Ontario

Ministry of Transportation

Pavement Distress Survey and Evaluation with Fully Automated System

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Presentation Highlights

- 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

MTO ARANs

Switching to fully automated data collection system

- **In 2013, MTO started to use a fully loaded ARAN-9000 system in data collection, evaluation and reporting of pavement surface conditions (IRI,RUT,DMI and PCI) for all provincial King's highways, and using an ARAN-7000 system for all secondary and local roads' condition – to achieve the objective-oriented, consistent, high-speed and automated assessment and reporting of pavement conditions at network level**

MTO ARAN 9000

- Laser-based measures of pavement longitudinal profiles to calculate roughness (IRI)
- **Transverse profile to calculate wheel path ruts**
- 2 Camera HD Right of Way Image collection
- **LCMS for Pavement Distress and Texture**
- GPS position and position and orientation system (POS) for LV

More sensors, more data, less computers!

ARAN 9000

- 2nd HD Camera
- Right facing view

Turret Mounted

- Better safety
- Stable mounting for asset calibration

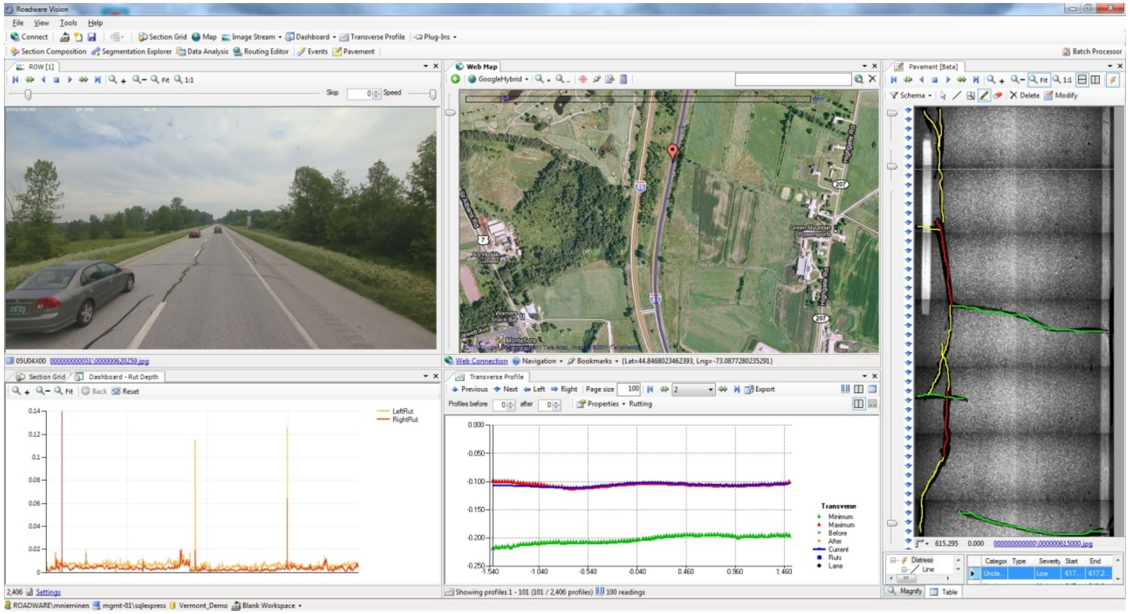
LCMS 3D Measurement System

KEY FEATURES

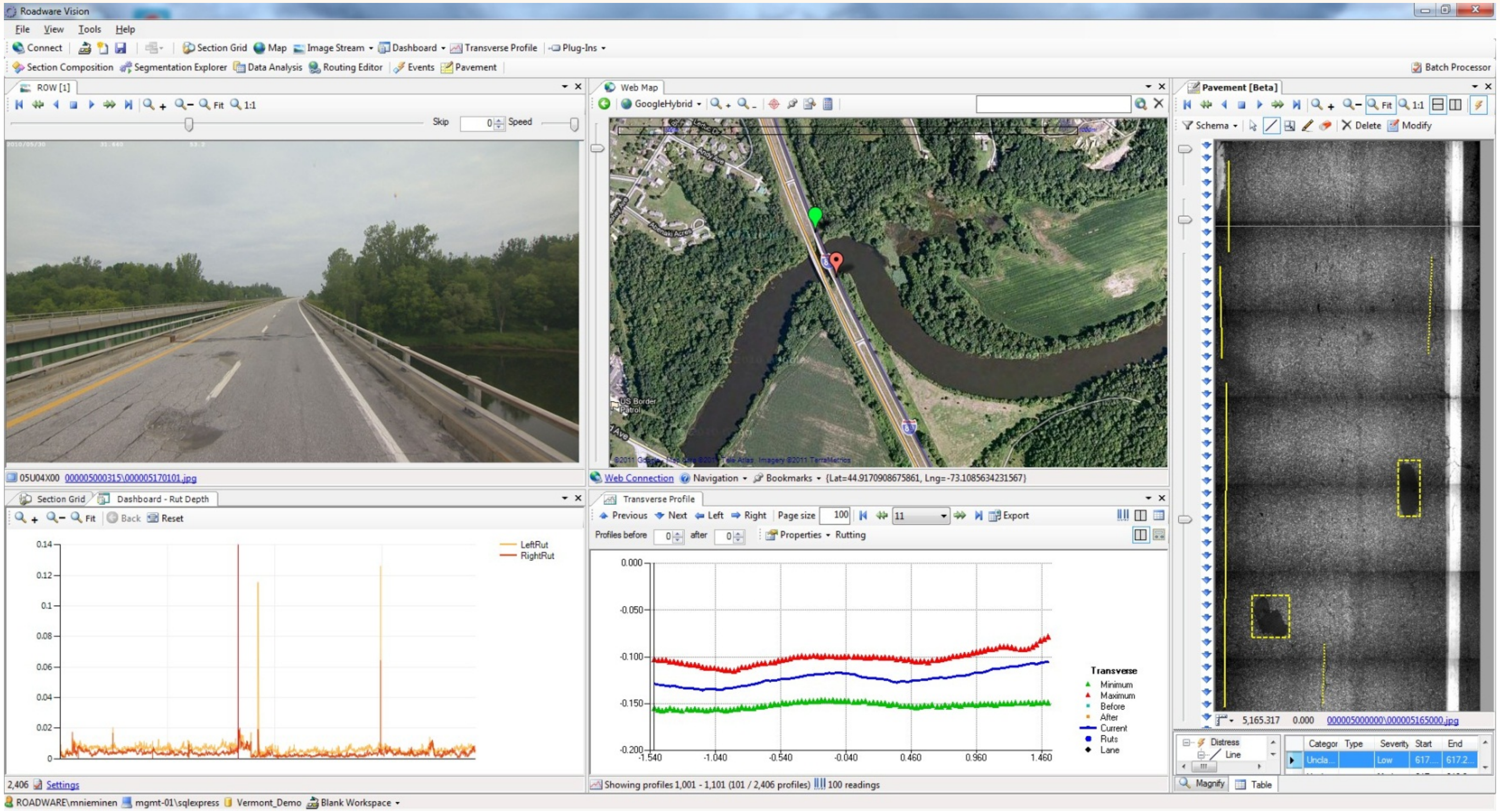
- Crack detection and severity
- 4160 point rutting (rut depth, rut type)
- Multiple macro-texture measurements (MPD)
- 3D and 2D data to characterize:
  - Pot holes, patching, raveling,
  - Sealed cracks, Joints
- 2800 profiles per second
- Field of view: 4 m
- Vertical resolution: 0.5 mm
- Lateral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

