   Load Related Distresses   Y   N

_____

B.   **Non-load Related Distresses**   Y   N

_____

C.   **Roughness**   Y   N

_____

D.   **Rut Depth**   Y   N

_____

5.   **Is roughness an important concern on this road? Y   N**

Comment _____

6.   **Is rutting a safety issue that needs to be addressed on this road?   Y   N**

Comment _____

7.   **Do you think the following indexes are reasonable for the pavement you are evaluating and would they help you in making decisions on what to do with the pavement? (Please circle according to your opinion).**

	Reasonable?		**Helpful?**	
LDR **(load related distress)**	Y	N	Y	N

Comment _____

NDR **(non-load related)**	Y	N	Y	N

Comment_____

PRI **(roughness index)**	Y	N	Y	N

Comment _____

CCI **(combined index)**	Y	N	Y	N

Comment _____

Table D1 - SUMMARY OF PAVEMENT INDEX DATA EVALUATION

Section No.	A Q1	Q2	Q3	Q4A	Q4B	Q4C	Q4D	Q5	Q6	LDF	NDR	B Q1	Q2	Q3	Q4A	Q4B	Q4C	Q4D	Q5	Q6	LDF	NDR	C Q1	Q2	Q3	Q4A	Q4B	Q4C	Q4D	Q5	Q6	LDF	NDR
1	4.0	1	3	Y	Y	Y	Y	N	N	Y	Y	4.0	1	2	Y	Y	N	N	N	N	Y	Y	4.0	1	3	Y	Y	Y	Y	N	N	Y	Y
2	3.5	8	2	Y	Y	Y	Y	N	N	Y	Y	3.8	1	2	Y	Y	Y	Y	N	N	Y	Y	3.8	1	2	Y	Y	Y	Y	N	N	Y	Y
3	3.4	1	3	Y	Y	Y	Y	N	N	Y	Y	4.0	1	2	Y	Y	N	N	N	N	Y	Y	4.1	1	2	N	Y	Y	Y	N	N	N	Y
4	4.0	1	3	Y	Y	Y	Y	N	N	Y	Y	4.0	1	2	Y	Y	Y	N	N	N	Y	Y	4.2	1	3	Y	Y	Y	Y	N	N	Y	Y
5	2.5	6	1	Y	Y	Y	Y	Y	N	Y	Y	2.8	6	-	Y	Y	Y	Y	N	N	Y	Y	3.1	8	1	Y	Y	Y	Y	N	N	Y	Y
6	3.0	8	-	Y	Y	Y	Y	N	N	Y	Y	3.4	8	1	Y	Y	Y	Y	N	N	Y	Y	3.1	1	1	Y	Y	Y	Y	N	N	Y	Y
7	4.0	1	3	N	N	Y	Y	N	N	N	N	4.2	1	3	Y	Y	Y	Y	N	N	Y	Y	4.3	1	3	Y	N	Y	Y	N	N	Y	N
8	3.5	1	2	Y	Y	Y	Y	N	N	Y	Y	3.8	8	2	Y	Y	Y	Y	N	N	Y	Y	3.6	1	2	N	Y	Y	Y	N	N	N	Y
9	2.0	7	-	Y	Y	Y	Y	Y	N	Y	Y	2.5	7	-	Y	Y	Y	Y	N	N	Y	Y	3.0	7	-	Y	Y	Y	Y	N	N	Y	Y
10	3.5	8	2									3.0	8	2									3.8	8	2								
11	3.5	8	2									3.6	8	2									3.8	1	2								
12	4.2	8	3	Y	Y	Y	Y	N	N	Y	Y	3.6	1	2	Y	Y	Y	Y	N	N	Y	Y	4.0	8	3	Y	Y	Y	Y	N	N	Y	Y
13	4.4	8	2									3.5	8	2									3.8	8	3								
14	4.5	1	3									4.1	1	3									4.1	1	3								
