QUALITY ASSUANCE APPLIED IN MEASURING PAVMENT ROUGHNESS OF ONTARIO PROVINCIAL ROADS

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ABSTRACT

The Ministry of Transportation of Ontario (MTO) has recently developed its second generation of pavement management system (PMS2). The PMS2 system will be used primarily for providing the Ministry and public with information and a series of annual reports on pavement condition assessment, optimal pavement maintenance and rehabilitation (M&R) program and economic analysis. Pavement roughness or smoothness has been widely recognised as an extremely important indicator in the evaluation of riding quality and safety of a highway network. In 1997, the Ministry started to carry out the roughness measurements at network level by using laser based high-speed initial road profilers. Measurements of roughness in both wheel paths have been taken annually on the Ontario provincial highway network, and converted to International Roughness Index (IRI), in m/km.

One of the pavement condition data items collected for the PMS2 is pavement ride quality in terms of IRI, which outweighs ranking of pavement riding quality and overall pavement condition. This paper describes how pavement roughness is measured annually on the entire provincial road network in terms of quality assurance (QA), data process and transfer into the newly developed pavement management system. Several major issues concerned with pavement roughness measurements are discussed in the paper, including various profilers and their impacts on pavement roughness measurements. Factors influencing accuracy and reliability of the IRI measurements, such as type of profiling device, measuring speed, measuring locations and data process. Finally, some preliminary findings and analyses of pavement roughness measurements on different pavement types of the entire pavement network are presented.

BACKGROUND

Pavement roughness in terms of International Roughness Index (IRI) has been used as the primary parameter pavement performance evaluation in the process of pavement management. Many highway agencies in Canada and the United States of America have used IRI in their business plan as an objective measure of their pavement network conditions. For example, the U.S. Federal Highways Administration (FHWA) uses IRI as a performance measure for describing and monitoring pavement condition of its National Highway System. The states of Kansas and Washington use IRI to describe the condition of their network in terms of percentages of miles in IRI rating categories. The American Society for Materials and Testing (ASTM E1777-96) assigns roughness the highest priority among performance-related data for pavement management [1].

MTO has started to measure at network level pavement roughness for Ontario provincial roads by means of high-speed initial road profilers since 1997. Measurements of pavement roughness in both left and right wheel paths are converted to the average value of IRI for a measured pavement section. During 1986-1996, MTO used a response-type measuring device, Portable Universal Roughness Device (PURD), to monitor riding quality of the pavement network. The PURD measures roughness in terms of RMSVA (Root Mean Square Vertical Acceleration) values of a trailer axle. In view of the limitations of the response-type measuring device, the Ministry switched to IRI-based technology in 1997.

Because IRI is a geographically-transferable, repeatable and time-stable measure, it has an added attractiveness as a measure suitable for quality control of new pavement construction projects. As well, it is an important criterion for acceptance of a road contractor's product. A complete copy of the consultant's quality manual and a project specific internal quality plan were submitted to address the quality requirements of the specific assignment.

The internal quality plan describes the steps that will be taken to ensure the consistency, accuracy and overall integrity of the Dipstick data collected at each site. Vendor Selection was based on vendor's experience and capability of carrying out this type of assignment, five consulting firms were invited to submit their individual quotations for performing the assignment specified in the Request for Proposal (RFQ).

Recent research [2,3] have demonstrated an approach for adopting IRI calculated from high precision profilometers for effective quality assurance (QA) evaluation of roughness on paving projects. By its definition, IRI is a summary statistic representing an aggregation of the profile elevation data. When it is used as an end-result specification for newly constructed asphalt concrete pavements, a relatively long base length (i.e, 100 m) would ensure the overall quality of the pavement, and a relatively short base length (i.e., 10 m) would identify very short sections of high roughness levels that would otherwise go undetected.

Measurement of pavement roughness at network level has become a routine practice for many road agencies in recent years. At the network level, roughness is measured on an annual or biennial basis as part of pavement evaluation that is critical to formulating maintenance and rehabilitation priorities. On the other hand, IRI measurement at the project level is required primarily for accepting or price adjusting a paving contractor's product. Therefore, there is a need to standardize the pavement roughness evaluation protocol both at the project and at network levels.

As summarized in reference [4], the methods and devices developed to qualify pavement roughness over the past few decades are divided into three basic categories: a) profile measuring devices - used directly to obtain pavement profile data; b) response measuring devices - which measure vehicle response from the movement ver a pavement surface and c) subjective ratings. The most commonly used roughness methods and equipment have been categorized according to scale of accuracy and reliability developed as a part of the International Road Roughness Experiment [5] completed in Brazil in the mid-1980s.

OBJECTIVE AND THE STUDY

The main objectives of this study are: 1) to review the first five years of roughness measurements conducted annually on 1700 pavement management sections with a total about 18,600 km of the Ontario highway network, 2) to present the methodologies used in the Ministry for quality assurance of the annual network roughness measurements performed by outsource contractors, 3) to investigate the impacts of different measuring devices, varying longitudinal profiles and measuring speeds on measure of pavement roughness, and 4) to discuss some issues derived from roughness measurements that are concerned in pavement management.

