Adapting BC's Pavement Management System to Keep Pace with Data Collection Technology

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ABSTRACT

Over the last two decades, the British Columbia Ministry of Transportation and Infrastructure (BCMoT) has kept pace with advancements in technology to collect pavement condition data for managing its 53,000 lane-km of paved highways. When the Roadway Pavement Management System (RPMS) program was first initiated in the early 1990’s, data collection was based on best practice at the time including ultrasonic sensors, tire based distance measurement instruments, rudimentary linear referencing, video-tape recording, and windshield assessments.

Fast forwarding to today, the RPMS program now uses advanced technologies such as global positioning, improved linear referencing, scanning lasers, 3D-laser profiler systems, high resolution digital images, automated pavement distress, and real time data processing. These changes have had a profound impact on the way pavement condition data are collected and interpreted.

This paper describes how the Ministry has structured its RPMS program to be agile and adaptive, while ensuring the right data has been collected to support its pavement management needs. The first sections provide an overview of the Ministry’s pavement management program followed by a discussion of how the program has been adapted in terms of what pavement condition information is collected, how it is collected, and how it is being applied to support better asset management decision making. This includes data procurement, quality assurance processes, data management and technological changes. The paper also looks forward to highlight anticipated issues that will need to be considered for its pavement management system with further advancements in data acquisition technology.

INTRODUCTION

The Ministry's Roadway Pavement Management System (RPMS) program was initiated almost 20 years ago in response to the need for a more structured, asset management based, and planning process to support rehabilitation investment requests. The program included the development and implementation of a corporate pavement management system along with province-wide pavement condition data collection. Today, data collected on surface deterioration, roughness, and rutting are used across a wide range of the Ministry's business needs including strategic investment planning, project planning, corporate performance reporting, and more recently, for supporting the performance monitoring of Public Private Partnership projects.

When the program was first initiated, data collection was based on best practice at the time including ultrasonic sensors, tire based distance measurement instruments, rudimentary linear referencing, video-tape recording, and windshield assessments. Fast forwarding to today, the program now uses advanced technologies such as global positioning, improved linear referencing, scanning lasers, 3D-laser profiler systems, high resolution digital images, automated pavement distress, and real time data processing. These changes have had a profound impact on the way pavement condition data are collected and interpreted.

The paper describes how BCMoT has responded to the technology advancements by adapting its pavement management system in terms of what pavement condition information is collected, how it is collected, how it is being applied to support better asset management decision making and looks forward to adapting future potential technology.

BC PAVEMENT REHABILITATION PROGRAM

BCMoT is responsible for the management and operation of more than 90,000 lane kilometres of roads of which, approximately 53,000 lane kilometres are asphalt surfaced (see Figure 1). The main numbered highway network comprises about 47% (25,000 lane km) of the asphalt surfaced inventory and the provincial side road network accounts for the remaining 53%. The estimated replacement value of the asphalt surfaced highway network is in the order of $75 billion. It represents the highest value asset class owned by the Ministry and therefore, protecting and preserving it from deterioration is a priority for the Ministry.

Presently, 94% of the main highway network is in fair or better condition based on the RPMS survey data. Over the past decade, through targeted investment, the condition of the main highways has been held relatively constant. However the condition of the paved side roads has declined to approximately 73% in fair or better condition today. As part of the latest strategic plan (BC on the Move: A 10 Year Transportation Plan, 2015), the Ministry has identified side roads as a top priority for the province and has committed additional resources to improve their condition.

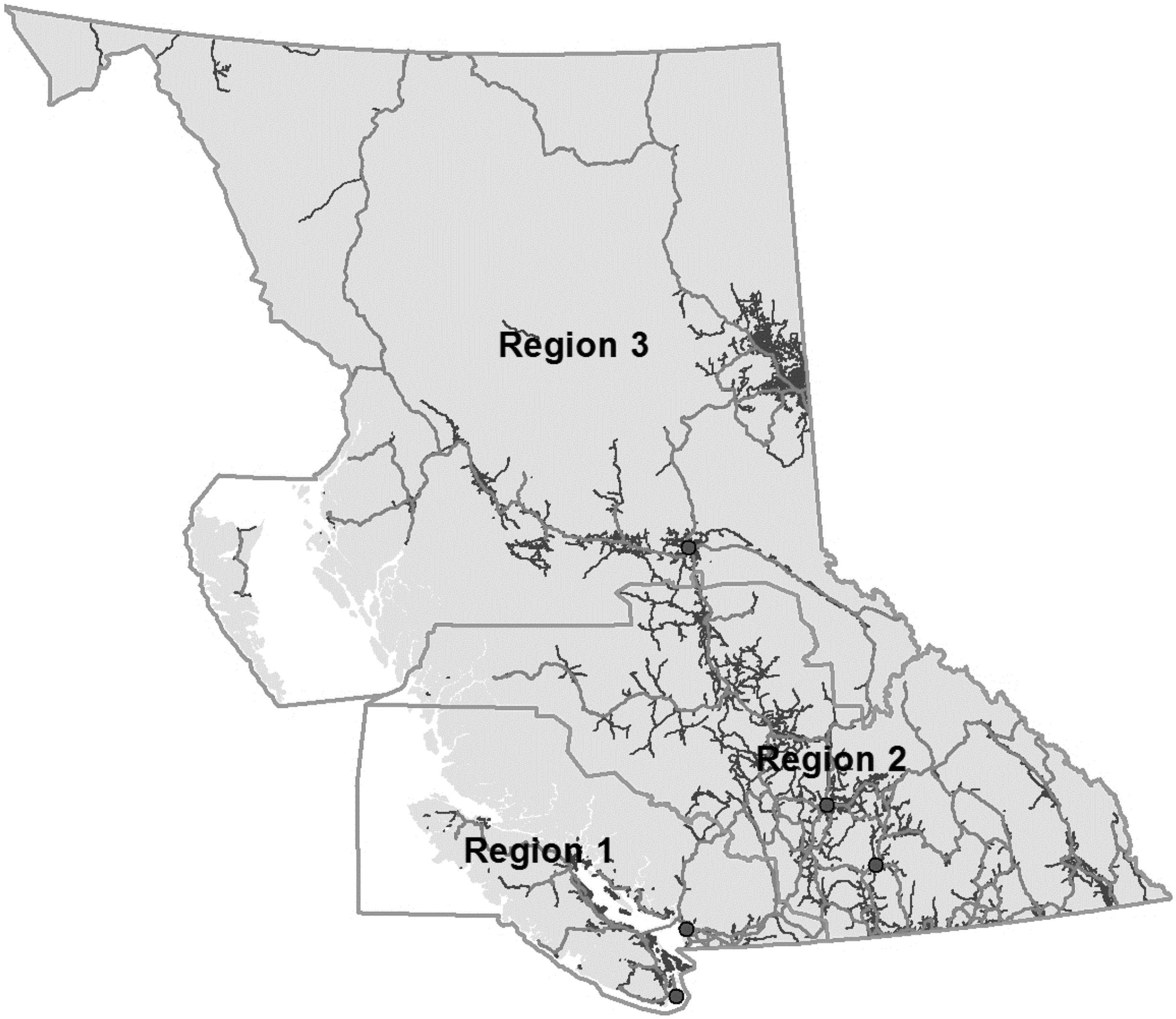

Figure 1: BCMOT Numbered Highway System Map

Every year, approximately 1,500 kilometres of roads are resurfaced through more than 40 paving projects at a cost exceeding $150 million. The main resurfacing strategies used include, mill and fill, overlay, hot in place recycling, and single and double sealcoats.

Preparation, programming and delivery of the rehabilitation program follow a well-defined and structured process that is administered by the Ministry. It is based on a planned strategy of applying cost-effective rehabilitation and improvements to the existing infrastructure to extend the life or improve the serviceability of the highway pavements by:

- Correcting pavement safety related defects;
- Maintaining structural integrity;

- Maintain consistent standards across all highways;
- Focusing on primary highways followed by secondary highways and side roads;
- Integrating resurfacing projects with other Ministry Programs; and
- Supporting specific Government economic initiatives.

The road resurfacing asset management framework used by the Ministry is based on the following hierarchy of plans:

- 10-year strategic plan
- Rolling 4-year tactical plan; and
- Annual operational plans.

Collectively, these plans include strategies, performance measures, and annual targets that are aligned with Ministry wide strategic goals and service plans.

BC PAVEMENT MANAGEMENT SYSTEM AND SURVEYS

In order to cost effectively manage such a large paved highway network, the Ministry relies on its pavement management system to monitor and track pavement condition, forecast future pavement condition and investment needs, and develop an annual resurfacing program. The Ministry's RPMS was implemented in the mid 1990's throughout the province. It is a Commercial-off-the-Shelf (COTS) application developed and supported by Stantec. A relational Oracle database forms the core of the RPMS supported by data analysis modules for network condition monitoring /reporting, rehabilitation programming and model updating. Asset inventory data has been populated over the years through the use of multiple data sources including spatial mapping, high speed surveys, field measurements and manual extrapolation from various sources.

The Ministry has been conducting road condition surveys for more than 30 years. In the early years, each of the six regions that existed at the time, was conducting surveys using a variety of different methodologies based on a fairly simplistic rating system.

Coinciding with the RPMS implementation, in 1994, the Ministry published its first pavement surface condition rating manual and has released updates since then incorporating continuous improvements identified through experience, best practice and changes in technology.

The Ministry measures pavement performance according to surface distress and pavement roughness (BCMoT Pavement Surface Condition Rating Manual 5th Edition, 2015). High speed pavement surface condition surveys are conducted on a cyclical basis for the provincial road network. Primary highways are surveyed biennially, secondary highways on either a two or four year basis depending on priority and paved side roads are sampled every four years. The objective of these surveys is to obtain performance data that is sufficiently accurate, representative and consistent to support network level analyses. This in turn dictates the rating methodology and measuring equipment that are used for the surveys.

The surveys capture the severity and density of eight surface distress types within each surveyed lane, as well as rut depth and roughness measurements in both wheel paths as detailed in Table 1. The detailed distress data are combined into a Pavement Distress Index (PDI) using a mathematical model and an overall composite index called the Pavement Condition Rating (PCR) which is a combination of PDI and the International Roughness Index (IRI).

Table 0: RPMS Pavement Condition Surveys Overview

Category	Type	Data Scope	Method
Surface Distress	Defects	• Longitudinal Wheel Path Cracking Longitudinal joint cracking Pavement Edge Cracking Transverse Cracking Meandering Longitudinal Cracking Alligator Cracking Bleeding Potholes • 3 levels of severity • 5 levels of density	• Pre-2012 - windshield surveys with the rating is performed in real time, by a rater using a programmable event keyboard / processor, while the vehicle traverses the roadway • Post-2012 - Digital image rating performed during post processing using the collected pavement imagery and viewing / analysis software to visually rate the severity, with the density levels automatically calculated
	Rutting	Rut depths (average and maximum) are calculated for each wheel path using the straight-edge method	• Pre 2012 - 11 sensor rut profiler (both ultrasonic and laser) • Post 2012 - scanning lasers • ASTM E1703/E1703M
Roughness	IRI	IRI for each wheel path determined in accordance with ASTM E1926	• Laser based Class 1 inertial profiler as defined by ASTM E950, or better

Note: All data collected continuously and reported at 50 metre intervals.

In addition to the condition data noted, right of way images and since 2012, downward facing images of the pavement have also been collected. All data is collected spatially and linearly according to defined procedures. Surveys are conducted along one direction of travel only and along both directions for divided highways. Studies confirmed that the pavement condition of the opposite direction of travel is comparable to the direction in which the surveys are conducted. Data is collected in the summer months starting in June with the processed, finalized data being available around December of each year.

RPMS SURVEY PROCUREMENT STRATEGY

Multi-year pavement condition survey contracts are outsourced to contractors with multi-functioned pavement evaluation vehicles equipped with sophisticated on-board systems and instrumentation. Using third party contractors supports objectivity and consistency throughout the province.

A number of procurement strategies have been used over the past two decades. In 1994, the province was divided into two geographical areas (i.e. north and south) that had similar survey lane quantities. While this achieved some economies of scale, in the following year, the surveys were combined into a single contract with a two-year duration. The contract duration extended to three years in 1999 and subsequently increased to four years starting in 2005.

With the continued development of technology and the ability of contractors to collect a variety of data simultaneously, in the early 2000's the Ministry combined its province-wide highway video-logging data collection contract with the pavement condition contract. This ability for single pass data collection achieved considerable cost savings.

Overall, the four year contracts have been the most beneficial to the Ministry in terms of costs, consistency and project management. For example, having the same contractor and rating crew for multiple years, was found to improve the accuracy of the ratings. One of the key elements that has contributed to the continued evolution of the data collection program is the end product specification used by the Ministry to procure the collection of pavement condition data. This has allowed industry to propose innovative and better ways to collect data. As an example, the Ministry has worked closely with the vendors to improve the accuracy of the highway linear referencing system used for the surveys and in 2012, progressed from real time windshield surveys to digital image post processing, which may become the new minimum standard.

SURVEY QA PROCESSES

With different vendors being used to conduct the annual surveys, quality assurance plays an integral role to ensure the data collected is consistent and accurate. The pavement condition surveys are carried out according to the Ministry's Quality Assurance (QA) Specifications which were established in the mid 1990's. The specifications have been developed collaboratively working with the Ministry's data collection contractors and incorporating best practice (TAC Standardization of IRI Data Collection and Reporting, 2001) as well as AASHTO / ASTM guidelines and standards.

The Ministry's QA procedures include two levels of testing:

- Initial Tests - conducted prior to the start of the surveys; and
- Survey Tests - conducted during the surveys.

The initial tests are completed to confirm that the contractor's distress rating and survey instrumentation and data processing are operating properly prior to the start of the production surveys. The accuracy of the surface distress ratings and equipment are then further monitored throughout the surveys. Both levels of QA testing are based on using manual control surveys at designated sites.

The initial QA testing include four test sites that are selected to provide a sufficient sample of distresses, wheel track rutting and roughness and be representative of the survey conditions. Manual surveys are conducted in advanced of the testing as outlined in Table 2. Once on site, the contractor is required to conduct multiple passes over the site and report results for comparison to the manual survey results. The accuracy of the contractor's surface condition rating and equipment is also closely monitored during the surveys as a further measure of quality assurance.

Table 2: Manual Pavement Condition QA Surveys

Category	Survey Procedure	Benchmark Statistic
Surface Distress	Crack mapping and visually rating the distress types present for each 50 metre segment according to the Ministry's Pavement Surface Condition Rating Manual	Average of the calculated 50 m PDI values over 500 m
Roughness	Longitudinal profile and IRI measurements in outside wheel path using a Ministry ICC SurPRO Class 1 profiler	Average outside wheel path IRI value over 500 m
Rut Depths	Transverse profile measurements in each wheel path at 10 metre intervals using a two metre rut measuring gauge	Average combined wheel path rut depths over 500 m

The survey testing includes:

- Manually surveyed test sites that are situated along various highways in each region and are of unknown location to the contractor; and
- Retesting of the initial QA test sites at the mid-point of the surveys and at the conclusion following the same testing processes.

Table 3 summarizes the QA acceptance criteria for both the initial and survey testing. Should the contractor fail to meet the criteria for acceptance, it is their responsibility to provide remedy until such time that the acceptance criteria are met. Looking back over the past decade of QA test results, the Ministry has found the IRI and rut depth measurements to be very accurate and well within the specifications. Surface distress accuracy, while within the stated tolerances, has been more of a challenge with the real time windshield surveys due to different raters, lighting conditions and subjectivity. The change to digital image post processing has seen improved accuracy.

Table 3: Survey QA Acceptance Criteria

Category	Criteria	Acceptance Criteria Value
Surface Distress	Measure Calculation Unit Accuracy Repeatability	PDI value 500 m average based on 50 m values Lane +/- 1 PDI value of manual survey +/- 1 standard deviation of the PDI values for five runs
Roughness	Measure Calculation Unit Accuracy Repeatability	IRI 500 m average based on 50 m values Outside wheel path 10% of Class I profile survey 0.1 mm/m standard deviation for five runs
Rut Depths	Measure Calculation Unit Accuracy Repeatability	Rut depth (mm) 500 m average based on 50 m values Averaged for both wheel paths +/- 3 mm of manual survey +/- 3 mm standard deviation for five runs

While the Ministry's surface distress rating system is one of the least complicated, it is recognized that data collection contractors are required to learn and apply multiple distress rating methodologies depending upon the client. As a result, re-orientation can be challenging and where most effort is required during the initial QA testing each year.

In 2012, the Ministry introduced a web based training tool to assist contractors to better understand and apply the BCMoT rating methodology. The website training tool is intended to provide a more comprehensive orientation before contractors come on site. It allows for a wider range of examples than can be captured with the initial QA testing and was purposely designed to target the more common problem areas such as transverse cracking density, alligator cracking and potholes. The website incorporates high resolution digital right-of-way images of varying severity and density pavement conditions for each distress type. It allows the user to review the distress rating methodology, conduct ratings and view the resulting scores, with explanations provided when incorrect. The testing includes both single distress rating and simulated windshield testing where multiple distress types are rated (See Figure 2).

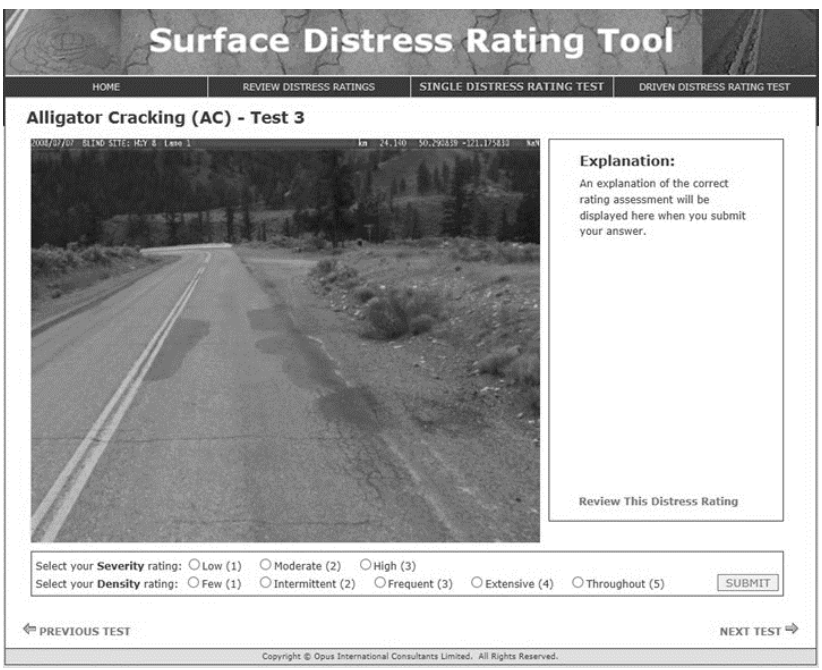

Figure 2: Surface Distress Website Training Tool

A new desktop QA process was piloted in 2014 to assess whether it could be used to compliment the survey testing. It was based on comparing data samples (5 km in length) from the survey results to the prior data collection cycle recognizing that generally there should not be significant deterioration and variation in distresses present. The results were inconclusive due to subsequent maintenance activities and locational referencing issues. An alternative approach will be piloted in 2015 based on using the contractor's distress analysis viewing software and prior survey cycle pavement images.

DATA MANAGEMENT

Data management is an important aspect for any corporate asset management system. The Ministry's RPMS asset register supports a wide array of asset inventory and condition data as described in Table 4. Building and maintaining this asset register over the years has required adapting the way the Ministry collects and manages the data within the RPMS as discussed below.

Table 4: RPMS Asset Inventory and Condition Data Management

Category	Type	Description	Source / Status
Inventory	Geometrics	Number of lanes, widths, ROW, median, etc.	Corporate system / RPMS surveys, assumed widths
	Cross Sectional Profile	Lanes, shoulders and ditches relative to the centreline	Lanes only
	Shoulders	Paved, gravel, widths, thickness	Surface, assumed widths
	Functional Classification	Highway classes, owner	Complete
	Administrative Areas	Province, federal, municipal, electoral, maintenance, etc.	Major municipal, electoral & maintenance
	Traffic	Volumes, percent trucks, ESALs, growth rates, etc.	Based on functional class and not integrated
	Rehabilitation & Maintenance	Treatment activity, year, surface thickness, cost, etc.	No data
	Pavement Layers	Material type, thickness, year, lane, etc.	No data
	Environmental	Climate zones, drainage, etc.	Environment Canada mapping and not complete
	Accident	Total, by type, user definable	Not used – in corporate system
	Other Events	User definable events (i.e. bridges, culverts, railway crossing, etc.)	Not used – in corporate system
	Roadway Landmarks	LRS reference points	Complete
	Digital Images	Right-of-way imagery	RPMS Surveys
Condition	Roughness	IRI values by wheel path	RPMS Surveys
	Rutting	Rut depth measurements by wheel path (average and maximum)	RPMS Surveys
	Surface Distress Ratings	Detailed severity and density ratings by distress type	RPMS Surveys
	Composite Distress Rating	Composite distress index based on Paver model	RPMS Surveys
	Friction	Skid resistance and friction measurements	Not Collected
	Deflection	Deflection testing measurements	Not Collected
	Overall Pavement Condition Rating	Composite index combining multiple measures	PDI & IRI based

a) Linear Referencing

Building the original asset inventory was a major undertaking and has been a challenge to maintain over the years due to the RPMS not being integrated with other Ministry corporate systems in terms of a common Linear Referencing System (LRS). When originally implemented in the mid 1990's, the RPMS was to be based on the Ministry's new corporate LRS initiative which was also underway at the time. The RPMS adopted this LRS with all inventory and early condition survey data based on its methodology. However, the corporate LRS was subsequently cancelled, leaving the RPMS with its own unique LRS that was not compatible with the other Ministry applications. This required Ministry RPMS personnel to maintain the LRS, and using collected RPMS pavement condition data to make adjustments to the base roadway network referencing.

In the early years, the LRS was fairly manageable since the surveys were only being collected on the major highways. With the expansion of the RPMS surveys to the province's side road network in mid-2000's, combined with more accurate GPS data collection, maintaining the LRS has become more onerous. As well, the ability to now access spatial data from other sources for creating inventories and performing analyses, has made the LRS compatibility issues more apparent. In response, the Ministry recently conducted a data rectification project and is undertaking a review of its pavement management system LRS.

b) Side Road Data Collection

In the mid-2000's the Ministry expanded the RPMS pavement condition surveys to include the side road network which, as noted previously, totals over 25,000 lane-km of asphalt paved surfaces. This very large network is comprised of local and rural roads that can be less than 100 metres to several kilometers in length with traffic volumes ranging from less than 50 to over 1000 vehicles per day. Collecting condition data on all of the side roads was not financially feasible, so a sampling based data collection program was developed. A statistical analysis was completed to establish a representative subset of the provincial side roads to survey (approximately 25%).The analysis considered surface type, traffic volumes, and geographical areas (maintenance areas). The survey program was initiated in 2004 based on a four year survey cycle with adjustments to the sampling program having also been made over the years.

c) Evolution of Condition Surveys

Over the years, there have been several changes to the RPMS pavement condition surveys that required adapting process and systems including:

- Changing from a 20 metre to 50 metre reporting interval (late 1990's) following as analysis that had a significant impact on data storage requirements, for only a nominal loss of accuracy;

- Reducing the number of distress types surveyed from the original 12 to the current nine, with elimination of ravelling, shoving and distortion which were consistently difficult to rate by windshield surveys;
- Adding alligator cracking, which was originally defined as a fourth level of severity as a separate distress;
- No longer requiring raters to evaluate pavement drainage and crack sealing as the timing of the surveys in summer months made drainage assessments problematic and crack sealing data was not found to be useful. Reducing the number of elements to be rated during the windshield surveys, also enabled the raters to focus on what was important (i.e. cracking / defects); and
- Changing the pavement surface distress composite model following changes to the distress rating methodology.

d) Other Data Improvements

Over time the Ministry has undertaken a number of other improvements to the data to ensure that it continues to be valid that included:

- Flagging of 'non-network level survey data' within the RPMS to ensure that project level survey data does not skew network level analyses results;
- Updating the side road cardinal directions, start and stop point definitions etc., as required for future surveys to ensure data is collected in the proper direction; and
- Using spatial mapping derived from Environment Canada weather statistics to define the climatic zones within RPMS more accurately.

TECHNOLOGICAL CHANGES

Changes in data collection technology have had a profound impact on the RPMS program in terms of how data is collected, managed, interpreted and reported. These are briefly discussed below.

a) Data Collection

Over the past 20 years, there have been significant advancements in the data collection capability and technology used by the Ministry's contractors including:

- The transition from ultrasonic sensors to lasers, with more precise measurements has resulted in more accurate rut depth and roughness data collection and better reliability during field surveys;
- For many years, Ministry surveys were conducted using an 11 sensor transverse profiler which was found to produce acceptable results with the exception of wide travel lanes and locations with double wheel rutting;
- The recent transition to scanning lasers has seen a notable increase in the level of accuracy during the survey QA testing; and
- Improvements in on-board hardware data processing and storage capability have vastly improved from the early days of limited disk space, additional data

collection time, and reliability to where today, data storage is not an inhibitor resulting in the ability to process data on the fly with shorter turn-around times for data submissions.

b) Distress Rating Methods

Up until three years ago, surface distress rating had been primarily conducted using visual windshield surveys. Distress ratings were conducted in real time by a rater using programmable keyboards to record severity levels. Since 2012, surface distress have been rated from digital pavement view images using analysis software to visually rate the severity, with the density levels automatically calculated. This transition has resulted in a higher level of accuracy being achieved and required changes to the Ministry's survey QA program and project management processes.

c) GPS Collection

The introduction of GPS data collection has perhaps been one of the most significant impacts on RPMS surveys. Originally, the Ministry data collection was based solely on Distance Measurement Instrumentation (DMI) wheel mounted encoder, and while the survey specifications included provisions, there were always accuracy issues associated with data drift and landmark referencing. Correcting section lengths (i.e. wheel mounted encoder measurements) and start / stop locations was a reoccurring annual requirement. The transition to fully integrated differential GPS has completely transformed how the data is collected, verified and used by the Ministry. Over time and as GPS technology has improved, the Ministry has been able to improve its LRS as noted previously.

d) GIS Spatial Mapping

GIS spatial mapping has been a significant improvement for both the RPMS survey procurement, and the user experience with the RPMS application. Single use AutoCAD maps of the planned survey routing that took an enormous amount of time to generate, have been replaced with spatial mapping that is readily available and easily maintained for subsequent surveys. The ability of contractors to use the spatial mapping to plan their surveys, locate start / end locations during the surveys, especially for the side road network, has been a real positive step forward. Similarly, with the widespread usage of digital mapping, the RPMS application was modified to add a spatial interface that enables users to query and view condition data spatially. This has also proven to be a very effective communication tool for the Ministry.

e) Digital Images

Digital image data acquisition was piloted in the early 1990's and subsequently adopted as the standard for the RPMS condition surveys. Prior to that, contractors were required to collect SVHS video of the right-of-way images which was cumbersome to manage in terms of route referencing, storage and viewing. Digital right-of-way images are now captured with 1920 x 1080 pixels resolution using HDTV, 3CCD broadcast quality digital cameras. Pavement lane width images are collected at 1392 x 1040 pixels resolution for using two high-resolution, monochrome digital cameras. Modifications to the RPMS application, enable the images to be accessed directly by the user, which again has significantly improved the user experience.

SUMMARY

The RPMS program supports a wide range of business needs including Ministry strategic goals / priorities, strategic investment planning, project planning, corporate performance reporting, and more recently, for supporting the performance monitoring of Public Private Partnership projects.

The past two decades has seen considerable changes in the way the Ministry collects, uses and reports on pavement condition. This has required the RPMS program to be agile and adaptive, while ensuring the right data has been collected to support its pavement management needs as they evolve.

Looking forward, there is an expectation that the cost of data collection will be reduced as automation replaces expensive labour intensive data collection processes. Quality control will continue to be a necessity to ensure that automated processes provide clients with accurate data. The Ministry will continue to focus on end product specification to allow technological improvements to flourish.

Looking forward, the BCMoT is planning to continue to improve its pavement management system. Some of the areas where improvements may take place include:

- Fully automated distress rating using 3D scanning lasers and image recognition;
- Reintroducing ravelling condition rating based on 3D scanning laser technology;
- Increasing pavement condition data collection frequency of the side road network;
- Expanding the RPMS survey program to collect additional types of data (i.e. inventory, geometrics, etc.) using single data pick up;
- Pavement structural evaluation using rolling FWD;
- Compressing the data collection cycle so that data is available shortly after collected; and
- Revising the QA program as necessary to adapt with new technologies.

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