Collection and Processing Workflow

- **Advanced features and options**
  - Routing data creation and import
  - Segmenting
  - Events editing
  - Distress rating
  - WiseCrax
  - 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

- Portable and light weight hitch mounted Laser RoLine Profiling for Roughness
- **GPS and Right-of-Way Video for Condition View**
- Rutting can be collected depending on sensors installed
- Replay the video to visual evaluation of road Condition

MTO ARAN 7000

Video Image of Pavement Conditions

Major Differences Between Fully Automated and Manual Surface Distress Surveys

- **Different number of surface distresses (coverage of distresses), severity levels and quantity measurements**
- **Different scales of performance measurement and ranking method**
- **Different performance reporting forms (section length, chart, table and image)**

Distresses Not Identified by LCMS Currently

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

Capabilities of 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)

The 8 different cracks, 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

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:

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

(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.

Performance Indices from ARAN 9000

Key Indices and Their Calculation Coefficients:

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

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

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

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

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.

Rutting (RUT) Calculated from MTO ARAN

- 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.

Distress Detection, Classification, Rating and Evaluation from MTO ARAN

- A metric is a specific characteristic measurement, the ARAN collects several metrics for the 8 types of cracking: total crack length, crack width, crack extent, crack count, and crack area (the product of the extents)
- 3 severity levels of Rutting Depth (mm) are classified: **Level 1(0 - 10), Level 2 (10 - 20) and level 3 (>20),** representing slight, moderate and severe respectively.
- Alligator cracking is identified based on crack density (a certain density would cause multiple cracks to be aggregated into an area of alligator cracking)
- There was no historical data to calculate DMI based on automatically collected data with defined metrics, as opposed to manual scale rating (also very important to note that the comparison of manual historical values to the new automated values is essentially meaningless)

DMI Calculation in MTO ARAN 9000

Distress Reporting Data From ARAN:

- **DMI_{Long}**: a DMI value calculated for the 4 longitudinal crack types; since this value will be 0-100, a classification-specific maximum for longitudinal cracking must be determined based on the relevant metric(s)

  DMI_{Long} is calculated based on the longitudinal extents of 4 different crack types classified as longitudinal, each with 3 severity levels, for a total of 12 values in the summation

- **DMI_{Trans}**: a DMI value calculated for the 1 transverse crack type; since this value will be 0-100, a classification-specific maximum for transverse cracking must be determined based on the relevant metric(s)

- **$DMI_{Alligator}$**: 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)

New DMI Calculated from MTO ARAN

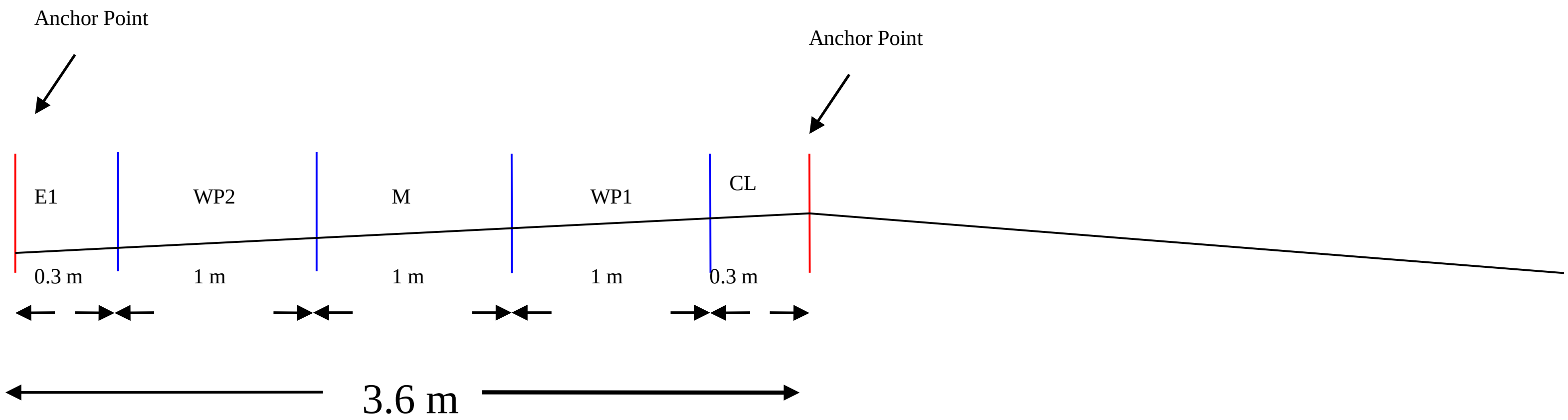
- With 3 separate pavement condition index calculations yielding 3 separate classification-specific DMI values, an overall DMI value is calculated in the following formula:

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

(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).

(DMI$_{Long}$) - Longitudinal Cracking



- For longitudinal cracking, the 4 crack types fall under the wheel path, pavement edge, mid-lane and centreline, i.e., two 1-m wheel paths, one 1 m mid-lane, one 0.3 m pavement edge and one 0.3 m centreline, together make up the entire lane, so it is best to consider longitudinal cracking in terms of the entire lane rather than by zone.

- As shown in the figure above, a pavement lane is divided by five zones and five separates of cracking data (severity is based on cracking width and density is given by either length or area)

(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, α is undetermined coefficient.

$(DMI_{Alligator})$ – 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 of DMI Contributing Factors

%	Poor	Fair	Good
DMI(Long)	3.03	6.52	90.45
DMI(Trans)	1.48	10.85	87.68
DMI (Alligator)	0.01	0.09	99.90
DMI(0.4L/0.4T/0.2A)	0.52	4.55	94.93
DMI(0.4L/0.5T/0.1A)	0.90	6.07	93.03
DMI Performance Distribution in PMS2 (2013)	0.3	10.0	89.8

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
PMS	3.8	19.0	77.1

PCI Distribution Of Primary Roads in 2013

Chart from PMS2

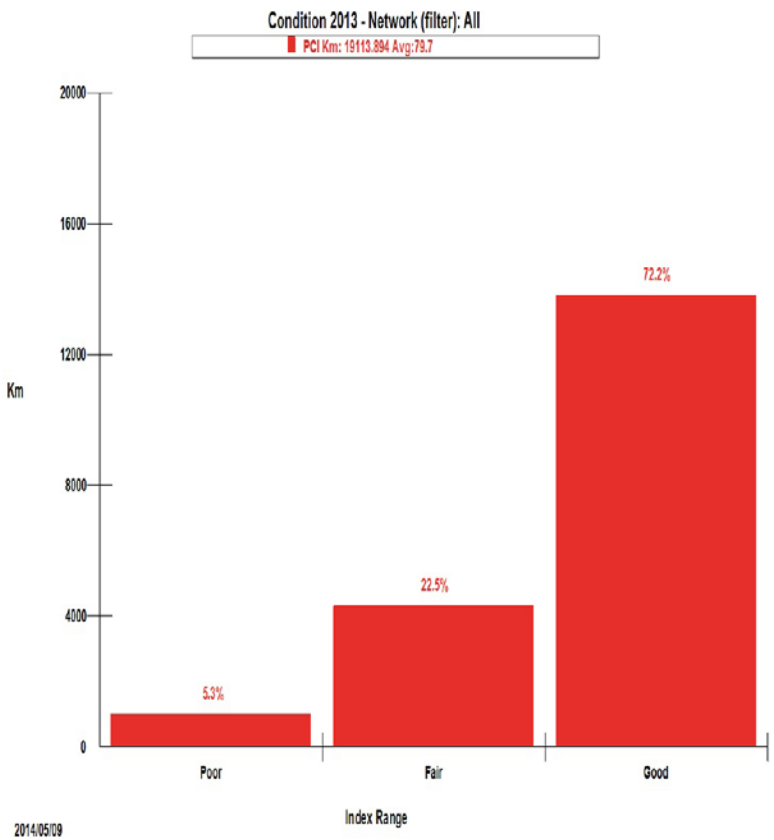
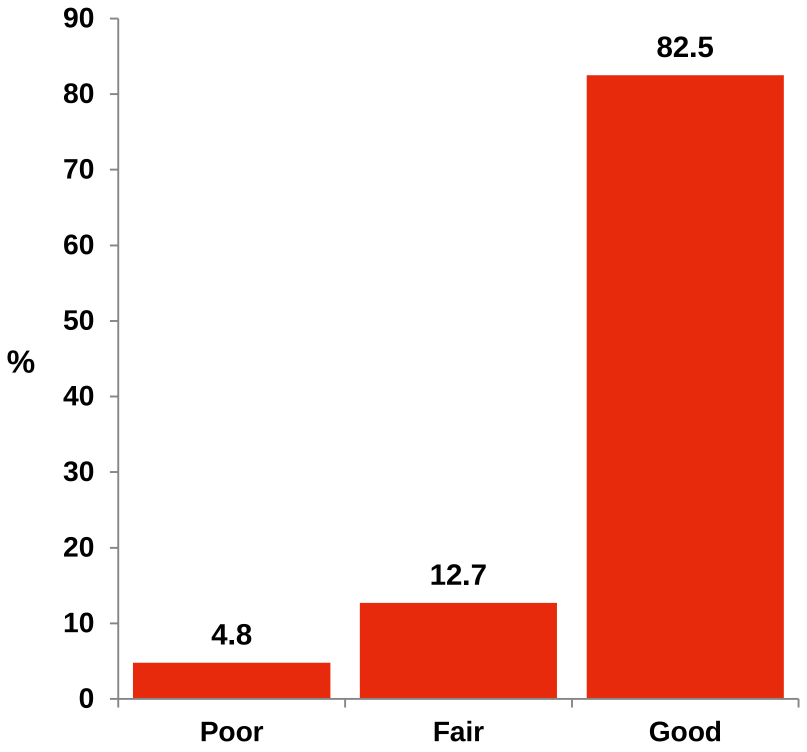


Chart (used new model)



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 ≤ PCI ≤ 60
Fair : 60 < PCI ≤ 75
Good: 75 < PCI ≤ 100

Trigger Levels: Poor : 0 ≤ PCI ≤ 60
Fair : 60 < PCI ≤ 80
Good : 80 < PCI ≤ 100

Defining Trigger Levels

- The following sets of trigger levels:
  - **Poor: $0 \le PCI \le 60$**
    Fair : $60 < PCI \le 75$
    Good: $75 < PCI \le 100$

  - **Poor: $0 \le PCI \le 60$**
    Fair : $60 < PCI \le 80$
    Good: $80 < PCI \le 100$

  - **Poor: $0 \le PCI \le 55$**
    Fair : $55 < PCI \le 75$
    Good: $75 < PCI \le 100$

- The second set gives the results close to the historical observed data in MTO PMS.

Setting Trigger Levels

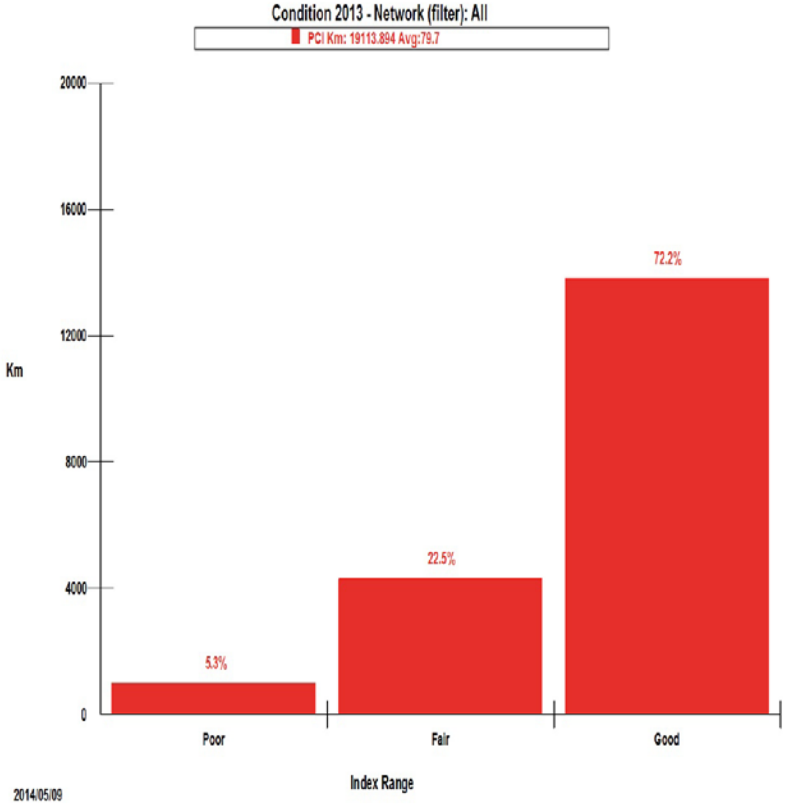
	Poor	Fair	Good	Reason
Set 1	**0≤x≤55**	**55<x≤75**	**75<x≤100**	Above tables show that Poor condition has relatively more weight compare to the PMS2 data and oppositely, Fair condition has less weight. Therefore, shifting weight from Poor to Fair may change this situation.
Set 2	**0≤x≤60**	**60<x≤75**	**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

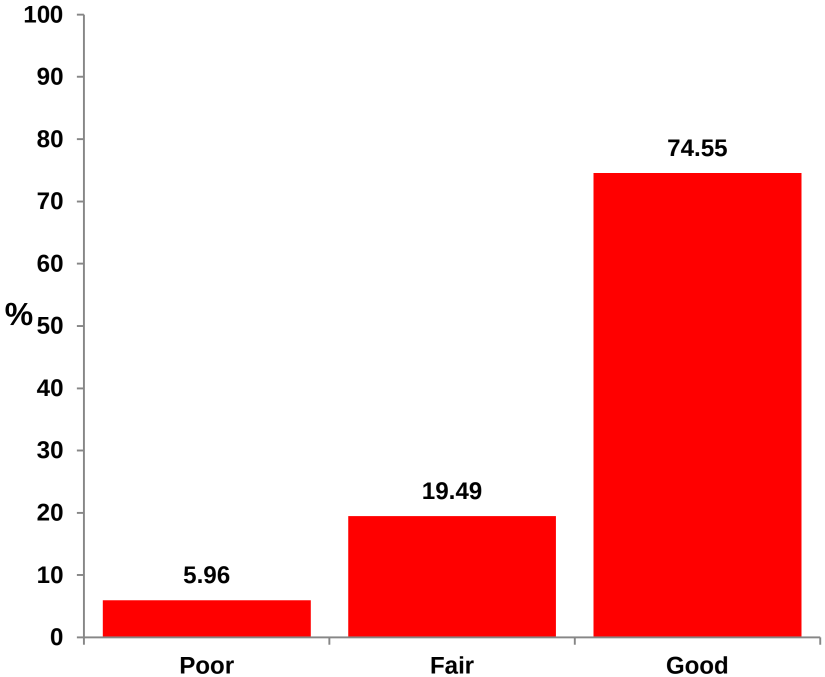
	Poor				Fair				Good			
%	0≤x≤55	0≤x≤60	0≤x≤60	PMS2	55<x≤75	60<x≤75	60<x≤80	PMS2	75<x≤100	75<x≤100	80<x≤100	PMS2
DMI	0.41	0.90	0.90	0.3	6.56	6.07	11.31	74.4	93.03	93.03	87.79	89.8
RUT	0.26	0.49	0.49	NA	4.32	4.09	9.37	NA	95.42	95.42	90.14	NA
IRI (RCI)	10.74	14.20	14.20	4.1	27.48	24.02	41.97	21.5	61.78	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

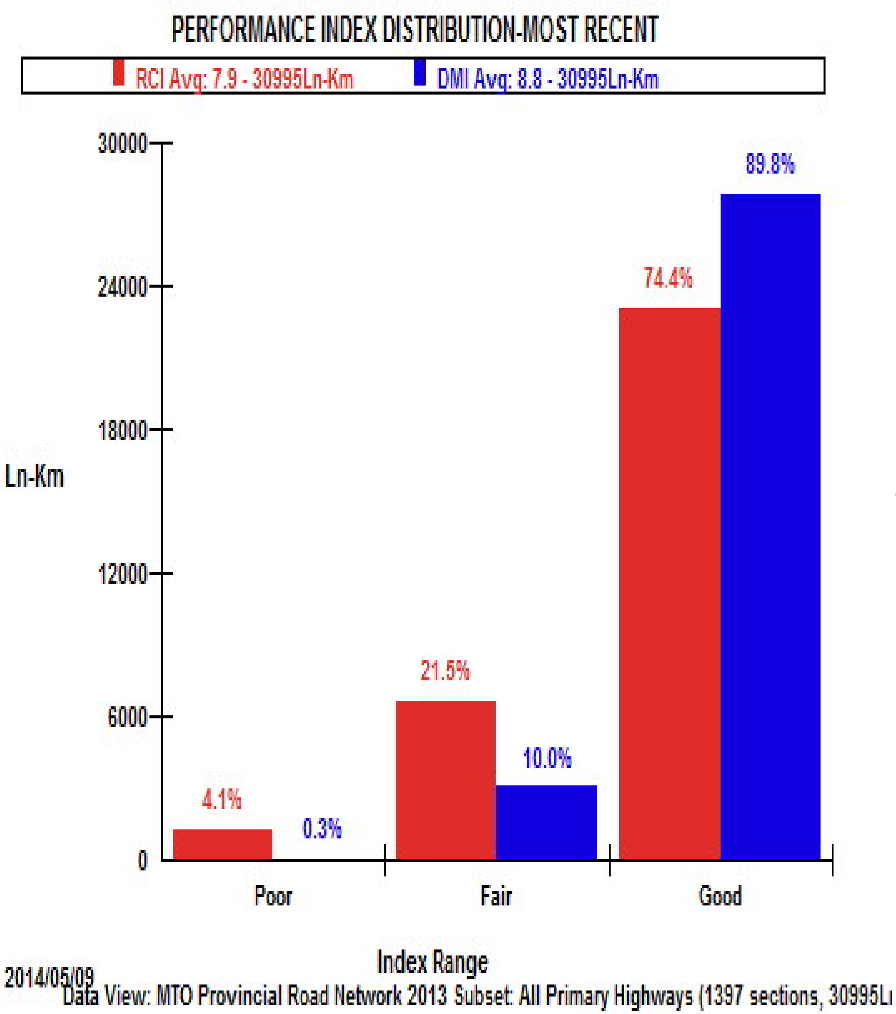


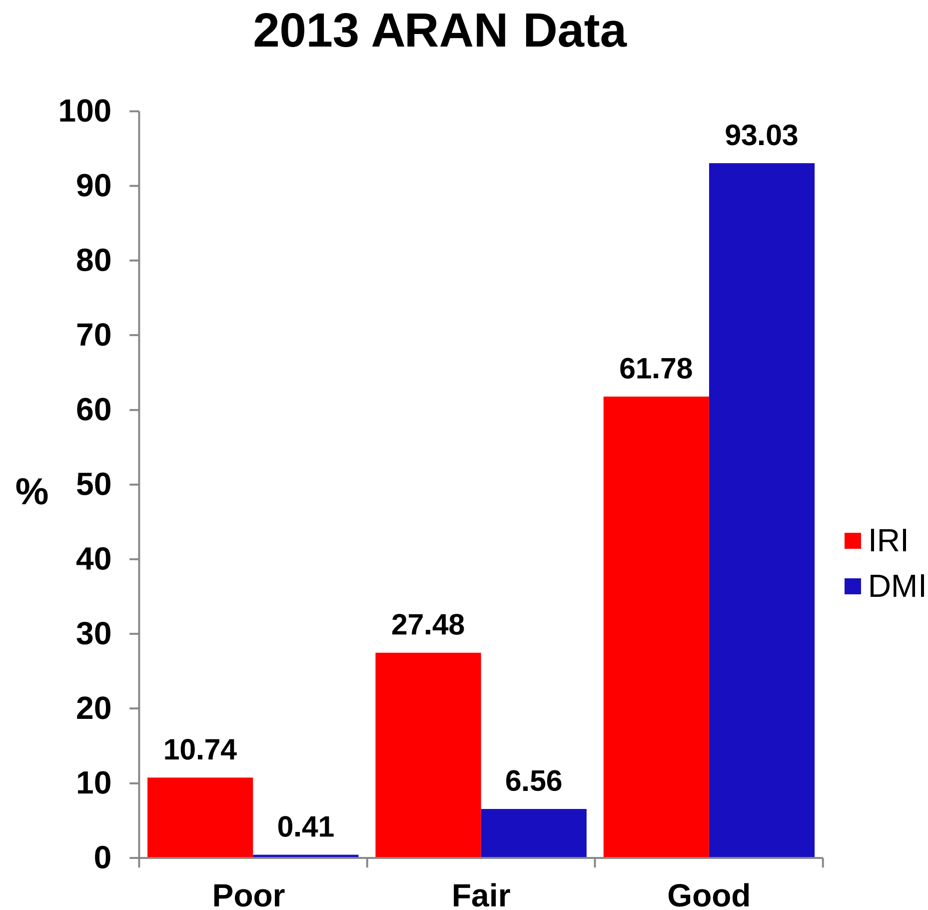
2013 ARAN Data (New trigger level)



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



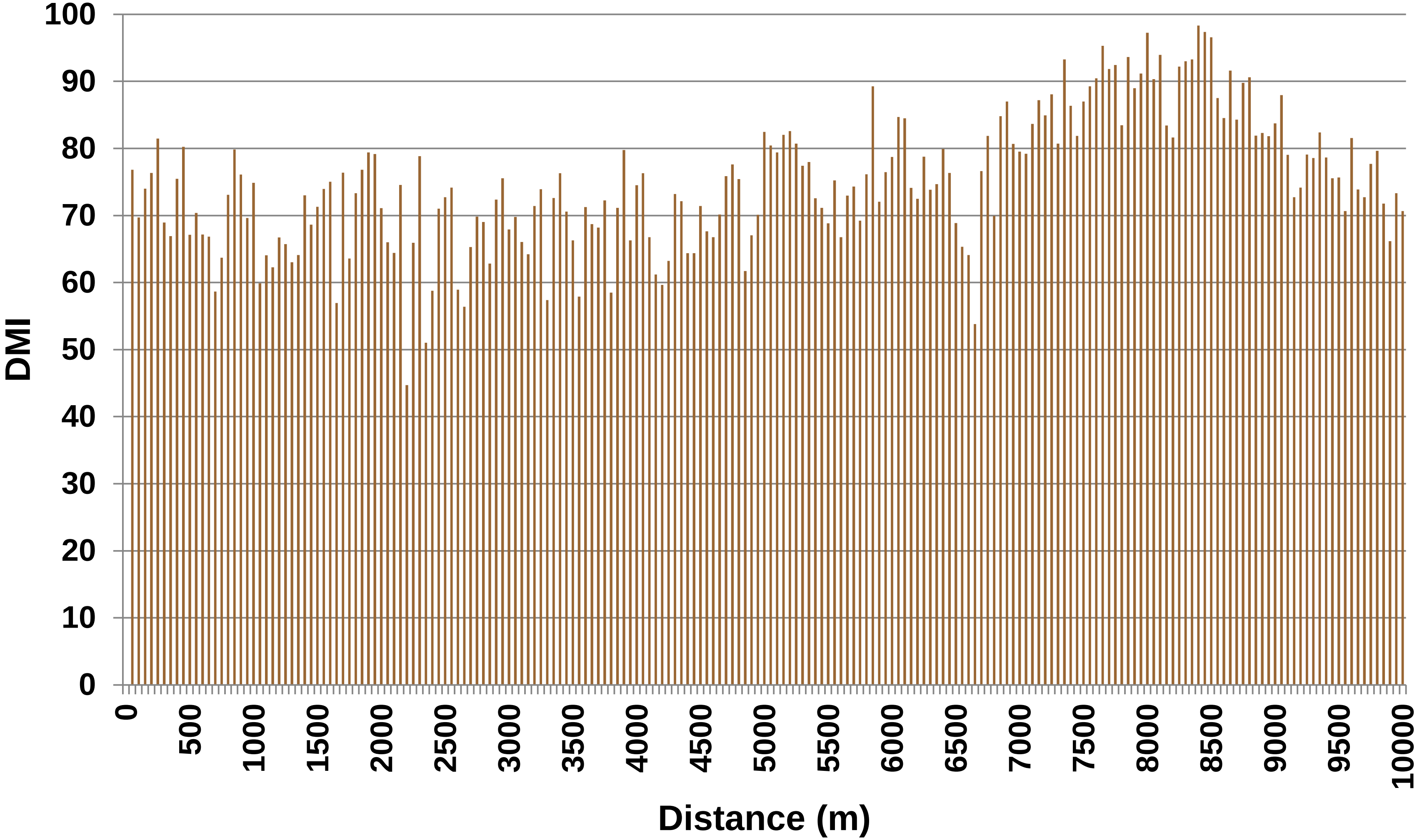


Rating criteria: Poor: 0 ≤ PCI ≤ 60
Fair: 60 < PCI ≤ 80
Good: 80 < PCI ≤ 100

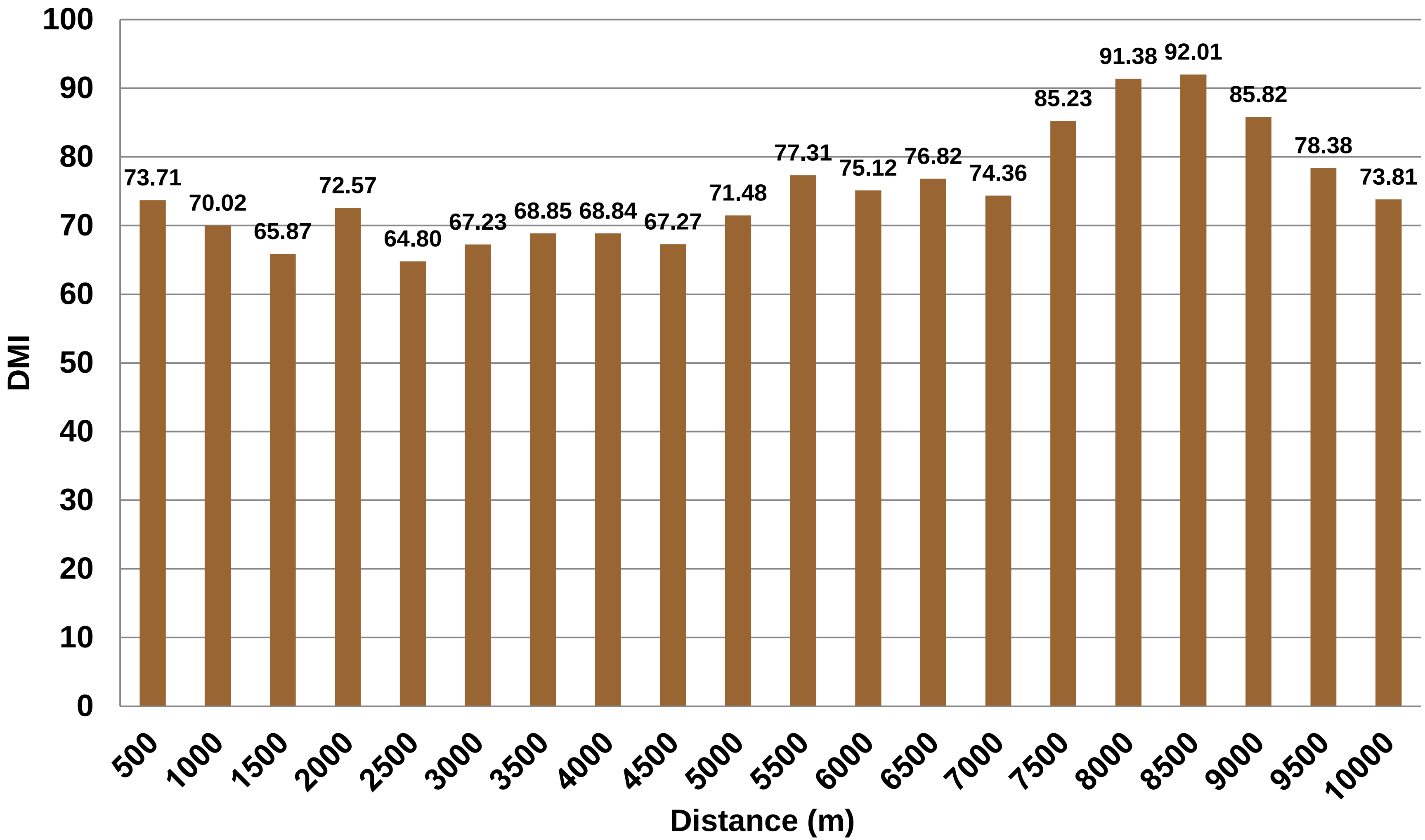
Impact of PMS Section Length on Pavement Condition Reporting

- **Reporting pavement condition and performance evaluation summarized by different length of road sections: 50m, 500m, 1000m, 3000m, 5000m and 10000m intervals**
- **Increasing interval length, the indices trend to stable and have an average**
- **An example of IRI reporting values calculated from different length sections (Data collected from Highway 401 E in MTO Central Region), as shown in the next few slides**

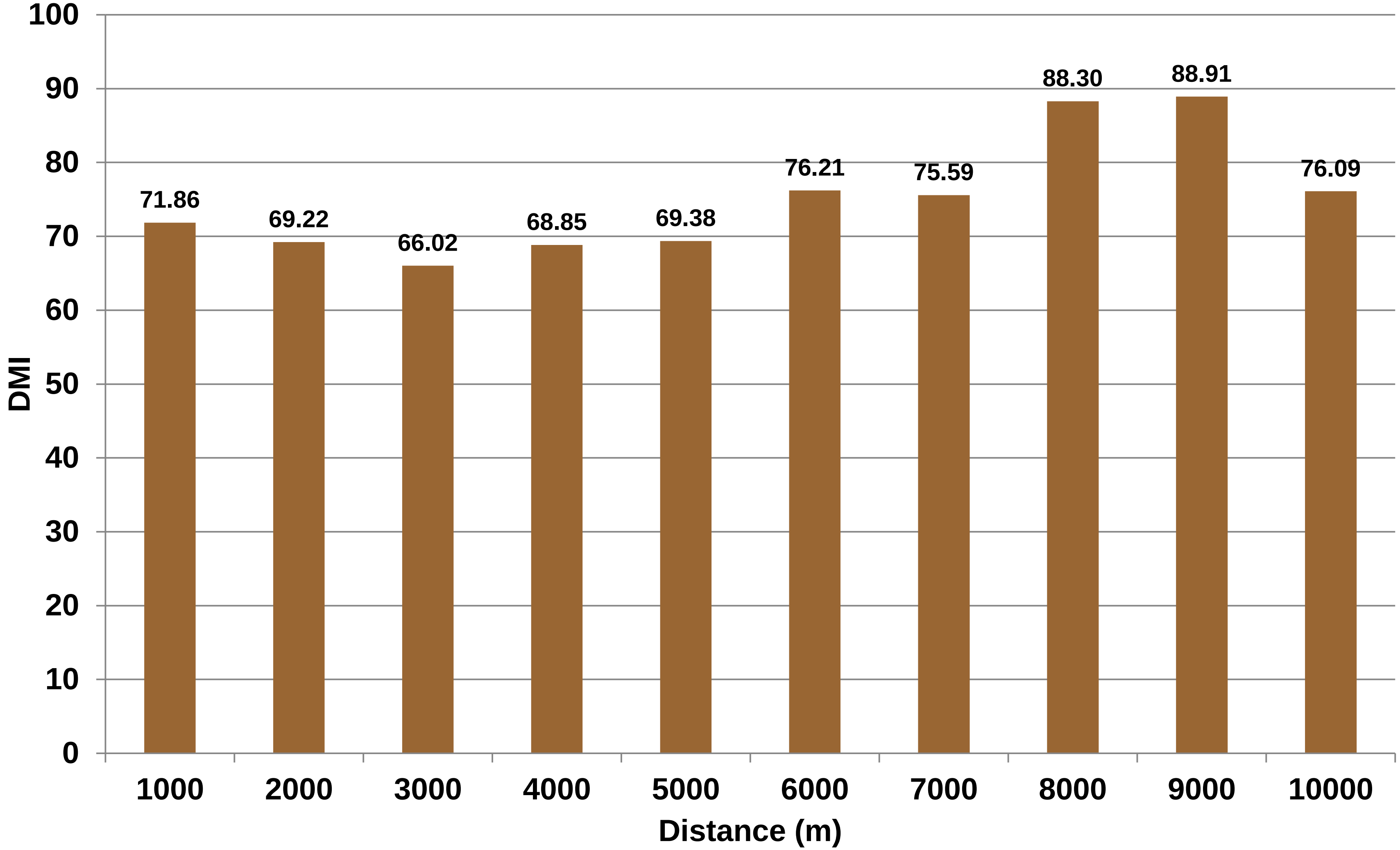
DMI at 50m per Section



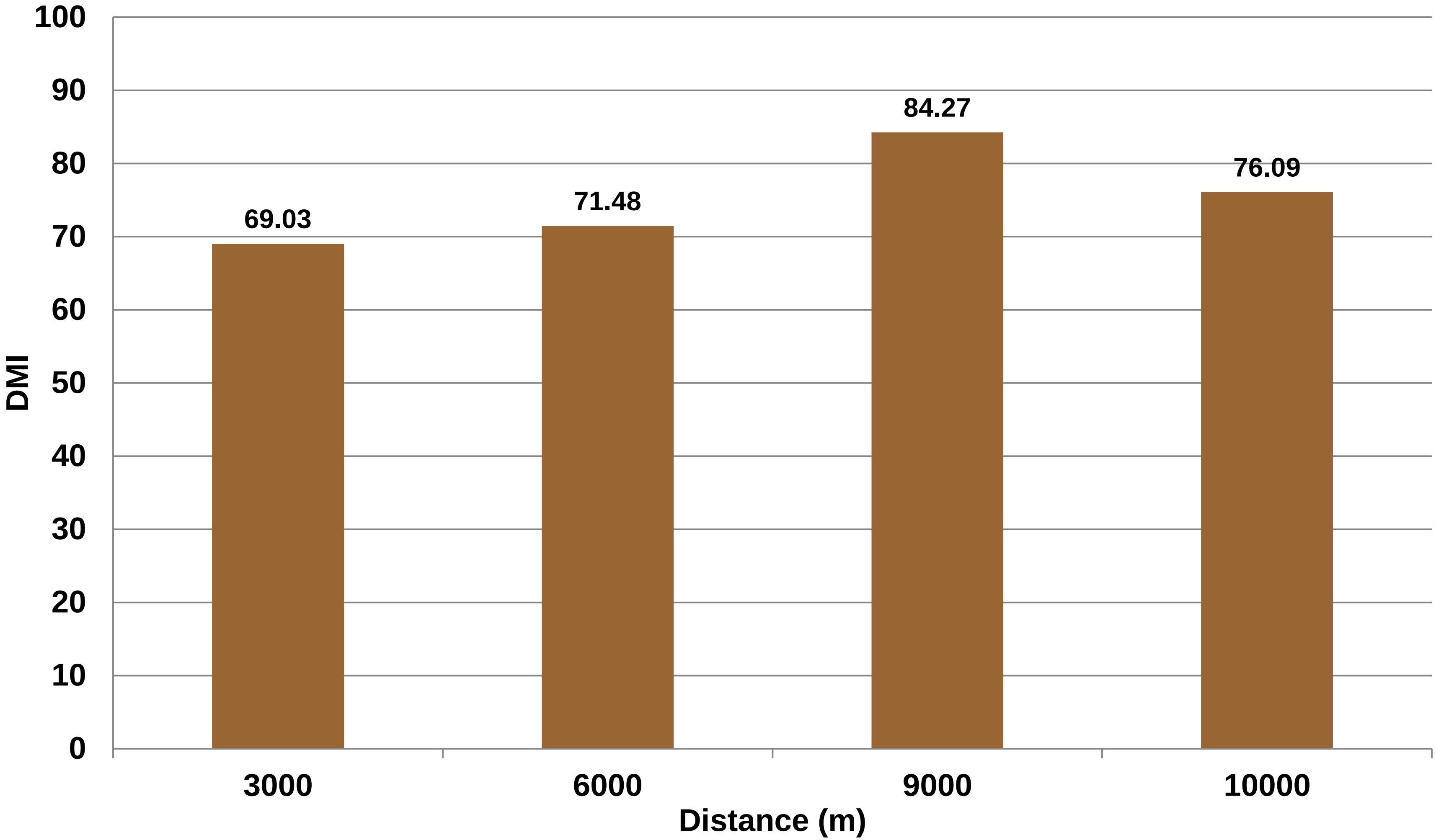
DMI at 500m per Section



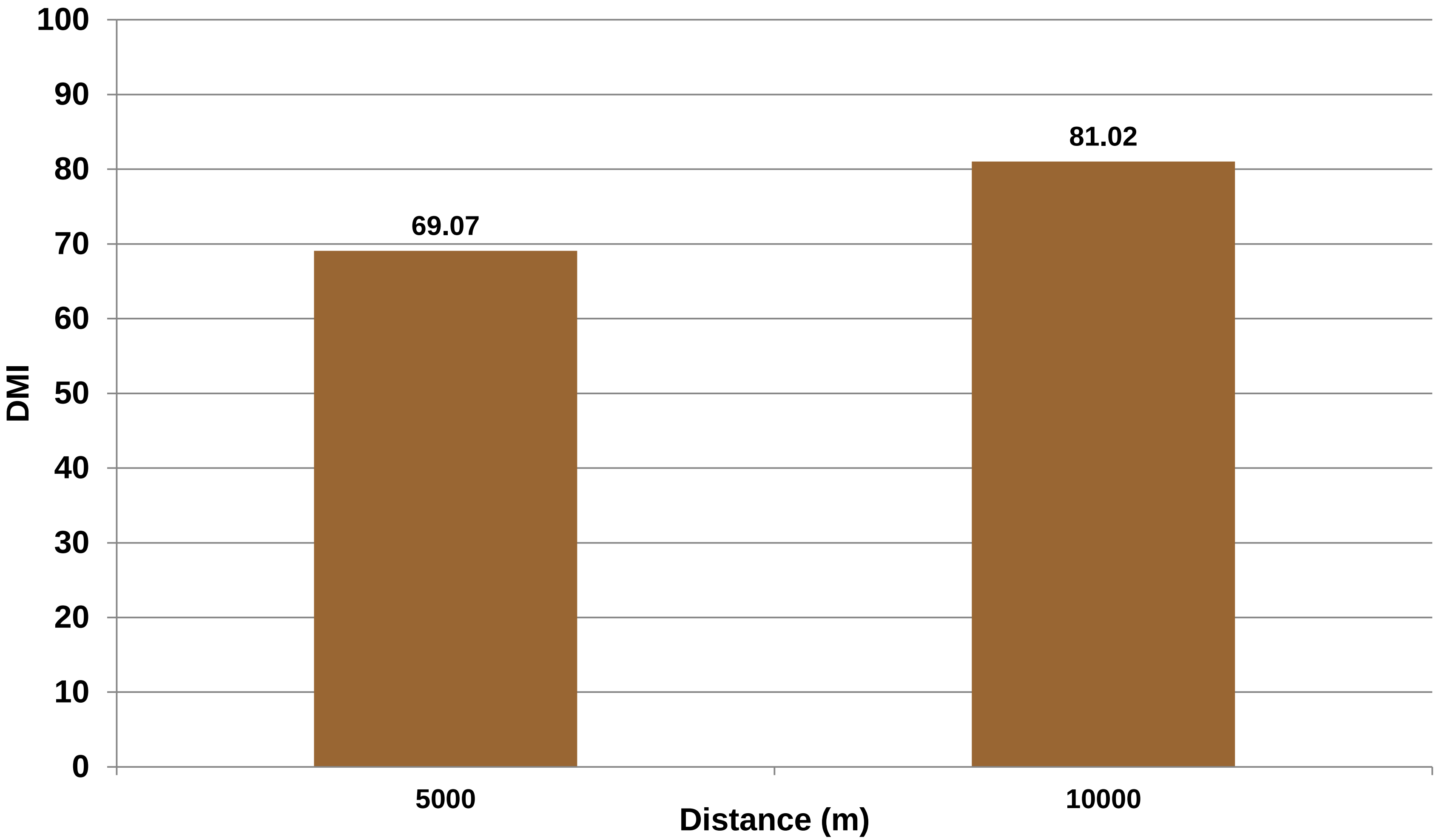
DMI at 1000m per Section