15	4.5	1	3									4.2	1	3									4.0	1	3								
16	3.6	1	2									3.5	1	2									3.6	3	-								
17	3.5	1	2	Y	Y	Y	Y	N	N	Y	Y	3.8	1	2	Y	Y	Y	Y	N	N	Y	Y	4.0	4	3	Y	Y	Y	Y	N	N	Y	Y
18	3.6	1	3	Y	Y	Y	Y	N	N	Y	Y	3.8	1	2	N	Y	Y	Y	N	N	N	Y	4.0	1	3	Y	Y	Y	Y	N	N	Y	Y
19	3.4	1	2	Y	Y	Y	Y	N	N	Y	Y	3.5	8	2	N	Y	Y	N	N	N	Y	Y	4.2	1	3	Y	Y	Y	Y	N	N	Y	Y
20	2.1	6	-	Y	Y	Y	Y	N	N	Y	Y	2.5	6	-	Y	Y	Y	Y	N	N	Y	Y	3.2	6	-	Y	Y	Y	Y	N	N	Y	Y
21	4.2	1	3	Y	Y	Y	Y	N	N	Y	Y	4.2	1	3	Y	Y	Y	Y	N	N	Y	Y	4.3	1	3	Y	Y	Y	Y	N	N	Y	Y
22	3.6	1	2	Y	Y	Y	Y	N	N	Y	Y	3.2	1	2	N	Y	Y	Y	N	N	N	Y	4.0	1	2	Y	Y	Y	Y	N	N	Y	Y
23	3.5	1	2	Y	Y	Y	Y	N	N	Y	Y	3.6	1	3	Y	Y	Y	Y	N	N	Y	Y	3.8	1	3	Y	Y	Y	Y	N	N	Y	Y
23a	2.0	7	-	Y	Y	Y	Y	Y	N	Y	Y	2.8	7	-	Y	Y	Y	Y	N	N	Y	Y	2.5	7	-	Y	Y	Y	Y	N	N	Y	Y
24	2.0	7	-	Y	Y	Y	Y	Y	N	Y	N	2.0	7	-	Y	Y	Y	Y	N	N	Y	Y	2.1	7	-	Y	Y	Y	Y	N	N	Y	Y
25	1.6	7	-	Y	Y	Y	Y	N	N	Y	Y	2.6	7	-	Y	Y	Y	Y	Y	Y	Y	Y	2.2	7	-	Y	Y	Y	Y	N	N	Y	Y
26	3.5	1	2	N	Y	Y	Y	N	N	N	N	3.5	1	2	Y	Y	Y	Y	N	Y	N	Y	3.2	1	2	Y	Y	Y	Y	Y	N	Y	Y
27	2.0	7	-	Y	Y	Y	Y	N	Y	Y	Y	2.8	7	-	Y	Y	Y	Y	N	N	Y	Y	4.0	1	2	Y	Y	Y	Y	N	N	Y	Y
28	2.2	7	-	Y	Y	Y	Y	Y	Y	Y	Y	3.0	6	-	Y	Y	Y	Y	N	N	Y	Y	3.0	1	1								
29	3.0	6	-	Y	Y	Y	Y	N	N	Y	Y	3.2	8	1	Y	Y	Y	Y	N	N	Y	Y	4.0	1	3								
30	3.5	1	2	Y	Y	Y	Y	N	N	Y	Y	3.8	1	2	Y	Y	Y	Y	N	N	Y	Y	3.8	1	3	Y	Y	Y	Y	N	N	Y	Y
31	2.0	7	-	Y	Y	Y	Y	Y	Y	Y	Y	2.2	7	-	Y	Y	Y	Y	N	N	Y	Y	2.6	7	-	Y	Y	Y	Y	N	N	Y	Y
32	2.5	7	-	Y	Y	Y	Y	N	N	Y	Y	3.2	1	2	Y	Y	Y	Y	N	N	Y	Y	3.2	1	2	Y	Y	Y	Y	N	N	Y	Y
33	3.5	7	*	Y	Y	Y	Y	N	N	Y	Y	3.8	1	2	Y	Y	Y	Y	N	N	Y	Y	3.8	1	2	Y	Y	Y	Y	Y	Y	Y	Y
34	3.5	1	2			Y	Y	N	N	N	Y	3.8	8	1	Y	Y	Y	Y	N	N	Y	Y	3.5	1	2	Y	Y	Y	Y	N	N	Y	Y
35	3.5	1	2	Y	Y	Y	Y	N	N	Y	Y	3.8	1	1	Y	Y	Y	Y	N	N	Y	Y	4.2	1	3	Y	Y	Y	Y	N	N	Y	Y
36	2.0	7	-	Y	Y	Y	Y	Y	N	Y	Y	2.2	7	-	Y	Y	Y	Y	N	N	Y	Y	2.6	7	-	Y	Y	Y	Y	N	N	Y	Y
37	3.0	1	1									3.2	6	-									3.3	1	1								
38	2.5	7	-									2.8	7	-									3.6	1	1								
39	2.0	7	-									2.2	6	-									3.2	8	1								
40	2.5	7	-									2.5	7	-									2.5	7	-								
41	**											**											3.0	7	-								
