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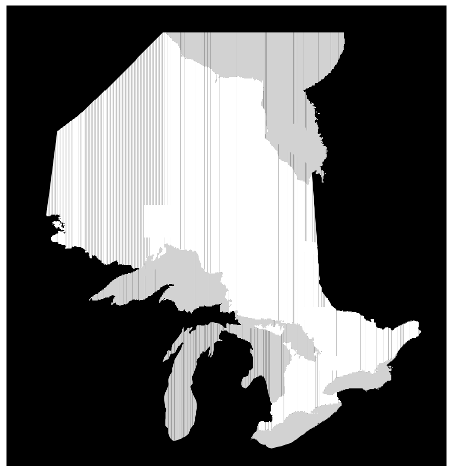

Field Test and Evaluation of a Mobile Automated Winter Road Condition Reporting System

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Abstract	Timely and accurate monitoring of road surface conditions (RSC) in a winter season is essential to the winter road maintenance (WRM) mangers, commercial vehicle operators, as well as the travelling public. Existing RSC monitoring methods rely heavily on manual reporting by patrollers, lacking objectivity, reliability, and timeliness required to optimize decision-making of maintenance and commercial vehicles and drivers. This project evaluates the performance of a smartphone based road surface condition monitoring system called AVL-Genius. The system was installed on eight patrol and maintenance vehicles, which were operated on a section of Highway 6 to collect field data in the Winter 2013/14 season. The performance of the AVL-Genius system was evaluated in three aspects, namely, spot-wise monitoring, route-level monitoring and reliability, by comparing its monitoring results to those of manual classifications, patrol reports and MTO's Travellers Road Information Portal (TRIP). This report details the main methodology and analysis results along with an overview of various RSC monitoring technologies. The main findings and recommendations for further research and development are highlighted.
Key Words	Road surface conditions, winter road maintenance
Distribution	Universal technical audience.

Ministry of Transportation
Highway Standards Branch Report

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Field Test and Evaluation of a Mobile Automated Winter Road Condition Reporting System

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Table of Contents

Executive Summary

This project investigates the performance of a smartphone based road surface condition (RSC) monitoring system called AVL-Genius. The system uses a smartphone to capture images of the road surface along a route and automatically classifies each image into one of several distinct RSC classes. It can also generate route level RSC statistics that can be used for bare pavement reporting. This report documents the main outcome of the project, including an overview of various RSC monitoring technologies, a detailed description of the field test, and a comprehensive analysis of the test data.

The field tests were conducted on a section of Highway 6, in South-Western Ontario, Canada near Owen Sound. Four dedicated patrol vehicles, two from Ministry of Transportation Ontario (MTO) and two from the Area Maintenance Contractor (AMC), and three maintenance trucks were installed with the system. In addition, the AVL-Genius was also installed on a dedicated mobile data collection unit along with a friction meter. Over 105,000 images were collected during 50 days of field experiment, covering 40 snow events in the Winter 2013/14 season.

AVL-Genius was evaluated for its performance as a spot-wise monitoring tool. This was done by comparing its classification results of individual images with those of manual classification. Over 16,000 images were used and the system was shown to have an average classification accuracy of 73%. A detailed analysis on the misclassification cases has identified the main causes contributing to the problem, including poor image quality due to dirty windshields, low visibility, glare from the sunlight, and residual salt on the road surface, and shades of roadside trees.

The system was then evaluated for its performance for aggregate route level condition monitoring, using the same manual classification results as the ground truth. It was found that the performance varied across different classes of RSC. However, if a single RSC class is to be designated for the whole test route, following MTO's three-class RSC classification guidelines (which are adopted from those of Transportation Association of Canada), the system would provide highly accurate results.

The third analysis focused on comparing AVL-Genius results with those from MTO's existing condition monitoring method - patrol reports, including Winter Patrol Records (WPR), Winter Operations Records (WOR) and Road and Weather Information Sheets (R&WIS). The patrols reports are all descriptive recounting the overall conditions of the test route at specific times and as a result the comparison is limited to the route level and being qualitative in nature. It was found that there was good consistency between the two monitoring methods, with the AVL-

Genius offering additional quantitative details about the individual RSCs observed along a patrol route through summary statistics.

Lastly, the map displayed RSC from AVL-Genius were compared to those by MTO's Travellers Road Information Portal (TRIP). It was found that AVL-Genius was much timelier and spatially detailed than TRIP. These additional details allow for easy identification of areas with less than desirable RSCs, which could prove to be valuable for maintenance operators and travelers.

In summary, this field test has shown that the AVL-Genius system is capable of providing reliable results in comparison with MTO's current method of patrol reporting for route-level monitoring of winter road conditions. The system also has the added advantages of being more objective and of higher granularity. The test has also revealed the areas of improvement for the system, including classification accuracy for spot-wise detection, night-time monitoring, and lateral snow cover classification. Lastly, it should be noted that a smartphone based condition monitoring system be installed on any smartphones and operated on any vehicles, which means it has the potential to become a crowdsourcing solution for obtaining RSC information from the traveling public. This potential should be considered as another incentive for further exploring this solution.

Introduction

A. INTRODUCTION

Winter storms have a significant impact on the safety and mobility of travelers on Ontario highways. Slippery pavement conditions and poor visibility during a winter storm increase road accidents and create unbearable travel conditions for travelers. To reduce the impacts of winter storms, MTO spends a significant amount of resources every year to keep roads and highways clear of snow and ice for safe and smooth travel conditions (Perchanok 1998; (Buchanan & Gwartz, 2005). Like other government agencies, MTO is under increasing pressure to improve its maintenance services and reduce the operating costs.

One of the proven means for improving the efficiency of winter road maintenance is adopting innovative technologies for road weather and surface condition monitoring (Perchanok and Raven 1994; MTO 2004). Accurate and timely information on weather and road surface conditions of maintenance routes allows maintenance operations to access information on current and future road surface and weather condition, making it possible to deliver the right deicing and anti-icing treatments at the right location and right time. Accurate and timely road weather and condition information is also invaluable for the travelling public as it enables them to make informed decisions on when, where and in what mode to travel in face of adverse weather events.

Road surface conditions are traditionally monitored via observation by patrollers travelling along the highways. This manual monitoring method, while trustworthy, suffers the significant limitations of being lack of objectivity, granularity and timeliness. To address these limitations, several technology based solutions such as Road Weather Information System (RWIS), continuous friction measurement equipment (CFME), and webcams have been applied by winter maintenance personnel for obtaining real-time road weather information and improving their decision-making. Another new technology of increasing interest is a smartphone based road condition monitoring and reporting solution. The system consists of smartphone being mounted to the windshield of a patrol/maintenance vehicle and taking pictures of the road at a specific interval and sending them to a central server via a wireless connection. The acquired images are then processed and classified using a computer algorithm for generating real-time road surface condition maps and reports.

While this new technology holds great promise due to the pervasiveness of smartphones, its application for winter road condition monitoring is still at an experimental stage. Many questions remain with respect to its effectiveness, reliability, and benefits. How reliable is the system as an alternative real-time monitoring solution for real world operations? What are its accuracy, timeliness and granularity in comparison to the existing methods? How extensively should this technology be adopted? A field experiment is required to address these issues.

B. PROJECT OBJECTIVES

The goal of this project is to evaluate a new smartphone based winter RSC monitoring technology called AVL-Genius. The specific objectives of this project include

- Field evaluation of the functionality of the system as real time RSC monitoring and reporting tool;
- Evaluation of the reliability, timeliness and granularity of the system in comparison with MTO’s current TRIP road condition information;
- Evaluation of the reliability, timeliness and granularity of the system in comparison with MTO’s current West Region TOC Road and Weather Information Sheet.

A field study is to be conducted in the winter 2013-2014 season on a selected section of an Ontario Highway.

Winter RSC Monitoring – Technology Overview

This section provides a general description of the smartphone based road surface condition (RSC) monitoring system being evaluated in this project, namely, AVL-Genius. The section also provides an overview of the various existing road weather and surface condition monitoring technologies that are utilized in practice for improving winter road maintenance.

A. MOBILE AUTOMATED RSC MONITORING SYSTEM

The smartphone-based automatic RSC monitoring system tested in this research is called AVL-Genius. The system includes a front-end device for collecting RSC data and a cloud based server for data processing and reporting. The data collection data device consists of an Android smartphone with a dedicated App and a data box for interfacing with other sensors as IR pavement thermometer, salt rate controller and GPS, as shown in Figure 1. Once started, the smartphone takes pictures of the roadway at a configurable interval. The images could be uploaded to the cloud server either in real time via wireless cellular data connection or off-line at any Wi-Fi spots. The uploaded images are processed and classified in terms of snow coverage using an automated image recognition algorithm. The RSC classification results are then displayed in a standard colour scheme on a Google Map interface. The device operates with little human intervention, and the customizable frequency of taking images offers flexibility in spatial resolution for the kinds of information needed by WRM operators and the travelling public.

The device takes from a few seconds to automatically classify images captured of a road surface. The primary output of each automatic image classification is the RSC in the form: bare, partly snow covered, or fully snow covered. The system is however capable of providing other characteristics of the road surface such as percentage of snow cover and an indication of road detection. Each image is GPS-tagged and time-stamped, facilitating both aggregated and disaggregated views of RSC for a particular route. For example, it can provide detailed visualization of snow and ice covered hotspots along a route accompanied by images. It can generate route level statistics for classification of the overall condition of a route (e.g., bare pavement regain status). If there is sufficient temporal coverage of a maintenance route, it is also feasible to derive critical performance information such as bare pavement regain time.

Figure 1 - AVL-Genius Device - Smartphone and Control Box

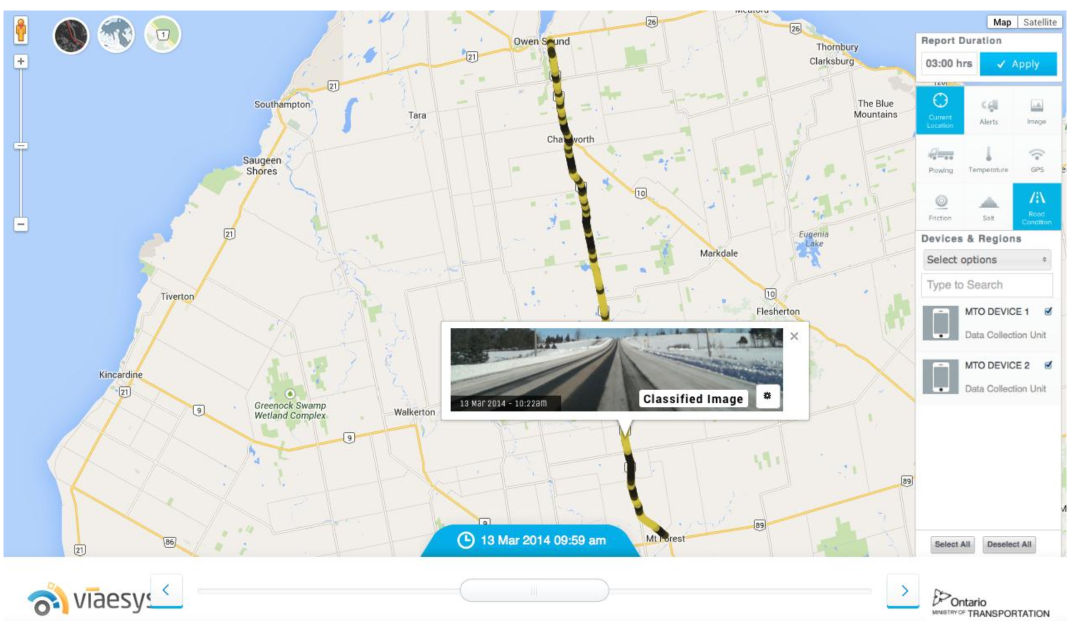


Figure 2 - AVL-Genius Web Interface Showing Classified RSC and Images

B. EXISTING RSC MONITORING TECHNOLOGIES

ROAD WEATHER INFORMATION SYSTEM (RWIS) STATIONS

An RWIS station consists of a group of environmental sensors to collect real-time localized weather and pavement condition data, such as air and pavement temperatures, type and intensity of precipitation, dew point, and surface contaminants, amount of deicing chemical on roadway. MTO currently has over 140 RWIS stations installed across the provincial highway network, which has become an important decision support tool for winter road maintenance (Buchanan & Gwartz, 2005; Kwon & Fu, 2013).

An RWIS station with basic functionality carries an installation cost of more than $50,000. The overall cost increases when additional in-pavement sensors are added and maintenance is included. (Buchanan & Gwartz, 2005). Considering the economic element, it is therefore infeasible to consistently install RWIS stations with high spatial density along the highway network. This lack of high spatial density creates an incomplete picture of roadway conditions along the network, since it is only possible to obtain spot-wise measurements scattered along the different highway sections.

It is not uncommon for a maintenance route to experience a multitude of conditions such as drifting snow, snowfall, sunlight and freezing rain. Similarly, several types of maintenance operations such as plowing, sanding and salting may also be performed on the same route. Since these phenomena as well as varying traffic conditions all affect the RSC to varying degrees, multiple RSCs often occur along a particular route. The result of this possible significant variation in RSC makes it questionable to use RWIS observations at a single spot to represent the conditions along an entire route. This is one of the main drawbacks in using RWIS data to report RSC, especially to the travelling public.

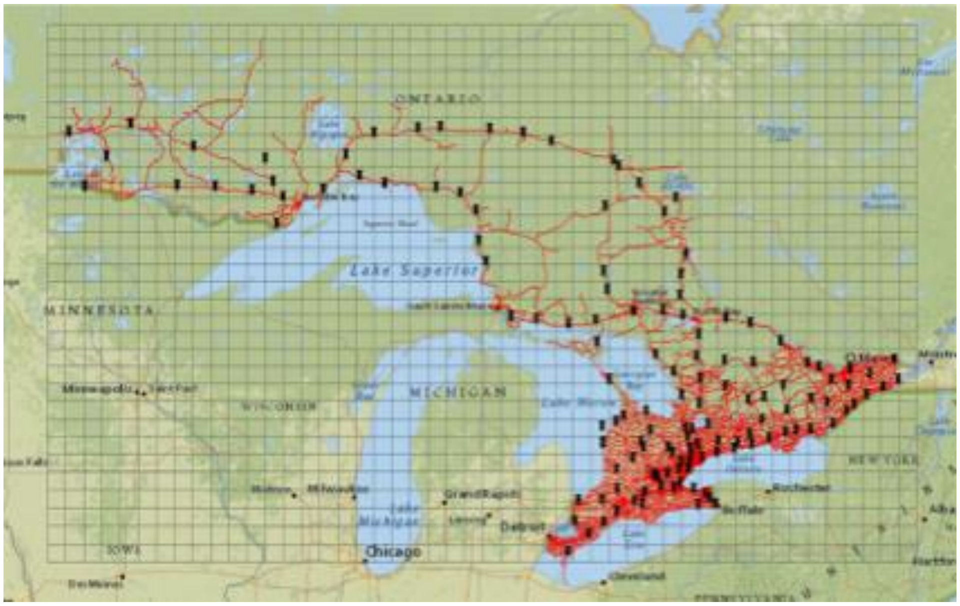


Figure 3 - RWIS Stations across Ontario

THERMAL MAPPING (TM)

Thermal mapping (TM) is a process of determining the spatial distribution of pavement temperature over a highway or highway network using temperature sensors such as infrared (IR) thermometers. Thermal surveys are usually carried out by a fleet of vehicles equipped with IR devices measuring the road surface temperature on winter nights under various weather conditions (The Institution of Civil Engineers, 2000). Thermal fingerprints (or maps) can subsequently be generated for different types of weather and climate conditions, as illustrated in Figure 4 (Erpicum et al, 2005). The resulting thermal maps allow visual identification of areas prone to freezing and other "cold-spots" in which specialized maintenance activities are necessary to keep the road safe. Identification of these locations allows maintenance operators to adjust material application rates accordingly, or notify road users via appropriate media.

While TM has the ability to capture spatial variation in pavement temperature that is otherwise lacking in point measuring technologies such as RWIS stations, it also has the limitations of low temporal resolution and incomplete representation of various winter events and conditions. For example, this technology does not provide any information on the state of snow and ice cover. Therefore, while the technology is advantageous in providing high spatial variation in pavement temperature, it is insufficient as a maintenance decision support tool for providing full information about winter RSC that is required by maintenance operators and the travelling public.

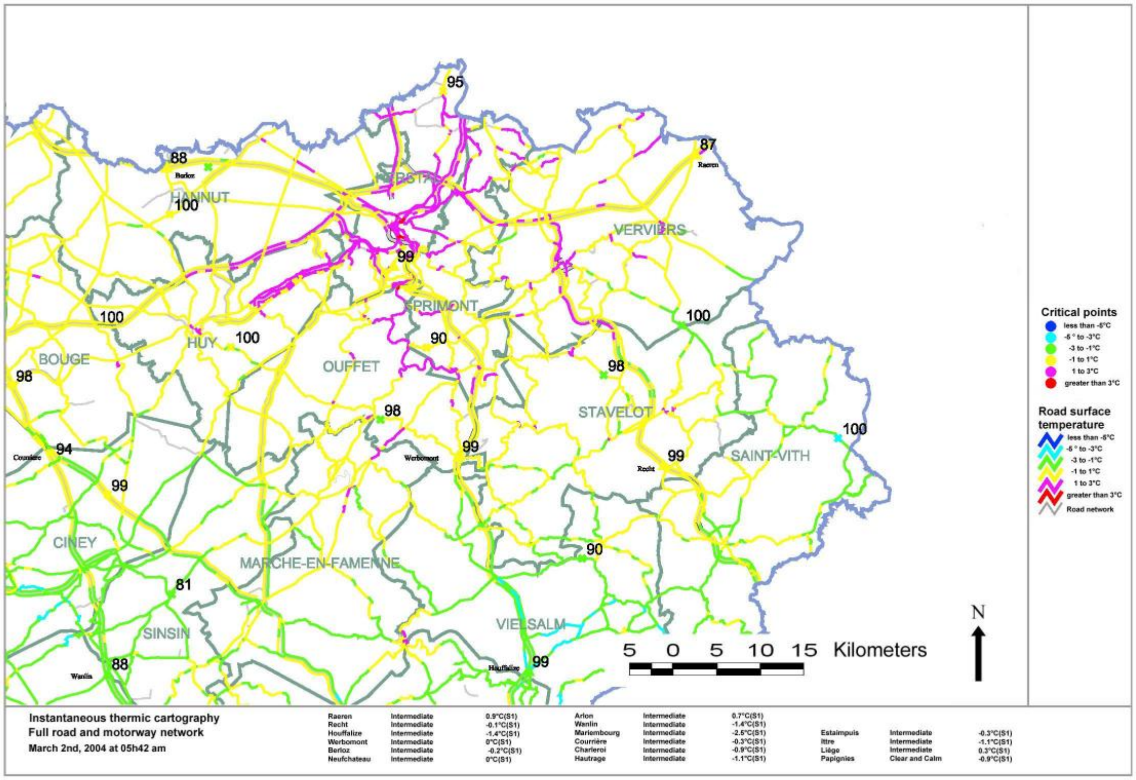


Figure 4 - An Example of Thermal Mapping (Erpicum et al, 2005)

SPECTROSCOPIC SENSORS

Spectroscopic sensors represent the latest technology available for monitoring road surface conditions during winter events. Unlike the embedded pavement temperature sensors often used as part of a RWIS station, spectroscopic sensors work in a non-intrusive way by emitting light towards the road surface in one or several different wavelengths, usually in the near infrared spectrum, and then receiving and analysing the reflected light to infer the status and amount of the contaminants on the surface spot being detected (Pilli-Sihvola et al., 2006; Jonsson, 2011; Riehm, 2012). Some spectroscopic devices can also provide additional information such as grip level, freezing point temperature, water film depth, or percentage of ice in water. However, similar to the embedded pavement sensors, spectroscopic sensors are also limited to the small spots being monitored, which is even more an issue for monitoring conditions of high spatial variation such as snow cover.

Several transportation agencies including MTO have field evaluated the performance of this type of sensors as an add-on to the existing RWIS stations while a few have also tested the sensor for mobile monitoring (Feng & Fu 2008; Joshi, 2002; Ye et al., 2012). Because of their high costs and limited performance advantages, significant feature improvements are needed before they can become a cost-effective condition monitoring alternative.

Figure 5 - Spectroscopic Sensor (Barber Insys)

CONTINUOUS FRICTION MEASUREMENT EQUIPMENT (CFME)

Continuous friction measurement equipment (CFME) measures the coefficient of friction or friction number of a pavement surface using specially designed tires attached to a device that is mounted on a travelling vehicle. CFME can be used to collect spot-wise friction data along a maintenance route during winter events, thus having the potential to support maintenance decision-making and performance management. This type of high spatial resolution data, when made available in real-time or near real-time, allows maintenance operators and road users to make informed decisions in a timely manner (Perchanok, 1998; Al-Qadi, et al., 2002; Feng, 2013; Nixon, 1998). For example, friction measurements allow identification of maintenance “hotspots” in a road network where a greater attention may be needed. Friction data with sufficient spatial and temporal coverage could also be used for performance measurement. Several Nordic countries have already used friction as a performance measurement tool for improved WRM decision-making (Cloutier & Donaldson, 2007). MTO has also been experimenting with this technology for many years; however, it has mostly been used as a research tool to evaluate alternative snow and ice control methods and technologies (Fu et al., 2008; Feng & Fu, 2009 ; Feng et al. 2010)

Amidst the advantages associated with the use of CFME to monitor RSC, several issues exist with this technology. For example, it remains to be a challenge to map friction levels to road surface snow cover and type uniquely, which means friction data alone does not provide a full description about the RSC that may observed in real world, which is often important to both maintenance operators and travellers. This is partially due to the fact that CFME covers only a small area - wheel path of the cross section of a roadway. As a result, its lateral representation is limited. Also, CFMEs are costly and require a significant amount of work for installation and calibration. Its cost-effectiveness for application as a network-wide monitoring tool remains to be questionable.

Figure 6 - An Example of CFME (Halliday Technologies Inc.)

PATROL REPORTING

Patrolling the road network and reporting its prevailing road weather and surface conditions represent the state-of-the-practice method for collecting RSC data used by most maintenance agencies. Patrollers travel along designated routes and record their conditions on a patrol report, describing the bare pavement status, the extent and types of surface contaminants, and active maintenance operations being deployed.

MTO currently adopts a self-monitoring approach in which AMCs are responsible for patrolling their maintenance routes and reporting the conditions during a winter season, with the number of daily observations dependent on the weather conditions and RSC being experienced. The Ministry also sends out its own personnel to check the road conditions on a random basis to ensure the accuracy of the patrol reports submitted by the AMCs. In addition to the AMC oversight, MTO also conducts daily patrols at least 5 times a day, the results of which become available to the public at designated times. Figure 7 below shows the steps involved in a typical reporting procedure, from the surveying of the maintenance route to recording and reporting, to publication on the Ministry's road information portal – TRIP for the travelling public. The details of the process and the types of data being collected are described in the next section.

Patrol reporting is a labor intensive and manual process, thus suffering the drawbacks of low efficiency, high subjectivity and low granularity.

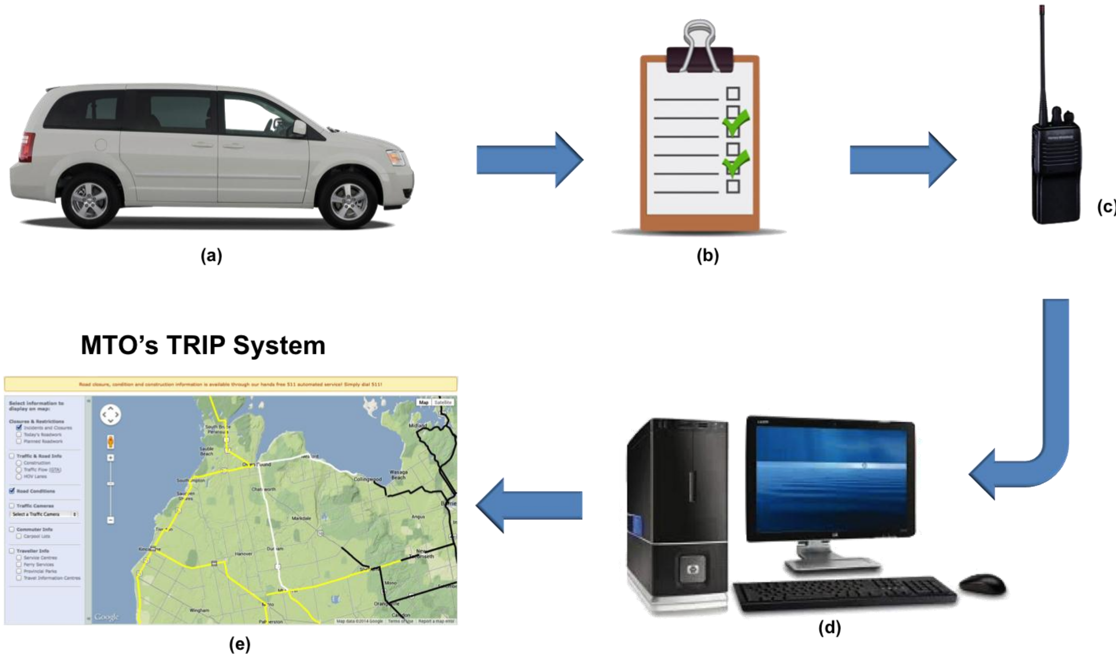


Figure 7 – The current process of RSC reporting

WEB-BASED SURVEILLANCE VIDEO

Road surface conditions can also be monitored remotely using a video based system that transfers images of the road surface in real time to maintenance personnel and road users via the Internet. Closed-Circuit Televisions (CCTVs) and web cameras are often method by which these images are captured, and these media are frequently components of a more integrated system, such as found in RWIS stations. MTO's Traveller's Road Information Portal (TRIP) enables road users to access the website and CCTV cameras at specific locations.

The images captured in these cameras are sometimes used to confirm reports of RSC and even plan maintenance activities. These devices are often mounted roadside and give a snapshot of the RSC for the road sections in view, leading to the issue of lack of spatial coverage along maintenance routes. During heavy precipitation the devices also risk of capturing images obscured by low visibility conditions and or the physical device being covered by dried precipitation.

The issue with using this technology is that it still requires manual observation and classification. This means analysing a network of images comprising a maintenance route may still require considerable human resources if those images are used for WRM decision-making and public reporting.

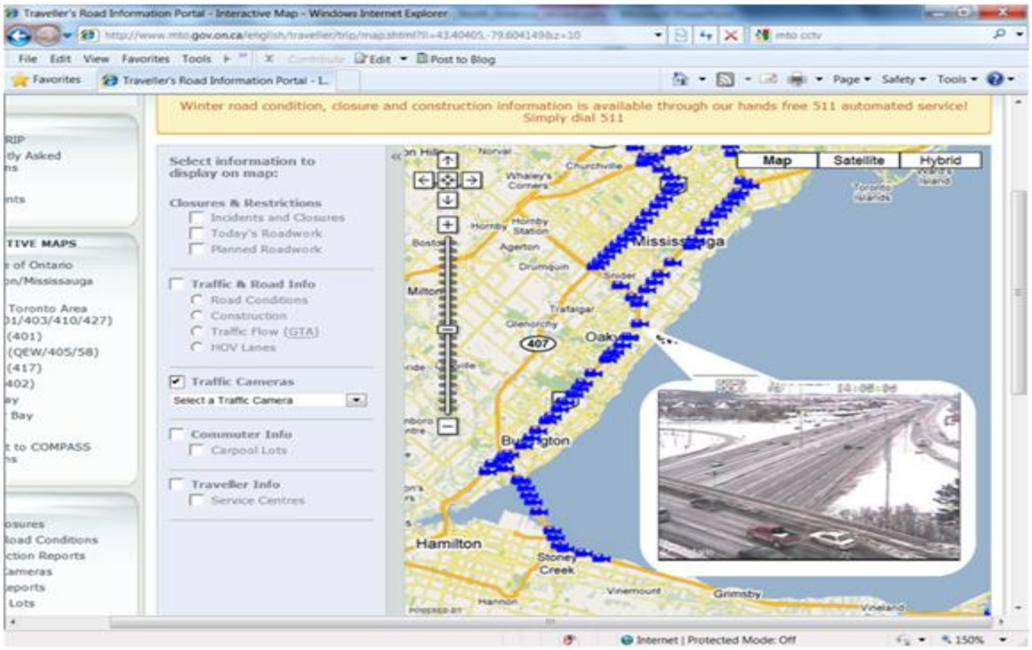


Figure 8 - MTO's Traveller's Road Information Portal

Data Collection and Processing

In order to evaluate the performance of the smartphone based winter road condition monitoring system – AVL-Genius, a field test was conducted in the winter season of 2013-2014 from Feb 24th 2014 to April 6th 2014. This section details the test site, data collection method, and processing procedures.

A. TEST SITE

Field tests were carried out in the winter on a section of a two-lane, two way, Class 2 highway - Hwy 6 near Owen Sound, Ontario, as shown in Figure 9. The test section is approximately 70km long with asphalt pavement surface and has uniform geometrical features with few horizontal curves. There is one RWIS station along the test route (SW25), which provides additional data on road weather conditions along the route. The route is maintained by an area maintenance contractor – Integrated Maintenance and Operations Services (IMOS).

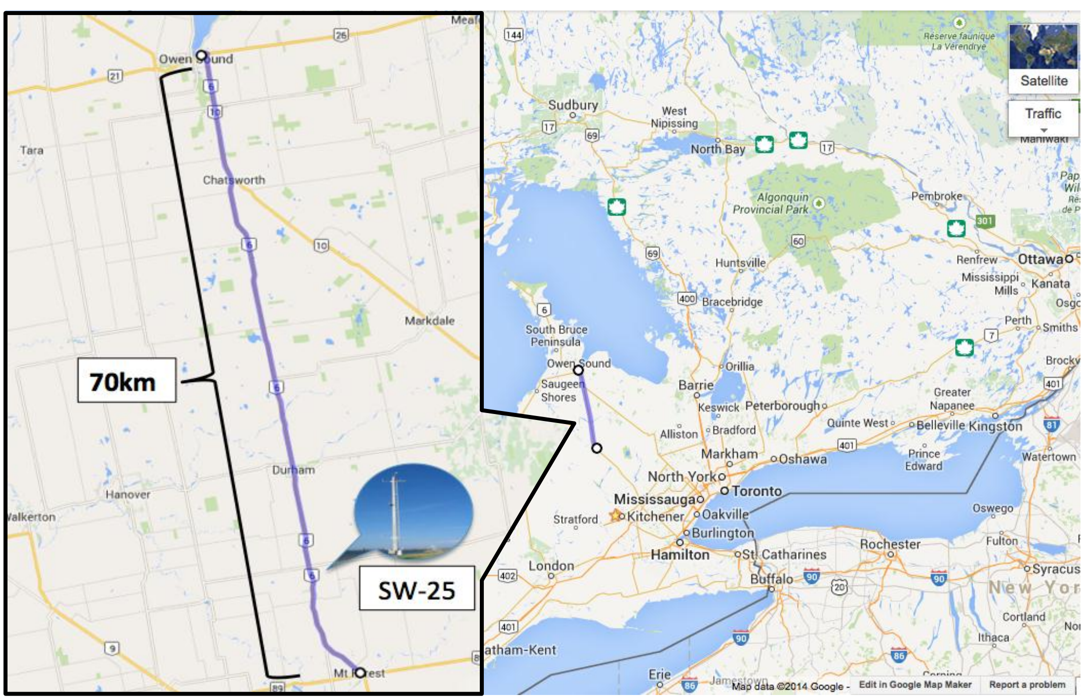


Figure 9 - Test Route and RWIS Location

B. DATA COLLECTION

For the purpose of this project, seven patrol vehicles and maintenance trucks covering the test route were installed with the smartphone based automatic road surface condition monitoring system – AVL-Genius, including two MTO patrol vehicles, two AMC patrol vehicles and three combination maintenance trucks. The analysis performed in the following sections was done using data collected from the patrol trucks.

Figure 10 – IMOS combination unit

The maintenance trucks followed the normal operational routines in terms of the timing and maintenance activities performed while the patrol vehicles had an increased number of observational trips during and after snowstorms. In addition, patrollers conducted their usual patrolling activities by recording their observations of the RSC of the test route on the paper patrol forms.

Once turned on at the start of each trip, the AVL-Genius operates automatically, recording images at a spatial frequency of 450 meters. The GPS tagged and time-stamped images of the roadway were then automatically uploaded onto a cloud server and classified by an image-processing. As discussed previously, AVL-Genius classifies each image into one of the one of three distinct types: Bare, Partly Snow Covered and Fully Snow Covered. This classification scheme is Transportation Association of Canada's guidelines for road surface condition terminology (Transportation Association of Canada, 2011) and is currently adopted by MTO.

In addition, a dedicated mobile data collection truck was also operated to collect additional data along the test route. This truck was outfitted with a RT3 friction meter (Real Time Traction Tool) and air and pavement temperature sensors.

Figure 11- Dedicated Mobile Data Collection Unit

The sampling frequency of the RT3 was set to 10 seconds. Images were captured with the smartphone-based system once every 350m and temperature readings (air and pavement) were recorded once every 29s. Each measurement has a corresponding timestamp and GPS record. The mobile unit collected data between the RWIS stations for 34 winter events during the Winter 2013/14 season.

C. OTHER DATA SOURCES

1) Patrol Records

For each maintenance route, there are three types of winter road maintenance reports prepared by field operators and patrollers, including:

- Winter Patrol Records (WPR): These reports are prepared by MTO and AMC staff and include information such as weather conditions (precipitation and, highway conditions (RSC) and maintenance operations observed.
- Winter Operations Records (WOR): This report is prepared by AMC and includes information on maintenance operations performed as well ass material type and amount.
- Road and Weather Information Sheets (R&WIS): These reports are prepared by MTO patroller five times a day as indicated in the literature review. Information on precipitation, atmospheric and road conditions are included, as well as maintenance operations observed.

The details on the data collection process for the patrol reports are described below.

The patroller travels the maintenance route and RSC are recorded on the patrol forms. The RSCs fixed based on the patrol form and the patroller checks the boxes corresponding to the RSCs observed along the route. There is no provision to indicate the frequency of observation of a particular road condition. The possible conditions according to the forms are:

- Bare and Dry
- Bare ad Wet

- Track Bare
- Centre Bare
- Snow Covered
- Snow Packed Drifted Sections
- Icy Sections
- Frost
- Slushy

In addition to the road surface conditions, information on the type of maintenance operations observed (salting, plowing, sanding etc.), weather conditions (precipitation type and intensity, wind direction and intensity, cloud cover) and the air and pavement temperature.

As the patroller travels the maintenance route the road surface conditions are recorded on their respective patrol forms. Both the maintenance contractor and MTO patroller conduct these steps (parts (a) and (b) shown in Figure 7) and have the format for RSC reporting. These types of patrols are usually carried out for a couple hours for contractor performance monitoring by MTO personnel. Meanwhile, maintenance contractors update winter patrol records as often as deemed necessary according to the prevailing conditions. In intense storms it is not uncommon for a single contractor winter patrol records to show upwards of 8 hours of observation for a particular route.

After patrollers travel a route and record their observations on the patrol form, the results are radioed into the central location responsible for the maintenance area. This information is then manually entered into the system where it later becomes available to the public on MTO's TRIP website. The reported RSC adhere to Transportation Association of Canada's guidelines and are graphically displayed on the TRIP website and color coded to represent the intensity of the reported conditions as follows (Transportation Association of Canada, 2011):

- Bare (Black)
- Partly Snow Covered (Yellow)
- Fully Snow Covered (White)

Road and weather information sheets provide atmospheric, weather and precipitation conditions in addition to the road surface conditions in the following available categories:

- Bare and Dry
- Bare and Wet
- Partly Snow Covered
- Snow Covered
- Partly Snow Packed
- Snow Packed
- Partly Ice Covered

- Ice Covered

These conditions are reported five times a day at 03:00, 09:00, 13:00, 15:00 and 21:00.

The resulting visualization of the RSC according to the TRIP system is dependent on the order in which the conditions are entered into the system. For instance, a patrol form may indicate partly snow packed and snow packed conditions. If partly snow packed was entered first into the system, indicating primary condition followed by snow packed, the resulting RSC would be partly snow packed with snow packed sections, visualized by yellow color on the TRIP website. Alternately, if snow packed is entered first, indicating its primary condition, the resulting RSC would be snow packed with partly snow packed sections, translating to a white color on the TRIP website.

There is unfortunately no current indicator of the primary RSC according to the forms, with the only distinguisher being the visualization offered by TRIP, which is a result of the patroller’s identification via radio of the primary RSC observed along a route. This means that patrol forms often show a myriad of RSCs observed along the route without any indication of the dominant conditions. In lieu of specified order according to the patroller, it is common practice to lead with the more intense condition. i.e. in the previous example snow packed with partly snow packed sections. While this is safe from an accountability perspective, it can lead to an exaggeration of current RSCs, which when reported to road users can affect their trip decision-making. Additionally, updates to the website are made only five times per day, which means displayed RSCs can be hours old at the time of accessing the TRIP website. Several can make a significant difference between a fully snow covered highway and a bare highway section when maintenance has been performed, and vice versa during an event.

Maintenance Operations are also recorded and include the following information:

- Patrolling
- Plowing
- Sanding
- Salting
- Anti-icing
- Clean-up

This report details the maintenance operations performed on a particular route. Unlike the other types of reports, these records are not made via patrol vehicles, but instead by the maintenance units during their procedures on the route. The type of maintenance operations are noted and including the following:

- Anti-icing

- Spreading Only
- Plowing Only
- Combination
- Plowing

Additionally, material information is specified as follows:

- Dry Salt Amount (tonnes)
- Pretreated Salt Amount (tonnes)
- Sand
- Application Rate
- Liquid (litres)
- Liquid application rate (%)

Winter Operations Records make no mention of observed RSC, since the recording of those conditions is reserved for contractor and government patrollers.

All manual patrol reports were processed and entered into a database via a Microsoft Access forms. Field interviews were also conducted with maintenance personnel to further understand the process in which the winter road surface conditions were observed and made available to the public and any accompanying issues involved in the process.

Samples of each type of patrol report are included in the Appendix.

2) TRIP Data

TRIP Data was made available through MTO's web-based interface that is updated five times daily: 03:00, 09:00, 13:00, 15:00 and 21:00. Screenshots were recorded after the RSCs visualized on the website were updated throughout the day (Figure 12) .

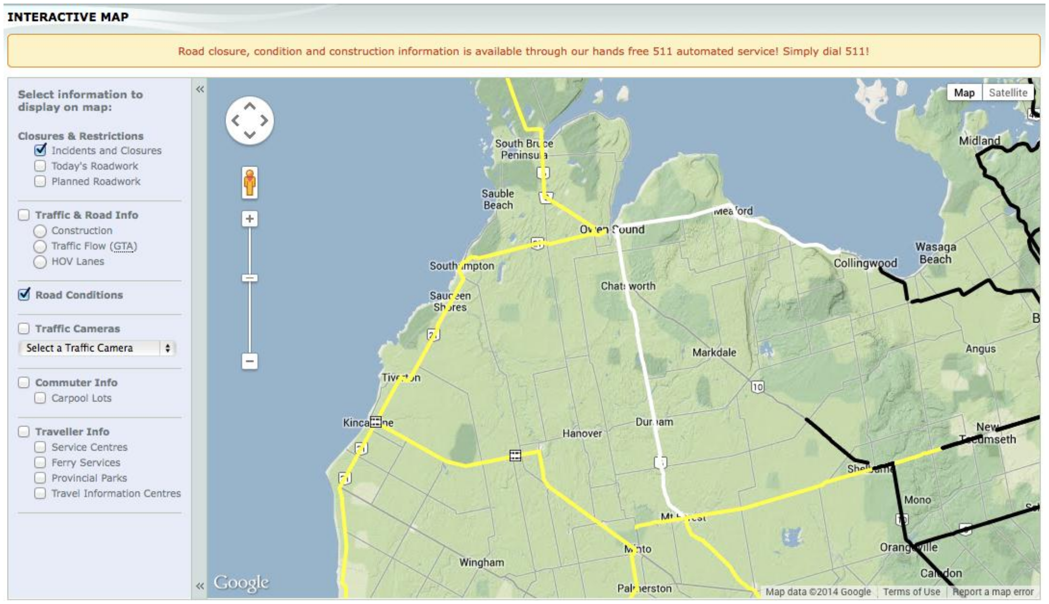


Figure 12 – MTO's Web-based TRIP Interface

3) RWIS Data

Data is available for RWIS Station SW-25 that is located on the test site. Several types of information are included with this source, even though the analysis of RWIS data is not a part of in the main focus of this research.

In the latter part of the season, a non-invasive RSC sensor called NIRS31-UMB was installed near the RWIS station SW-25. The sensor is capable of providing spot measurements on the RSC such as presence of ice/snow, water film height, and equivalent grip level; however, its data were not used in this project because it was not operational until the end of the season.

D. DATA PROCESSING AND PREPARATION

Data was processed according to the requirements involved in answering the research questions. Details on the method by which this was done for each question are explained below.

Classification of Spot-level RSC

In order to evaluate the accuracy of AVL-Genius's RSC classification algorithm, a form of "ground-truth" to which AVL-Genius classification results can be compared must first be obtained. AVL-Genius took a sequence of images along the test route with each capturing the RSC of the short section covered by the image view. The individual images could be considered as point or spot observations along the test route. For the purpose of comparison, each image was manually classified in terms of snow coverage, which was then compared to the computer classification result. The manual classification task was completed by a group of students trained with the same level of understanding of the classification rules to minimize the possible inconsistency and subjectivity. If the automatic RSC classification was found to be the same as the corresponding RSC classification, the status of that image was said to be matching. If the opposite occurred, the image status was said to be non-matching.

Figure 13 shows the interface of a web-based application that was developed for facilitating manual classification of RSC. The user is presented with images taken by AVL-Genius's smartphone camera and asked to choose of the following categories in terms of snow/ice coverage on the pavement surface:

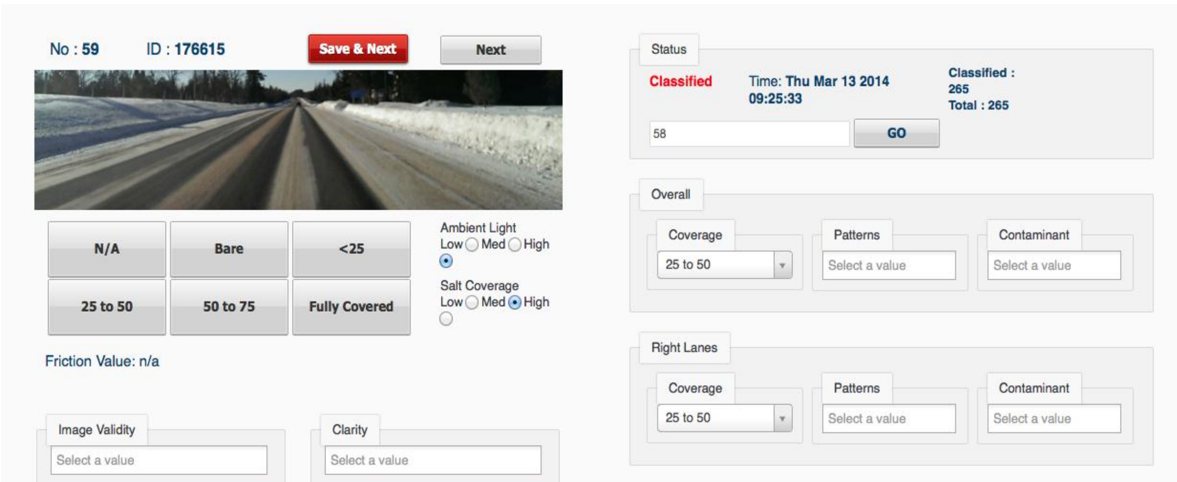
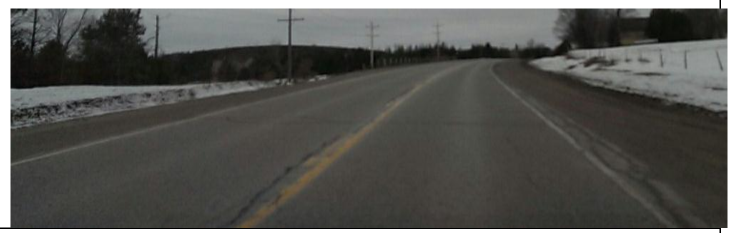
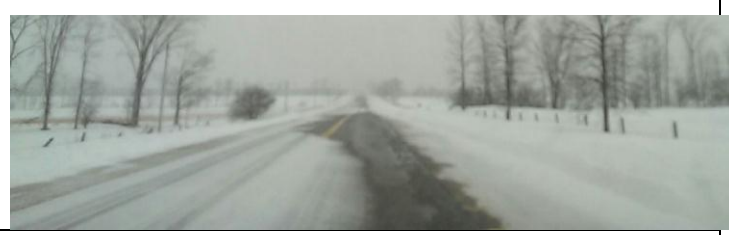
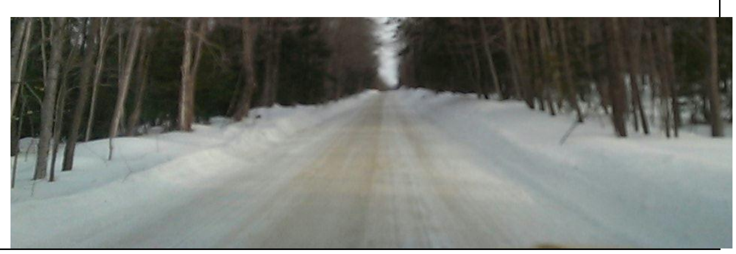


Figure 13 - Manual RSC Classification Interface on AVL-Genius

Table 1 - Definition of Different Types of Lateral Snow Coverage

Lateral Snow Coverage	Description	Sample Image
Bare	At least 3 meters of the pavement cross-section in all lanes is clear of snow or ice.	
<25	Track between two wheel paths are clear of snow or ice.	
25 to 50	Both wheel paths are clear of snow or ice.	
>50	Only one wheel path is clear of snow or ice.	
Full	No wheel path is clear of snow or ice.	

In addition, information on ambient light, salt coverage, image quality, and lane position are also to be recorded, which could be used to identify the causes of the poor classification performance of computer classification system. Salt coverage refers to the level to which dried salt is observed on the road surface. There are three options available: low, medium and high. Residual salts on pavement could give the impression of snow. Ambient light refers to the light that is available in the environment of the image. Darkened images and images of poor quality due to insufficient ambient light are manually distinguished with these options.

This process was carried out for 23 days and over 16,000 images covering a variety of weather conditions. If we consider the data recorded on one device for a particular day as one device-day, this procedure was carried out on a sample of 49 device-days; a combination of four devices operating for 23 days.

Generation of Route-level RSC Classification Statistics

The "point" observations from the mobile system, regardless how they are classified, could be aggregated to the route level to obtain summary statistics on the RSC of the whole test route. Assume each point observation (i) represents segment i of length l_i, the classification results for each trip run are combined to generate a summary statistics for the whole route using Equation (1).

$$P_k = \frac{\sum_i l_i \times \delta_i^k}{L} \qquad \text{Equation (1)}$$

Where: P_k = percent of the route having RSC class k;

l_i = length of the segment i;

L = total length of the route, $L = \sum_i l_i$

δ_i^k = 1 if the segment i has the RSC class of k; 0 otherwise.

If a single condition (class) is to be designated for the whole route, the TAC winter RSC classification guidelines can be followed to determine the class based on the extension of each condition class over the route. For example, if less than 10% of the route is affected by snow or ice, the RSC is considered to be bare. The resulting data were summarized by patrol time and event.

This data step of aggregating point observations to the route level is also necessary as one of the objectives of this project is to compare the results from AVL-Genius to those from patrol reports and MTO's TRIP system, both of which report RSC at a (patrol) route level. The patrol reports and the summary statistics from the automatic classification system are compared to identify the discrepancy between these different RSC monitoring methods.

Data Analysis and Results

A. SUMMARY OF TEST DATA

Over 105,000 images were collected during 50 days of test runs, covering 40 events of varying weather and road conditions. Figure 14 and Table 2 show the summary statistics of the field tests and the associated event characteristics.

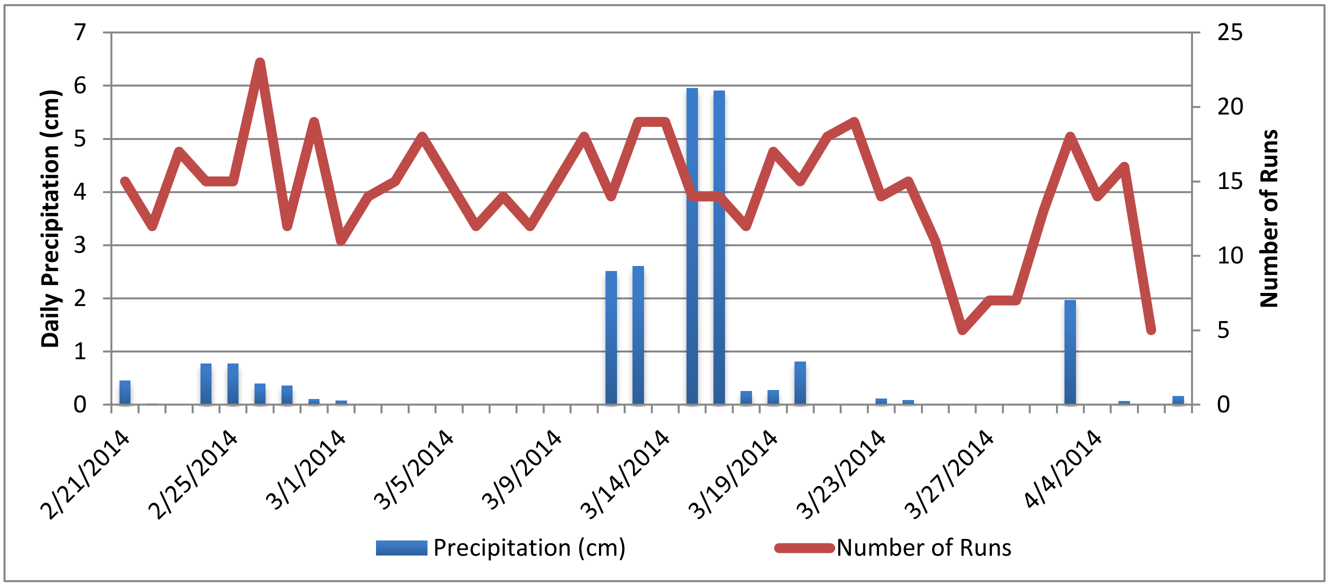


Figure 14 - Events, Test Runs and Images

Table 2 - Summary of Event Attributes and Test Runs

	Min	Max	Mean	Stdev
Events	40			
Total Precipitation (cm)	0	5.95	0.59	1.39
Pavement Temperature (°C)	-22.6	24.8	-3.7	8.2
Air Temperature (°C)	-30	17	-7.4	7.8
Wind Speed (km/h)	0	54	17.8	9.2
No. of Runs	5	23	14.3	3.9

B. SPOT-WISE CONDITION MONITORING ACCURACY

One of the key features of the AVL-Genius system is its ability to collect RSC data at specific locations or spots along the route being monitored. The first question of interest for this investigation therefore concerns with the accuracy of the system for spot-wise condition monitoring, that is, how accurately can it distinguish the RSC at individual locations based images? This performance is important as it reflects the system's ability to detect local spots of poor road surface conditions, namely, hotspots.

In answering this question, we must first obtain "ground truth" of the RSC showing in each image. As discussed previously, this was done by manually classifying all images. Table 3 shows the confusion matrix of the classification results by AVL-Genius using the manual classification results as the "ground-truth". A total of 16,664 images collected by the data collection units over 23 events were manually classified and used for evaluating this spot-wise condition monitoring performance of the system.

Of all the images collected, a total of 11160 images (67%) were classified as Bare in manual classification. The AVL-Genius system correctly classified 83% of these Bare condition images. Approximately 15% of the images were misclassified as Partly Snow Covered, which is somewhat expected considering the fact that for some of the images there is only a small difference between Bare and Partly Snow Covered, especially in the events of low precipitation. 2% of the Bare conditions were misclassified as Fully Snow Covered, which could be caused by the effect of glaring and residual salts as detailed in the later section.

There were a total of 4511 images (27%) that were manually classified as Partly Snow Covered. Approximately 57% of these images were classified as such by AVL-Genius, 41% of them were classified as Bare and the remaining 2.3% as Fully Snow Covered. Interestingly, 31% of the images were associated with the lower end of the snow cover scale (< 25%), which could have caused a high number of Partly Snow Covered conditions being misclassified as Bare. The other main reason is the presence of dark colored slush could not be accurately detected by the current classification algorithm.

The classification accuracy for Fully Snow Covered conditions was much lower. Of the 973 Fully Snow Covered images, about 34% were classified correctly as such while 47% of them classified as Partly Snow Covered and the remaining 19% as Bare. One of the main reasons for this problem was due to the high proportion of conditions with wheel paths covered by slushy snow, which could appear to be track-bare and thus classified as Partly Snow Covered. The misclassification from Fully Snow Covered to Bare could also be caused by glaring, which could make the snow cover appear to be black or brown. A detailed discussion on the associated issues is provided the following section.

Table 3 - Confusion Matrix of AVL-Genius Classification Results

<table>
<tr><td colspan="6">By number</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Classified by AVL-Genius</td><td rowspan="2">Total</td></tr>
<tr><td>BP</td><td>PS</td><td>FS</td></tr>
<tr><td rowspan="3">Manually (Ground Truth)</td><td>BP</td><td>9222</td><td>1673</td><td>265</td><td>11160</td></tr>
<tr><td>PS</td><td>1830</td><td>2577</td><td>104</td><td>4511</td></tr>
<tr><td>FS</td><td>189</td><td>452</td><td>332</td><td>973</td></tr>
<tr><td colspan="2">Total</td><td>11241</td><td>4702</td><td>701</td><td>16644</td></tr>
<tr><td colspan="6">By percentage</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Classified by AVL-Genius</td><td rowspan="2">Total</td></tr>
<tr><td>BP</td><td>PS</td><td>FS</td></tr>
<tr><td rowspan="3">Manually (Ground Truth)</td><td>BP</td><td>82.6%</td><td>15.0%</td><td>2.4%</td><td>100%</td></tr>
<tr><td>PS</td><td>40.6%</td><td>57.1%</td><td>2.3%</td><td>100%</td></tr>
<tr><td>FS</td><td>19.4%</td><td>46.5%</td><td>34.1%</td><td>100%</td></tr>
</table>

C. ROUTE LEVEL CONDITION MONITORING ACCURACY

The previous section evaluates the performance of the AVL-Genius system in classifying the RSC based on the point-wise observations - images taken at individual locations along the test route. The AVL-Genius can also provide summary statistics at a route level in terms of shares of individual types of RSC along a route. These route level statistics could be used to assess the performance of the system in providing aggregate information on the overall conditions of a patrol route, which represents the current practice and needs by MTO. This section compares AVL-Genius outputs against manual classification, patrol observations and MTO's TRIP system.

AVL-Genius vs. Manual Classification

This section evaluates the system's performance in generating aggregate condition information for a whole patrol route. Table 4 shows summary statistics of classification results from the two approaches, i.e., manual vs. AVL-Genius, for the images collected over two events. The last column of the table provides the single-class classification results for the whole route based on the TAC definition (Appendix B). As seen from the table, the performance of the AVL-Genius system varies significantly by the three classes of RSC being estimated and across the individual test runs. However, for the aggregate estimates of RSC class, with the exception of one time period, AVL-Genius classifications matched perfectly to the "ground-truth" of the manual classifications. This result underscores the point that although there is variation in spot-wise classification accuracy, AVL-Genius' classification performance at the route level is quite satisfactory.

Table 4 – Comparison of AVL-Genius and Manual Classifications for Route-level Conditions (Device: IMOS 4)

Feb 28th								
Trip	BP (%)		PS (%)		FS (%)		TAC/MTO	
	Manual	AVL Genius	Manual	AVL Genius	Manual	AVL Genius	Manual	AVL Genius
1	11	38	87	62	3	0	PS	PS
2	4	21	93	79	4	0	PS	PS
3	72	33	25	61	3	6	PS	PS
4	94	86	6	14	0	0	BP	PS
5	83	53	17	47	0	0	PS	PS
Mar 15th								
Trip	BP (%)		PS (%)		FS (%)		TAC/MTO	
	Manual	AVL Genius	Manual	AVL Genius	Manual	AVL Genius	Manual	AVL Genius
1	0	4	100	86	0	11	PS	PS
2	21	25	75	71	4	4	PS	PS
3	0	6	72	44	30	50	PS	PS
4	0	0	52	66	48	34	PS	PS
5	0	7	85	72	15	21	PS	PS

AVL-Genius vs. Patrol Reports

As discussed previously, MTO relies on patrollers to monitor and report road surface conditions during winter events. The patrol reports give a qualitative description of the road weather and surface conditions over specific routes and the extent to which these conditions are observed.

To enable a comparison to the qualitative patrol reports, the point-wise condition classification data from AVL-Genius are aggregated to generate route-level condition statistics such as percentage of route with individual types of snow coverage.

Table 5 shows time-stamped conditions reported by patrollers as compared to those from AVL-Genius for two events occurred on Mar. 10, 2014 and Mar. 12, 2014. The results show that the two methods are very consistent in terms of the types of RSC reported. In the first event the patroller observed three types of RSC along the route from the patrolling trip around 9:17-9:37am: bare and dry, bare and wet and partly snow covered conditions. The route level condition summary from the AVL-Genius for the same trip indicated a mixed of two types of conditions: 87% Bare and 13% Partly Snow Covered. Note that AVL-Genius does not distinguish between Bare Dry and Bare Wet. Similar conditions were reported for the observation trip at 9:37-9:52am. For the subsequent three trips, the patrol reports indicated completely bare conditions (Bare Wet and Bare Dry) while AVL-Genius reported that 92%~97% of the route was bare and the remaining Partly Snow Covered.

For the more severe event occurring on Mar. 12, 2014, three RSC conditions, including track bare, partly snow covered and fully snow covered, were observed by the patroller over the first patrolling trip at 11:49-12:00am, which was well captured by AVL-Genius (4% Bare, 85% Partly Covered, and 11% Fully Snow Covered). In the following observation trips, there is again a good correspondence between the patrol reports and AVL-Genius RSC, with the only difference being that the later provided quantitative information on the extent of each RSC.

Similar comparative analyses were performed on all events covered by the field test and the findings are similar to these from the two example storms shown in Tables Table 5 and Table 6.

Table 5 – Patrol Reports vs AVL-Genius

Mar. 10, 2014; MTO Device 1		
Time	**Patrol Reports**	**AVL-Genius**
9:19 - 9:37	Bare and Dry Bare and Wet Partly Snow Covered	87% Bare 13% Partly Snow Covered
9:37 - 9:52	Bare and Dry Bare and Wet Partly Snow Covered	93% Bare 7% Partly Covered
9:54 - 10:10	Bare and Dry Bare and Wet	97% Bare 3% Partly Covered
10:24 - 10:41	Bare and Dry Bare and Wet	97% Bare 3% Partly Covered
10:49 - 11:04	Bare and Wet	100% Bare
11:04 - 11:26	Bare and Wet Bare and Dry	92% Bare 8% Partly Snow Covered

Table 6 – Patrol Reports vs. AVL-Genius

Mar. 12, 2014; IMOS Device 4		
Time	**Patrol Reports**	**AVL-Genius**
11:49 - 12:00	Track Bare Partly Snow Covered Snow Covered	4% Bare 85% Partly Snow Covered 11% Fully Snow Covered
14:10 - 14:20	Track Bare Partly Snow Covered Snow Covered Bare and Wet Partly Ice Covered	25% Bare 71% Partly Snow Covered 4% Fully Snow Covered
14:35 - 15:00	Track Bare Snow Covered Snow Packed Drifted Sections Slushy	6% Bare 44% Partly Snow Covered 50% Fully Snow Covered
15:00 - 15:30	Snow Covered Snow Packed Partly Snow Covered Partly Snow Packed	66% Partly Snow Covered 34% Fully Snow Covered
15:37 - 15:48	Partly Snow Covered Partly Ice Covered Snow Covered/ Packed Bare and Wet	7% Bare 72% Partly Snow Covered 21% Fully Snow Covered

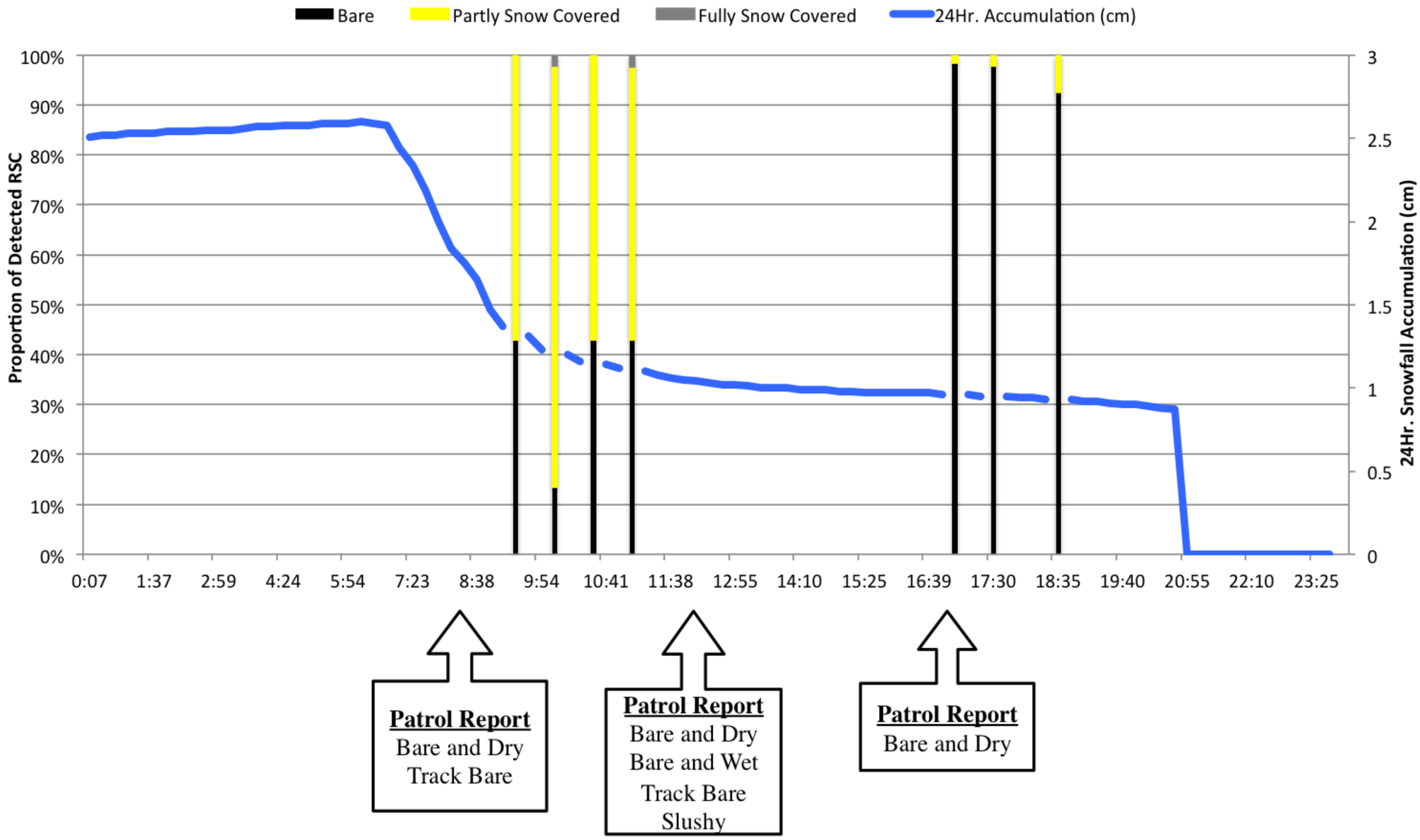


Figure 15 – Timeline of a winter event for test route on Mar. 13, 2014

AVL-Genius offers an additional advantage over current monitoring methods through its ability to quantitatively observe the changing RSC from within-storm conditions, to the point at which bare pavement has been regained. Bare pavement regain times (BPRT) are important performance measures for WRM, especially for areas such as Ontario that follow Bare Pavement policies.

Figure 15 illustrates the changing RSC for Mar 13, 2014 for a storm with a reported start and end time of Mar 12, 2014 6:56am and Mar. 13 2014 at 9:00am respectively; and a BPRT of 9:45am. However, according to AVL-Genius 55% partly snow covered and 45% bare RSCs were detected until 11:00am. Figure 16 shows time-stamped images of the RSCs along the route, which confirm occurrence of partly snow covered sections. This potential to more objectively monitor BPRT using route level RSC summary statistics from AVL-Genius can therefore provide a valuable tool for AMC's snow and ice control operations as well as MTO's AMC performance monitoring.

It can therefore be reasonably concluded that AVL-Genius is an effective alternative to the current method of patrol reporting. More importantly, AVL-Genius has the added advantages of being objective and providing condition statistics that allow for better performance measurement and condition forecasting.

Figure 16 – Partly Snow Covered Conditions Observed on Mar 13, 2014

AVL-Genius vs. TRIP System vs. Patrol Reports

As discussed in the earlier section, MTO's TRIP is a Traveller Information Service providing road information for provincial highways in Ontario via an interactive Internet map application. While the road surface conditions showing on the TRIP map interface also come from the field patrol reporting channel discussed previously, there is a lag between the time that TRIP updates the conditions and the time that the conditions are actually observed and reported. This section provides a comparison between the conditions displayed in MTO's TRIP and those reported by AVL-Genius. Because the TRIP condition database was not available to this project, snapshots of TRIP's interactive map display were taken during individual snowstorms over the test period. For the comparison purpose, the same were done for obtaining condition display from the AVL-Genius system. Note again that both systems provide visualization of the RSC according to the national conventions established by TAC.

Figure 17 shows a side-by-side comparison of the conditions of the test route showing on TRIP and AVL-Genius for the event that occurred on March 10th 2014. The snapshots were taken at 9:00am, in which MTO's TRIP system displayed bare conditions for the entire test route while AVL-Genius detected the route as 95% bare and 5% Partly covered. According to the latter, the dominant condition detected is bare but certain locations along the 70km route are Partly snow covered. Patrol reports indicated a combination of three conditions: partly snow covered, bare and dry and bare and wet conditions. According to TAC definition, the whole route can be considered as reaching bare pavement conditions, which suggests that the two methods are consistent in reporting the route-level conditions. The granularity provided by AVL-Genius allows for identification of the hotspot locations in which conditions differ from the majority. If this becomes a trend during or after a particular event, maintenance personnel can identify areas that require additional maintenance operations. Moreover, motorists can identify specific locations of deteriorated road surface conditions along the route and drive accordingly in an effort to reduce risk of collisions.

Figure 18Figure 19 give another two examples of visual comparison between the two methods for a more severe event occurred on March 15th 2014. At 9:00am, MTO's TRIP System showed fully snow covered road surface conditions while AVL-Genius shows 54% Bare, 21% Partly Covered, and 24% Fully Snow Covered conditions. The dominant condition observed is bare pavement according to AVL-Genius; however approximately half of the route is either partly or fully snow covered. Again, according to the TAC definition, a single designation for the conditions of the whole route should be Fully Snow Covered, which is exactly consistent with what was displayed on MTO's TRIP system. The manual patrol records for this time reported "snow covered", "partly snow covered", and "bare and wet conditions", confirming the output from AVL-Genius. Again, the former lacks details on the location and extent of these different types of RSC over the route.

For the TRIP output at 13:00pm, Fully Snow Covered conditions were displayed again while AVL-Genius detected 27% Bare, 55% Partly Snow Covered, and 18% Fully Snow Covered conditions. The dominant condition detected was Partly Snow Covered. Patrol reports indicate bare, Partly covered and fully covered conditions, again with no specificity on the extent to which these conditions occur along the route. Additional reports such as the WPR-OSH indicated bare and several types of Partly covered conditions (drifting snow, partly snow packed, partly snow covered). Based on the TAC definition, the route should have been designated as Partly Snow Covered instead of Fully Snow Covered as shown in TRIP. This could be due to the time lag between TRIP system and patrol reporting, that is, MTO’s TRIP system was yet to update the conditions based on field reports, or was experiencing technical errors.

Table 7 provides a summary of ten side-by-side comparisons between AVL-Genius and TRIP with the visual comparisons being included in Appendix C. As can be seen from this summary, while there is a remarkable consistency between the conditions reported by AVL-Genius and those from the patrol reports, there is a noticeable discrepancy between these two data sources and TRIP system. As mentioned previously, this discrepancy was most likely due to the time lag between TRIP updating and patrol reporting. This finding also underscores the issue with how MTO’s current TRIP system obtains and updates RSC data, and the need for automating its RSC monitoring and data collection methods.

Table 7 – Summary of AVL-Genius and TRIP Comparison

Date	Time	MTO's TRIP RSC	Road & Weather Info Sheet	AVL-Genius	
				RSC Classification	TAC Classification
28-Feb-14	13:00	Bare	Partly Snow Covered Partly Snow Packed Bare and Wet Bare and Dry	49% Bare 51% Partly Snow Covered	Partly Snow Covered
04-Mar-14	9:00	Bare	Partly Snow Covered Bare and Wet Bare and Dry	91% Bare 6% Partly Snow Covered 3% Fully Snow Covered	Bare
04-Mar-14	15:00	Bare	Partly Snow Covered Bare and Wet Bare and Dry	85% Bare 11% Partly Snow Covered 5% Fully Snow Covered	Partly Snow Covered
10-Mar-14	9:00	Bare	Partly Snow Covered Bare and Wet Bare and Dry	95% Bare 5% Partly Snow Covered	Bare
10-Mar-14	15:00	Bare	Bare and Wet Bare and Dry	97% Bare 2% Partly Snow Covered 1% Fully Snow Covered	Bare
14-Mar-14	9:00	Bare	Partly Snow Covered Bare and Wet Bare and Dry	69% Bare 23% Partly Snow Covered 8% Fully Snow Covered	Partly Snow Covered
15-Mar-14	9:00	Fully Snow Covered	Snow Covered Partly Snow Covered Bare and Wet	54% Bare 21% Partly Snow Covered 24% Fully Snow Covered	Partly Snow Covered
15-Mar-14	13:00	Fully Snow Covered	Partly Snow Packed Partly Snow Covered Bare and Wet	27% Bare 55% Partly Snow Covered 18% Fully Snow Covered	Fully Snow Covered

Table 7 – cont'd

Date	Time	MTO's TRIP RSC	Road & Weather Info Sheet	AVL-Genius	
				RSC Classification	TAC Classification
21-Mar-14	9:00	Bare	Snow Packed Partly Snow Covered Partly Snow Packed Bare and Wet Bare and Dry	78% Bare 22% Partly Snow Covered	Partly Snow Covered
25-Mar-14	9:00	Bare	Partly Snow Covered Partly Snow Packed Bare and Wet Bare and Dry	68% Bare 30% Partly Snow Covered 2% Fully Snow Covered	Partly Snow Covered

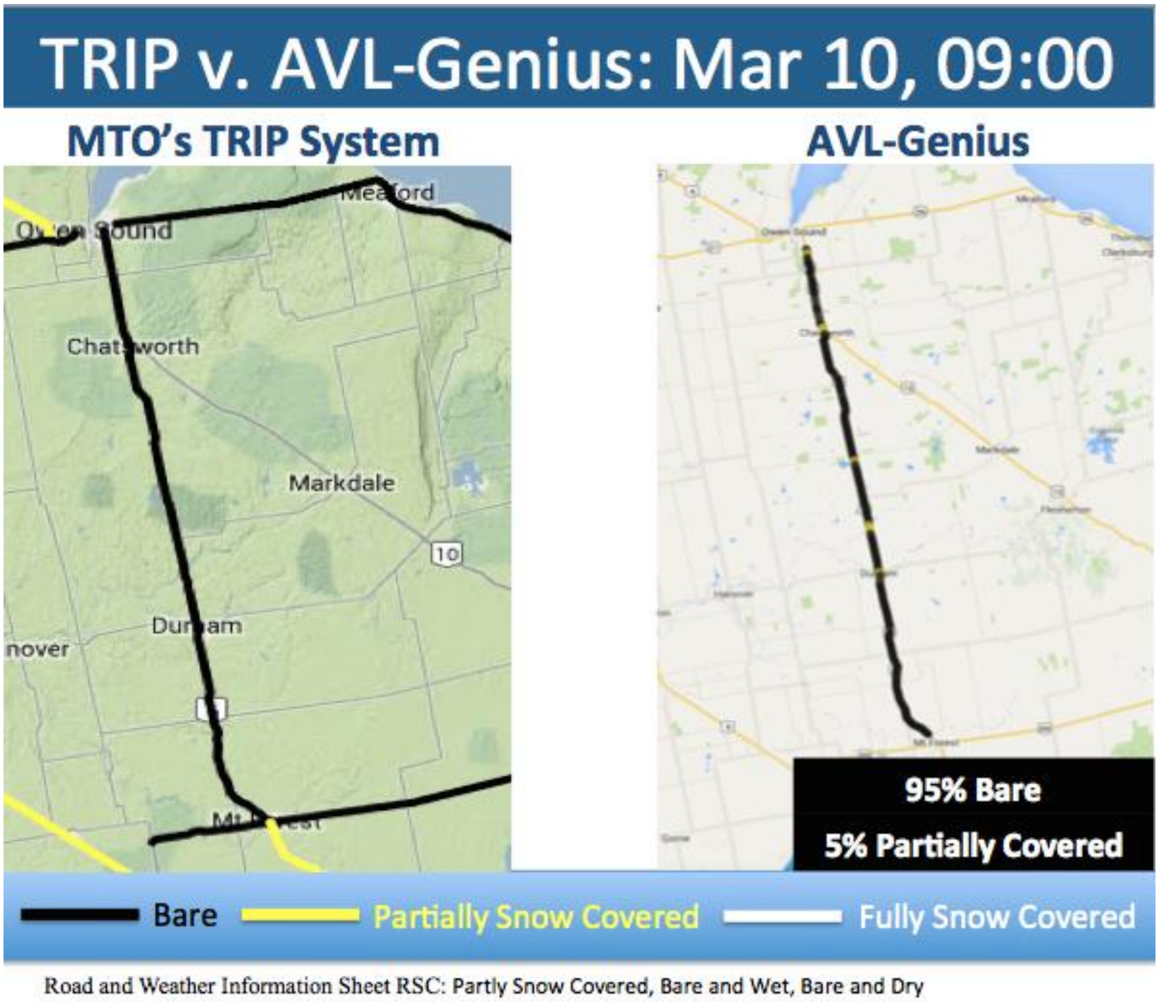


Figure 17 - Side-by-side comparison between MTO's TRIP System and AVL-Genius for Mar 10th at 9:00am

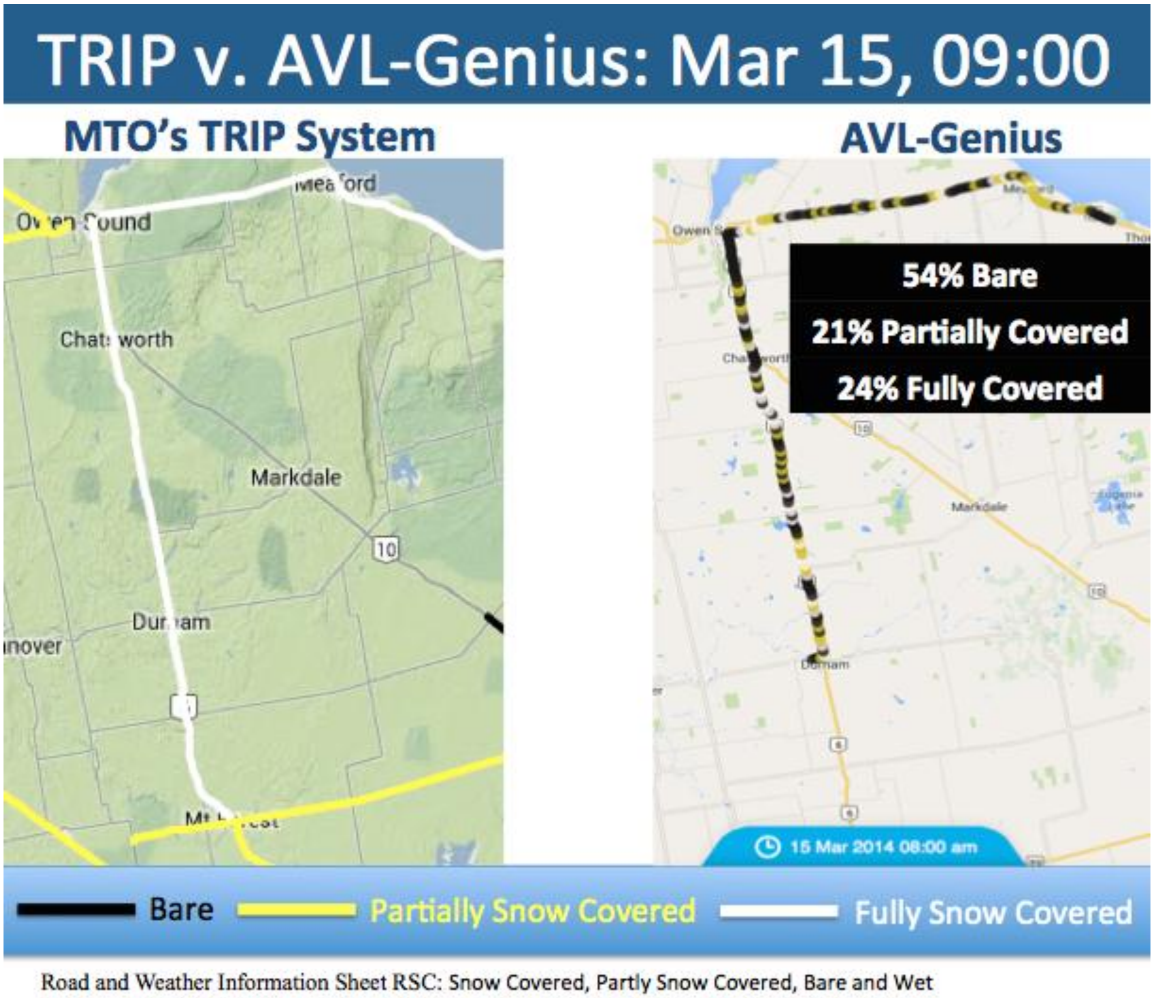


Figure 18 - Side-by-side comparison between MTO's TRIP System and AVL-Genius for Mar 15th at 9:00am.

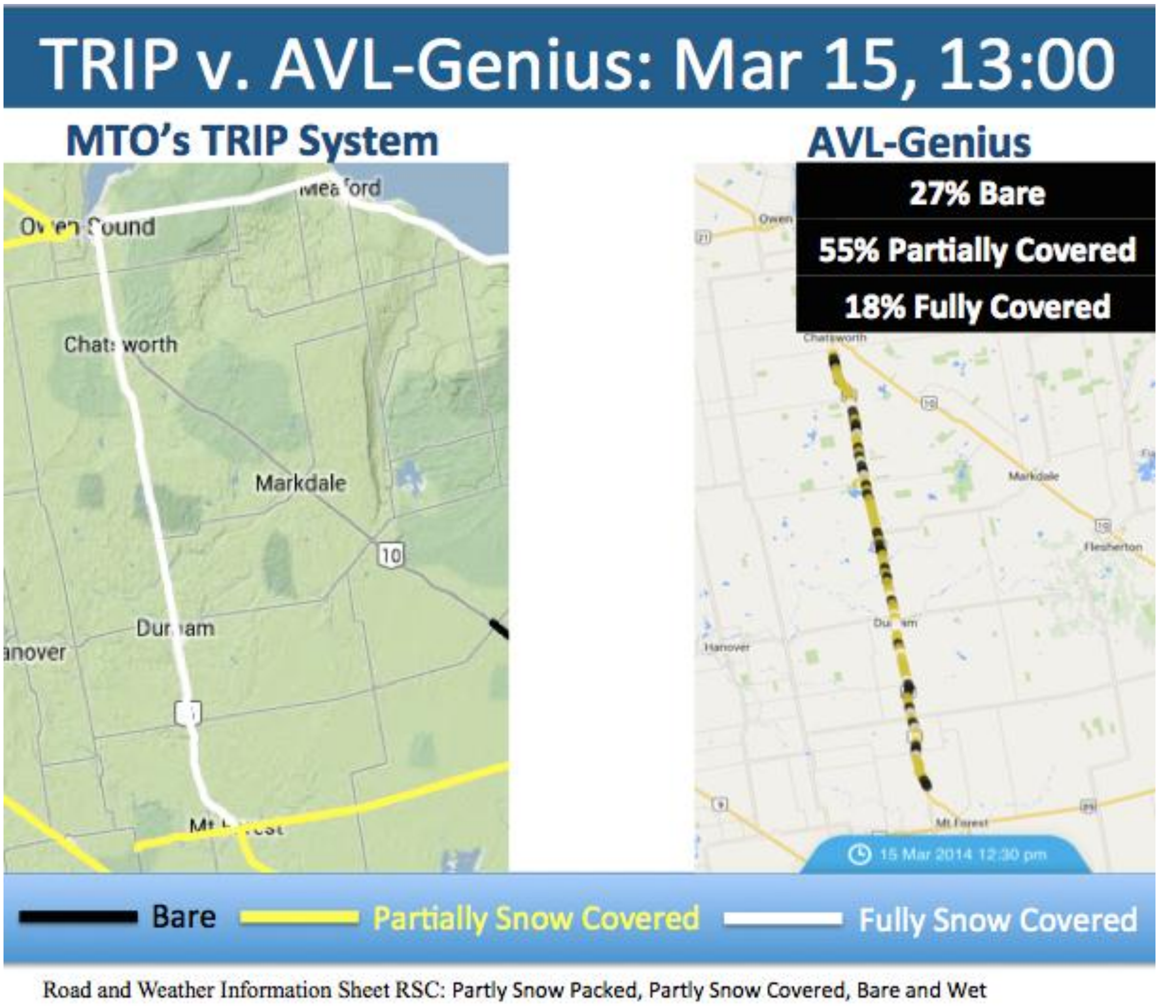


Figure 19 - Side-by-side comparison between MTO's TRIP System and AVL-Genius for Mar 15th at 1:00pm.

D. SYSTEM RELIABILITY

This project was also set to evaluate the reliability of the AVL-Genius in terms of how dependable the system is in performing its intended functions, i.e., obtaining the RSC data of a given route. There are two main factors affecting the reliability of an image based condition monitoring system such as AVL-Genius, including availability of useful images and image classification accuracy. The availability performance is defined as the proportion of images taken by its smartphone camera on a given data collection run that are classifiable, i.e., useful for classification. Image classification accuracy is defined as the percentage of the classifiable images that are classified correctly. This section describes the evaluation results of the availability performance of the system while the accuracy performance is detailed in the previous section.

The images taken by a smartphone camera are not always useful for identifying RSC due to the effects of windshield conditions, lights and sight obstruction of windshield wiper and front vehicle. AVL-Genius has a pre-processing algorithm to detect whether or not an image is valid and can be used to determine the RSC. Table 8 shows the availability statistics reported by AVL-Genius. As expected, this performance varied by devices and trips, ranging from 60% to 100%. In average, 86% of the images were found to be classifiable.

There are several reasons why a particular image could not be used by the automatic image processing algorithm. Firstly there are circumstances where the vehicle and its attached device were not pointed towards the roadway. Images could be captured when the vehicle had stopped on the shoulder, or when it was travelling closely behind other types of vehicular traffic that obscure the view of the roadway ahead. Obscured views of the roadway can also occur when images are captured at the instant that vehicles are travelling in the opposing directions. These types of cases occur more frequently on lengthy patrol routes where drivers may need to make stops on a shoulder to record RSC information in their paper patrol reports. Other types of situations that would cause a image to be excluded by the classification system include instances when the vehicle is pointed towards a garage or building front instead of a road surface.

Table 8 - Summary Statistics of Image Availability

Date	Device	Obtained	Classified	Image Availability
24-Feb	MTO Device 1	332	300	90.4%
04-Mar	IMOS Device 4	160	94	58.7%
10-Mar	MTO Device 1	250	225	90.0%
10-Mar	IMOS Device 4	356	300	84.3%
12-Mar	IMOS Device 4	200	200	100.0%
13-Mar	MTO Device 1	265	262	98.9%
15-Mar	IMOS Device 4	859	687	80.0%
22-Mar	IMOS Device 4	136	133	97.8%
	TOTAL	**2558**	**2201**	**86.0%**

E. KEY PERFORMANCE FACTORS

As observed in the field test results discussed previously, the performance of a mobile image based condition monitoring system such as AVL-Genius is affected by a number of factors such as sampling frequency, availability of useful images, lights, and weather conditions. This section provides an overview of these factors based on the experience gained from the field test.

1) Sampling Frequency

Sampling frequency is refereed as to the temporal or spatial interval by which the system takes data or pictures in this case along the route. The higher is the sampling frequency, the higher is the number of pictures that become available for condition monitoring and the higher is the granularity of the collected RSC data. In this field test, all AVL-Genius devices was set at a sampling interval of about 450 meters, or, one picture for every 450 meters. With these high-frequency data, it is possible to examine the effect of sampling frequency on the monitoring performance, which in turn would give indication on the minimum sampling frequency required to produce results of a desired level of reliability or accuracy. This can be done by systematically removing images at a fixed interval. For example, if every other image was removed from the original dataset with a sampling interval of 450 meters, the resulting dataset would represent the case as if the sampling interval was set to 900 meters.

Table 9 shows the route level RSC condition statistics using data collected by an IMOS device over an event on March 12th, 2014. Two additional sampling intervals were simulated, namely, 900 meters and 1350 meters. As it can be observed, the effect of the sampling frequency varies significantly. For example, the estimation results were similar across the three levels of sampling frequencies for the data from the first observation trip (8:19am-9:02am). The shares of the three classes of RSC - Bare, Partly Snow Covered, and Fully Snow Covered were estimated to be 54%, 22%, and 24%, respectively, based on the original dataset, and were 58%, 16% and 26% if the sampling interval were increased to 900 meters (or the sampling frequency is reduced to half). However, for the period from 15:28pm-15:41pm, the effect of the sampling interval is much more prominent, especially for the less dominant RSC type (12% vs. 0% vs. 22% for the three sampling intervals).

It should be noted that these findings from the field test can also be confirmed through a theoretical analysis based on sampling theory from statistics, as described in Appendix E.

Table 9 – Patrol Reports and Corresponding AVL-Genius Classification Results at Different Sampling Intervals (Mar 12 – IMOS Device 4)

Time	Classification			
	Patrol Reports	**AVL-Genius 1 in 450m**	**AVL-Genius 1 in 900m**	**AVL-Genius 1 in 1350m**
08:19 -09:02	Center Bare Track Bare Drifted Sections Slushy Bare and Wet	54% Bare 22% Partly Snow Covered 24% Fully Snow Covered	58% Bare 16% Partly Snow Covered 26% Fully Snow Covered	58% Bare 21% Partly Snow Covered 21% Fully Snow Covered
12:15 - 12:50	Track Bare Drifted Sections Slushy Bare and Wet	27% Bare 55% Partly Snow Covered 18% Fully Snow Covered	19% Bare 64% Partly Snow Covered 17% Fully Snow Covered	38% Bare 58% Partly Snow Covered 4% Fully Snow Covered
12:50 - 13:07	Track Bare Drifted Sections Slushy Bare and Wet	26% Bare 55% Partly Snow Covered 19% Fully Snow Covered	25% Bare 50% Partly Snow Covered 25% Fully Snow Covered	10% Bare 50% Partly Snow Covered 40% Fully Snow Covered

Table 9 – cont'd

Time	Classification			
	Patrol Reports	AvL-Genius 1 in 450m	AVL-Genius 1 in 900m	AVL-Genius 1 in 1350m
15:28 - 15:41	Drifted Sections Slushy Bare and Wet Bare and Dry	46% Bare 42% Partly Snow Covered 12% Fully Snow Covered	50% Bare 50% Partly Snow Covered	33% Bare 44% Partly Snow Covered 22% Fully Snow Covered

2) Visibility

Low visibility could occur due to various weather and vehicle related factors such as dirty windshields, heavy precipitation, and fogs. While these situations did not occur frequently during the field test, the underlying issue still needs to be addressed for the potential users. For example, for the test run conducted on Mar 12th, 2014, the system reported that over 40% of the images were taken under the conditions that can be characterized as low/poor visibility. This poor visibility was the main reason why the image classification algorithm had performed poorly for this test run with a matching rate of 59% as compared to manual classification. Figure 20 shows an example of conditions with reduced visibility due to the presence of snow on the windshield, causing the algorithm to classify the RSC as Fully Snow Covered. The developer is currently working on developing an automated procedure to detect these cases so that the associated images can be excluded from further consideration.

Figure 20 - Image with low visibility due to dirty windshield

3) Road Surface Contamination

Presence of dried residual salts on a pavement surface poses another challenge for identifying the RSC as their whitish appearance is somewhat similar to those of snow and ice, as shown in Figure 21. These conditions were obtained on of the test days - March 13th, 2014 with 15-20% of the collected images showing whitish dried salt. Even for manual classification, it requires additional care and scrutiny to distinguish the two conditions. The automatic classification algorithm had the tendency to classify images laden with dried salt as Partly or Fully Snow Covered. This problem however had been partially addressed recently by an improved classification algorithm from the developer.

Figure 21 - Bare RSC Covered with Dried Residual Salt

4) Ambient Lighting

AVL-Genius's image recognition algorithm has not yet been calibrated to classify nighttime images; however, this feature is to be included in the coming phases of development. It is expected that as long as the images are not tainted with high reflectivity (e.g., from oncoming headlights), the automatic RSC classification system should equally work under these conditions. In its present state, AVL-Genius is therefore dependent on images with sufficient ambient light, or in the daytime. Image quality therefore plays a pivotal role affecting the performance of the current system. As discussed in the review of literature, automatic classification of wet and dry road surfaces have been previously done for nighttime images as well as images where the road surface is illuminated only using passing vehicle headlights. This is an indication of potential for the system being operated under nighttime conditions.

Figure 22 - Image taken in the nighttime

E. CORRESPONDENCE WITH FRICTION MEASUREMENTS

As discussed previously, as part of this field test, a dedicated mobile data collection unit equipped with a friction meter was operated to collect friction data along with RSC collection data from AVL-Genius. The percentage of bare pavement was selected as the performance measure to compare with friction because they represent similar physical measures of RSC.

The minute averages for friction were visually illustrated to find trends by finding moving averages and plotting them according to the distance travelled. This was done because friction measurements are spot measurements, and literature confirms that using mean friction is more reasonable in RSC estimation. Images on the mobile data collected unit were captured on an interval of once every 350m. Figure 23 below shows the moving minute average along the data collection route for both percentage of snow cover and corresponding CFM.

Figure 23 shows the time-series plot of the two measures, namely, friction in terms of friction number and % of bare pavement across the travelling lane. The figure clearly shows the correlation between these two measures, with higher percentage of bare lane associated with higher level of friction. It should be noted that the investigation on the relationship between friction and bare pavement status was not the focus of this report and as such no amount of detail was spent exploring this concept.

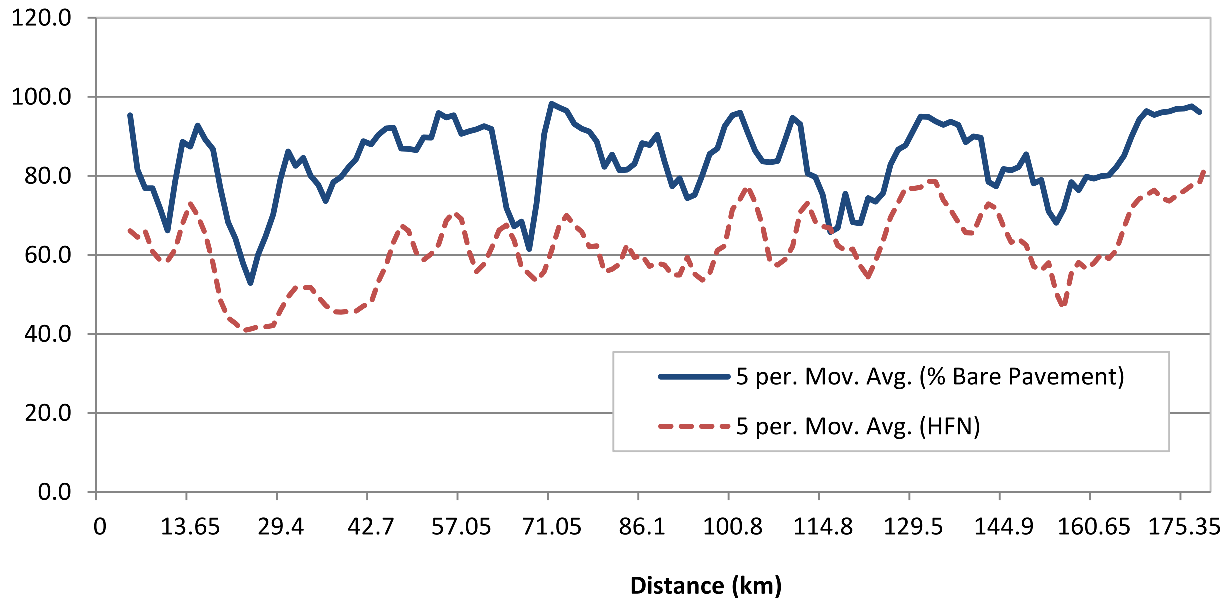


Figure 23 – Moving Average Comparison between % Bare Pavement and Friction

Conclusions and Future Work

In this project we have conducted a field study to evaluate the performance of a smartphone based automated road surface condition (RSC) monitoring technology called AVL-Genius. The project is motivated by the potential of this technology for complementing or replacing existing methods that are employed by MTO for road condition monitoring. The tests were conducted on a 70km stretch of Hwy 6 near Owen Sound. The monitoring technology was deployed on four patrol vehicles – two operated by MTO and two by the AMC – IMOS responsible for this patrol route. Additionally, two maintenance trucks and one dedicated mobile data collection unit were equipped with the system. The instrumented vehicles were operated along the test route from Feb. 24th, 2014 to Apr. 6th, 2014 and a total of 40 events were covered with 105,998 images being collected. The results from AVL-Genius were compared to manual classifications, patrol reports and MTO's TRIP system. This section summarizes the main findings and provides some recommendations for future research.

MAJOR FINDINGS

- The AVL-Genius system was first evaluated for its spot-wise condition monitoring function. The RSC classification results from ALV-Genius's automatic image recognition algorithm were compared to the "ground-truth" from manual classification. It was found that the system achieved an average of 73% perfect matching of the conditions being detected. A detailed examination of the mismatched cases showed several main causes of problems, including poor quality of images due to windshield conditions, poor visibility, presence of dry salt and glare of sunlight.

- The route-level conditions generated by AVL-Genius were found to be highly consistent with those reported by the field personnel in their routine patrol records. However, the AVL-Genius has the advantage of providing quantitative details on individual types of RSC, compared to the descriptive nature of the patrol reports. This allows patrollers and maintenance operators to see the dominant conditions and the extent to which RSC changes during winter weather events, thus making more informed decisions.

- Compared to MTO's TRIP system, AVL-Genius has been shown to provide more timely and spatially detailed information about snow cover along a maintenance route. This information of high temporal and spatial granularity is invaluable to MTO, AMCs, and the travelling public. MTO could use this information for improved performance management while AMCs could use this information to delivery better targeted treatment operations, thus reducing operating costs and salt usage and improving service quality.

- The field study has also identified several key issues and areas to be improved with the current version of the smartphone based monitoring system.

    - The system needs to be extended to include night-time RSC monitoring function.
    - Currently AVL-Genius classifies RSC into three major classes: bare, partly covered or fully covered. While this classification system is sufficient for visualization and supporting current TAC classification scheme, more detailed information on lateral snow coverage and contaminant type is useful for maintenance operations and drivers. For example, details on snow cover could include bare wheel path, bare track, bare centre, and bare shoulder. