Transition from Manual to Automated Pavement Distress Data Collection and Performance Modelling in the Pavement Management System

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ABSTRACT

Since 2013, the Ministry of Transportation Ontario (MTO) has been making the transition from manual to fully automated network pavement condition data collection, detection and distress characterization using a new generation of Automated Road Analyzer (ARAN) equipped with Laser Crack Measurement Systems (LCMS) and associated software. The ARAN's subsystems are configured to measure, record and provide continuous output for multiple data streams. Pavement condition data collected by MTO's ARAN is recorded and processed using the Pave3D software suite.

Subsystems discussed in this paper include the high speed inertial profiler that measures and report the pavement roughness as International Roughness Index (IRI) and automated LCMS systems that capture rutting, cracking and macrotexture data. The new MTO ARAN subsystems are capable of providing accurate and repeatable measurements of pavement distresses. A few distresses such as raveling, flushing, shoving and distortion are detected by the ARAN subsystems but the distress categorization algorithms are under development or being completed.

In the interim, the ministry has developed three DMI and three PCI formulations based on manual, automated LCMS and a combination of manual and automated LCMS rating datasets. Comparison and validation analyses of these formulations were performed using data collected from 934 pavement segments surveyed both by manual visual and automated LCMS methods. Conversion of automated LCMS distress rating into equivalent manual distress rating is presented. This conversion is necessary to provide compatible distress rating value for the existing PMS/AMS system to function.

This paper presents the development and validation of the interim pavement performance indices obtained using the various combinations of manual and automated distress datasets and rating formulations.

Automated LCMS distress data collection changed the way how some pavement distresses are detected, characterized, evaluated and reported. An opportunity exists as part of this transition, to use selective automated LCMS metrics that will provide harmonization of metrics used and direct linkages between metrics measured and pavement performance in the pavement design, contract specification, construction acceptance, maintenance and pavement management activities.

1. BACKGROUND

The Ministry's network pavement distress data collection is traditionally done using manual visual rating method. This manual visual distress rating is usually conducted by Pavement Design Evaluation Officer (PDEO) and the rating result is compiled using a computerized application called Pavement Distress Data Collection (PDDC). Since 2013, the Ministry's network pavement condition rating has transitioned from manual visual rating (PDDC) to full automated LCMS distress data collection using a new generation of Automated Road Analyzer (ARAN) equipped with 2D and 3D laser systems. Transition to automated LCMS distress rating provides an opportunity to improve staff safety by reducing exposure to traffic related work. In addition, the automated method also provides distress rating metrics that are objective, data is sampled a very high rate at highway speed, results that are repeatable and accurate which lend itself to be used in performance based specification.

Some of the pavement distress metrics collected using the new Laser Crack Measurement Systems (LCMS) are different from those of the traditional manual method. Since 2013, developments and assessments were performed to assess how these new LCMS distress metrics contribute/impact the individual and composite Distress Manifestation Index (DMI); Pavement Condition Index (PCI); strategy selection decision trees and budgeting models.

To maintain the functionality of the existing Pavement Management System (PMS)/Asset Management System (AMS), these new LCMS metrics and rating results need to be converted into equivalent manual rating metrics that are compatibility to requirements of the current PMS/AMS. Development and assessment of DMI computations using manual, LCMS and combined manual and LCMS methods are presented.

From 2015 onwards, the ministry's network pavement distress data collection will be using only the automated method except for surface treated and gravel highways.

1.1 Current Pavement Condition Index

PCI is composed of two sub-indices namely International Roughness Index (IRI) and DMI. IRI is a representation of the pavement roughness, whereas DMI is a representation of the distress manifestation. These two indices when combined under a certain formulation would provide a PCI value for a defined performance range that represents the overall pavement condition. PCI formulas are unique for different pavement types, and below is an example of the PCI calculation for asphalt pavement:

AC Pavement: $PCI = Max(0, Min(100, 13.75 + 9 \times DMI - 7.5 \times IRI))$

Where,

PCI is the pavement condition index, ranging from 0 to 100
DMI is the subjective distress manifestation index, theoretically ranging from 0 to 10, where 0 indicates the worst condition and 10 represents the excellent condition
IRI is the international roughness index

DMI is a critical component that contributes to the overall PCI for all pavement types. This report presents the development and verification of DMIs based on manual, LCMS and a combined manual methods for asphalt pavement. New DMI computation which involved only the fully automated data collection by ARAN is expected to be implemented by 2017.

2. DISTRESS MANIFESTATION INDEX COMPUTATION

2.1 Manual Visual Distress Data DMI

Prior to 2013, the conventional way to calculate DMI is based on the manual rated pavement distress data (1). DMI is a subjective rating index, theoretically ranging from 0 to 10, where 0 indicates the worst pavement condition and 10 represents a perfect pavement. For the purpose of this study, the focus is to evaluate and validate the asphalt pavement model only.