42	2.0	7	-	Y	Y	Y	N	N	N	Y	Y	2.6	7	-	Y	Y	Y	Y	Y	Y	Y	Y	2.5	7	-	Y	Y	Y	Y	N	N	Y	Y
43	3.5	1	2									3.5	4	2									3.5	1	2								
44	3.0	1	1									3.2	1	1									3.5	1	2								
45	4.0	1	3									3.5	1	2									4.0	1	3								
46	3.5	1	2									3.1	1	1									3.4	1	2								
47	2.5	6	-									2.5	6	-									3.6	3	-								
48	4.0	1	3									3.2	5	2									3.8	1	2								
49	3.5	4,8	2									3.1	4,8	2									3.6	4,8	1								
50	3.2	4	2									3.2	4,8	2									-	3	-								
51	3.0	8	2									2.8	1	1									3.5	6	-								
52	3.5	8	2									2.8	6	-									3.3	6	-								
53	2.8	4	1									2.9	6	-									3.1	6	-								
54	2.6	6	-									2.3	6	-									2.5	6	-								
55	3.5	1	2									3.5	1	2									3.8	1	3								
56	3.1	8	1									3.0	8	1									3.2	4	2								
57	3.2	8	1	Y	Y	Y	Y	N	Y	Y	Y	2.0	7	-	Y	Y	Y	Y	N	N	Y	Y	3.2	1	1	Y	Y	Y	Y	N	Y	Y	Y
58	3.8	1	2	Y	Y	Y	Y	N	N	Y	Y	3.0	1	1	Y	Y	Y	Y	N	N	Y	Y	3.8	4	3	Y	Y	Y	Y	N	N	Y	Y
59	2.8	1	1	Y	Y	Y	Y	N	N	Y	Y	**	**	**	Y	Y	Y	Y	N	Y	Y	Y	3.0	8	1	Y	Y	Y	Y	N	Y	Y	Y
60	3.4	1	2	Y	Y	Y	Y	N	N	Y	Y	3.5	1	2	N	N	Y	Y	Y	N	N	N	3.8	1	2	Y	Y	Y	Y	N	N	Y	Y
61	2.5	7	-	N	Y	Y	Y	N	N	N	Y	3.0	1	1	Y	Y	Y	Y	N	N	Y	Y	3.0	1	1	N	Y	Y	Y	N	N	Y	Y
62	2.8	8	1	N	N	Y	Y	N	N	N	N	3.4	1	1	N	N	Y	N	Y	Y	N	Y	3.3	8	2	N	N	Y	Y	N	N	N	Y
63	2.8	8	1	Y	Y	Y	Y	N	N	Y	Y	2.7	6	-	Y	Y	Y	Y	N	N	Y	N	2.8	6	-	Y	Y	Y	Y	N	N	Y	Y
64	2.8	1	1	Y	Y	Y	Y	N	N	Y	Y	2.6	6	-	Y	Y	Y	Y	N	N	Y	Y	2.6	6	-	Y	Y	Y	Y	N	N	Y	Y
65	3.0	8	1	Y	Y	Y	Y	N	N	Y	Y	3.0	6	-	Y	Y	Y	Y	N	N	Y	Y	3.0	8	1	Y	Y	Y	Y	N	N	Y	Y
66	2.5	8	1	Y	Y	Y	Y	N	N	Y	Y	2.8	7	-	Y	Y	Y	Y	Y	N	Y	N	3.2	8	1	Y	Y	Y	Y	N	N	Y	Y
67	3.8	1	3	Y	Y	Y	Y	N	N	Y	Y	3.8	1	2	Y	Y	Y	Y	N	N	Y	Y	3.8	1	3	Y	Y	Y	Y	N	N	Y	Y
68	3.2	8	2	Y	Y	Y	Y	N	N	Y	Y	2.8	8	1	N	Y	Y	Y	N	N	N	Y	3.2	8	1	N	N	Y	Y	N	N	N	N
69	4.2	1	3	Y	Y	Y	Y	N	N	Y	Y	3.3	8	2	N	N	Y	Y	Y	N	N	N	3.8	1	2	N	N	Y	Y	N	N	N	N
Mean	3.15											3.19												3.45										
Star	0.09											0.07												0.07										
%Agreement				89	93	100	98			89	91				84	93	96	93			84	91				84	93	100	100			88	93

*Lanes not taped are failing.
** Section too variable to rate.

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APPENDIX E

HMAC Index Models

APPENDIX E –HMAC CONDITION INDEX MODELS

To build the indices data is used from 1/10th mile records. All index and intermediate numbers are calculated every 1/10th mile and then simply averaged for the homogenous sections (which are of variable length). The individual field names correspond to the ACCESS database field names. The units must be the same as those in the ACCESS tables. All intermediate and index names are shown in caps and italic, all field names are shown in caps.

LENGTH AND AREA CALCULATIONS
First calculate the actual length (*ACT_LEN*) of the section (typically 1/10 mile or 528 ft). This is done by subtracting the begin milepost from the end milepost. Note that the measured length is *not* used. If the actual length is 0 or less for a particular section (due to rounding) then it is ignored for any other calculations:

Equation 1

> *ACT_LEN* = 5280 * (END_MP – BEG_MP)
> Round to 0 decimals, delete section from further calculations if *ACT_LEN* is 0.

Next calculate three areas … the pavement area (*PAV_AREA*), the wheel path area (*WP_AREA*), and the non-wheel path area (*NWP_AREA*):

Equation 2

> *PAV_AREA* = 12 * *ACT_LEN*

Equation 3

> *WP_AREA* = 7 * *ACT_LEN*

Equation 3a

> *NWP_AREA* = *PAV_AREA* – *WP_AREA*

LOAD RELATED DISTRESS INDEX (LDR) CALCULATIONS
This is divided into initial calculations, individual deduct calculations and final index calculations:

Initial Calculations
The two types of patching are combined together into one number. High severity alligator cracking, potholes and delaminations are combined into another number. These two numbers as well as low and medium severity alligator cracking are then converted into percentage of wheelpath area:

Equation 4

Step 1

> *PAT_TOTSF* = L_PA1_SF + S_PA1_SF   (total patching sq. ft.)

$OTHRLD\_SF$ = A_CR3_SF + POT1_NO + DELAM1_SF   (total other load related distress sq. ft.)

Step 2

A_CR1_P = 100 * A_CR1_SF / WP_AREA (low severity alligator crk percentage)

if A_CR1_P > 100 then A_CR1_P = 100

A_CR2_P = 100 * A_CR2_SF / WP_AREA (med. severity alligator crk percentage)

if A_CR2_P > 100 then A_CR2_P = 100

PAT_TOP = 100 * PAT_TOTSF / PAV_AREA (total patching percentage)

if PAT_TOP > 100 then PAT_TOP = 100

PAT_WP = ($PAT\_TOP/WP\_AREA)*100$ (percentage wheel path patching)

$OTHRLDR\_P$ = 100 * $OTHRLD\_SF$ / WP_AREA (total other load related distress percentage)

if $OTHRLDR\_P$ > 100 then $OTHRLDR\_P$ = 100

Deduct Value Calculations

Individual deduct equations are used for rut depth, low severity alligator cracking, medium severity alligator cracking, total patching and other LDR distress

Rut deduct equation:

Equation 5

Step 1

if RUT_AVG > 0.65 then RUT_AVG = 0.65

Step 2

RUT_DED = - 634.132091 * RUT_AVG^3 + 686.305766 * RUT_AVG^2 - 60.384474 * RUT_AVG

Step 3

if RUT_DED > 75 then RUT_DED = 75

Step 4

if RUT_DED < 0 then RUT_DED = 0

Low severity alligator cracking deduct equation:

Equation 6

Step 1

A_CR1_DED = 0.000108 * A_CR1_P^{3} - 0.025576 * A_CR1_P^{2} + 2.056227 * A_CR1_P

Step 2

if A_CR1_DED > 58 then A_CR1_DED = 58

Medium severity alligator cracking deduct equation:

Equation 7

Step 1

$A\_CR2\_DED = 0.000189 * A\_CR2\_P^3 - 0.040419 * A\_CR2\_P^2 + 2.825464 * A\_CR2\_P$

Step 2

if $A\_CR2\_DED > 64$ then $A\_CR2\_DED = 64$

Total patching deduct equation:

Equation 8

Step 1

$PAT\_WP\_DED = 0.0002 * PAT\_WP^3 - 0.0419 * PAT\_WP^2 + 2.6117 * PAT\_WP$

Step 2

if $PAT\_WP => 50$ then $PAT\_WP\_DED = 50$

Total other load related distress deduct equation:

Equation 9

Step 1

$OTHRLD\_DED = 0.000245 * OTHRLDR\_P^3 - 0.051341 * OTHRLDR\_P^2 + 3.399676 * OTHRLDR\_P$

Step 2

if $OTHRLD\_DED > 68$ then $OTHRLD\_DED = 68$

Index Value Calculations

Load related index is calculated using the deducts shown above:

Equation 10

Step 1

$LDR = 100 - RUT\_DED - A\_CR1\_DED - A\_CR2\_DED - PAT\_WP\_DED - OTHRLD\_DED$

Step 2

if $LDR < 0$ then $LDR = 0$

NON-LOAD RELATED DISTRESS INDEX (NDR) CALCULATIONS
This is divided into initial calculations, individual deduct calculations and final index calculations:

Initial Calculations

Low severity transverse and longitudinal cracking are combined together into one number, medium severity transverse and longitudinal cracking are combined together into another number. The same process is used with reflective cracking. In addition a total reflective cracking number (across all severity levels) is also generated. Block

cracking and bleeding severities are combined into one number as well. All these numbers are then converted into the percentage of total pavement area:

Equation 11

Step 1

$LN1\_TOTLF = T\_CR1\_LF + L\_CR1\_LF$ (total low severity linear crk lin. ft.)

$LN2\_TOTLF = T\_CR2\_LF + L\_CR2\_LF$ (total high severity linear crk lin. ft.)

$RF1\_TOTLF = RCTJ1\_LF + RCLJ1\_LF$ (total low severity reflective crk lin. ft.)

$RF2\_TOTLF = RCTJ2\_LF + RCLJ2\_LF$ (total med. severity reflective crk lin. ft.)

$RF3\_TOTLF = RCTJ3\_LF + RCLJ3\_LF$ (total high. severity reflective crk lin. ft.)

$BLK\_TOTSF = B\_CR1\_SF + B\_CR2\_SF$ (total block crk sq. ft.)

$BLD\_TOTSF = BLEED1\_SF + BLEED2\_SF$ (total bleeding sq. ft.)

Finally, the percentage of non-wheel path patching is determined:

$PAT\_NWP = PAT\_TOP*NWP\_AREA/PAV\_AREA$ (percentage non-wheel path patching)

Step 2

$REF\_TOTLF = RF1\_TOTLF + RF2\_TOTLF + RF3\_TOTLF$ (total reflective crk lin. ft.)

Step 3

$LN1\_TOTP = 100 * LN1\_TOTLF / PAV\_AREA$ (total low severity linear crk percentage)

if $LN1\_TOTP > 100$ then $LN1\_TOTP = 100$

$LN2\_TOTP = 100 * LN2\_TOTLF / PAV\_AREA$ (total high severity linear crk percentage)

if $LN2\_TOTP > 100$ then $LN2\_TOTP = 100$

$RF1\_TOTP = 100 * RF1\_TOTLF / PAV\_AREA$ (total low severity reflective crk percentage)

if $RF1\_TOTP > 100$ then $RF1\_TOTP = 100$

$RF2\_TOTP = 100 * RF2\_TOTLF / PAV\_AREA$ (total medium severity reflective crk percentage)

if $RF2\_TOTP > 100$ then $RF2\_TOTP = 100$

$RF3\_TOTP = 100 * RF3\_TOTLF / PAV\_AREA$ (total high severity reflective crk percentage)

if $RF3\_TOTP > 100$ then $RF3\_TOTP = 100$

REF_TOTP = 100 * *REF_TOTLF* / *PAV_AREA*   (total reflective crk percentage)

if *REF_TOTP* > 100 then *REF_TOTP* = 100

OTHRNDR_P = 100 *(*BLK_TOTSF*+*BLD_TOTSF*)/ *PAV_AREA*   (total other non load distress %age)

if *OTHRNDR_P* > 100 then *OTHRNDR_P* = 100

Deduct Value Calculations

Individual deduct equations are used for low severity linear cracking, medium severity linear cracking, reflective cracking (low, medium and high severity) as well as patching and other non load distress.