In addition, through examination of the data and information collected at the IRI measurement verification circuit, this study discusses the procedure used to ensure quality of pavement roughness measurements at the MTO's road network. More specifically, the study addresses the following technical issues:

a) Review of the IRI profiles measured on the verification circuit, taking into account pavement structures, section length and IRI measuring devices used for raw data collection. If IRI measurements are done by different roughness contractors in subsequent years, it is essential to ensure that a consistent IRI measuring protocol be established which encompasses variability in measuring devices, operation procedures and verification methods.

b) Comparison of IRI values calculated on different base length distances ranging from 10 to 150 meters. The 150-metre long base length would ensure assessment of the overall quality of the pavement and the relative short base length distance (i.e. 10 meters) would identify the localized areas of rough pavement that would otherwise go undetected.

c) The influence of pavement type and wheelpath on IRI measurements based on the IRI measurements and other information collected at the IRI verification circuit.

d) Establishment of a protocol that would be able to convert the roughness measurements performed by different measuring technologies to a standard IRI rating scale and compare the measurements with other jurisdictions.

3. COLLECTION OF ROAD PROFILES AND ROUGHNESS DATA

3.1 MTO Road Network

Based on the road condition surveys conducted in 2000, the Ministry has about 18,680 kilometres of provincial highways in five geographic regions comprising 3,697 km of freeways, 4,460 km of collectors, and 10,522 km of other roads. The majority of the highways are paved with asphalt concrete and surface treatments. The length of each pavement section ranges from a few hundred metres to 75 kilometres. Each highway is divided into individual sections based on homogeneity of pavement type, materials, traffic loads, and pavement performance.

Based on the survey conducted in 2000, there are approximate totally 1700 sections for the entire road network for the purpose of pavement management. Among the road network, there are five pavement types, including asphalt concrete (AC), composite pavement (COM), Portland cement concrete pavement (PCC), asphalt surface treated pavement (ST), and very small amount of gravel surface pavement. Table 1 gives detailed information of the Ministry's current highway network in terms of IRI measured in 2000 for each classified road and pavement type. Of the 18,646 km of roads, 80 percent is paved with asphalt concrete and approximate 17 percent of roads are surface treated by asphalt materials. The total exposed Portland Cement Concrete (PCC) pavement is about 0.7 percent of roads in the network.

Table 1 MTO Road Network Compositions Surveyed in 2000

Length of Each Classified Road			**Length of Each Classified Pavement**		
Road Class	Length (km)	Percentage	Pavement Type	Length (km)	Percentage
Arterial	6120	(32.8%)	Asphalt Concrete	14,259	(76.5%)
Collector	4324	(23.2%)	Composite	444	(2.4%)
Freeway	3654	(19.6%)	Portland Concrete	121	(0.7%)
Local	2890	(15.5%)	Surface treated	3318	(17.8)
Secondary	1658	(8.9%)	Grave Surface	505	(2.6%)
Note: The length of total roads surveyed in 2000 was 18646 km					

Table 2 and Table 3 present the results of pavement roughness surveys conducted over the last four year period between 1997 and 2000. The average IRI value of the all pavements in the network has improved over the last three year, consistently decreased attributed to rehabilitation programs and investment made over the last 4 years.

It is evident from Table 2 that Central region's road has the substantial improvement in terms of IRI values, improved from 1.94 to 1.54. Since this region has relatively higher percentage of freeways and it has received a number of rehabilitation and reconstruction treatments related pavement performance improvements.

On the other hand, the surveys show that pavement ride quality in Northern and Northwestern Regions's have been improved with decrease of 0.08 IRI values each year. Partially because of a large amount of low volume roads with surface treatment roads, plus environmental conditions are generally hashed or rougher than that in Southern Region. Overall, pavement condition is improved with incremental of 0.10 IRI value every year over the last four years.

The average IRI values measured on exposed PCC pavements are generally higher than those measured on asphalt concrete pavements in the same regions, reflecting the increased average age and lack of maintenance activities on the rigid pavement. The IRI values of all surface-treated pavements, which are mainly located in Northwestern and Northern regions, are nearly two times higher than those of asphalt concrete pavements.

It should be indicated that most surface-treated pavements are located in Northern and Northwestern regions while most Portland concrete pavements are located in Central region. There are no composite and exposed concrete pavements in Northern and Northwestern regions and no surface-treated pavements in Central and Southwestern regions.

Table 2 Improvement of Pavement Roughness Observed From 1997 to 2000 Surveys

Region	**IRI Value History (1997-2000)**				**Change of the IRI Value**	
	1997	**1998**	**1999**	**2000**	**Δ IRI (1997-2000)**	**Rate (ΔIRI /Year)**
Southwestern	1.85	1.63	1.52	1.52	0.33	0.11
Central	1.96	1.68	1.54	1.54	0.42	0.14
Eastern	1.94	1.71	1.58	1.56	0.38	0.13
Northern	2.55	2.46	2.33	2.30	0.25	0.08
Northwestern	2.55	2.54	2.42	2.29	0.24	0.08
Average	**2.19**	**2.06**	**1.92**	**1.89**	**0.30**	**0.10**

Table 3 Results of Roughness Measurements Summarised by Pavement Type

Pavement Type	**Average IRI History (1997-2000)**				**Change of the IRI Value**	
	1997	**1998**	**1999**	**2000**	**Δ IRI (1997 - 2000)**	**Rate (ΔIRI /Year)**
AC	2.01	1.83	1.67	1.66	0.35	0.12
COM	1.88	1.68	1.71	1.63	0.25	0.08
PCC	2.38	2.19	2.11	2.12	0.26	0.09
ST	3.54	3.33	3.31	3.16	0.38	0.13
Gravel	N/A	N/A	N/A	N/A	N/A	N/A
Mean IRI	**2.19**	**2.06**	**1.92**	**1.89**	**0.30**	**0.10**

3.2 Quality Assurance of Roughness Data Collection

Prior to awarding the Ministry's annual roughness contract, all contractors were required to specify in the bidding document the type of roughness profile measuring device to be used and the accuracy level of the device when calibrated to an ASTM Class 1 [1] survey device such as a Dipstick. In addition, the following five individual verification measurements throughout the contract are required as part of quality assurance (QA) process:

a) Pre-contract Qualification Calibration
b) Initial Calibration
c) Mid-Survey Calibration
d) Post-Survey Calibration, and

e) Final Calibration

Pre-Contract Qualification Calibration To ensure that contractor candidates meet the basic qualification requirements, pre-contract calibration measurements are required as part of the bidding process for IRI measurements. It is imperative that pre-contract calibration be performed with the same equipment to be used for the rest of the survey work.

Initial Calibration The selected contractor was required to conduct the initial calibration prior to the start of the production surveys. In the event the calibration data is found unacceptable, the contractor would be required to repeat the initial calibration at no extra cost to the Ministry. Actual survey will not proceed until such time that the Ministry finds the initial calibration results to be satisfactory. The requirement of the initial calibration may be waived if the contractor can demonstrate that the full-scale field survey work will start within 30 calendar days of completing the pre-contract qualification calibration. Otherwise, the contractor must conduct the initial calibration.

Mid-Survey Calibration Upon completing half of the network IRI measurements, survey work should not proceed until such time that the Ministry finds the mid-survey calibration results satisfactory. At any rate, the contract shall not carry out more than 60 percent of the entire survey before providing the Ministry with satisfactory mid-survey calibration results.

Post-Survey Calibration Upon completing the entire survey, the contractor should repeat the calibration procedure and submit the calibration results to the Ministry within 3 work days. If the calibration results fail to meet the criteria for acceptance, it will be the contractor's responsibility to provide satisfactory results, which may include repeating some or all of the previous measurements done during the period between the last (successful) monitoring site measurement and the (unsuccessful) post-survey calibration. Remedial survey work shall not proceed until such time that the Ministry finds the post-survey calibration results satisfactory.

Final Calibration The final calibration was required to ensure year-to-year consistency of the survey data. The results of the final calibration shall be submitted within five work days. If the calibration results fail to meet the criteria for acceptance, it will be the contractor's responsibility to repeat the calibration survey at no extra cost to the Ministry until the calibration results meet the acceptability criteria.

Monitoring Site Surveys The contractor's pavement roughness measurements are monitored during the production surveys using 30 "blind" monitoring sites that were randomly selected throughout the network. The contractor is informed within one working day when the survey crew has passed over a "blind" monitoring section. It is required that the contractor submit to the Ministry the monitoring section's IRI summary results (i.e., average IRI value for the monitoring section) within three work days following the notification by the Ministry. If there is a large unexplained discrepancy between the IRI values reported by the contractor and those obtained independently by the Ministry (i.e. a difference greater than 20 percent), investigation and detailed analysis is required.

3.2 Verification of IRI Measurements

For the purpose of implementation of quality assurance for the annual measures of the Ontario provincial pavement ride conditions, the Ministry has established a verification circuit consisting of several road sections with different pavement types located in the area of Brantford, Ontario, as shown in the attached map. The circuit is used to verify and adjust pavement network roughness measurements performed by a roughness service provider on an annual basis. The measurements take place along 3 different segments of 150 meters each located at the start, middle and end of every 7 pavement sections selected by the MTO, for a total of 21 segments.

During May 2000, five different profilers including the Dipstick were used to measure IRI profiles on the twelve selected pavement sections comprising the verification circuit. Those used for roughness measurements at the verification circuit included the Dipstick, one response-type measuring system, and three profile-based measuring devices. The purpose of the comparison was to evaluate and select a contractor for doing the entire network pavement roughness IRI measurements on the basis of the individual vendor's IRI measurement results as compared with that measured by the Class 1 Dipstick IRI measuring device.

The verification circuit was used to compare the IRI values measured on the same pavements but with different devices. These individual measuring devices are described in Table 4 below. Device A is Dipstick, which was considered as Class 1 Device in both ASTM and the World Bank's classification of roughness measuring devices standard.

Table 4 Basic Parameters of the Profiling Devices Used at the Verification Circuit

Device	Type of Device	Key Parameters	Description
A	Digital Incremental Dipstick	300 mm sampling and recording intervals, manual	Capable of measuring longitudinal profiles (as a series of elevation points) at sampling interval less than 250 mm and precision of less than 0.5 mm. Class 1 Device
B, C, D	Laser - based High Precision Road Profilometers	< 150 mm sampling interval Operating speed: 80 km/hr 1.65 - 1.670 m wheelpaths	The profile sensors, spaced 1.67 m apart, are mounted in the front of vehicle. One of the devices has been used by LTPP-North Atlantic Regional Office for LTPP Testing sites. Class 2 Device.
E	Response Type Measuring Systems	< 300 mm sampling interval, 80 km/hr operating speed	Measures a vehicle's response travelling on the profile or measures surface distortion relative to reference platform moved along the road. Class 3 Device.

Device B, C and D are all laser-based, high-precision profilometers and they all meet the requirements of ASTM Standard E950, with a precision of 0.35 mm, a vertical resolution of 0.05 mm, and ability to perform longitudinal sampling at 25 mm intervals when travelling at 80-100 km per hour. All of the road profilers are non-contact, sensor-based IRI measuring systems that record pavement profiles. The comparison of differences between IRI measurements did not include an assessment of accuracy or bias.

