Integrating Laser Crack Measuring System into the Saskatchewan Pavement Management System

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ABSTRACT

Saskatchewan's Ministry of Highways and Infrastructure (SMHI) has replaced the visual assessment method for collecting pavement condition information with data measured using the Laser Crack Measuring System (LCMS). Pavement bleeding, stone pick outs, ravelling, wheel path rutting, bumps & dips and all types of pavement cracking have been incorporated into the Saskatchewan pavement asset management system.

The paper discusses how the field calibration site and testing fit into the overall project. The site was set up to understand repeatability of the categorization and severity of each measured distress. The design, construction and results from the field calibration site are discussed. Analysis of multiple measurements taken at the site was used to modify and fine tune the metrics developed for the Pavement Asset Management System.

The paper includes:

- An over view of the LCMS integration project
- Design, set up and operation of a field calibration site for surface distress measured by the LCMS including cracking, bleeding, potholes, delamination, pick outs and ravelling
- Findings from the analysis of the calibration testing
- Improvements that will be incorporated into the next cycle of data collection

INTRODUCTION

In 2016 Saskatchewan Ministry of Highways and Infrastructure (SMHI) transitioned to the Laser Crack Measuring System (LCMS) for automated collection of pavement condition data. Rutting, cracking, bleeding, potholes, delamination, pick outs, texture and raveling data is collected using LCMS sensors mounted on a high speed Automated Road Analyzer (ARAN) survey vehicle.

LCMS replaced a visual assessment method completed by Ministry staff each fall using a spot sampling method. The visual assessment method provided details about cracking and surface distresses used to trigger pavement preservation treatments including graded aggregate seal coats, chip seal coats, fog seals, microsurfacing, thin lift overlay and repaving. The visual assessment method was designed to capture road condition information required by the SMHI integrated Asset Management System which includes both a Pavement Management System and Maintenance Management System.

Replacement of the visual assessment method with the automated LCMS system has:

- improved worker safety by removing people from the road surface,
- made pavement condition information available 3 months earlier as the survey is completed during the summer months,
- replaced spot sampling with continuous measurement of distresses resulting in more representative data, and;
- significantly improved data quality and accuracy.

LCMS data collection survey is contracted to an engineering consulting firm that specializes in collecting and analyzing road condition data. Survey data includes international roughness index (IRI), wheel path rutting, surface distress and cracking. Rutting, surface distress and cracking must be collected using the Laser Crack Measuring System (LCMS).

LCMS INTEGRATION PROJECT

The LCMS integration project began with a pilot sampling of 1000 lane kilometers using cracking data collected with an LCMS system. The pilot survey was completed in 2014 during the annual collection of automated International Roughness Index (IRI) and Wheel Path Rutting data. The pilot LCMS data was limited to cracking information only. The cracking data was compared to visually assessed cracking information and verified in the field. The continuous LCMS crack information provided a very granular data set. However, the categorization of crack type and severity did not match the visual assessment crack information. Direct comparison of the results of the two methods was limited.

A jurisdictional scan of agencies who had adopted the LCMS revealed that bleeding and pick out data was not available. Analysis of cracking data to quantify amount and severity of block and fatigue cracking had been done by almost all of the agencies. A variety of methods are used. Many analysis methods were proprietary to the consulting company providing the LCMS data analysis services.

LCMS technology was developed by Canadian company Institute National d'Optique (INO). Pavemetrics is an INO company dedicated to marketing and enhancing the LCMS. The LCMS system includes both the sensors and data processing software. The processing software includes a library of modules that detect and report distresses found in the imagery collected by the sensors. The library includes data processing modules for rutting, cracking, macro-texture, potholes, sealed cracks and raveling.

SMHI began work translating the visual assessment method into standards that could be specified in the road condition survey contract using a LCMS sensor system. To assist in the development of the specifications SMHI contacted Pavemetrics to inquire about expansion of the processing library to include modules for pick outs and bleeding. Pavemetrics agreed to partner with SMHI to complete work required to add these modules to their software. The LCMS data collected during the SMHI pilot project was used to refine the algorithms. The data processing modules for pick outs and bleeding were completed and made available in the LCMS processing library with the January 2016 software update.

