Development of Automated Pavement Condition Assessments for Ontario Provincial Pavement Network Management

Li Ningyuan
Ministry of Transportation of Ontario

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Some Highlights of Presentation

- Automation of pavement condition detection, classification, rating and reporting processes
- Description of the key pavement performance indices - International Roughness Index (IRI), Rut Depth Index (RDI) and surface distress index in terms of DMI, and overall Pavement Condition Index (PCI) for individual pavement sections
- Challenges to automated pavement condition data collection and evaluation process
  - Data coverage and surveying method
  - Pavement condition ranking method
  - Performance reporting method
- Discussion of the ongoing tasks of pavement data collection and evaluation methods
- Engineering criteria needed for pavement assessment

MTO ARAN-9000

In 2013, MTO started to use a fully loaded ARAN-9000 system in pavement surface distress detection, classification, rating reporting of pavement surface conditions of all provincial King's highways, including:

- **International Roughness Index**
- **Rutting Depth Index**
- **Distress Manifestation Index**
- **Overall Pavement Condition Index**

MTO ARAN-7000

Use an ARAN-7000 system to collect secondary and local roads' condition data

- Portable and light weight hitch mounted Laser Roline Profiling for calculating pavement roughness
- GPS and Right-of-Way Video for Condition View
- Visual evaluation of road condition through video types and images

Key Performance Indices and Measures

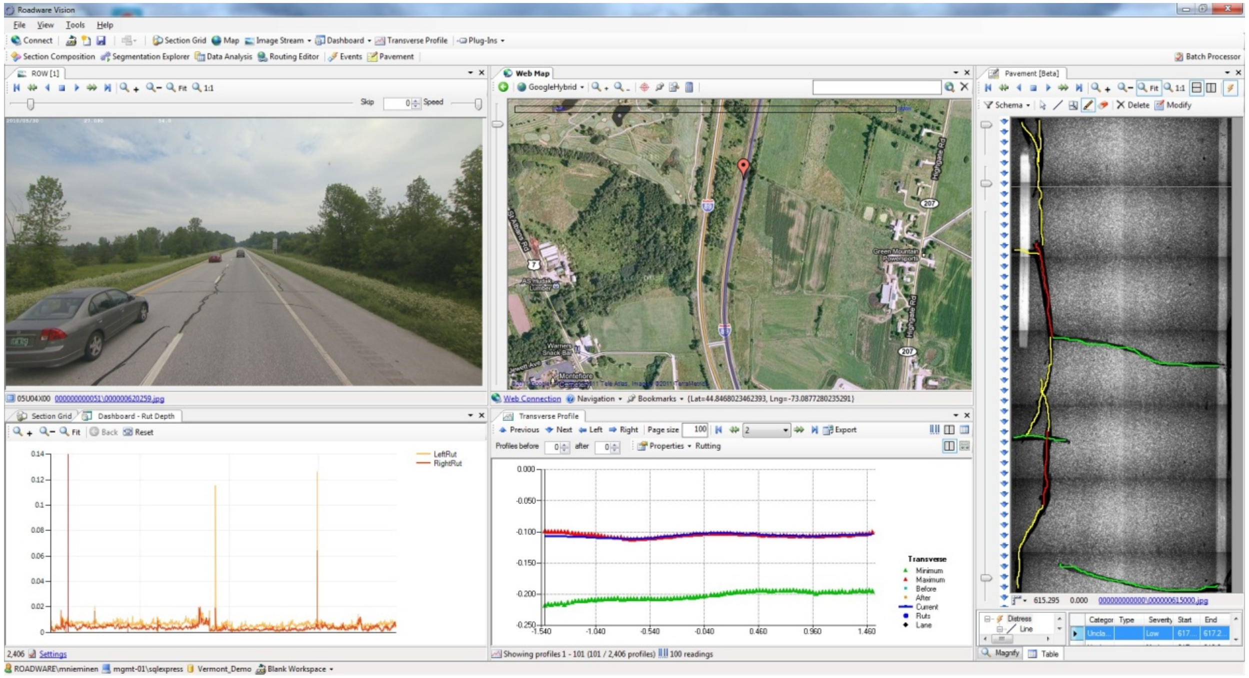
ARAN Type	Key Performance Indices			
	IRI	DMI	RDI	PCI
ARAN 9000	Yes	Yes	Yes	Yes
Trigger for Maintenance	N/A	N/A	N/A	Yes
ARAN 7000	Yes	No	No	Yes
Trigger for Maintenance	Yes	Yes/No	N/A	Yes

Main Features of LCMS 3D System

- Crack detection and severity
- 4160 point rutting (rut depth, rut type)
- Multiple macro-texture measurements (MPD)
- 3D and 2D data to characterize:
  - Pot holes, patching, raveling,
  - Sealed cracks, Joints
- 2800 profiles per second
- Width of lateral measures: 4 m
- Lateral resolution: 1.0 mm
- Vertical resolution: 0.5 mm
- Data rate: 5.2 Gb/km and can be compressed to 360 Mb/km

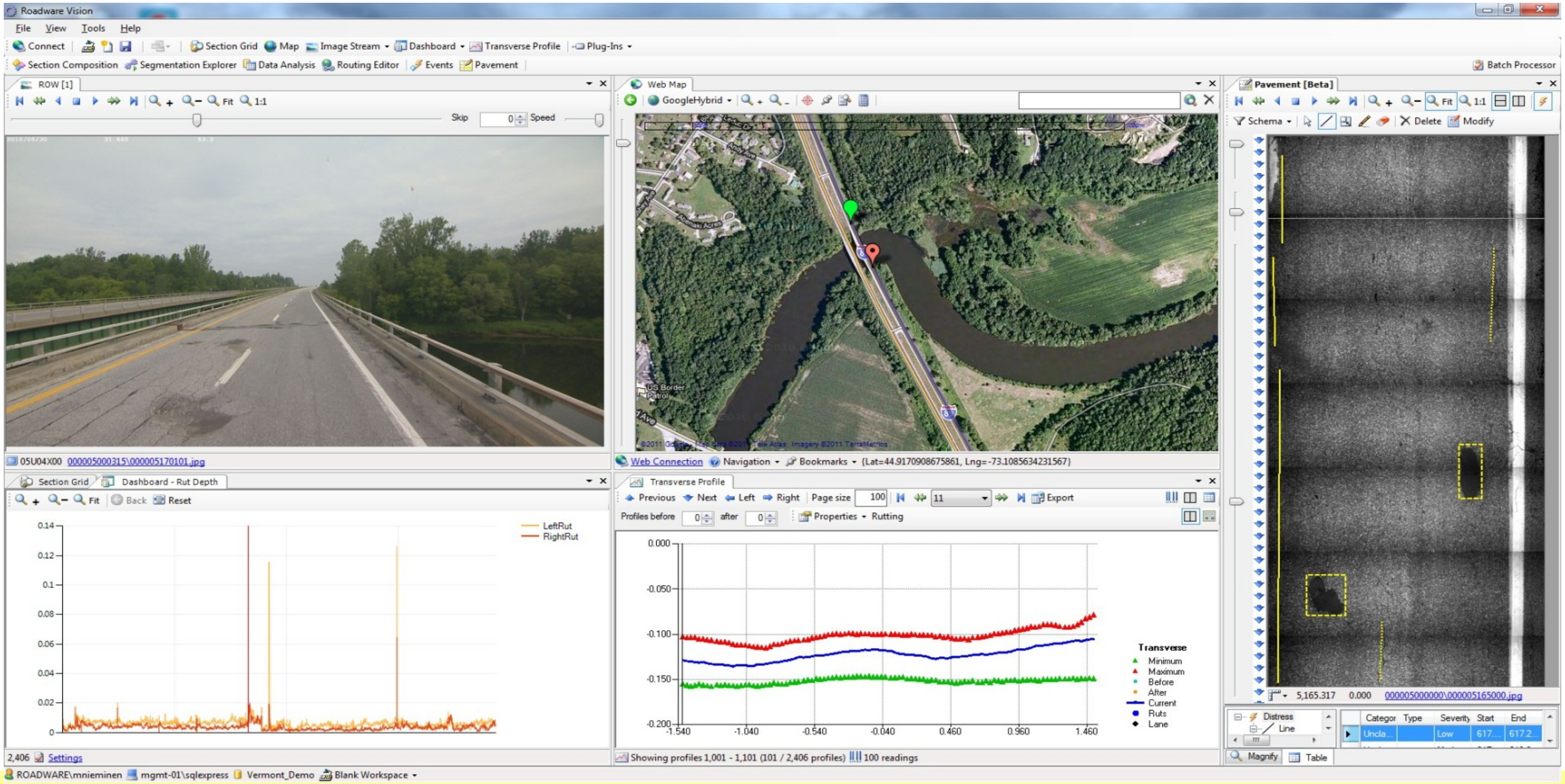
Data Collection and Processing Workflow

- **Advanced features and options**
  - Routing data creation and import
  - Segmenting
  - Events editing
  - Distress rating
  - WX importing
  - Asset inventory
  - Post-processing
  - Custom reports