Precision accelerometers measure the vertical displacement of the vehicle-to-road surface at every recording intervals while the vehicle moves along the road for compilation of longitudinal profile of the measured pavement section. Modern profilometers use the latest computer technology, non-contact sensors (infrared or laser), and accelerometers to accurately and quickly measure the longitudinal profile of a road. It should be noted that ultrasonic sensors are not adequate for accurate true profile measurement. All measurements are independent of variation in vehicle weight, speed, temperature, wind or pavement colour and texture. The profile data points were averaged and recalculated at 304.8 mm intervals to obtain the 1057 points required in ASTM Standard E950 to calculate the precision and bias. All of the individual IRI measuring devices are efficient with data collection and delivery capabilities. All of these devices have on-board computers which provide automatic calculation of roughness statistics such as IRI and Ride Number (RN).

Roughness measured by response-type devices, such as Device E defined in the study, are dependent on the system dynamics and operating procedures including vehicle characteristics (suspension, spring/damper, tire stiffness, etc.), the travel speed and other operating factors. Output from Device E measuring system gives RMSVA, which is converted into the RCI and then converted into IRI through regression equation connecting the two indices.

4. MEASURES OF PAVEMENT ROUGHNESS

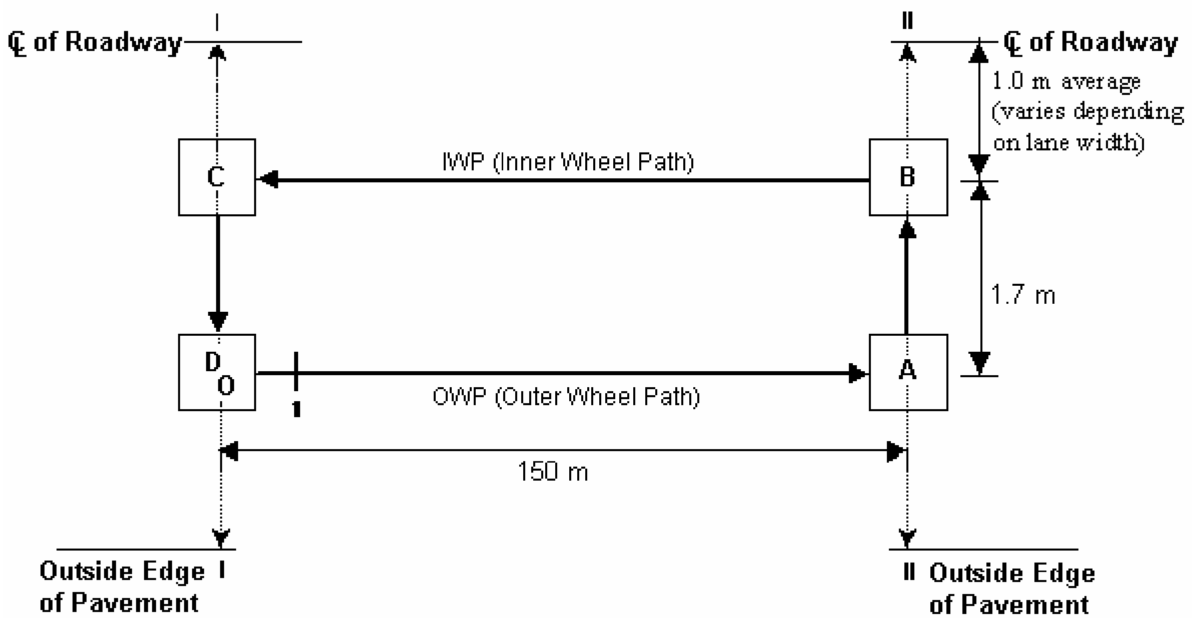
4.1 Guidelines for Measuring Roughness

The measurement of IRI using the Dipstick on each pavement section in the verification circuit is illustrated in Figure 1. Before performing profile measurements, the Dipstick was calibrated in conformity with the specifications and terms defined in the Annual Book of ASTM Standards (Vol 04.03 Designation: E 950-94) [1]. Collection of pavement surface profile data of the wheelpaths is conducted in a continuous, closed-loop fashion (i.e., up one wheelpath, cross over, down the other wheelpath and cross over to the starting point) using the Dipstick at 300 mm spacing. Using the closed-loop method the testing point at each segment (loop) is measured at the beginning and end of the loop. The difference in the measured elevation at this point is called the error correction factor and is distributed uniformly over the measurements in the segment in order to "close the loop".

All measurements within a pavement section were taken at three different subsections of equal length, i.e., 150 metres at the starting segment (or sub-section), 150 metres in the middle segment and 150 metres at the ending segment of the section, as shown in Figure 2. The total length of the 72 pavement longitudinal profiles measured on the 12 pavement sections was 10,800 metres (2 paths ×150 metres × 3 segments × 12 sections). For the Dipstick profiler, results of IRI measurements on the verification circuit were required to report at least the following key elements:

a) Average IRI for every 10 metres, 50 metres and 150 metres (the entire length) of each pavement segment measured along the inner wheelpath, the outer wheelpath and the average of the two paths;
b) Average IRI of the three pavement segments measured, which will be used to represent the mean IRI value of an entire pavement;
c) The error or correction factor to each segment used to adjust the measurements.

