

Advanced 3D Technology for Rut Measurements: Apparatus on Board of the Quebec Ministry of Transportation Multifunction Vehicle

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Abstract

The Quebec Ministry of Transport is responsible for over 25,000 kilometers (15,500 miles) of roadways. A harsh climate and a major increase in the number of heavy vehicles in recent years are two factors behind the rapid deterioration of roadways and the formation of ruts. In response to this situation and to optimize the upkeep and resurfacing of roads, the Ministry surveys half of its road network every year using a multifunction vehicle equipped with video cameras to measure cracks, an inertial profiler to measure the IRI, and a 3D laser transverse profiling system to measure rutting conditions.

This latest system was developed by INO in cooperation with the Quebec Ministry of Transport. A first prototype was originally tested in 1997 and this technology has been commercially available since 2000. The Ministry has used it to survey over 100,000 km (62,000 miles) of roads to date. It has the unique capability of measuring 4 meter wide (13 feet) pavement with 1,024 point transverse profiles at 1 meter intervals. Transverse profile measurements are accurate to within 1 mm at inspection speeds of up to 90 km/h (55 mph) and are processed on-board in real time. The intensity of the pulsed laser profilers is high enough to allow for data collection day or night, whatever the pavement and ambient lighting conditions are. In recent years, a stringent quality assurance program has shown that the data fully meets the needs of the Ministry.

Once collected and processed, data is fed into the pavement management system (Visual PMS by TRDI). The program is configured to account for a number of other indicators, such as IRI, cracking, and the effects of freezing and thawing. This paper presents the Quebec Ministry of Transport multifunction vehicle and discusses the results of its various data collection systems, including the 3D laser transverse profiling system.

INTRODUCTION

The Quebec road network under the responsibility of the MTQ accounts for nearly 29,000 kilometers of pavement. This network is composed of highways, provincial roads, and regional roads. The following table presents some statistics allowing an assessment of the features of the Quebec road network and its environment in comparison with two of its neighbors and France.

Statistics of the Quebec road network in comparison with its neighbors and France				
	Quebec	Ontario	New York	France
Length (km)	29,000	16,500	26,500	36,500
Population (millions)	7.4	11	19	59
Mean annual precipitation (mm)	1,000	850	750	800
Frost duration (days/year)	147 to 218	100 to 200	10 to 100	0 to 90
Frost depth (m)	1.2 to 3	1 to 2.6	Under 1.4	0 to 0.5
Maximum single axle load (tons)	10	10	9	11.5

This table shows that Quebec pavements are subjected to a tougher environment than its neighbors: more abundant precipitation, greater frost duration and depth as well as higher loads. The temperature variations are also considerable between day and night (20°C) and between summer and winter (60°C). It should also be noted that the road network extends over a greater distance, serving a relatively small population scattered over a large territory.

These special conditions require the use of asphalt mixes containing a large proportion of asphalt to withstand bad weather, temperature variations and frost depth. Such asphalt mixes are more flexible and therefore more subject to develop ruts by creep in the summer period. To remedy these stresses, most of the asphalt mixes used in Quebec contain a large proportion of polymers.

OVERVIEW OF THE MTQ'S MULTIFUNCTION VEHICLE

In Quebec, road conditions are measured with the multifunction vehicle owned by the MTQ. Every year, this vehicle covers about half of the road network under its responsibility. The entire network therefore is covered in two years.

In addition to rutting, the vehicle measures surface roughness with an inertial profilometre manufactured by K.J. Law Engineers Inc. and records video images of the pavement which will serve to analyze cracking, among other purposes. Figure 1 shows the MTQ's Multifunction vehicle.



Fig. 1: MTQ Multifonction vehicle

3D Laser Transverse Profiling System

The 3D laser transverse profiling system used on board MTQ's multifunction vehicle was developed by INO in collaboration with the MTQ. A first prototype of this system was tested by the MTQ in 1997 and has been marketed by INO since the year 2000 under the name "Laser Rut Measurement System (LRMS)".

The LRMS is a transverse profiling system that detects and characterizes pavement rutting. It can acquire 4-metre wide profiles of a highway lane at normal traffic speeds. The system uses two laser profilers that digitize transverse sections of the road pavement. Custom optics and high-power laser line projectors allow the system to operate in daylight or in night-time as well as under varying pavement conditions. Road transverse profile data is collected and processed in real time on board the vehicle. Data filtering and rut extraction algorithms have been developed to automatically measure rut depth and rut width according ASTM 1703 standard. The system operates with a Windows NT/2000 software library allowing MTQ to integrate the LRMS functionality into its own software application.

Specifications

The LRMS specifications are given in the following table.

Specification	Value	Notes
Nb. of laser profilers	2	Each laser profiler measures half of the roadway.
Sampling rate (max.)	25 profiles/s	CPU performances may reduce the maximum sampling rate. Sampling rate affects profile spacing.
Vehicle speed	0 to 120 km/h	There is no technical limitation for vehicle speed. However, vehicle speed affects profile spacing.
Profile spacing	Adjustable	Profile spacing depends on sampling rate and on vehicle speed (ex: 1 m at 25 profiles/s and 90 km/h).
Transverse resolution (max.)	1280 points/profile	The transverse resolution can be reduced by a sampling factor of 2 or 4 (640 or 320 points per profile).
Transverse field-of-view (nominal)	4 m	The transverse field-of-view depends on laser profilers configuration (height, separation and tilt angle).
Depth range of operation	500 mm	The depth range of operation is optimal when the laser profilers are mounted vertically 800 mm above the ground.
Z-axis (depth) accuracy	± 1 mm	The Z-axis accuracy is the statistical 3σ depth error measured in laboratory on each laser profiler's overall working area.
X-axis (transverse) accuracy	± 3 mm	The X-axis accuracy is the statistical 3σ transverse error measured in laboratory on each laser profiler's overall working area.
Laser profiler dimensions	140 mm (width) 1052 mm (height) 305 mm (depth)	
Laser profiler weight	20 kg	
Power consumption (max.)	300 W at 120/240 VAC	

Laser profilers

The main hardware components of the LRMS are the two laser profilers. These components are responsible for the measurement of the left and right side transverse profiles. The laser profilers are mounted side-by-side on the back of the multifunction vehicle according to a given configuration. Each laser profiler is composed of a high-power infrared pulsed laser line projector and a special camera to measure deformations of the laser line profiles. Figure 2 shows the laser profiler units.

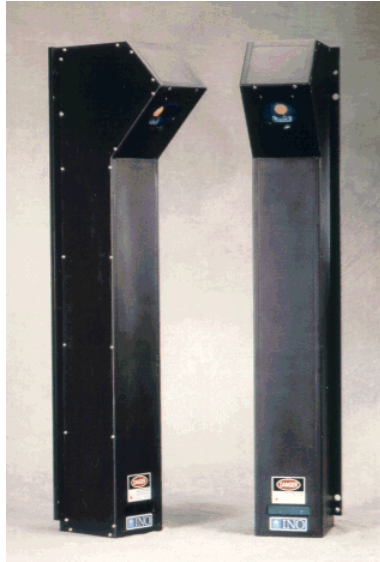


Figure 2: Laser profiler units

The MTQ has installed them inside the inspection vehicle. Of course, such an installation requires openings on the rear of the vehicle to allow light transmission. External windows with special anti-reflection coating that optimized light transmission are used to fill these openings.

The two LRMS laser profilers were precalibrated before delivery. A verification is done each 10 days during the campaign with a known calibration object which is measured with each laser profiler in order to confirm the calibration validity.