Vision – Data Viewing

- View all processed data
- Charts, tables, profile views
- Integrated map component
- Report Generator

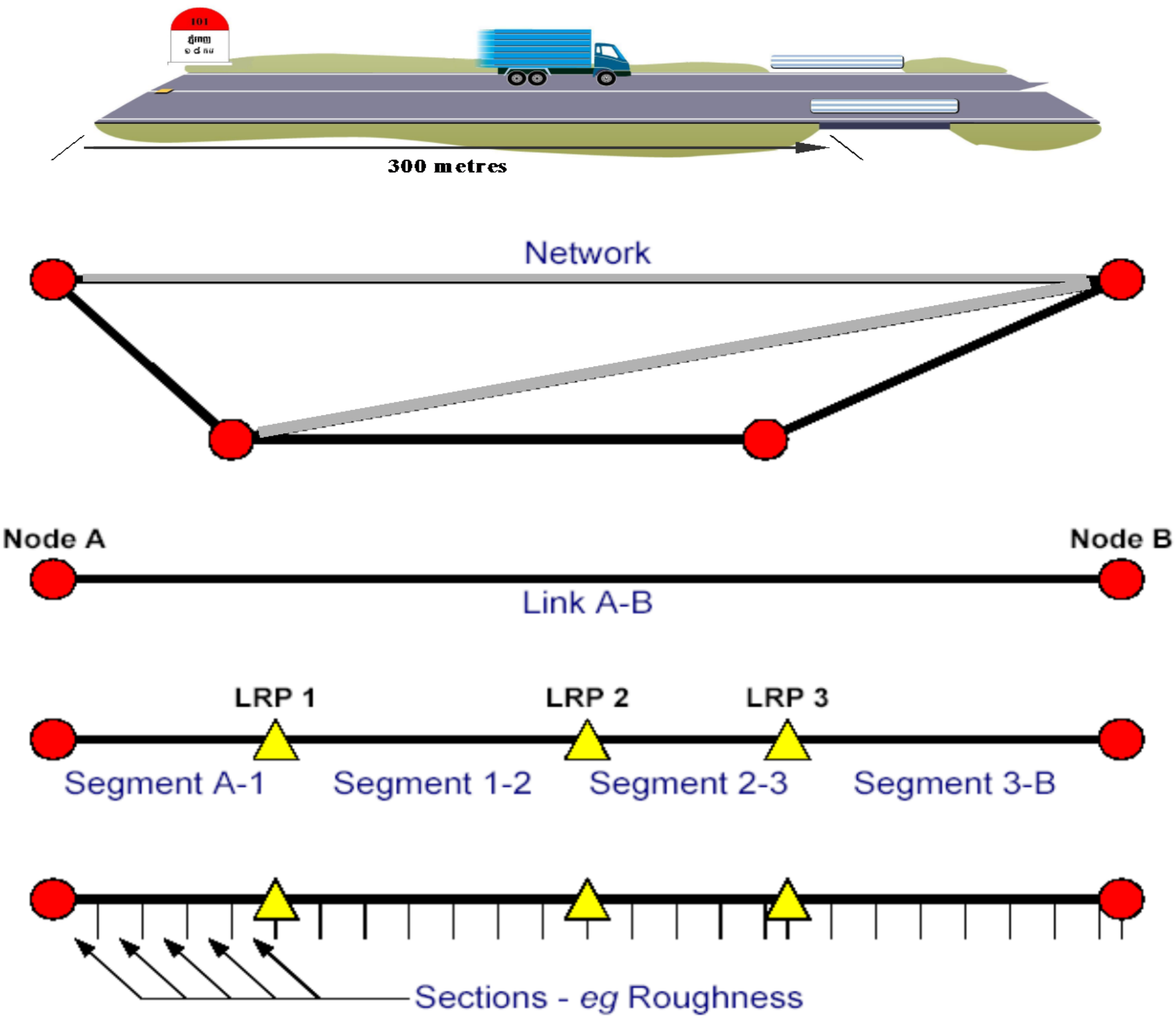


MTO ARAN 7000

Challenges to Automated Data Collection

- Data issues and availability
  - Section length of data summary
  - Data coverage, category/classification
  - Value and quantity of data and evaluation
  - Understand uncertainty around data
- Concept and application of KPI (IRI, PCI, IFI, DMI)
  - Link to objectives
  - Relate to pavement functional and structural evaluation
  - Select maintenance and rehabilitation treatments
  - Predict pavement performance and life-cycle costs
- Framework for road asset management

Rationalizing Pavement Segmentations

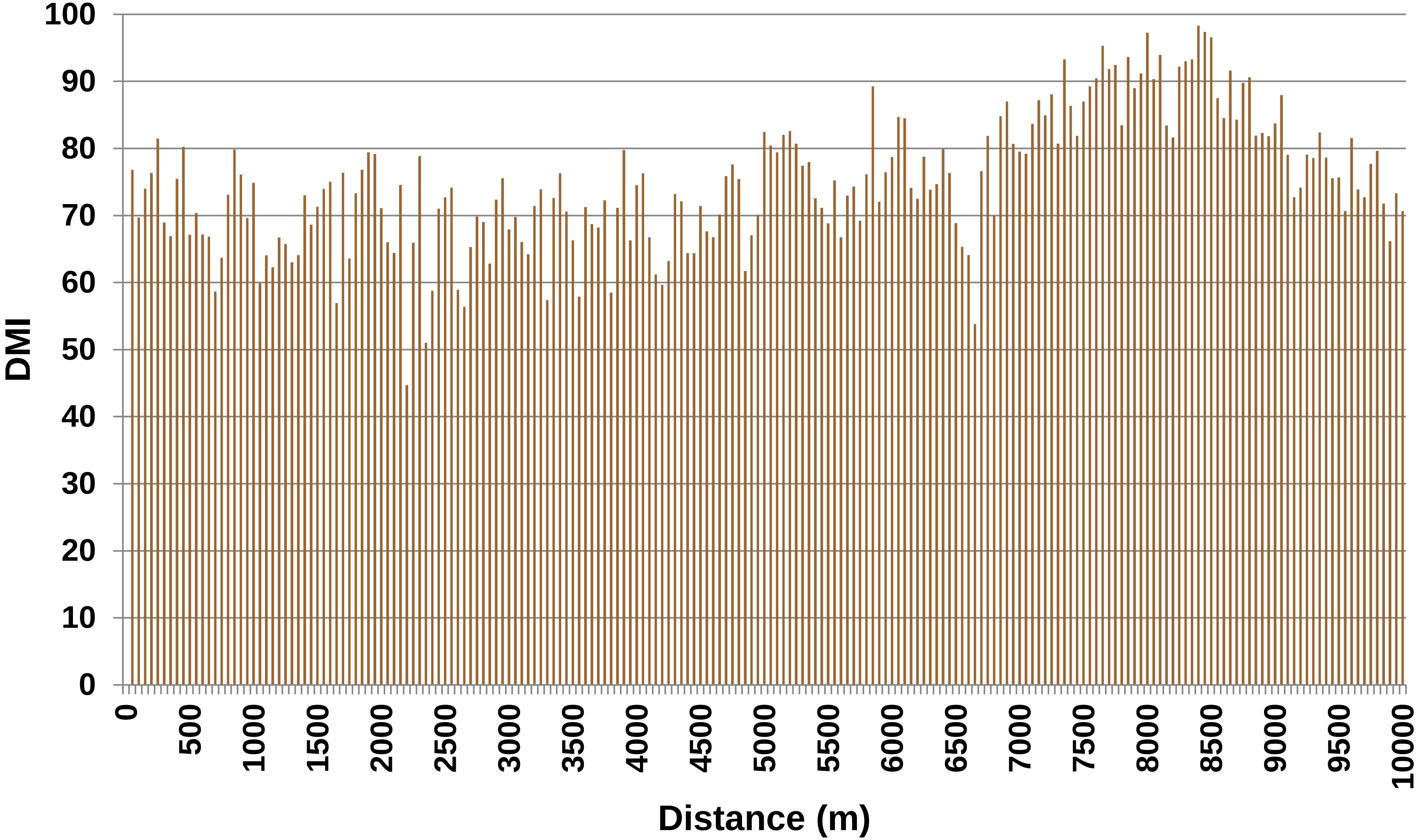


Source World Bank

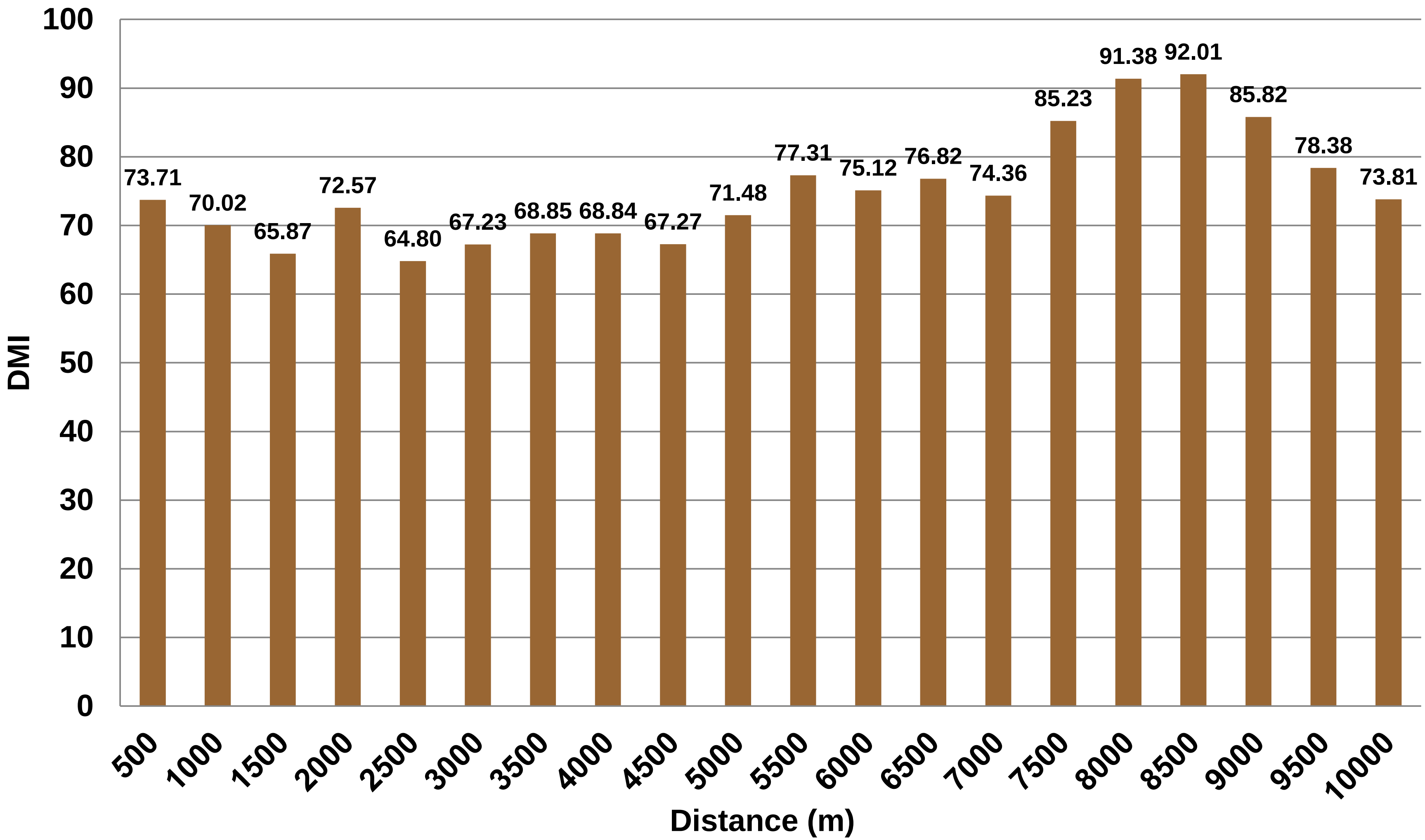
Impacts of PMS Road Section Length on Reporting Pavement Conditions

- **Pavement condition measures are summarized by different length of road sections: 50m, 500m, 1000m, 3000m, 5000m and 10000m intervals**
- **While increasing interval length, all indices trend to be stable and average values**
- **An example of pavement condition reporting values (DMI, IRI, RUT and PCI) summarized on the basis of different length, as shown in the next few slides (Data collected from Highway 401 E in MTO Central Region)**

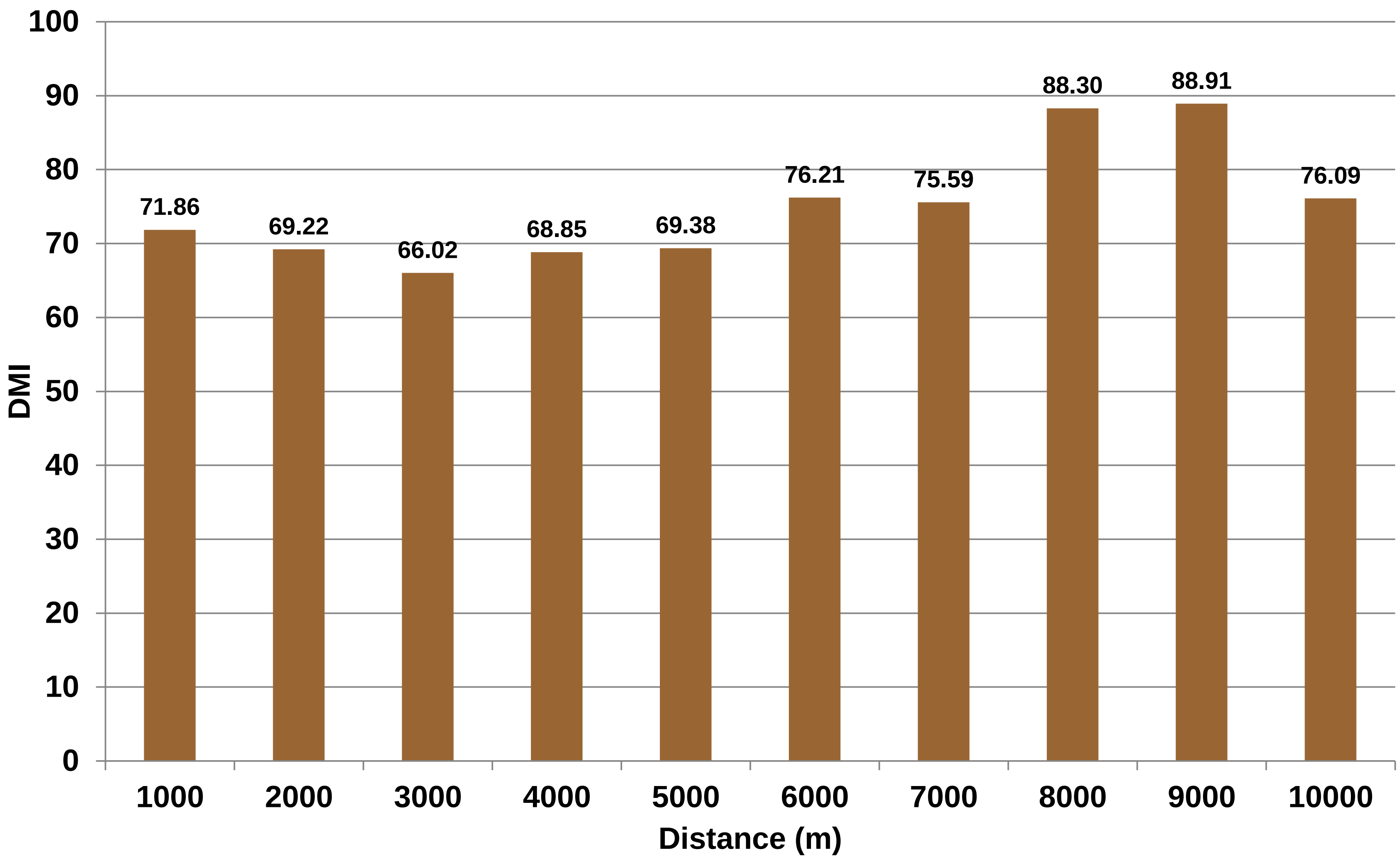
DMI at 50m per Section



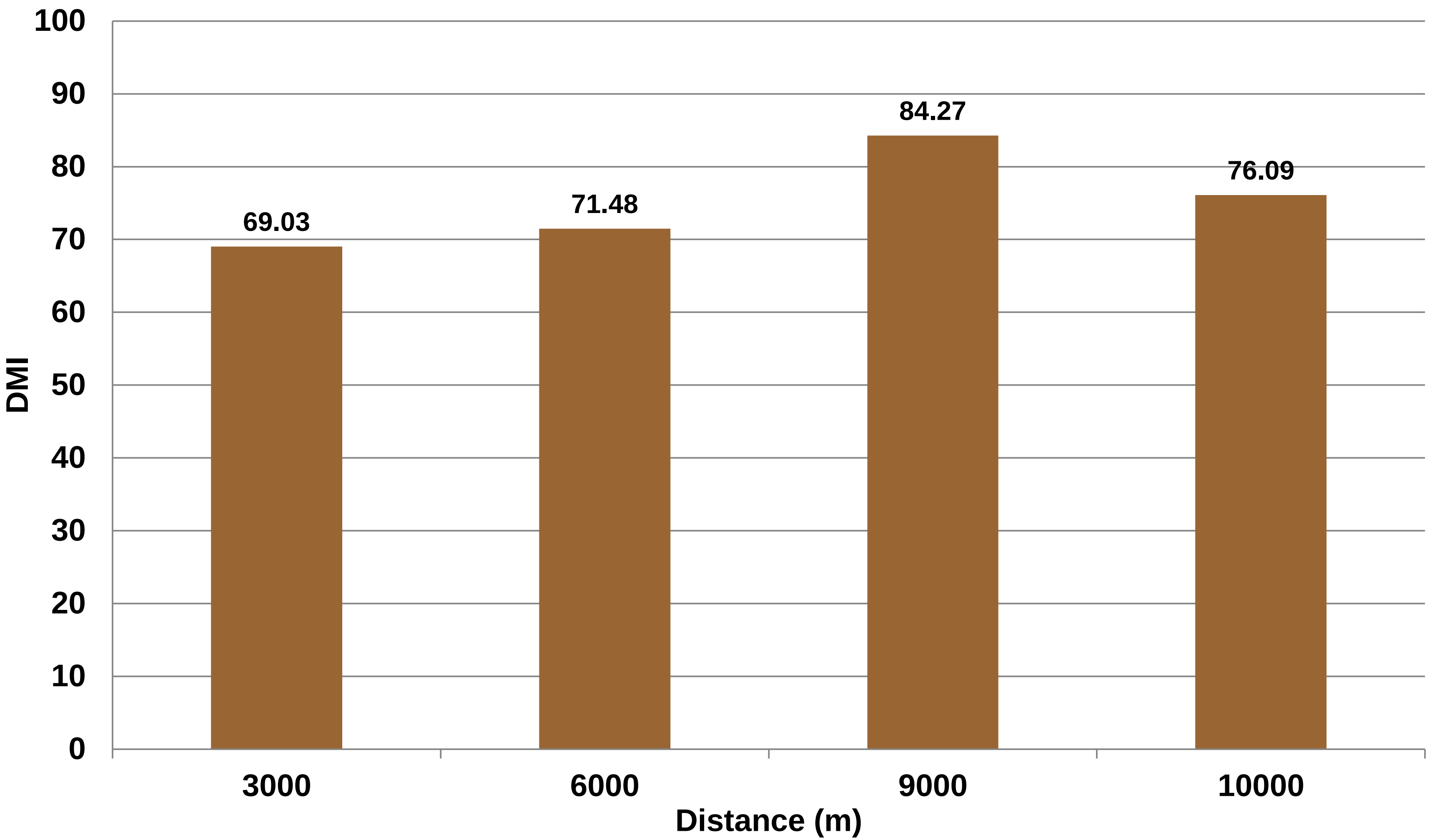
DMI at 500m per Section



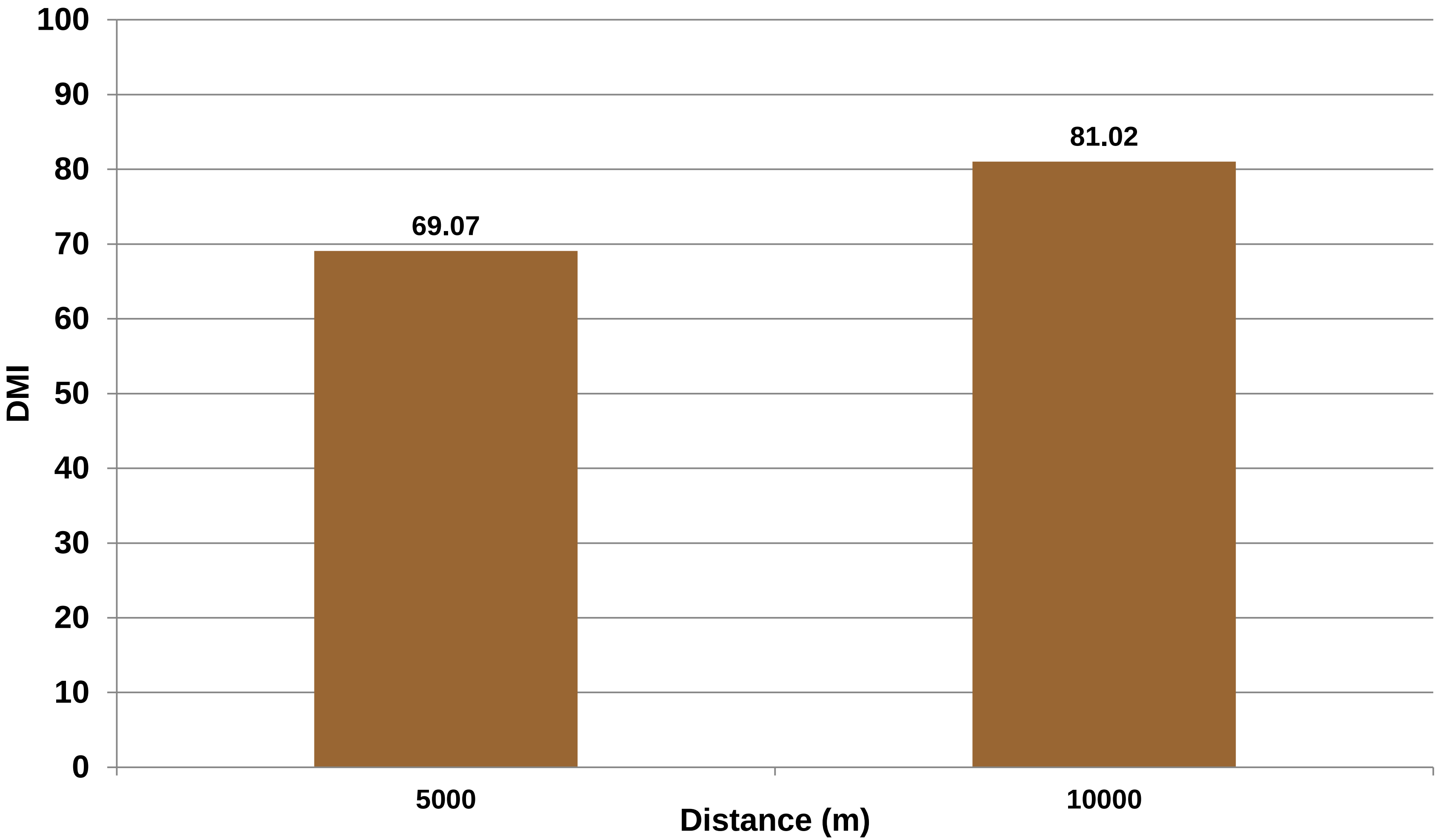
DMI at 1000m per Section



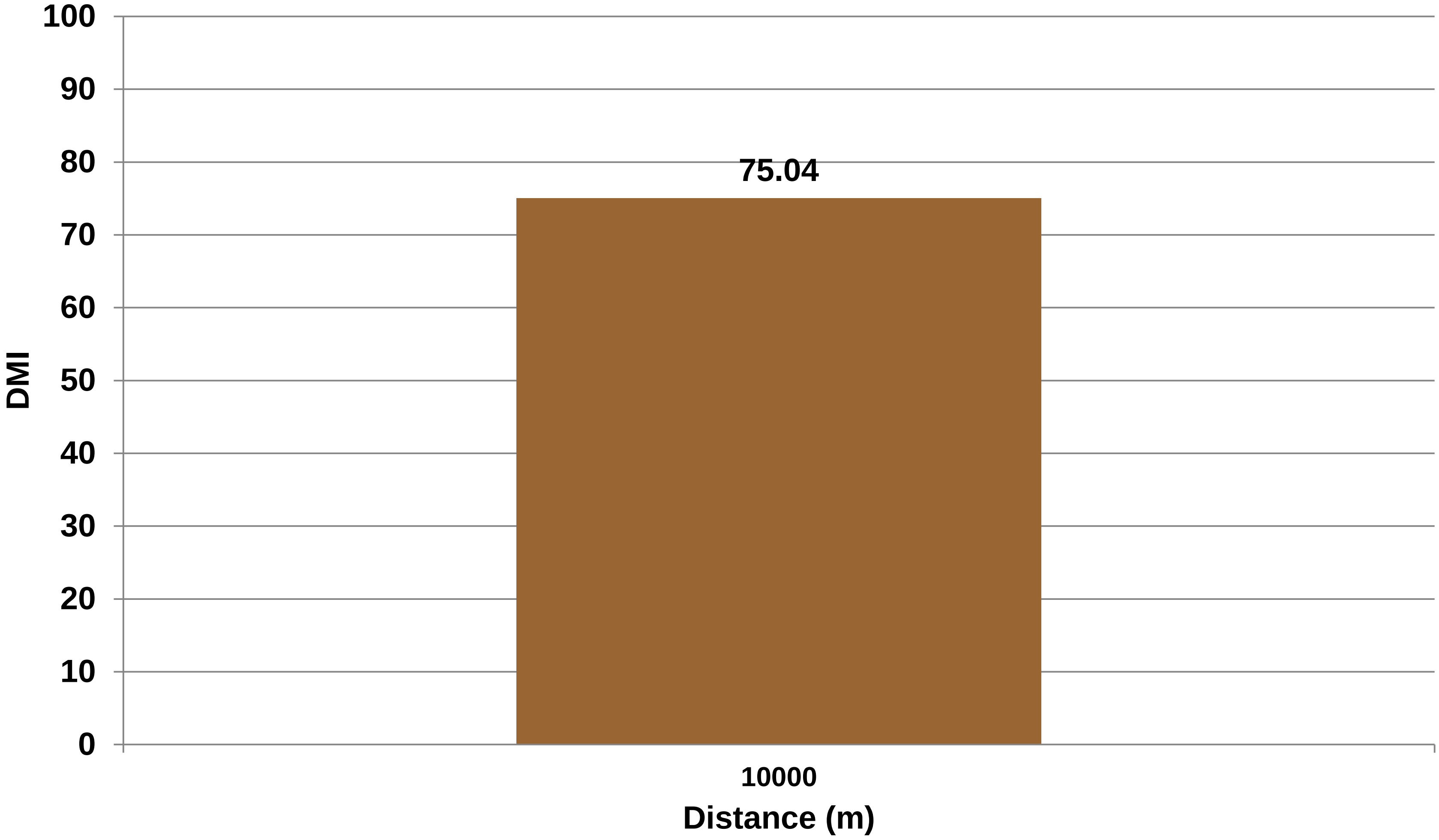
DMI at 3000m per Section



DMI at 5000m per Section



DMI at 10000m per Section



Main Differences Between Fully Automated and Manual Surface Distress Surveys

- **Different number of surface distresses (coverage of distresses) detected, severity levels and quantity measures**
- **Different scales of performance measurement and ranking method**
- **Different performance reporting forms (section length, chart, table and image)**
- **Different overall assessment of pavement condition**

Progress of Distresses Identified by LCMS

Individual Distresses for Asphalt Concrete (AC) Pavement	ARAN/LCMS Capability
Ravelling and Coarse Aggregate Loss	x
Flushing	x
Rippling and Shoving	x
Wheel Track Rutting	✓
Distortion	x
Longitudinal Wheel Track: Sing. / Multi.	✓
Longitudinal Wheel Track: Alligator	✓
Longitudinal Meandering and Midlane	✓
Transverse: Half, Full and Multiple	✓
Transverse: Alligator	x
Centreline: Single and Multiple	✓
Centreline: Alligator	✓
Pavement Edge: Single and Multiple	✓
Pavement Edge: Alligator	✓
Random/Map	✓

- Of the 15 individual distresses known to effect AC pavements the ARAN registers seven.
- Ravelling and Course Aggregate Loss, Distortion, and Flushing have been omitted because no automated algorithm has been created. Texture data is collected but not readily usable.
- Map cracking is included in alligator cracks identified in all zones
- Rutting data is collected, measured and reported separately
- No aggregated DMI is provided by LCMS

Current MTO ARAN 9000 System

- ARAN/LCMS is able to identify 8 individual cracking related distresses, and to provide evaluation results in six quantitative metrics for a given highway section (10 meter long pavement section):

- **List of Eight Individual Distresses:**
  1. Midlane Single & Multiple Cracking
  2. Single & Multiple Pavement Edge Cracking
  3. Longitudinal Wheel Track Cracking
  4. Single & Multiple Transverse Cracking
  5. Centre Single & Multiple Cracking
  6. Centre Lane Alligator Cracking
  7. Wheel Path Alligator Cracking
  8. Alligator Pavement Edge Cracking

- **Quantitative Metrics**
  1. Extent (m)
  2. Count
  3. Area (m^2)
  4. Length (m)
  5. Width (m)
  6. Transverse Extent (m)

Distress Manifestation Index (DMI)

Eight different cracking types, categorized by longitudinal, transverse, and alligator, measured by quantity and three severity levels: slight, moderate, severe, respectively

- Longitudinal
  - Mid-lane (Single & Multiple) Cracking
  - Pavement Edge (Single & Multiple) Cracking
  - Centreline Cracking
  - Wheel Track Cracking
- Transverse
  - Transverse (Single & Multiple) Cracking
- Alligator
  - Centreline Alligator Cracking
  - Wheel Path Alligator Cracking
  - Pavement Edge Alligator Cracking

Performance Indices from ARAN 9000

Key Indices and Their Contributing Factors:

$$PCI = \left(0.70 \times IRI_{scaled}\right) + \left(0.20 \times DMI\right) + \left(0.10 \times RUT_{scaled}\right)$$

$$IRI_{scaled} = \max\left[0,\ \ 100 \times \left(1 - \frac{IRI}{5}\right)\right]$$

$$DMI = \max\left[0, \left(\left(0.4 \times DMI_{Long}\right) + \left(0.4 \times DMI_{Trans}\right) + \left(0.2 \times DMI_{Alligator}\right)\right)\right]$$

$$RUT_{scaled} = \max\left[0{,}100 \times \left(1 - \frac{RUT}{30}\right)\right]$$

Pavement Condition Index (PCI)

- A PCI value ranges from 0 to 100, with 100 representing perfect pavement condition, and 0 representing the poorest condition

- PCI is a function of IRI, DMI, RUT independent variables and it is calculated as:

$$PCI = \left(\alpha \times IRI\right) + \left(\beta \times DMI\right) + \left(\gamma \times RUT\right)$$

(where α, β and γ are coefficients such that α + β + γ = 1)

- The weighting factors are analyzed to adjust PCI values in consideration of historical pavement performance values.

International Roughness Index (IRI) Calculated from MTO ARAN

- For the sake of simplicity comparison with other parameters, IRI is rescaled to a new index in the 0-100 scale. The formula is shown:

$$IRI_{scaled} = \max\left[0,\ \ 100 \times \left(1 - \frac{IRI}{\theta}\right)\right]$$

(where θ is an undetermined coefficient)

- Adjustable θ has been examined for many scenarios by using 2013 ARAN data and when θ = 5, the performance distribution are close to the historical one.

Calculation of Pavement Wheel Path Ruts

- Similarly to IRI, RUT also rescale to a new index in the 0-100 scale and it is calculated as the following formula:

$$RUT_{scaled} = \max\left[0,100\times\left(1-\frac{RUT}{\omega}\right)\right]$$

(where ω is an undetermined coefficient)

- Adjustable ω has been examined for many scenarios by using 2013 ARAN data.

- RUT values have to be adjust in consideration of the historical pavement performance values.

- This model uses ω = 30.

DMI Calculation in MTO ARAN 9000

- **DMI_{Long}**: A DMI value component, ranging from 0 to 100, is calculated based on quantity of the cracks (3 severity levels) classified and calculated as longitudinal cracks. There are totally 12 values in the summary of the 4 longitudinal crack types

- **DMI_{Trans}**: A DMI value component, ranging from 0 to 100, is calculated based on summary of all transverse crack within the length of pavement section

- **$DMI_{Alligator}$**: a DMI value calculated for the 3 alligator types; since this value will be 0-100, a classification-specific maximum for alligator cracking must be determined based on the relevant metric(s)

Integration of DMI Calculation

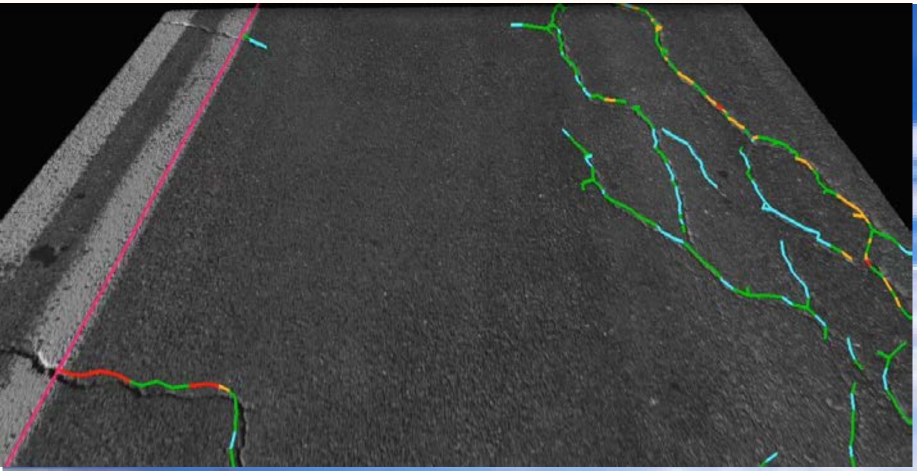
- With 3 pavement condition index components, an integrated DMI value for a specified section is calculated in the following formula:

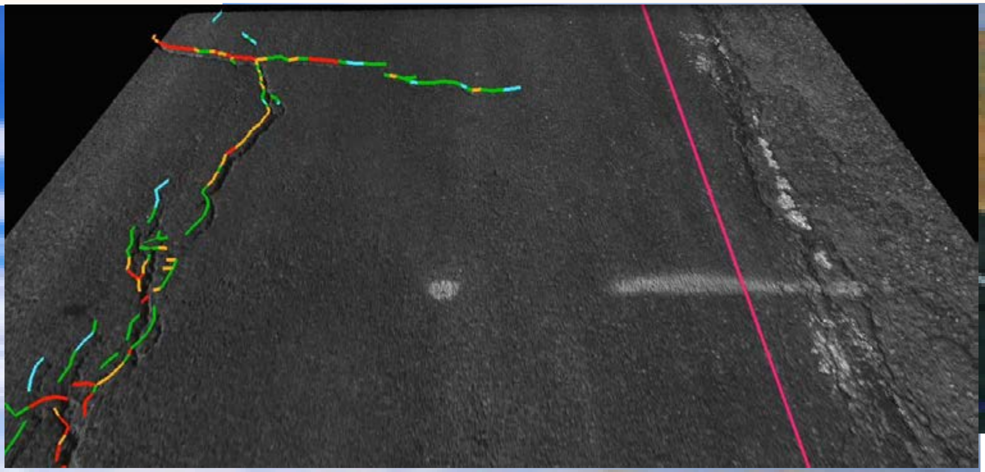
$$DMI = \left(A \times DMI_{Long}\right) + \left(B \times DMI_{Trans}\right) + \left(C \times DMI_{Alligator}\right)$$

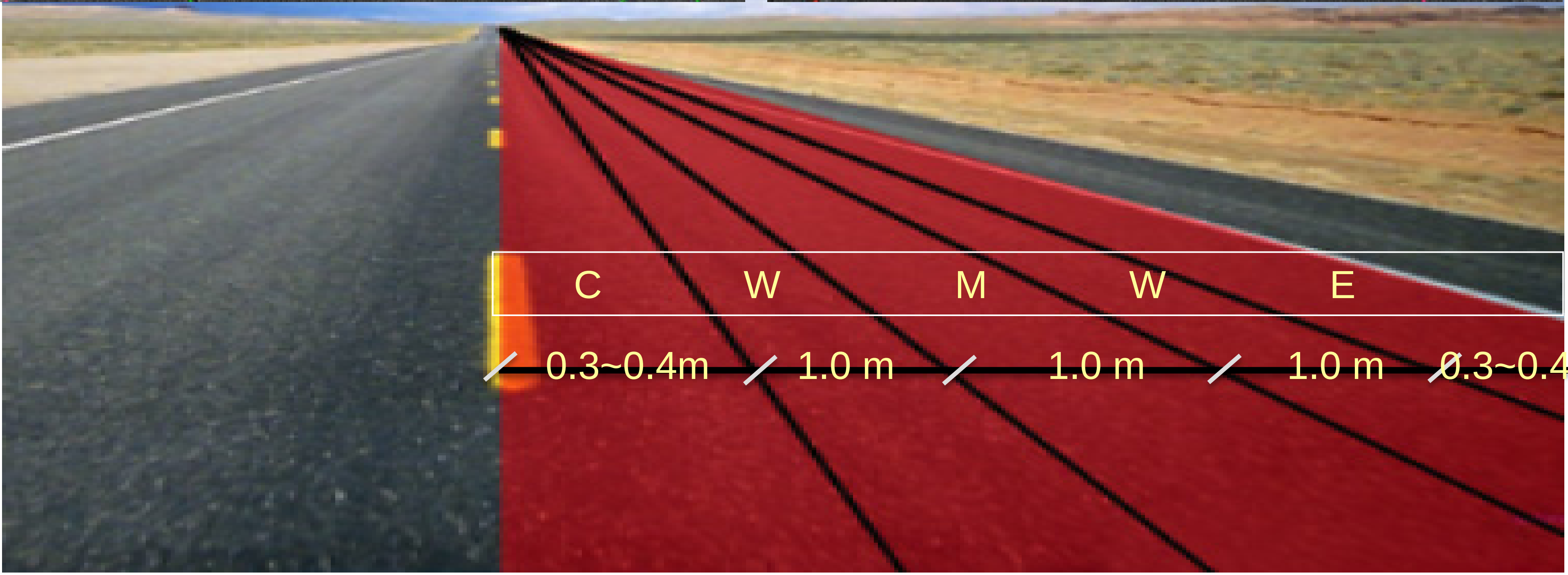
(where A/B/C are factored in such as A + B + C = 1)

- Adjustable series of A / B / C weighting factors were examined for many scenarios by using 2013 ARAN data. DMI module such as 0.40 / 0.40 / 0.20 was used for long/trans/gator cracking, and 0.80 / 1.0 /1.2 was used for the severity distinction calculation component (slight, moderate and severe).

New DMI Calculated from MTO ARAN







(DMI_{Long}) - Longitudinal Cracking

- After try-and-test analyses, using the DMI_{Long} values for the King's highways in 2012(updated with 2013), it was concluded that the ideal value to use is the primary highway level maximum of 4 m/m. Thus, the DMI_{Long} equation takes the form below.

$$DMI_{Long} = Min\left[0,100\times\left(1-\frac{\sum_{i=1}^{3}\left(\sum_{j=1}^{4}W_h\times LongitudinalExtent\right)}{4\times SectionLength}\right)\right]$$

NOTE:

- i = 1 to 3 represents the 3 severity levels, and j = 1 to 4 represents the 4 pavement zones, W_h = weighting factors 0.8, 1.0, and 1.2, respectively.

(DMI$_{Trans}$) – Transverse Cracking

- Calculation of DMI$_{Trans}$ Uses the following Formula:

$$DMI_{Trans} = Min\left[0{,}100\times\left(1-\frac{\sum_{i=1}^{3}\left(\sum_{j=1}^{1}W_h\times TransExtent\right)}{1\times SectionLength}\right)\right]$$

NOTE:

- Though this methodology may not be ideal, it found to be applicable to Ontario's road network and still yield a good data in terms of a distribution pertaining to the amount of transverse cracking in the province.

- i = 1 to 3 represents the 3 severity levels, and j = 1 represents the 1 pavement zone, W**h** = weighting factors 0.8, 1.0, and 1.2, respectively

($DMI_{Alligator}$) – Alligator Cracking

- Given that alligator cracking in Ontario is hardly an issue in the first place, this standard proves to be ideal, and in actuality even too low of a standard for assessing alligator cracking for the King's highways. It would follow that the expression for scaling alligator cracking into a 0-100 value would be:

$$DMI_{Alligator} = Min\left[0{,}100 \times \left(1 - \frac{\sum_{i=1}^{3}\left(\sum_{j=1}^{3} W_h \times AlligatorCrackingArea\right)}{3.6 \times SectionLength}\right)\right]$$

NOTE:

i = 1 to 3 represents the 3 severity levels, and j = 1 to 3 represents the 3 pavement zones, W_h = weighting factors 0.8, 1.0, and 1.2, respectively.

Comparisons PCI Calculations

%	Poor (0 ≤ x ≤ 60)	Fair (60 < x ≤75)	Good (75 < x ≤ 100)
PCI (0.5IRI / 0.25DMI / 0.25RUT)	4.60	12.89	82.51
PCI (0.6IRI / 0.2DMI / 0.2RUT)	6.34	14.85	78.82
PCI (0.7IRI / 0.2DMI / 0.1RUT)	8.13	16.77	75.10
PCI (1IRI / 0DMI / 0RUT)	14.20	24.02	61.78
Average PCI in PMS	3.8	19.0	77.1

PCI Distribution Of Primary Roads in 2013

Chart from PMS2

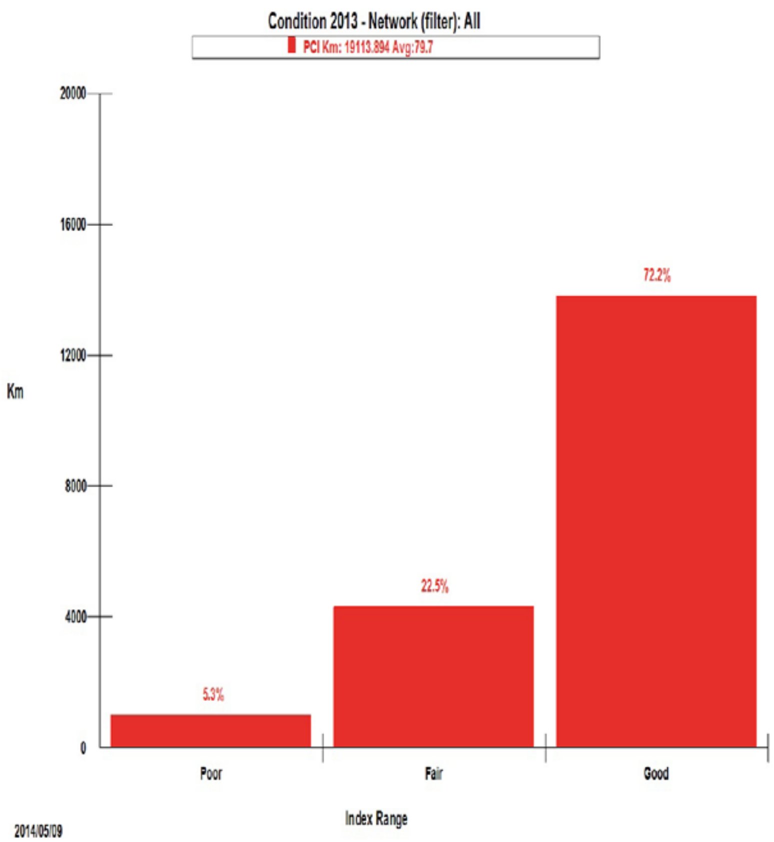
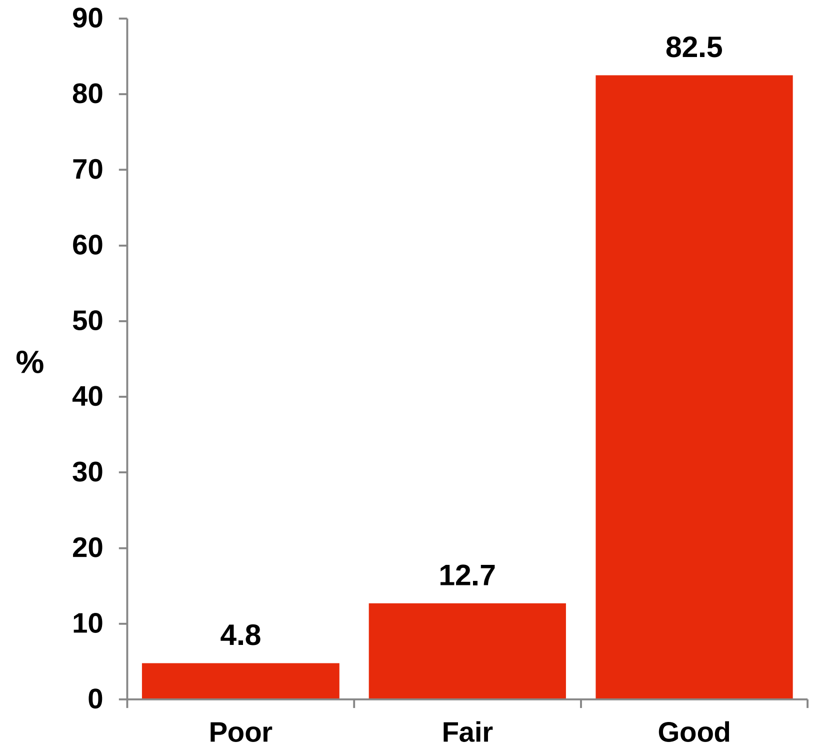


Chart (used new model)



Trigger Levels: Poor: 0 ≤ PCI ≤ 60
Fair : 60 < PCI ≤ 75
Good: 75 < PCI ≤ 100

Impact of Defining Performance Category and Trigger Levels

Trigger Levels: Poor: $0 \leq PCI \leq 60$
Fair : $60 < PCI \leq 75$
Good: $75 < PCI \leq 100$

Trigger Levels: Poor : $0 \leq PCI \leq 60$
Fair : $60 < PCI \leq 80$
Good : $80 < PCI \leq 100$

Defining Trigger Levels

- The following sets of trigger levels:
  - **Poor: 0 ≤ PCI ≤ 60**
    Fair : 60 < PCI ≤ 75
    Good: 75 < PCI ≤ 100
  - **Poor: 0 ≤ PCI ≤ 60**
    Fair : 60 < PCI ≤ 80
    Good: 80 < PCI ≤ 100
  - **Poor: 0 ≤ PCI ≤ 55**
    Fair : 55 < PCI ≤ 75
    Good: 75 < PCI ≤ 100
- The second set gives the results close to the historical observed data in MTO PMS.

Setting Trigger Levels

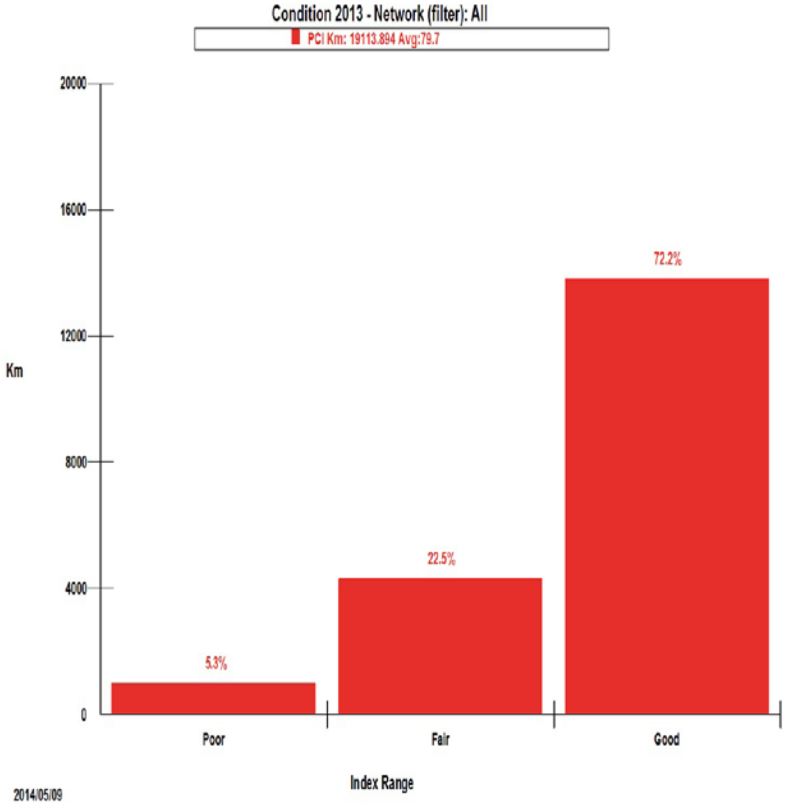
	Poor	Fair	Good	Reason
Set 1	**0≤x≤55**	**55<x≤75**	**75<x≤100**	Above tables show that Poor condition has relatively more weight compare to the PMS2 data and oppositely, Fair condition has less weight. Therefore, shifting weight from Poor to Fair may change this situation.
Set 2	**0≤x≤60**	**60<x≤75**	**75<x≤100**	Original setting
Set 3	**0≤x≤60**	**60<x≤80**	**80<x≤100**	Past tables reveal that Good condition has more weighting than historical one and Fair condition has less weight. Adding more weight to Fair and decreasing weight from Good condition might change that.

Comparisons of Defining Trigger Levels

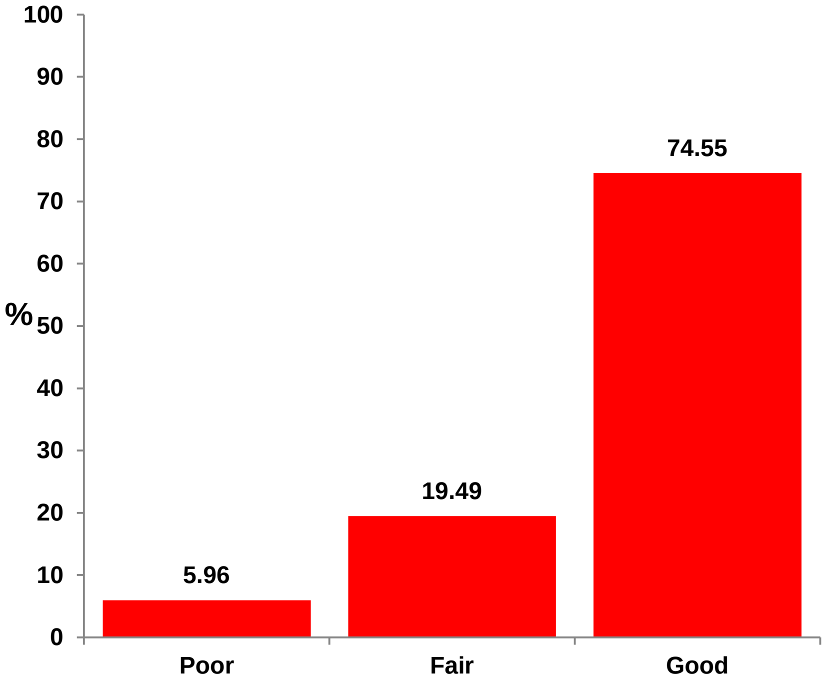
	Poor				Fair				Good			
%	0≤x≤55	0≤x≤60	0≤x≤60	PMS2	55<x≤75	60<x≤75	60<x≤80	PMS2	75<x≤100	75<x≤100	80<x≤100	PMS2
DMI	0.41	0.90	0.90	0.3	6.56	6.07	11.31	74.4	93.03	93.03	87.79	89.8
RUT	0.26	0.49	0.49	NA	4.32	4.09	9.37	NA	95.42	95.42	90.14	NA
IRI (RCI)	10.74	14.20	14.20	4.1	27.48	24.02	41.97	21.5	61.78	61.78	43.84	74.4
PCI	5.96	8.36	8.36	3.8	19.49	17.08	30.51	19.0	74.55	74.55	61.13	77.1

PCI Distribution Of Primary Roads in 2013 (new trigger levels)

Chart from PMS2

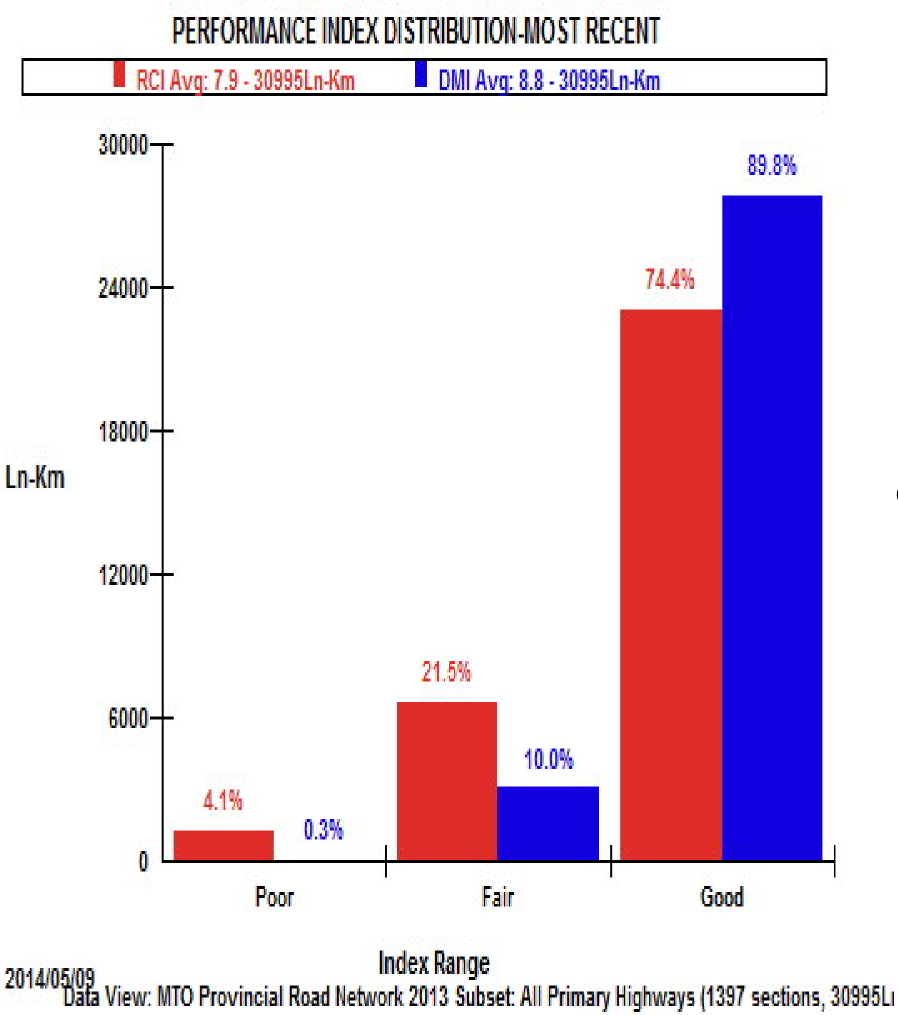


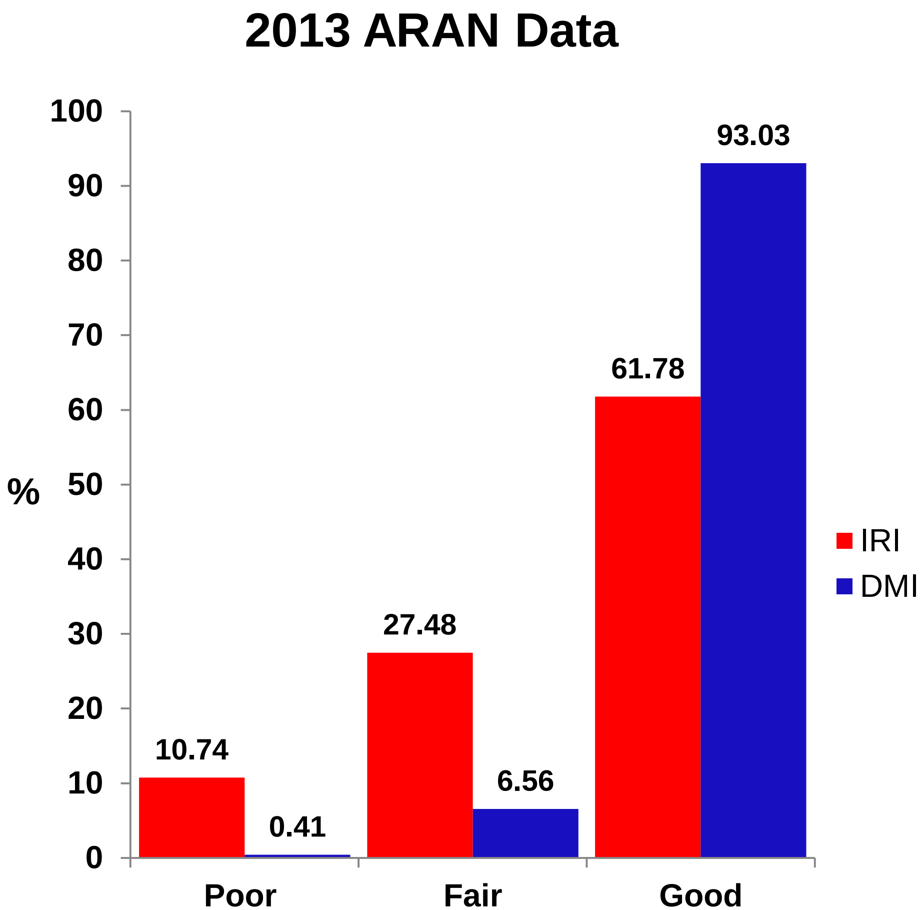
2013 ARAN Data (New trigger level)



Rating criteria: Poor: 0 ≤ PCI ≤ 60
Fair: 60 < PCI ≤ 80
Good: 80 < PCI ≤ 100

Comparison of IRI & DMI Historical Performance Measures (2013) VS ARAN Processed Values





Rating criteria: Poor: 0 ≤ PCI ≤ 60
Fair: 60 < PCI ≤ 80
Good: 80 < PCI ≤ 100

Summary and Discussions

- MTO started in 2013 to implement a fully automatic pavement condition data collection, evaluation and reporting to support maintenance management of Ontario provincial road networks.
- Data collected for key pavement performance indices include International Roughness Index (IRI), Rut Depth Index (RDI) and surface distress index in terms of DMI, which are used to generate overall Pavement Condition Index (PCI) for pavement sections.
- Issues with current data collection and condition evaluation
  - Data coverage and surveying method
  - Pavement condition ranking method
  - Performance reporting by section
- Target and ongoing tasks for enhancement of the automated system for pavement data collection and evaluation
- Engineering criteria needed for pavement assessment