For this assignment, Dipstick profilers were used to measure: i) longitudinal profile along the inner and outer wheel paths (i.e., CB and DA lines as shown in Figure 1) in the closed loop fashion, ii) transverse profile along the starting and ending cross section lines (i.e., I-I and II-II lines) at each pavement segment, beginning at the shoulder edge and moving towards the middle of the pavement and terminate at the roadway centerline. It is required that the service provider's Dipstick be calibrated as per manufacturers requirements before performing this work. Collection of pavement surface profile data of the wheel paths shall be conducted in a continuous, closed loop fashion (i.e., up one wheel path, cross over, down the other wheel path and cross over to the starting point) using the Dipstick with 300 mm footprint. Figure 2 illustrates how a pavement profile is to be measured by using the Dipstick in the closed loop



fashion.

Figure 1 Process of IRI Measurements Using a Dipstick Profiler

The key elements of Figure 1 are listed as follows:

O = beginning of loop

1 = first reading at 300 mm (also first reading used in the OWP IRI calculation)

A = reading at the end of the outer wheel path (OWP)

B = reading at beginning of inner wheel path (IWP)

C = reading at end of IWP

D = final reading at end of loop (at O)

In Figure 1, O is an initial reading point which is usually set as zero elevation reading in reference to other successive readings. The O and D points are physically identical, but may have two different readings, and the difference between these two readings is to be considered as a closure error.

It must be noted that all longitudinal measurements be conducted by means of a Dipstick with 300mm footprint along each wheel path in the closed loop fashion. All transverse profile should be measured using a Dipstick with 100mm footprint. The transverse profiles should be measured along I-I and II-II cross sections of a pavement segment, as shown in Figure 2. For Sections 5N and 5S, it is required that transverse profiles must be measured in 30m intervals along the pavement segment including the starting and ending cross sections within the segment (i.e., 6 transverse profiles are to be measured for each segment, 3 segments per pavement section). The transverse profiles should be performed separately from longitudinal profiles measurements.

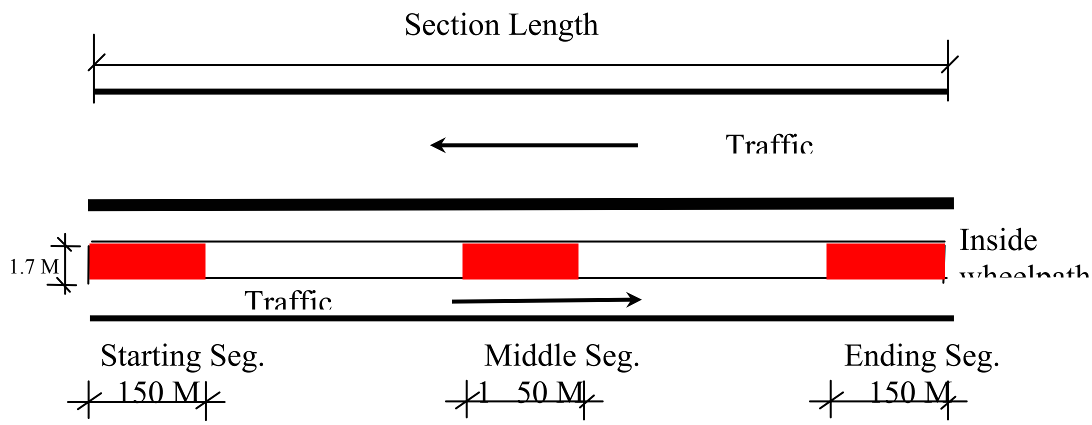


Figure 2. A Sketch showing the segments to be measured on a pavement section

4.2 Required Deliverables

a) Timeframe

The service provider shall be required to perform the work during the period of April 30 - May 4 and it may be continued during May 14-18, 2001 if it becomes necessary. A final report, together with all data and analysis results related to this assignment must be submitted to the Ministry by May 25, 2001. *Penalties for late delivery will be assessed at 10% of quoted price for each week delayed at May 25, 2001, for example.*

b) Reporting

The service provider's reporting documents must include at least the following key elements:

- Average IRI of every 10 meters, 50 meters and 150 meters (the entire length) of each pavement segment measured along the inner wheel path, the outer wheel path and the average of the two paths;
- Average IRI of the three pavement segments measured, which will be used to represent the mean IRI value of an entire pavement section that ranges from 1.02 km to 2.40 km in length.
- Transverse surface profile plots of each individual pavement segment. For Sections 5N and 5S, it is required that transversal profiles must be measured in 30m intervals along the pavement segment including the starting and ending cross sections within the segment (i.e., 6

transversal profiles are to be measured for each segment, 3 segments per pavement section). In addition, the following results of analysis and calculation are required in report:

i) Calculated left and right rut depth based on stringline method for each transverse profile.

ii) Calculated average left and right rut for transverse profile.

iii) Calculated average left and right rut for each segment.

- Error or correction used to adjust the measurements in order to close the loop measured on each pavement segment.

Through the process of verifying and comparing longitudinal profile measurements using different profilers, the MTO has gained insight into the functional relationships and factors affecting profile measurements in terms of precision and bias. However, the results of individual measurements on the same pavement section may vary significantly due to the use of different measuring devices, varying longitudinal profiles and measuring speeds.

4.3 Average IRI Measured on Segments

Figure 3 shows the differences of the average IRI measured along the outer wheelpath on three segments of the pavement sections profiled by the three different types of measuring devices. By comparing with each other, it is obvious that Device B measurements are closer to the Dipstick measurements, although both Device B and C are laser-based, high-precision profilometers. Regression analysis was conducted to examine their individual relationships based on IRI measurements by the three measuring devices.