Below is the Manual Distress DMI calculation:

$$\boldsymbol{DMI} = \frac{\boldsymbol{DMI_{max}} - \sum_i^N (S_i + D_i) \times W_i}{\boldsymbol{DMI_{max}}} \times 10$$

Where,

$\mathbf{DMI_{max}}$ is the maximum DMI value, which assumes all distresses reach the most severe condition and extent. The DMI_{max} is a constant value based on different pavement types, and asphalt concrete (AC) pavement = 208

N is the number of distresses on the pavement
$\mathbf{S_i}$ represents the severity rate of distress i
rate value ranges from 0.5 to 4, where 0.5 represents very slight and 4 represents very severe
$\mathbf{D_i}$ represents the density rate of distress i
rate value ranges from 0.5 to 4, where 0.5 represents few (<10%) and 4 represents throughout (>80%)
$\mathbf{W_i}$ is weighting factor of distress i (refer to Table 1 below)

Table 1: AC Pavement Distress Weighting Factors (2)

No.	***Distress Type***	***Weight (W_i)***
1	Ravelling and Coarse Aggregate Loss	3.0
2	Flushing	1.5
3	Rippling and Shoving	1.0
4	Wheel Track Rutting	3.0
5	Distortion	3.0

No.	Distress Type	Weight (W_i)
6	Longitudinal Wheel Track: Single and Multiple	1.5
7	Longitudinal Wheel Track: Alligator	3.0
8	Centreline: Single and Multiple Cracking	0.5
9	Centreline: Alligator Cracking	2.0
10	Pavement Edge: Single and Multiple Cracking	0.5
11	Pavement Edge: Alligator Cracking	1.5
12	Transverse: Half, Full and Multiple Cracking	1.0
13	Transverse: Alligator Cracking	3.0
14	Longitudinal Meandering and Midlane Cracking	1.0
15	Random Cracking	0.5

2.2 Automated Distress Data DMI

DMI using automated LCMS distress data is calculated and displayed in a software platform called Vision. This DMI only include cracking distresses in the computation, unlike DMI done using manual rating method in section 2.1 that include other distresses (ie, flushing, distortion, ravelling, etc.).

There are total of 15 distress types used in the manual rating method to determine the DMI value of the AC pavement. LCMS data was collected for all these 15 distresses with some collected under new metrics and/or format. Detection and distress categorization algorithms were completed for 11 of these distress types (mainly cracking data) with the remaining under development or just being completed. Macrotexture data is collected and being used to develop segregation, ravelling and friction models. Map cracking is included and identified as either longitudinal and transverse cracks or pattern cracking.

Table 2 below shows the distresses captured by ARAN's systems and the status of the distress characterization and rating development.

Table 2: Distress Types Captured by ARAN

Individual Distresses for Asphalt Concrete (AC) Pavement	Detected/Rated by ARAN or LCMS
Ravelling and Coarse Aggregate Loss	✓
Flushing	Under development
Rippling and Shoving	Under development
Wheel Track Rutting	✓
Distortion	Under development
Longitudinal Wheel Track: Single / Multiple	✓
Longitudinal Wheel Track: Alligator	✓
Longitudinal Meandering and Midlane	✓

Individual Distresses for Asphalt Concrete (AC) Pavement	Detected/Rated by ARAN or LCMS
Transverse: Half, Full and Multiple	✓
Transverse: Alligator	✓
Centreline: Single and Multiple	✓
Centreline: Alligator	✓
Pavement Edge: Single and Multiple	✓
Pavement Edge: Alligator	✓
Random/Map	✓

Numerous iterations of regression analysis were carried out to establish a Crack-Only DMI formula. Below are the automated distress based DMI calculations being adopted, containing different weighting factors for the three major types of cracking – longitudinal, transverse and pattern. The Crack-Only DMI has a scale of 100; hence it is named DMI_{100}.

$$\boldsymbol{DMI100} = (0.4 \times \boldsymbol{DMI\ long}) + (0.5 \times \boldsymbol{DMI\ trans}) + (0.1 \times \boldsymbol{DMI\ gator})$$

Where,

$$\boldsymbol{DMI\ long} = 100 \times (1 - \frac{0.8\boldsymbol{A} + \boldsymbol{B} + 1.2\ \boldsymbol{C}}{4 \times |\boldsymbol{D}|})$$

$$\boldsymbol{DMI\ trans} = 100 \times (1 - \frac{0.8\boldsymbol{A} + \boldsymbol{B} + 1.2\ \boldsymbol{C}}{1 \times |\boldsymbol{D}|})$$

$$\boldsymbol{DMI\ gator} = 100 \times (1 - \frac{0.8\boldsymbol{A} + \boldsymbol{B} + 1.2\ \boldsymbol{C}}{3.6 \times |\boldsymbol{D}|})$$