Software Library

The LRMS software library is a standard Win32 DLL (Dynamic Link Library) for Microsoft Windows NT/2000. It is used to configure and operate the LRMS by the means of C-language declared functions. Integration of the DLL into the end users' software application is a simple process.

After transverse road profiles are acquired, it is possible to have access to the camera images corresponding to the left and right side profiles. Also, raw profile extraction data can be obtained. This information gives the location of the extracted profiles into the left and right side images.

The rut analysis can be performed in real time on board the vehicle or offline after all the road profile data have been gathered. The software performs the required data filtering and computes the rut depth/width according ASTM 1703 standard (see figure 3).

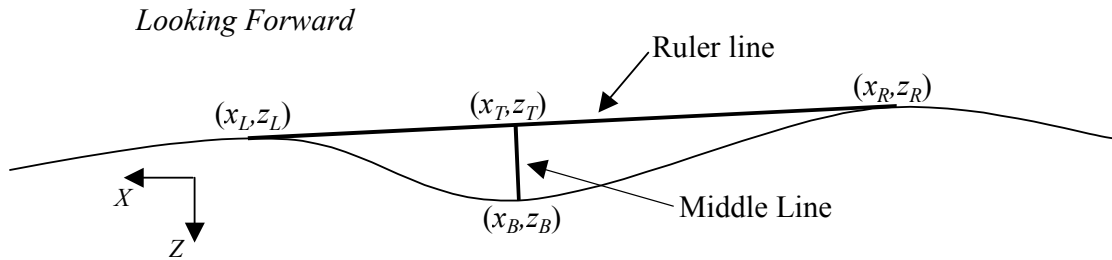


Figure 3: Rut extraction description

According to this figure, rut depth and rut width are given by:

$$\text{Depth} = \text{sqrt} \{ (x_B - x_T)^2 - (z_B - z_T)^2 \}$$

$$\text{Width} = \text{sqrt} \{ (x_R - x_L)^2 - (z_R - z_L)^2 \}$$

Configuration

The LRMS laser profilers are separated by a distance of 2 m center-to-center and are mounted 800 mm above the ground with no tilt angle with respect to the rear of the vehicle. The laser beam of each profiler is projected at a 21° angle towards the road surface (from the horizontal). It expands laterally at a 60° angle. The camera of each profiler looks at the projected laser line with an angle of 39° from the horizontal and with a field-of-view of 43°. This configuration allows each laser profiler to scan 2.2 m of the road pavement with a small overlap of 200 mm between each laser profiler and a total coverage of 4.2 m.

The laser profilers coordinate systems are shown in figure 4 below. Each laser profiler has its own coordinate system. The values on the X axis are centered on the center of the field of view of each profiler. On the Z axis, increasing values represent deeper ruts on the roadway. The value 0 represents the center position of the 500 mm working range when the laser profilers are located at the nominal depth (800 mm).