Low severity linear cracking deduct equation:

Equation 12

Step 1

$$LIN1\_DED = 0.048 * LN1\_TOTP^{3} - 0.993 * LN1\_TOTP^{2} + 6.858 * LN1\_TOTP$$

Step 2

if *LIN1_DED* > 20 then *LIN1_DED* = 20

High severity linear cracking deduct equation:

Equation 13

Step 1

$$LIN2\_DED = 0.144 * LN2\_TOTP^{3} - 2.979 * LN2\_TOTP^{2} + 20.575 * LN2\_TOTP$$

Step 2

if *LIN2_DED* > 50 then *LIN2_DED* = 50

Low severity reflective cracking deduct equation:

Equation 14

Step 1

$$RF1\_DED = 0.048 * RF1\_TOTP^3 - 0.993 * RF1\_TOTP^2 + 6.858 * RF1\_TOTP$$

Step 2

if $RF1\_DED > 20$ then $RF1\_DED = 20$

Medium severity reflective cracking deduct equation:

Equation 15

Step 1

$$RF2\_DED = 0.144 * RF2\_TOTP^3 - 2.979 * RF2\_TOTP^2 + 20.575 * RF2\_TOTP$$

Step 2

if $RF2\_DED > 50$ then $RF2\_DED = 50$

High severity reflective cracking deduct equation:

Equation 16

Step 1

$$RF3\_DED = 0.274 * RF3\_TOTP^3 - 5.661 * RF3\_TOTP^2 + 39.093 * RF3\_TOTP$$

Step 2

if $RF3\_DED > 85$ then $RF3\_DED = 85$

Patching deduct equation:

Equation 17

Step 1

$$PAT\_NWP\_DED = 0.0002* PAT\_NWP^3 - 0.0419* PAT\_NWP^2 + 2.6117* PAT\_NWP$$

Step 3

if $PAT\_NWP => 50$ then $PAT\_NWP\_DED = 50$

Other non load distress deduct equation:

Equation 18

Step 1

`if $OTHRNDR\_P > 80$ then $OTHRNDR\_P = 80$

Step 2

$$OTHRND\_DE = -\,0.000037 * OTHRNDR\_P^3 + 0.00168 * OTHRNDR\_P^2 + 0.696257 * OTHRNDR\_P$$

Step 3

if $OTHRND\_DE > 50$ then $OTHRND\_DE = 50$

Index Value Calculations

Non load related index is calculated using the deducts shown above:

Equation 19

Step 1

$NDR=100\text{-}LIN1\_DED\text{-}LIN2\_DED\text{-}RF1\_DED - RF2\_DED - RF3\_DED - PAT\_NWP\_DED\text{-}OTHRND\_DE$

Step 2

if $NDR < 0$ then $NDR = 0$

OVERALL COMBINED CONDITION INDEX (CCI)

This is simply the individual index (LDR or NDR) with the smallest value:

Equation 20

CCI = Minimum of LDR, NDR

DATA REPORTING

A typical homogenous section report should consist of index values as well as raw data and intermediate values. All these are averaged from 1/10th mile calculations.

> ***Raw Data & Intermediate Values***
> > VEH_SPD   (vehicle speed)
> > IRI_AVG   (avg. IRI of both wheelpaths)
> > RUT_AVG   (avg. Rut Depth of both wheelpaths)
> > A_CR1_P   (low severity alligator crk percentage)
> > A_CR2_P   (med. severity alligator crk percentage)
> > PATWP_TOP   (total patching percentage)
> > OTHRLDR_P   (total other load related distress percentage)
> > LN1_TOTP   (total low severity linear crk percentage)
> > LN2_TOTP   (total high severity linear crk percentage)
> > REF_TOTP   (total reflective crk percentage)
> > PATPAV_TP   (total patching percentage)
> > OTHRNDR_P   (total other non load distress percentage)

> ***Index Values***
> > LDR   (load related distress index)
> > NDR   (non-load related distress index)
> > CCI   (combined condition index)

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