A = *Extent of Slight Crack*
B = *Extent of Moderate Crack*
C = *Extent of Severe Crack*
D = Section length

2.3 Development of Hybrid DMI

As the ministry transition from manual to automated LCMS method, the interim DMI calculation is computed using automated distress metrics where available, with the remaining metrics supplemented using the PDDC data. Work is underway to complete the remaining distress categorization and rating to enable fully automated distress DMI computation in near future. Table 3, shows the distress types, its associated data source used in the Hybrid DMI development.

Table 3: Distress Type and Data Source

ID	Distress	Data Source
101	Ravelling & Coarse Aggregates Loss	PDDC (ARAN developed)
102	Flushing	PDDC (ARAN under development)
103	Rippling and Shoving	PDDC (ARAN under development)
104	Wheel Track Rutting	ARAN
105	Distortion	PDDC (ARAN under development)
106	Wheel Track Single and Multiple Cracking	ARAN
107	Wheel Track Alligator Cracking	ARAN
108	Centreline Single and Multiple	ARAN
109	Centreline Alligator Cracking	ARAN
110	Pavement Edge Single and Multiple	ARAN
111	Pavement Edge Alligator Cracking	ARAN
112	Transverse Half, Full and Multiple Cracking	ARAN
114	Longitudinal Meander and Mid-lane Cracking	ARAN
116	Mid-lane Alligator Cracking	ARAN (not in PDDC)
113	Transverse Alligator	ARAN (Rated as other alligators)
115	Random or Map Cracking	ARAN (Rated as transverse or longitudinal cracking)

2.3.1 Data Transformation from Vision to PDDC Format (3)

LCMS automated distress rating in the Vision platform quantifies the distress using cumulative length or area and the average crack width/size of each severity of the distress; whereas the PDDC manual method uses only the predominant extent and severity of that distress. Hence, to provide compatibility to existing PMS2/AMS system that uses the PDDC results, the LCMS automated data/results have to be transformed into equivalent PDDC data/results. This interim DMI will be used until a new set of DMI, deterioration curves, PCI and decision trees can be developed based on sufficient years of LCMS automated data.

The Section below shows the conversion processes for LCMS distress data into PDDC manual rating for longitudinal cracking, transverse cracking, alligator cracking and rut depth measurements.

Longitudinal Cracking:

Table 4: Longitudinal Cracking Severity Conversion

PDDC / SP-024			Vision / ARAN		
Severity	**Crack Width**	**Rating**	**Severity**	**Crack Width**	**Conversion to PDDC Rating**
Very Slight	< 3mm	0.5	--	--	(1 * Slight Cracking Length + 2 * Moderate cracking length + 3 * Severe cracking length) / Total Cracking Length
Slight	3 ~ 12 mm	1	Slight	<10 mm	
Moderate	12 ~ 19 mm	2	Moderate	10 ~ 20 mm	
Severe	19 ~ 25 mm	3	Severe	> 20 mm	
Very Severe	> 25 mm	4	--	--	

Table 5: Longitudinal Cracking Density Conversion

PDDC / SP-024			Vision / ARAN	
Density	**Affected Area**	**Rating**	**Density**	**Conversion to PDDC Rating**
Few	< 10%	0.5	Total length of cracking grouped by severity	**Density**: Use total cracking length/surveyed length to obtain the percentage. **Rating**: Use the max rating, 4 times the percentage to convert to PDDC rating scale
Intermittent	10 ~ 20%	1		
Frequent	20 ~ 50%	2		
Extensive	50 ~ 80%	3		
Throughout	> 80%	4		

Transverse Cracking:

Table 6: Transverse Cracking Severity Conversion

PDDC / SP-024			Vision / ARAN		
Severity	**Crack Width**	**Rating**	**Severity**	**Crack Width**	**Conversion to PDDC Rating**
Very Slight	< 3mm	0.5	--	--	(1 * Slight Cracking Length + 2 * Moderate cracking length + 3 * Severe cracking length) / Total Cracking Length
Slight	3 ~ 12 mm	1	Slight	<10 mm	
Moderate	12 ~ 19 mm	2	Moderate	10 ~ 20 mm	
Severe	19 ~ 25 mm	3	Severe	> 20 mm	
Very Severe	> 25 mm	4	--	--	