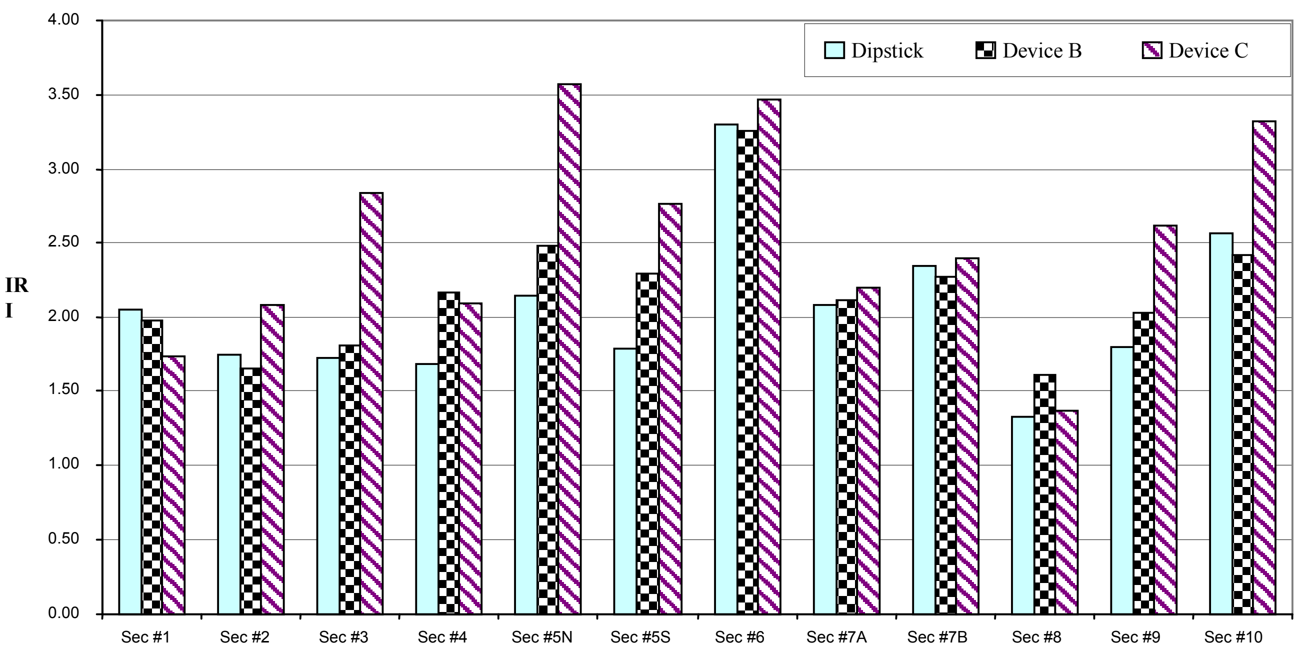


Figure 3 Comparison of Average IRI Measured on Three Segments Along the Outer Wheelpath

As shown in Figure 4, a good linear relationship exists between Dipstick measurements and Device B, while the relationship between Dipstick and Device C gives a less linear relationship with several scattered measurements. The figure compares the average IRI measurements obtained for all 12 sections of the verification circuit by the three IRI measuring systems. The higher R square value from the regression between the IRI measurements from the Dipstick and Device B indicates that 80 percent of measurements performed by these two devices can be explained or converted by using this the regression equation.

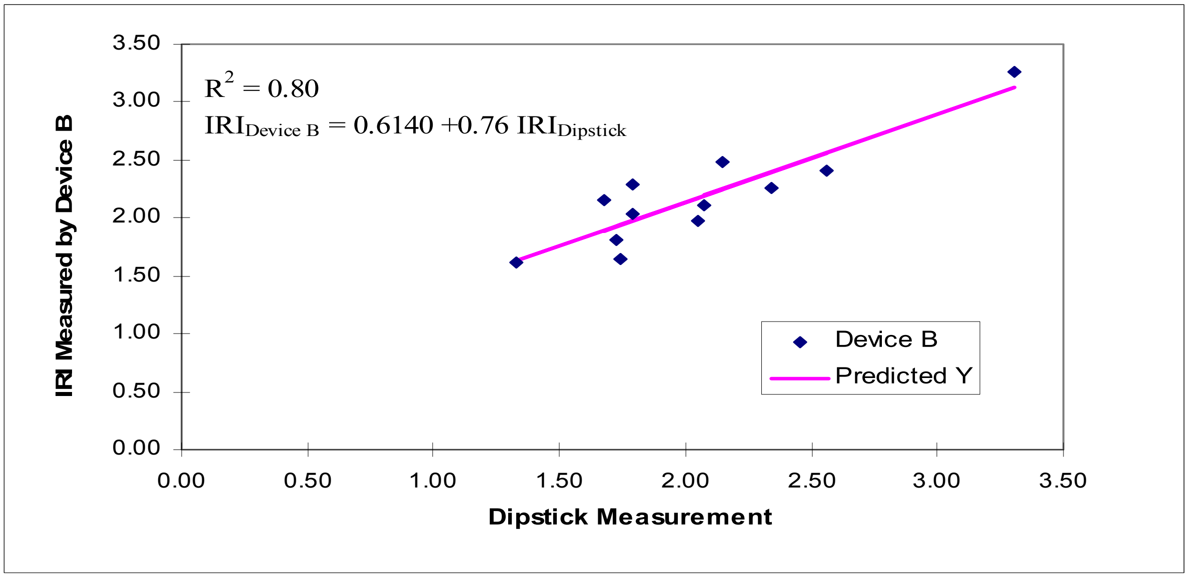


Figure 4 Relationship Between International Roughness Index (IRI) values Measured by Dipstick and Device B

It has been concluded that verification produces more consistent results if it is done on an individual wheelpath basis [6]. Both Device B and C produced good correlation with Dipstick based on the IRI measurements from the outer (or right) wheelpath. A specific study issue was the correlation between IRI values measured on the outer wheelpath of each individual pavement segments by Dipstick and two of the Class 2 sensor-based IRI measuring devices. A high correlation between the two devices would provide a mechanism of transforming IRI values measured from one to another for network-level monitoring.