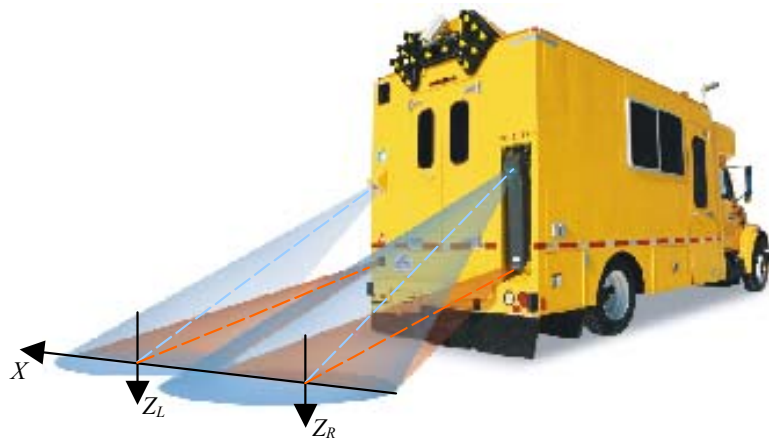


Figure 4: MTQ's multifunction vehicle with laser profiler coordinate systems

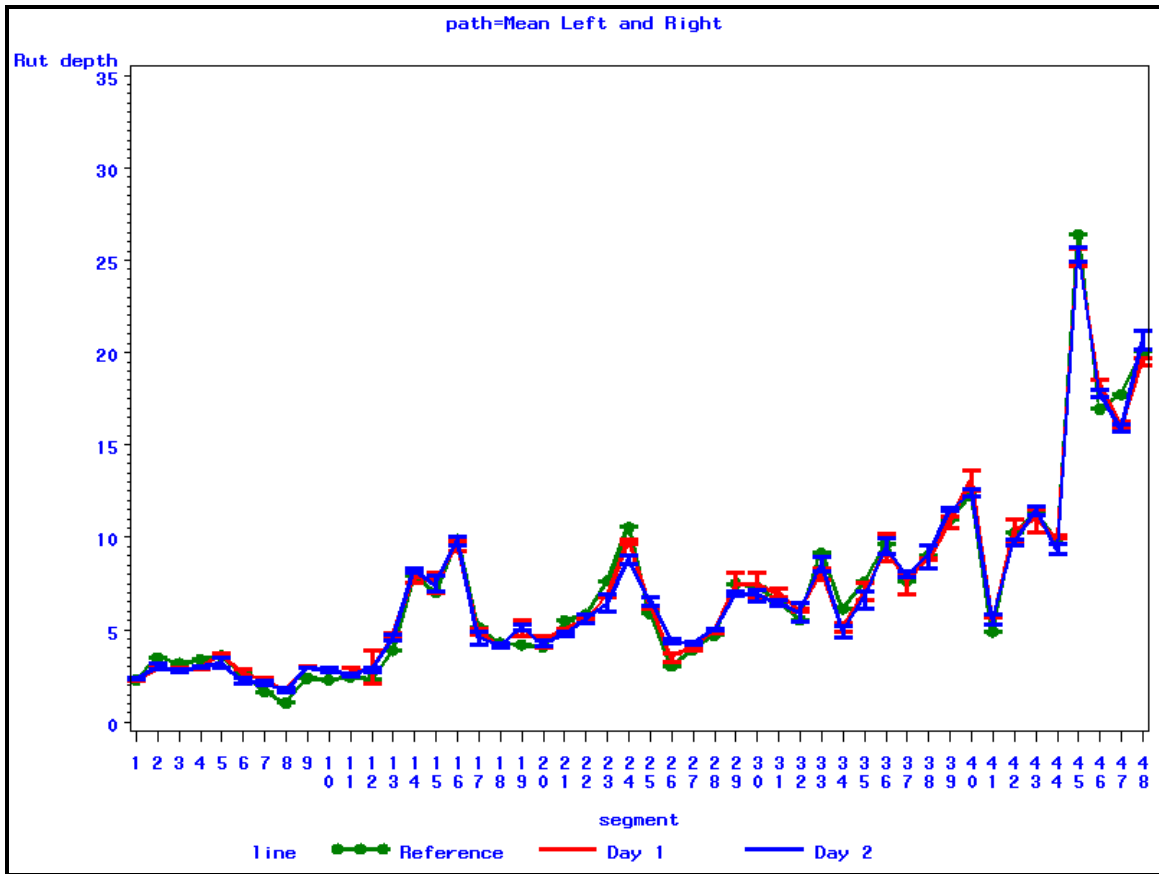
QUALITY ASSURANCE PLAN

Precision and accuracy of rut depth measurements

To ensure that it produces measurements which are precise (in terms of repeatability) and unbiased, the multifunction equipment is subjected to rut depth measurement validation on reference sites presenting varied deterioration conditions. Twelve 400 m sites are selected, allowing assessment of 48 segments of 100 m each. The rut depth is measured with the 1.8 m beam every 10 m and the mean of the ten readings is computed to obtain a mean depth per 100 m. The multifunction vehicle then passes three times in two series over each prepared site. The bias (mean deviation between the readings obtained by the multifunction vehicle and the values obtained with the beam) and the coefficient of variation (standard deviation/meanx100) are computed. As of spring 2002, the results obtained are presented in the following table:

Period	Path	Mean bias (mm)	% of times that the bias is less than 3 mm	Mean C.V. for a day	Mean C.V. for two days
Day 1	Left	0.4	100.0%	6.0%	
	Right	-0.3	98.0%	7.5%	
	Two-path mean	0.0	100.0%	4.6%	
Day 2	Left	0.5	100.0%	4.6%	
	Right	-0.6	95.8%	6.4%	
	Two-path mean	-0.1	100.0%	3.8%	
Both days combined	Left	0.4	100.0%	5.3%	6.2%
	Right	-0.4	96.9%	7.0%	8.4%
	Two-path mean	-0.0	100.0%	4.2%	5.2%

The following graph illustrates the detailed results. For each 100 m segment, the benchmark value is shown (green points) and the values obtained by the equipment for each of the two days. For each day, the three passes are represented by the mean, minimum and maximum value.



Regulation validation at territorial management (TM)

To ensure that there is no drift by the measuring equipment during the profiling campaign, a validation is performed for each profiled territory. A 2 km site is chosen before beginning the surveys. The transverse profile is measured by making five consecutive passes with the vehicle. The mean rut depths are calculated for each 100 m segment of the section. After completing the surveys in the territory, the profiling team performs other measurements on the same site and compares the results with those obtained on the first five passes. The maximum deviation must be less than 3 times the standard deviation of the first 5 passes.

The following graph gives an example of the results obtained in 2001 for a typical territory. It is noted that the three passes executed 20 days later rarely show deviations greater than 0.5 mm in relation to the mean established form the first five passes on day 0.

2001: Territory A, check for right wheel path



PAVEMENT MANAGEMENT

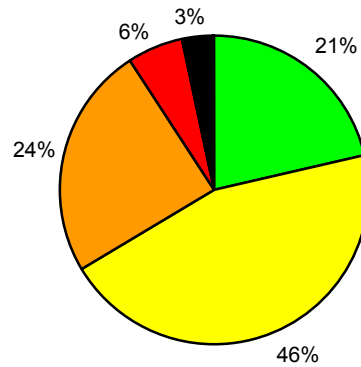
The rut depth and shape is measured every 10 m. The maximum value of the mean rutting computed for the two wheel paths is then kept for each 100 m of pavement. Finally, the mean rutting value per 100 m is computed for each rut management segment in order to obtain representative data for the entire segment.

The rutting results for the pavement management segments obtained following the assessment of the Quebec road network in 2001 are illustrated in the figure below. The average rut depth for the entire network is 6.9 mm.

Breakdown of weighted average rutting
by the length of pavement management segments

Rutting classes used:

- Rutting < 4 mm
- 4 mm ≤ Rutting < 8 mm
- 8 mm ≤ Rutting < 12 mm
- 12 mm ≤ Rutting < 15 mm
- Rutting ≥ 15 mm



These data are then loaded into the MTQ pavement management system (TRDI VPMS). The maintenance/repair intervention selection trees consider the rut depth and type (small or large radius). Every region of Quebec can therefore optimize its investments.

CONCLUSION

The Quebec Ministry of Transportation is using the Laser Rut Measurements System in network level over approximately 15 000 km/year since more than two years. The MTQ quality assurance plan enables to evaluate the performances of the system and to ensure an excellent data reliability.

The MTQ can affirm that this system meets its management needs. On the other hand, INO in collaboration with MTQ is improving the calculation of the rut depth starting from the raw signal.

This system allows the MTQ to improve the quality of the Quebec road network and its safety.