Table 7: Transverse Cracking Density Conversion

PDDC / SP-024			Vision / ARAN	
Density	Affected Area	Rating	Density	Conversion to PDDC Rating
Few	> 40m apart	0.5	Total length of cracking grouped by severity	Assume cracks are evenly distributed, distance of transverse crack **(Density):** Survey length/(total cracking length/lane width of 3.6 m)
Intermittent	30~40m apart	1		
Frequent	20 ~ 30m apart	2		
Extensive	10 ~ 20m apart	3		
Throughout	< 10m apart	4		

Alligator Cracking:

Table 8: Alligator Cracking Severity Conversion

PDDC / SP-024			Vision / ARAN		
Severity	Crack Width	Rating	Severity	Crack Width	Conversion to PDDC Rating
Very Slight	< 3mm	0.5	--	--	(1 * Slight Area + 2 * Moderate Area + 3 * Severe Area) / Total Alligator Area
Slight	3 ~ 12 mm	1	Slight	<10 mm	
Moderate	12 ~ 19 mm	2	Moderate	10 ~ 20 mm	
Severe	19 ~ 25 mm	3	Severe	> 20 mm	
Very Severe	> 25 mm	4	--	--	

Table 9: Alligator Cracking Density Conversion

PDDC / SP-024			Vision / ARAN	
Density	Affected Area	Rating	Density	Conversion to PDDC Rating
Few	< 10%	0.5	Total area of alligator cracking grouped by severity	**Density**: Use (total area of alligator cracking)/(total zone area) to obtain the occurrence percentage. **Rating**: Use the max rating, 4 times the percentage to convert to PDDC rating scale
Intermittent	10 ~ 20%	1		
Frequent	20 ~ 50%	2		
Extensive	50 ~ 80%	3		
Throughout	> 80%	4		

Rut Depth Measurement:

Table 10: Rut Depth Severity Conversion

PDDC / SP-024			Vision / ARAN	
Severity	**Rut Depth**	**Rating**	**Severity**	**Conversion to PDDC Rating**
Very Slight	3~6 mm	0.5	Reported as average rut depth for the entire section	Conversion by rating scale (same as PDDC/SP-024 scale)
Slight	7 ~ 12 mm	1		
Moderate	13 ~ 19 mm	2		
Severe	19 ~ 25 mm	3		
Very Severe	> 25 mm	4		

Table 11: Rut Depth Density Conversion

PDDC / SP-024			Vision / ARAN	
Density	**Affected Area**	**Rating**	**Density**	**Conversion to PDDC Rating**
Few	< 10%	0.5	Calculate the total surveyed length where rut depth >3mm	If average Rut depth>3mm, then assuming 80% area is affected, therefore always use 3 as density rating for rut
Intermittent	10 ~ 20%	1		
Frequent	20 ~ 50%	2		
Extensive	50 ~ 80%	3		
Throughout	> 80%	4		

2.3.2 New Hybrid DMI Computation

Conversion of some of LCMS automated distress ratings into equivalent PDDC manual ratings are described in the previous Section. The distress types, distress sources and the associated weighting factors used to determine the DMI_{max} are shown in Table 12. To compute this Hybrid DMI for AC pavement, 14 distress types were included, 10 distress types using LCMS automated distress rating and 4 distress types using PDDC manual rating.

Table 12: Distress Types and Weighting Factors for New Hybrid DMI

ID	Distress	Weight Factor	Max Severity	Max Extent	DMI_{max}	Data Source
101	Ravelling & Coarse Aggregates Loss	3	4	4	24	PDDC
102	Flushing	1.5	4	4	12	PDDC
103	Rippling and Shoving	1	4	4	8	PDDC
104	Wheel Track Rutting	3	4	4	24	ARAN
105	Distortion	3	4	4	24	PDDC
106	Wheel Track Single and Multiple Cracking	1.5	3	4	10.5	ARAN
107	Wheel Track Alligator Cracking	3	3	4	21	ARAN
108	Centreline Single and Multiple	0.5	3	4	3.5	ARAN
109	Centreline Alligator Cracking	2	3	4	14	ARAN
110	Pavement Edge Single and Multiple	0.5	3	4	3.5	ARAN
111	Pavement Edge Alligator Cracking	1.5	3	4	10.5	ARAN
112	Transverse Half, Full and Multiple Cracking	1	3	4	7	ARAN
114	Longitudinal Meander and Mid-lane Cracking	1	3	4	7	ARAN
116	Mid-lane Alligator Cracking	3	3	4	21	ARAN (not in SP024)
113	Transverse Alligator	3	4	4	24	Rated as other alligators
115	Random or Map Cracking	0.5	4	4	4	Rated as trans or long cracking