OVERVIEW OF SMHI LCMS DISTRESS DEFINITIONS & FLOW OF ANNUAL DATA PROCESSING

Figure 1: ARAN with LSMS sensors

How LCMS Works: Two sensors are mounted on the back of the data collection vehicle. Each unit contains a spread line laser and a 3D camera mounted off axis to the laser. The lasers cast a 4m long line with 1 mm resolution on the road surface. The 3D cameras capture an image of the laser line gathering two data types:

Range/height *– height of the pavement surface*

Intensity/reflection*-reflectivity of the pavement surface*

Range data displays cracks and texture. Intensity data finds surface texture and pavement markings. A 3D representation of the pavement surface is created by merging range and intensity data together. Algorithms inside of the LCMS data processing software interrogate the 3D road image to find and report pavement distresses.

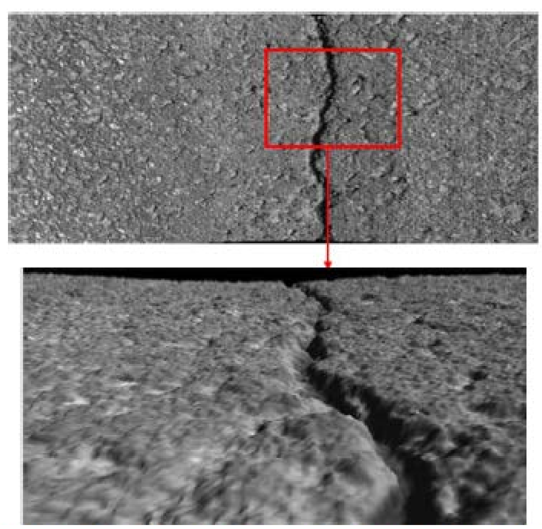

Figure 2: Visualization from the 3D LCMS Data (Feng LI, 2012 [1])

The location, orientation, severity, and extent of each distress is reported for a section of road surveyed. Each module in the LCMS processing library has settings available to adjust how the algorithms handle and report the data. For example, the minimum reportable crack length is set at 170 mm. Cracks shorter than this length will be ignored. SMHI standards for these settings are summarized in Table 1.

Table 1: LCMS Data Processing Module Settings

Module	Setting Name	Value	Description
Cracking	AutomaticPeakDetection	enable	enable automatic peak detection method
Cracking	MinCrackLength	170 mm	cracks shorter than 170mm are ignored
Cracking	FilterDeepANDWideCracks	or	cracks are removed if either the width **or** depth is greater than 100 mm
Cracking	WideCracks	100 mm	cracks wider than 100mm will be ignored
Cracking	DeepCracks	100 mm	cracks deeper than 100mm will be ignored
Cracking	EdgeCrackingEnable	enable	enable edge cracking detection (by default edge bands are 0.5m wide)
Bleeding	AvgInterval_m	0.5 m	Bleeding interval length. Used to divide up the wheel path bands.
Bleeding	DiffThreshold	2.0	This parameter is used to adjust the detection sensitivity of the algorithm
Pothole	MinWidth	100 mm	minimum pothole width in any direction
Pothole	MaxWidth	1000 mm	maximum pothole width in any direction
Pothole	MinAvgDepth	5 mm	Minimum Average depth of a pothole diameter
Pothole	MinArea	0.005 m^2	Minimum pothole area

With the exception of cracking, each module in the library will report all of the information needed about the distress. Potholes for example are counted by severity Low, Moderate, or High. LCMS crack processing module does not categorize cracks. The system produces an xml file with the location, length, width and orientation of each crack. The crack files must be further processed by the user to assign crack types and severity.

Distress Location: LCMS sensors pick up a 3D image that is 4m in width. To report the location of distresses within the lane, the image is divided up into five bands. This allows reporting of condition in the wheel paths, between wheel paths and along the edges of the image. SMHI sets the width of the wheel path and between wheel path bands to 1.0 m leaving 0.5 m on the edges for the centerline and shoulder bands.

Crack Types: SMHI has defined crack types according to the following

Transverse Cracking: cracks oriented at ≤ 30° from perpendicular to the direction of travel and the length of the crack is greater than 3m

Longitudinal Cracking: single cracks that run lengthwise down the pavement < 20° from the direction of travel.

Centerline Cracking:. Longitudinal cracks located in the centerline band.

Shoulder Edge Cracking: Longitudinal cracking in the outer shoulder band.

Meandering Cracks: Cracks that are not transverse, longitudinal or block cracks are classified as meandering cracks.

Block Cracking: Cracks are analyzed relative to the cracks around it by calculating crack density. When crack density is 1 or greater cracking is considered blocked. Block crack density and area is reported for the wheel paths and between wheel paths.

Fatigue Cracking: Block cracking where crack density is 3 or greater.

Crack Severity: crack severity is set according the width of the crack. Severity of block cracking is determined using a density value that considers the crack width and concentration relative to cracks around it.

Table 2: Summary of SMHI Distress Severity

Single Crack Severity	**Crack Width**
Slight	2 to 4mm
Low	> 4 and ≤ 12mm
Moderate	> 12 and ≤ 25mm
Severe	> 25 and ≤ 50mm
Extreme	> 50 and < 100mm
Multi-Crack Severity	**Crack Density**
Block	1 to 3
Fatigue	≥3
Pothole Severity	**Pothole Depth**
Delamination	< 25mm deep
Moderate	25 to 50mm
Severe	> 50mm
Pickout Severity	**Area of Stone Loss**
Single Pickout	0.75 cm^2
Multi Pickout	15 cm^2

The following illustration summarizes the LCMS data processing from surveying with an ARAN vehicle through to incorporation in the SMHI Pavement Management System.

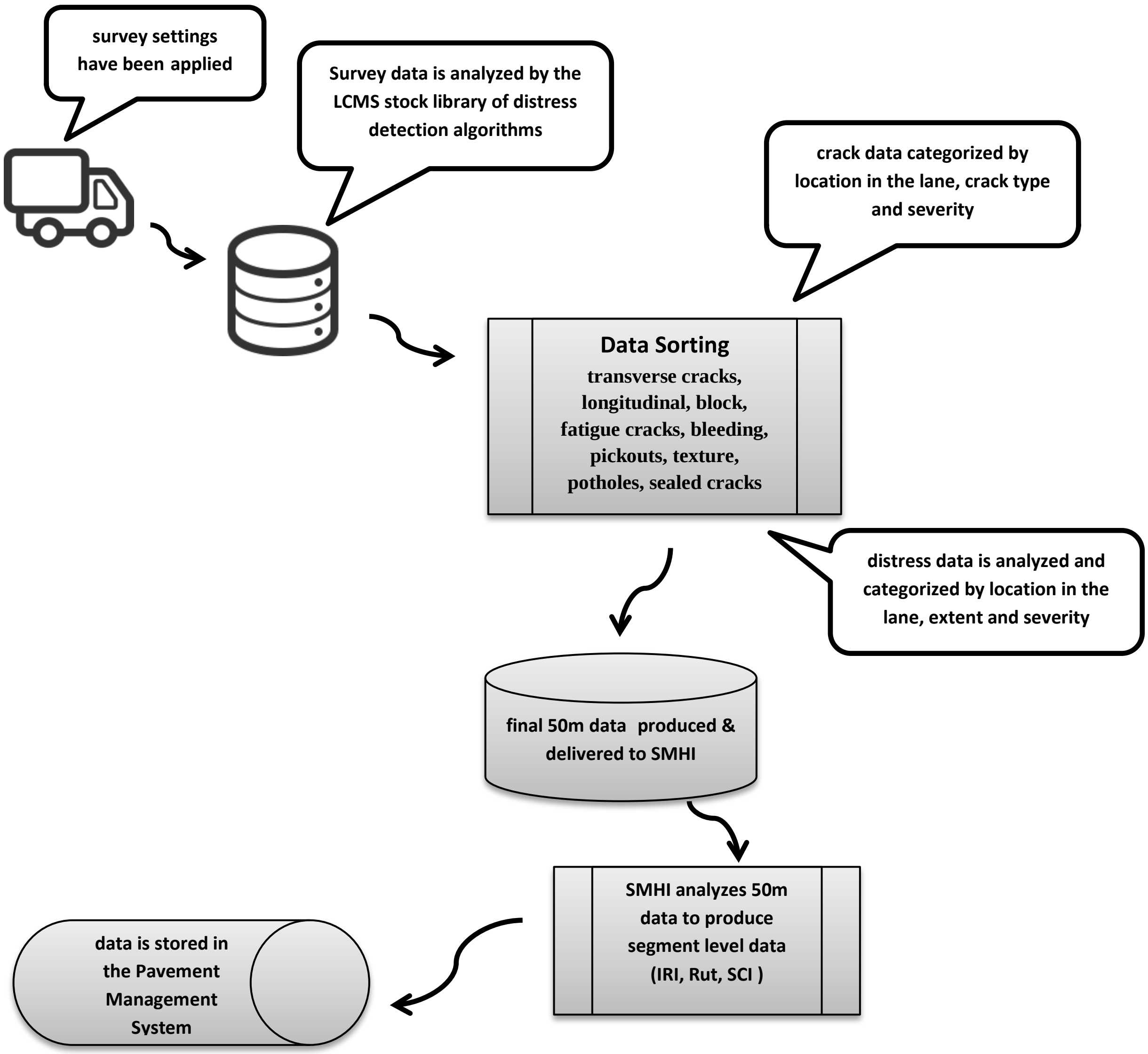

Figure 3: Overview of SMHI LCMS Data Processing Flow

CALIBRATION SITE DESIGN & CONSTRUCTION

A field test site was established to compare known distresses with measurements recorded by the LCMS. The site was designed to understand the repeatability and categorization of cracking and surface distress measurements.

The site is centralized in the province approximately 50 km north of Saskatoon. Highway 11 was bypassed around the town of Hague in 2008 leaving an orphaned section of two lane undivided highway just north of the town site. The pavement is old, oxidized with in situ cracking, raveling, and pickouts. The site served in the past as a training and certification site for Ministry staff preparing to conduct visual distress surveys.

The calibration site was converted to test LCMS surface distresses measurements in May 2016. The site was used in quality assurance and distress verification for the road condition survey completed in the summer of 2016. Quality control requirements specified in the road condition survey contract requires the survey vehicle(s) to complete repeatability runs over the site prior to start of the survey and every 5,000 lane km. This is done in conjunction with IRI and rutting calibration requirements.

Figure 4: Lane Markings & In situ Cracking

A 150-m long lane was selected at the site to set up the test area for verification testing. An array of cracks were already present at this location including both transverse and longitudinal cracks of varying severity.

Three 50-m cells were marked out using a surveyor's wheel and yellow reflective tape. Next, pavement marking paint was applied to delineate the edges of the lane. Dashed pavement markings were placed at approximately 4 m spacing denoting the edge of the lane. Reflective beads were added to the fresh paint to ensure the markings could be identified by the LCMS.

Once the boundaries of the test area were established the in situ distresses at the site were documented. A list of additional distresses required at the site was identified. The goal was to create a variety of distresses with in the test area to evaluate the LCMS ability to reliably detect and categorize a range of crack types, crack severity, potholes, delamination and bleeding.

The following subsections highlight the defects that were created and then used to test the prior mentioned crack detection thresholds.

Table 3 illustrates some of the measurements that were reported by the LCMS and shows a comparison of which defects were manually measured (Ground Truth), tested for repeatability, and not tested.

Table 3: LCMS Distresses Present at the Test Site

	Manual Measurements	Repeatability	Not Tested
Transverse Cracks	√	√	
Meandering Cracks	√	√	
Block Cracking	√	√	
Pick Outs		√	
Raveling		√	
Bleeding	√	√	
Texture (sand patch)		√	
Centerline Cracking		√	
Shoulder line Cracking		√	
Potholes	√	√	
Delamination			X
Rubber Asphalt Sealed Cracks			X
Bumps & Dips			X
Water Entrapment			X
Shoving			x

Figure 5: Fabricating Cracks using a Pavement Saw

In some cases the pavement saw was used to augment existing cracks. Five transverse cracks were created to test transverse crack severity. Wide transverse cracks were partially filled back in using cold mix cement to achieve the desired widths. Corrugated plastic strips were used as forms for partially filling in the cracks and letting the cold mix set. Figures 5 and 6 illustrate the method used to fabricate a severe transverse crack and shows what the finished crack looks like.

Figure 6: Manually Creating a Severe Transverse Crack (left) & Finished Transverse Crack (right)

Figure 7: Testing Minimum Transverse Crack Length

Figure 7 illustrates a transverse crack that was cut to test the minimum transverse crack length of 3.0 m. The cut crack is approximately 2.5 m long.

Several longitudinal and meandering cracks were cut into the test area. Cracks were created at different angles and lengths to test the crack classification definitions. Cracks were located in each wheel path and along the edges of the lane to test whether the LCMS would classify cracks as edge and centerline cracking.

Figure 8: Saw Cut Longitudinal Crack

Figure 9: Saw Cut Meandering Crack

Figure 10: Testing the Minimum Crack Length

Figure 11: Saw Cut Crack Width

As illustrated in Figure 11, crack width was limited to the width of the pavement saw blade. Slight severity cracks (<4mm) could not be added to the site.

Block cracking was simulated on site by cutting multiple cracks within close proximity to one another. The simulated block cracking was cut to test severity and how the LCMS sensors located the area of block cracking within the lane.

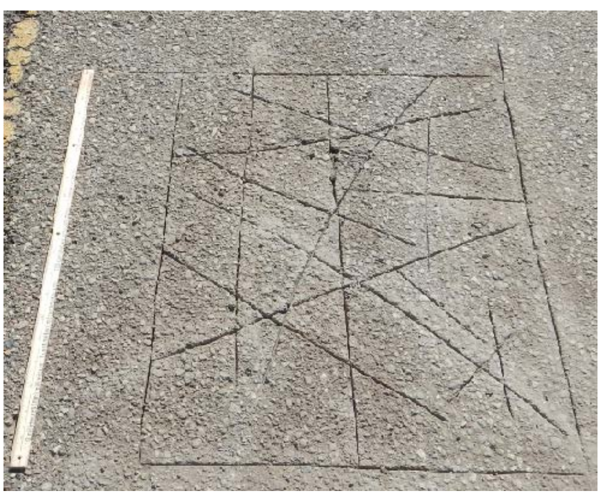

Figure 12: Saw Cut Wheel Path Block Cracking

Figure 13: Saw Cut Non-Wheel Path Block Cracking

Moderate and severe potholes were cut into the the pre-survey calibration site by running the pavement saw along the edges of a spalled out transverse crack. Cold mix cement was used to fill in the bottom of the potholes to depths matching moderate and severe pothole criteria.

Figure14: Severe Pothole

Figure 15: Moderate Pothole

To replicate bleeding in the test area an asphalt distributor was used to spray asphalt strips 15m in length at the start of the test area. Construction paper was used to mask off the start and end of the wheel paths. Figure 17 shows the bleeding section of the site.

Figure 16: Construction Paper used to mask off Bleeding Area

Figure 17: Bleeding added to the Test Area

Manual measurements of crack lengths and widths were achieved using measuring tape, calipers, and crack width gauges.

Figure 18 & 19: Crack widths measured using Automotive Brake Gauges (left) and digital calipers (right)

REPEATABILITY & DEVIATION ANALYSIS

Two ARAN vehicles were used to complete the road condition survey. Each ARAN completed 10 passes over the 150-m calibration site. Distress measurements were analyzed for both repeatability and deviation. The repeatability analysis indicates the ability of the LCMS sensors to provide the same measurement with each pass over the calibration site. Deviation compares the LCMS measured results to the manually measured results.

Average, repeatability, and coefficient of variation were calculated using Austroads Test Method AG:AM/T016 – Pavement Surface Texture Repeatability and Bias Error Checks for a Laser Profilometer[3]. Formulas used are:

[1] $$S_n\% = 100\left(\frac{S_{nm}}{\overline{X}_{nm}}\right)$$ [2] $$S_{nm} = \sqrt{\frac{\sum_{i=1}^{N}\left(X_{nmi}-\overline{X}_{nm}\right)^2}{N-1}}$$

Where

$S_n\%$ = Coefficient of variation (standard deviation expressed as a percentage of the mean)

S_{nm} = Repeatability of the measurements

$\overline{X}_{nm}$ = Average of the measurements

m = Measurement path

n = Segment number

N = Total number of measurements on measurement path

X_{nmi} = Value of individual measurement from run i (with i = 1 to N)

Deviation is calculated in accordance with ASTM C 670 and ASTM C 802 using the formula:

[3] $$\%\ of\ Deviation = \frac{(Manual\ measurement - Test\ Vehicle\ measurement)}{Manual\ \ measurement}\ X\ 100\%$$

Table 4: LCMS Repeatability Analysis

Distress	ARAN 45 Average	ARAN 45 Repeatability	ARAN 45 Coefficient of Variation	ARAN 47 Average	ARAN 47 Repeatability	ARAN 47 Coefficient of Variation
No Crack Area (m^2)	212.30	15.21	7%	231.20	10.81	5%
Block Crack Area Wheel Path (m^2)	30.39	5.52	18%	20.91	4.35	21%
Block Crack Area Non-Wheel Path (m^2)	42.95	8.62	20%	23.82	6.12	26%
Block Crack Density Wheel Path (m/m^2)	0.83	0.12	14%	0.71	0.06	9%
Block Crack Density Non-Wheel Path (m/m^2)	1.29	0.13	10%	0.88	0.08	9%
Transverse Cracks (m)	11.10	3.04	27%	7.26	3.95	54%
Meandering Cracks (m)	93.81	16.09	17%	88.37	6.53	7%
Longitudinal Cracks (m)	3.45	1.01	29%	3.22	1.16	36%
Single Pickouts (count)	784.90	30.18	4%	601.10	22.79	4%
Multi Pickouts (count)	25.10	5.59	22%	22.70	5.87	26%
Single Pickout Area (m2)	185.90	10.63	6%	179.60	12.04	7%
Multi Pickout Area (m2)	11.20	3.26	29%	8.20	3.49	43%
Moderate Potholes (count)	9.50	1.96	21%	10.50	1.43	14%
Severe Potholes (count)	1.10	0.32	29%	0.90	0.32	35%
Total Potholes (count)	10.60	2.07	19%	11.40	1.65	14%
Bleeding Area Right Wheel Path (%)	0.20	0.09	46%	0.00	0.00	-
Bleeding Area Left Wheel Path (%)	0.21	0.09	43%	0.00	0.00	-
Mean Texture Depth Right Wheel Path (mm)	0.92	0.01	1%	1.02	0.02	2%
Mean Texture Depth Left Wheel Path (mm)	1.04	0.01	1%	1.00	0.01	1%

All distress types and severities were analyzed for repeatability. Coefficient of variation differs significantly across distress types and between the two ARAN vehicles. Coefficient of variation less than 10% is considered acceptable for repeatability. A selection of the results is included in Table 4.

Conclusions from the results summarized above include:

- Area of no cracking, texture and pick outs were very repeatable for both ARAN.
- Variance in single crack lengths (longitudinal vs. meandering vs. transverse) ranged from 7% to 54%. High variance for transverse crack length can be attributed to portions of severe cracks being reported as a pothole. The individual run results support this conclusion.
- Bleeding was only detected by ARAN 45. There was an increase in the area of bleeding detected by ARAN 45 with each run. The asphalt emulsion that was sprayed to create bleeding was placed at the start of the 150m test section. Asphalt began to pick up and track through the site as testing progressed resulting in a high coefficient of variation as the area of bleeding actually increase at the site with each run. This was not identified during testing but confirmed later when reviewing the LCMS images for each run.

Table 5: Comparison of Manual Measurements vs. LCMS Measurements

Distress	Manual Measurement	ARAN 45 Average	ARAN 45 % of Deviation	ARAN 47 Average	ARAN 47 % of Deviation
Transverse Cracks (m)	17.3	11.1	36%	7.26	58%
Meandering Cracks (m)	60.15	93.81	-56%	88.37	-47%
Longitudinal Cracks (m)	93.77	3.45	96%	3.22	97%
Moderate Potholes (count)	1	10	-850%	11	-950%
Severe Potholes (count)	2	1	45%	1	55%
Total Potholes (count)	3	11	-253%	11	-280%
Bleeding Area Right Wheel Path (%)	8.00	20.00	-153%	0.00	100%
Bleeding Area LeftWheel Path (%)	14.00	21.00	-47%	0.00	100%

Deviation of LCMS reported total length of transverse cracks, meandering cracks, longitudinal cracks, potholes (moderate and severe), and bleeding from manual measurements are summarized in Table 5. Only eight distresses were analyzed for deviation. Deviation analysis of macro-texture, pick outs, sealed cracks, and raveling were not completed. Manual measurement of these distresses over the entire 150m test area was not feasible. Up to 90% deviation is considered acceptable. Distresses with high deviation values were investigated to identify reasons for the large differences in results. The following conclusions were made:

- Both ARAN LCMS identified a much higher occurrence of potholes at the site than expected. There are some very severe in situ transverse cracks at the site. Portions of these cracks may have exceeded the maximum crack width definitions and were reported as potholes.
- Bleeding shows a high deviation between manual and LCMS measurements. ARAN 47 did not detect any bleeding at the site. The consultant experienced software errors when running the bleeding processing module during post processing. This may account for the lack of data for bleeding from ARAN 47.
- ARAN 45 showed an increase in the area of bleeding detected with each run. The asphalt emulsion that was sprayed to create bleeding was placed at the start of the 150m test section. Asphalt began to pick up and track through the site as testing progressed. This increase in the area of bleeding due to asphalt tracking was not accounted for in the manual measurements.
- Both ARAN detected very little longitudinal cracking at the site. It appears that the majority of the cracking manually measured as longitudinal (angled less than 20° from direction of travel) was reported as meandering cracking. Some longitudinal cracks in the test area were tightly spaced and may have been classified as block cracking.

PAVEMENT MANAGEMENT SYSTEM INTEGRATION

Cracking and pick out data was integrated into a new metric called Surface Condition Index (SCI) for use in the SMHI Pavement Management System. SCI is one of three primary distress used in the pavement management system. The SCI formula uses the type, severity and amount of cracking and pick outs distress to assign an SCI value for every one of the 50 m section of road surveyed. These values are then aggregated at the segment level (typically 8 to 12 km in length) by calculating the 60th percentile value. The 60th percentile SCI along with the 60th percentile IRI and Rutting measurements become the representative condition values for the segment characterizing the condition of the segment.

SMHI's SCI formula will continue to be developed. Initial indications show that the metric works well for modeling Asphalt concrete pavements and prioritizing seal coating and fog seal candidates. Further work is required to review bleeding data for inclusion in the SCI formula as a better representation of segment level conditions of sealed granular pavements.

IMPROVEMENTS FOR THE NEXT CYCLE OF DATA COLLECTION

Planned improvements at the verification site for the 2017 data collection season include:

- Narrowing up the transverse cracks that are borderline between classification as potholes (100 mm wide) vs. Extreme Transverse cracks.
- Reverse the direction of travel of the vans at the site so that asphalt oil sprayed to create the bleeding distress does not track into the remainder of the site ie: at the end of the site.
- Assess the site to determine if a section with rubber asphalt crack sealant can be added. The pavement is very old and oxidized and may not support routing required for the installation. ARAN 45 reported up to 72m of sealed cracks. This is likely from the bleeding area of the site where low severity cracks were coated with asphalt emulsion when the bleeding patches were established. These cracks will be identified and manually measured.
- Survey in the pavement markings for the center and shoulder lines as solid lines at a set distance apart. This will eliminate changes in the LCMS anchoring location of the wheel path bands with in the lane from run to run.
- Conduct sand patch testing to establish manual texture measurements in the wheel paths.
- Reset cracks with the pavement saw to ensure crack depth well exceeds the minimum detection depth.
- Add dense block cracking to one 50m section of the test area to replicate fatigue cracking. This will test the repeatability of block vs. fatigue cracking.

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