Considering the time-consuming nature of the operation and associated costs, the Dipstick device was required to measure only three segments on each pavement section - the starting segment, the middle segment and the ending segment of the section - with each segment being 150 m long. IRI measurements on each segment are recorded as average IRI values at intervals of every 10, 50 and 150 metres. All measuring devices except the Dipstick were used to measure the whole pavement section with similar recording intervals.

4.4 Average IRI Measured on Sections

Except for the Dipstick, the other four IRI measuring devices were required to measure the entire length of each selected verification section. Figure 5 shows the average IRI value measured on both outer and inner wheelpaths of each pavement section in the verification circuit by the four devices. Among the 12 pavement sections measured, the IRI values calculated by the four different measuring devices are comparable to each other except for Sections 7 and 10. It should be noted that both Section 7A and 7B are exposed PCC pavements and Section 10 is a surface-treated pavement.

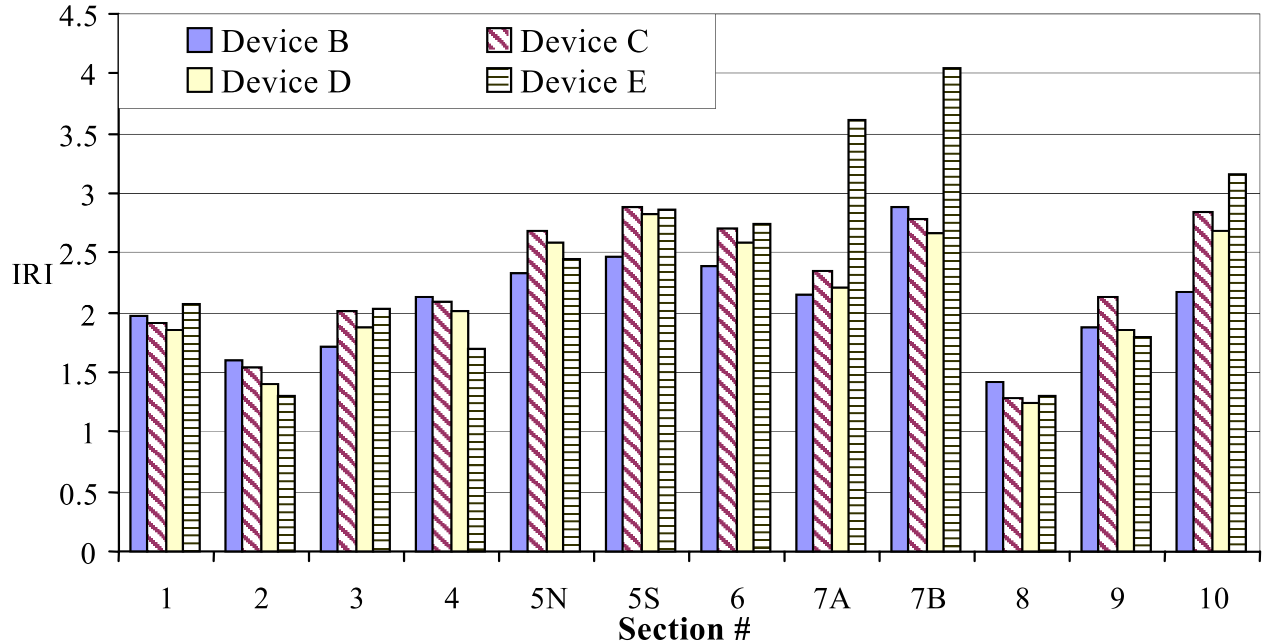


Figure 5 Comparison of Average International Roughness Index (IRI) Measured by Four Different Devices

The results show that the Device B can reproduce the Dipstick-IRI with a high level of confidence. The R square value indicates that 80 percent of the predicted values are explained by this equation. Device C results indicated a lower level of confidence when compared with the Dipstick. The overall mean IRI values of the three segments obtained for all sections by the three IRI-measuring systems were 2.04, 2.17 and 2.54 m/km, respectively for the Dipstick and Device B and C.

Based on the measurements shown in Figure 5, it leads to a conclusion that Device E is not suitable for measuring IRI of rigid pavements. The tined texture of this pavement type results in additional excitation of the accelerometer resulting in fictitiously high RMSVA values. A similar result occurs on surface-treated pavements with their coarse macro-texture.

5. FACTORS INFLUENCING IRI MEASUREMENTS

5.1 Influence of Wheelpath or Profile location

Essentially, the IRI is defined as a property of a single wheelpath profile. There are no strict guidelines regarding where the profiles should be located and how many of them should be used. Based on these findings, it is recommended to correlate roughness on individual wheelpath basis. For the purpose of calibrating various measuring devices, it is recommended that IRI profiles measured on either inner or outer wheelpath be used. In addition, a study was conducted to analyze the IRI values measured on the same wheelpath in opposite direction which may differ in spectral frequencies.

Table 5 shows a summary of the IRI profiles measured on both inner and outer wheelpaths by Device B and C, plus the IRI profiles measured on outer wheelpath and the profile between the two paths using Dipstick. The IRI values show significant variations between these different profiles or wheelpaths.

The IRI differences between the left, the middle and the right paths measured by Devices A, B and C are significant for some individual sections (e.g., Section 2, Section 4 and Section 10). However, the average IRI summarised for the all sections are not significant except for the last column (IRI measured along outer wheelpath of the all sections measured by Device C). Overall, the values in Table 5 suggest that, on the average, the right wheelpath was rougher than the left.

Table 5. Impact of Longitudinal Profile Locations on Pavement Roughness Measurements Conducted in May 2000

Section #	IRI (m/km) measured by Device B			IRI (m/km) measured by Device C			IRI (m/km) measured by Device E		
	IRI-1 (IWP)	IRI-2 (OWP)	IRI-1 - IRI2	IRI-1 (IWP)	IRI-2 (OWP)	IRI-1 - IRI2	IRI-1 (IWP)	IRI-2 (OWP)	IRI-1 - IRI2
Sec #1	2.03	1.92	0.11	2.09	1.71	0.38	2.02	1.68	0.34
Sec #2	1.33	1.83	-0.50	1.48	1.62	-0.14	1.39	1.38	0.01
Sec #3	1.71	1.75	-0.04	1.71	2.25	-0.54	1.68	2.01	-0.33
Sec #4	1.47	2.79	-1.32	1.74	2.44	-0.70	1.70	2.25	-0.55
Sec #5N	2.32	2.22	0.10	2.10	3.22	-1.12	2.07	3.01	-0.94
Sec #5S	2.51	2.39	0.12	2.61	3.18	-0.57	2.48	3.18	-0.70
Sec #6	2.26	2.55	-0.29	2.24	3.19	-0.95	2.17	2.93	-0.76
Sec #7A	2.15	2.17	-0.02	2.25	2.41	-0.16	2.16	2.27	-0.11
Sec #7B	2.54	3.24	-0.70	2.67	2.89	-0.22	2.53	2.78	-0.25
Sec #8	1.19	1.67	-0.48	1.25	1.33	-0.08	1.20	1.30	-0.10
Sec #9	1.72	2.00	-0.28	1.78	2.44	-0.66	1.74	1.93	-0.19
Sec #10	2.15	2.20	-0.05	2.26	3.45	-1.19	2.24	3.14	-0.90
Average	**1.95**	**2.23**	**-0.28**	**2.02**	**2.51**	**-0.50**	**1.95**	**2.32**	**-0.37**

5.2 Influence of Pavement Type

In view of Figure 5, the exposed PCC pavements (Section 7A and 7B) have significant influence on the IRI measurements performed by Device E, as against the IRI measurements performed by other three Class 2 devices. The surface-treated pavement (Section 10) has also shown a certain degree of difference (but not significant) between the IRI values measured by Device B and E. However, this does not apply to another surface-treated pavement (Section 6). A previous study showed that there were statistically significant differences between transfer functions obtained for asphalt concrete, rigid, and surface-treated pavements, as summarised in the first part of the paper.

Based on observations of the IRI measurements conducted on the 12 complete pavement sections at the verification circuit, there are significant systematic differences between the IRI measuring devices which can negatively affect monitoring of pavement performance trends on a network level and a project level. The output can be processed to give IRI at various distance intervals (e.g., 50, 100, 150m, etc.) or raw profile elevation data at various sampling intervals (e.g., 300 mm). The 50 m interval IRI value was used to check the uniformity of roughness over the verification sections. The 150 m interval IRI value (mean for each verification section) was used to correlate with Dipstick results.

6. SUMMARY

Some initial findings based on review and analysis of the measurements of pavement roughness are presented in this paper, including roughness trends of individual highway sub-networks and the entire MTO highway network, influence of varying longitudinal profiles on measure of roughness in terms of IRI values, and correlation analysis of individual measuring devices.

Although the IRI measurement of Ontario's road network and its verification circuit protocol is only four years old, in terms of observed riding quality and measuring device adjustment, it already has provided valuable and informative data for network-level performance evaluation. Based on the data analysis conducted in this study, it is recommended that road agencies design and implement regular annual programs for verifying roughness devices as a mandatory practice in standardizing their roughness databases. In order to ensure a consistent and transferable network-wide roughness database, it is important to establish a rigorous approach to verifying IRI measurements especially when different measuring devices are used each year. Some of the major findings to date can be summarized as follows:

a) A linear relationship between the Dipstick and the laser-based IRI measuring systems exists with high confidence level. It was demonstrated that with appropriate linear correlation equations these Class 2 devices can reproduce a Class 1 Device IRI with the 95 percent confidence level. The best correlation was found for single wheelpath in one direction. Averaging IRI values over the two wheelpaths produced lower but still acceptable correlation.

b) There were systematic differences between longitudinal profile measurements provided by different measuring devices. The average overall difference in profiles obtained for the 12 pavement sections ranged from 0.01 to 1.0 m/km in terms of IRI. The devices cannot be used interchangeably without proper verification and quality assurance protocol being established.

c) The study showed that individual measuring devices have correlation differences when compared with the Dipstick measured IRI due to mechanical and electronic variations between devices.

d) Although IRI measurement speed was not discussed in this paper, it is suggested that a correlation be used to normalize the IRI output to the standard speed. If measurements can not be taken at standard speed due to road geometry or traffic and safety related constraints, a functional relationship between IRI measured at standard speed versus IRI measured at another speed should be established for verification purpose.

e) A standardized IRI rating system needs to be developed for use across Canada. This will ensure consistency in reporting IRI results between jurisdictions and agencies.

7. REFERENCES

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