In the interim, to provide continuity and compatibility with existing PMS/AMS systems, an interim Hybrid DMI was developed using as much of the automated LCMS distress rating with completed categorization algorithms so as to mimic as close as possible the distress dataset used in the PDDC rating system. This new interim Hybrid DMI will use similar DMI_{max} formulas, the difference being some of the LCMS distress ratings will be converted into severity and extent ratings of equivalent PDDC distress types:

$$Hybrid\ DMI = \frac{DMI_{max} - \sum_i^N (S_i + D_i) \times W_i}{DMI_{max}} \times 10$$

Where,

N = 14, is the number of distresses on the pavement
S_i represents the severity rate of distress I

- For distress from PDDC, directly use the rating value
- For distress from Vision; **S_i =**(1*slight quantity + 2* moderate quantity + 3* severe quantity) / total quantity

D_i represents the density rate of distress i

- For distress from PDDC, directly use the rating value
- For distress from Vision; **D_i =** 4*(total distress quantity / surveyed length or area)

W_i is weighting factor of distress i
DMI_{max} = 190

3. DATA VALIDATION

In 2013, both PDDC manual visual and automated LCMS distress data collection and ratings were concurrently performed on 934 pavement segments through the province. These datasets provide the basis to assess and validate the suitability of using the automated LCMS distress data and rating to develop new DMI and PCI formulations. Impact on DMI value of the 934 pavement segments were assessed using the three types of DMI formulations below:

- PDDC DMI – calculated based on PDDC data (manual distress data collection)
- Crack-Only DMI (or DMI_{100}) – calculated based on LCMS crack types with completed crack detection and characterization rating algorithms (raveling, distortion, flushing under development)
- Hybrid DMI – ARAN cracking data + remaining distress from PDDC

The conventional PMS2/AMS system uses the PDDC manual rating data to compute the DMI (PDDC DMI), hence, this PDDC DMI will be used as the baseline for comparison. Both automated distress Crack-Only DMI and new Hybrid DMI are compared against the baseline. The automated distress Crack-Only DMI's scale ranges from 0 to 100, it is divided by 10 in this study to provide an equivalent 10 base scaled comparison. Although the objective is to verify the new Hybrid DMI computation, it is also important to validate if automated Crack-Only DMI alone will result in an acceptable computation.

3.1 DMI Comparison

Table 13 and Figures 1 and 2 below show the distribution of the DMI differences for the Crack-Only DMI and the Hybrid DMI compared to the PDDC DMI (baseline DMI).

Table 13: Distribution of DMI Differences

DMI Difference	PDDC DMI vs Hybrid DMI		PDDC DMI vs Crack-Only DMI	
	Number of Sections	Percent	Number of Sections	Percent
-2.5 ~ -2.0	0	0.0%	1	0.1%
-2.0 ~ -1.5	1	0.1%	4	0.4%
-1.5 ~ -1.0	2	0.2%	5	0.5%
-1.0 ~ -0.5	79	8.5%	25	2.7%
-0.5 ~ 0.0	338	36.2%	116	12.4%
0.0 ~ 0.5	351	37.6%	270	28.9%
0.5 ~ 1.0	119	12.7%	236	25.3%
1.0 ~ 1.5	37	4.0%	167	17.9%
1.5 ~ 2.0	4	0.4%	73	7.8%
2.0 ~ 2.5	3	0.3%	27	2.9%
2.5 ~ 3.0	0	0.0%	8	0.9%
3.0 ~ 3.5	0	0.0%	1	0.1%
3.5 ~ 4.0	0	0.0%	1	0.1%
Sum	934	100%	934	100%
Correlation (R^2)	**0.88**		**0.67**	