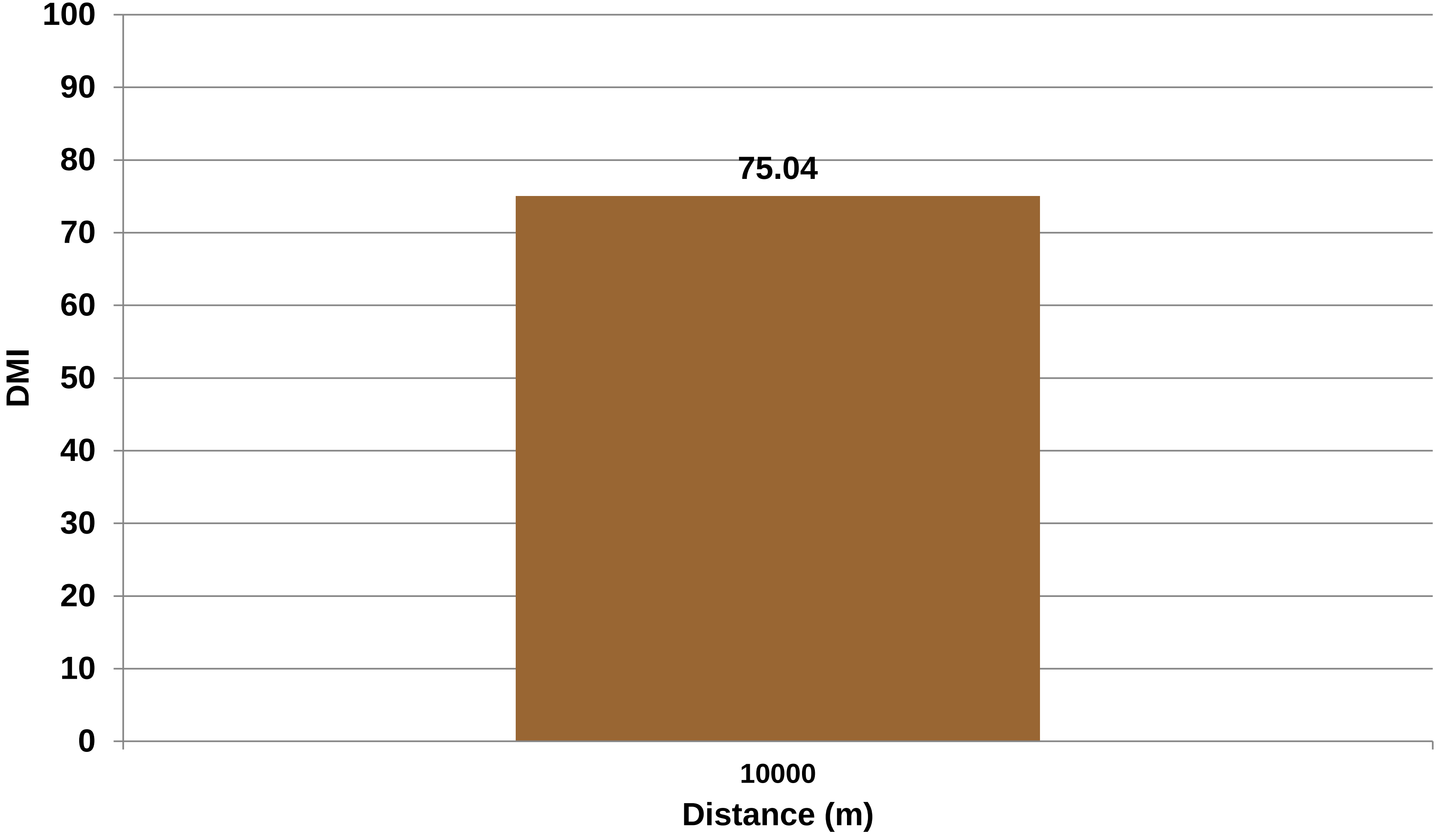
DMI at 3000m per Section



DMI at 5000m per Section



DMI at 10000m per Section



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**