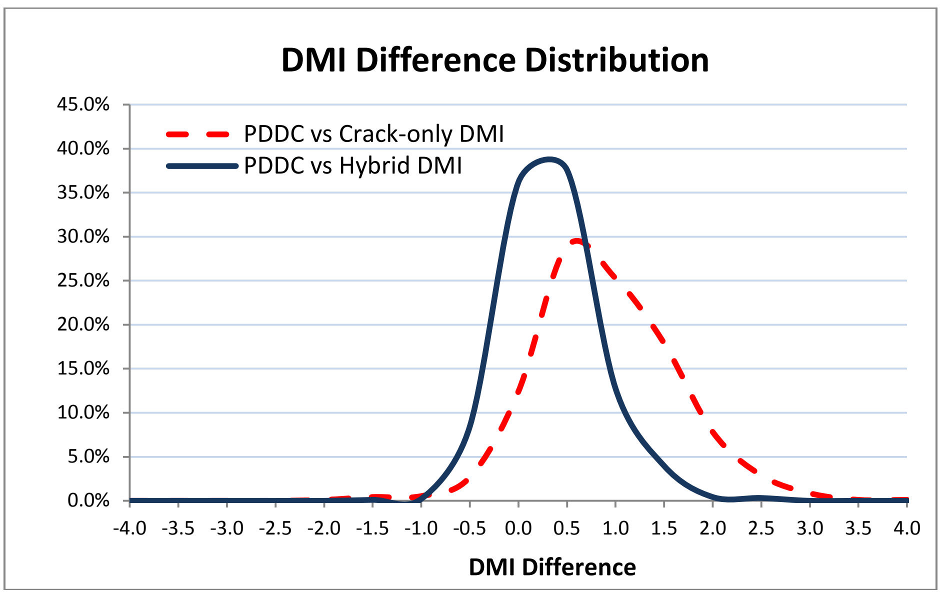

Figure 1: Graphical Distribution for DMI Differences

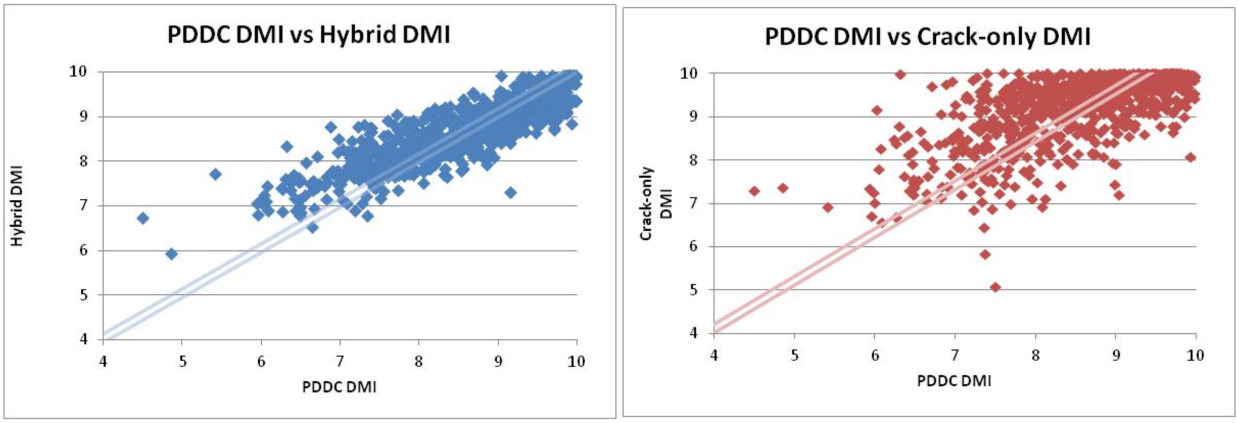

Figure 2: Correlation Comparison of PDDC vs Hybrid DMI and Crack-Only DMI

For the PDDC DMI versus Hybrid DMI, the analysis shows 95% (887 sections) having DMI differences less than 1.0 unit, and 75% (689 sections) having DMI difference less than 0.5 unit.

The graphs show the DMI differences between the Hybrid DMI versus PDDC DMI is less than the Crack-Only DMI versus PDDC DMI for same pavement segments. Results indicated the correlation of the Hybrid DMI is better than the Crack-Only DMI with R-squared values of 0.88 and 0.67, respectively.

<u>3.2 PCI Comparison</u>

Pavement Condition Index (PCI) is a numerical scaled index that provides a representation of the overall pavement condition. PCI is a calculated composite index that is dependent on pavement types (concrete, asphalt, composite, surface treated), IRI and DMI. The ministry Pavement Management System (PMS2) uses the PCI value to determine and project the network pavement performance and budget allocation. Therefore, it is important to assess the impact on PCI value as determined by the Hybrid DMI, Crack-Only DMI and PDDC DMI.

Similarly to the DMI comparison, the traditional PDDC PCI or PMS2 PCI is used as a baseline for PCI assessment comparison.

The Hybrid PCI is calculated using the PCI equation in PMS2 by substituting the PDDC DMI with Hybrid DMI as shown below:

Hybrid PCI *= Max (0,Min (100, 13.75 + 9 x Hybrid DMI – 7.5 x IRI))*

In the Crack-Based PCI formulation, other than it being a function of scaled IRI, the rut component of pavement distress is a separate independent factor with the remaining distresses included in the Crack-Only DMI as shown below:

Crack-Based PCI *= 0.7 x Scaled IRI + 0.2 x Crack-Only DMI + 0.1 x Scaled Rut*

Where **Scaled IRI** = 100 * (1 - IRI / 5)
Scaled Rut = 100 * (1 – Rut / 30)

Table 14 and Figure 3 show the distribution of the PCI differences for the Crack-Based PCI and Hybrid PCI compared to the PMS-2 PCI.

Table 14 Distribution of PCI Differences

PCI Difference	PMS2 PCI vs Hybrid PCI		PMS2 PCI vs Crack-based PCI	
	Number of Sections	Percent	Number of Sections	Percent
<-40	0	0.0%	0	0.0%
-40 ~ -35	0	0.0%	0	0.0%
-35 ~ -30	0	0.0%	0	0.0%
-30 ~ -25	0	0.0%	0	0.0%
-25 ~ -20	0	0.0%	1	0.1%
-20 ~ -15	1	0.1%	4	0.4%
-15 ~ -10	2	0.2%	5	0.5%
-10 ~ -5	79	8.5%	25	2.7%
-5 ~ 0	338	36.2%	116	12.4%
0 ~ 5	351	37.6%	270	28.9%
5 ~ 10	119	12.7%	236	25.3%
10 ~ 15	37	4.0%	167	17.9%
15 ~ 20	4	0.4%	73	7.8%
20 ~ 25	3	0.3%	27	2.9%
25 ~ 30	0	0.0%	8	0.9%
30 ~ 35	0	0.0%	1	0.1%
35 ~ 40	0	0.0%	1	0.1%
SUM	934	100%	934	100%
Correlation (R^2)	0.94		0.84	

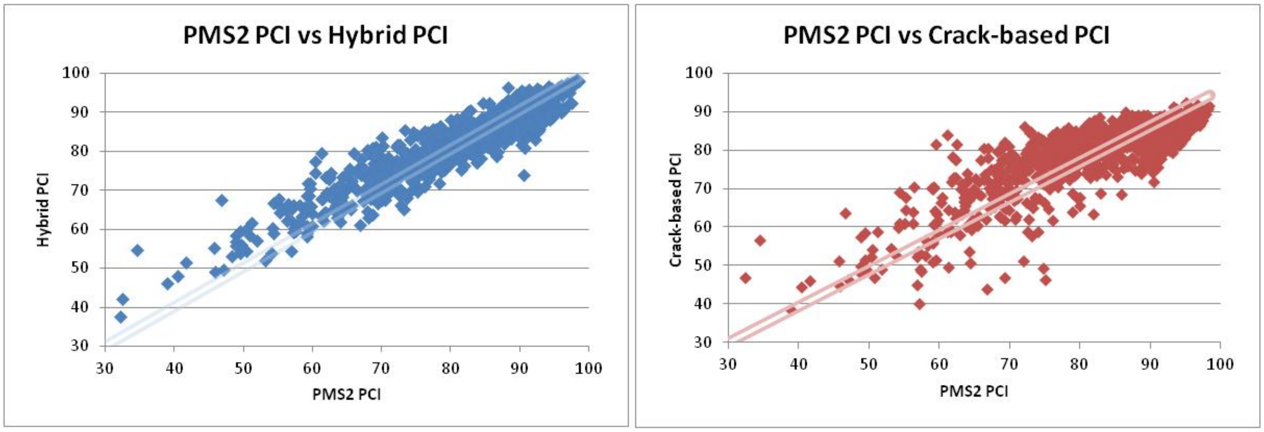

Figure 3: Correlation Comparison of PMS-2 PCI vs Hybrid PCI and Crack-Based PCI

From the analyses of PMS2 PCI (baseline) versus. Hybrid PCI and Crack-Based PCI, the graphs show the PCI correlation for the Hybrid PCI is better than the Crack-Based PCI with R-squared values of 0.94 and 0.84, respectively. This indicates the Hybrid PCI provides a better replacement of PDDC PCI value than Crack-Based PCI.

3.2.1 PCI and Network Performance

In the ministry pavement condition reporting, one of the metric uses the highway functional class and three different thresholds of PCIs to classify a pavement segment to be in the good-fair-poor condition. Table 15 below shows the PCI thresholds used in the ministry's PMS-2.

Table 15: Pavement Network Performance PCI Threshold

Function Class	Good	Fair	Poor
Freeway	PCI>=75	75>PCI>=65	PCI<65
Arterial	PCI>=75	75>PCI>=55	PCI<55
Collector	PCI>=70	70>PCI>=50	PCI<50
Local	PCI>=65	65>PCI>=45	PCI<45

To study the impact on PCI computed and the reporting of pavement condition using the various DMI and PCI formulations developed, a total of 15,165 km of pavement section was assessed excluding pavement segments with surface treatment. Figure 4 summarizes the results of pavement condition distribution for the provincial network using the three different PCI computation methods developed.

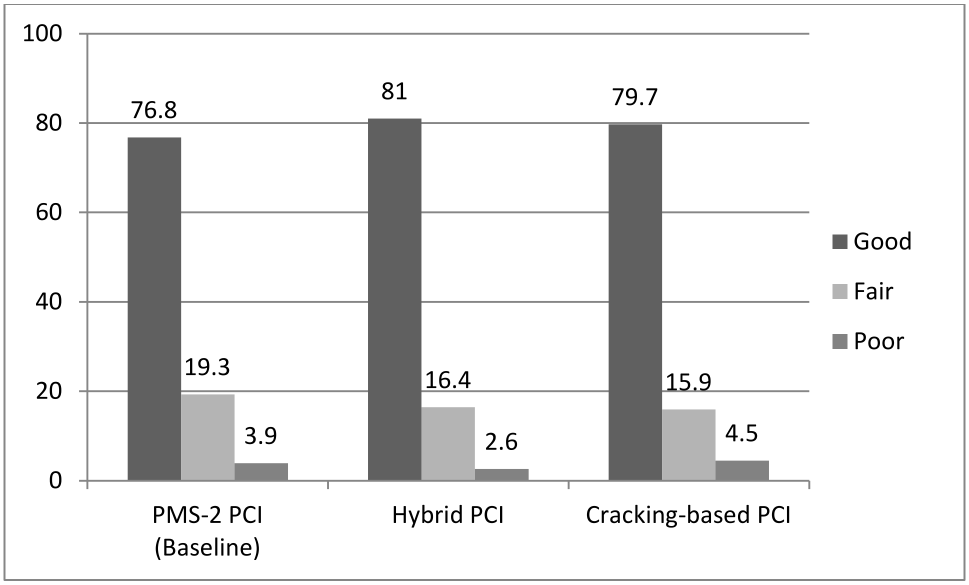

Figure 4: Provincial Network Performance Distribution for Different PCI

Using PMS-2 PCI as the baseline for comparison, the Hybrid PCI and the Crack-Based PCI under-predict the pavement in “poor and fair category” by about 4 and 3 percent, respectively. It is important to note the network impact difference between Hybrid PCI and Crack-Based PCI are minimal, with less than 2% difference in all good-fair-poor categories. The new automated LCMS distress method collects, detects and rates the distresses differently. Hence, it should be expected that reported results may be different. Interim formulations of DMI and PCI are based on regressions that will provide a result as similar as possible.

This section presents the DMI correlations, PCI correlations and the network performance impact compared to the baseline PDDC DMI and PMS-2 PCI. Table 16 below is the summary of the analysis showing the comparison to the baseline.

Table 16: Summary of the Impact of Different DMI Computations

	Hybrid (PDDC + ARAN)	**Crack-Only (ARAN)**
DMI Correlations	**0.88**	0.67
PCI Correlations	**0.94**	0.84
Network Performance Impact (Difference)	Good = 4.2	Good = **2.9**
	Fair = **2.9**	Fair = 3.4
	Poor = 1.3	Poor = **0.6**

The table shows the use of the Hybrid DMI calculation has much better DMI and PCI correlations to PDDC based DMI and PCI results.

Overall, both Hybrid DMI and Crack-Only DMI calculations generate acceptable DMI and PCI results for correlation to PDDC DMI and PCI and at reporting the network pavement condition.

4. CONCLUSIONS AND RECOMMENDATIONS

DMI is a critical index that contributes to the overall PCI value. This study uses the data from 934 AC pavement segments that were surveyed using the manual visual PDDC and automated LCMS methods to assess the various DMI and PCI formulations developed. Results from this study will facilitate the ministry's transition from manual visual metrics to automated LCMS metrics for pavement performance modelling, pavement design, construction administration and pavement management.

Up to 2014 with PDDC data being available, it was beneficial to include the PDDC data for the hybrid DMI calculation as it provides better DMI and PCI correlations. From 2015 onwards no new PDDC data will be available, replacement of PDDC distresses with equivalent automated LCMS metrics under development will need to be employed. However, the analyses indicated the Crack-Only DMI (ARAN cracking data only) will still provide an acceptable DMI and PCI results for network level pavement management administration if necessary.

Crack-Only DMI is computed using 11 LCMS detected distresses with completed categorization algorithms. With the advancement in the software distress categorization and verification work under development, it is expected the remaining PDDC distress and other new metrics will be incorporated in the automated distress formulation of DMI, PCI, distress deterioration model and pavement strategy decision tree in the pavement management system by 2017.

From 2015 onwards with only automated data available, and inclusion of additional automated distress metrics to the hybrid DMI and PCI will be carried as appropriate.

With the transitioning into the use of LCMS automated distress data collection, detection and rating, an opportunity exist to harmonize the use selected automated LCMS distress metrics that are common in the pavement design, contract specification, construction acceptance, maintenance and pavement management activities that also have direct linkages to pavement performance to the measured metrics.

5. REFERENCES

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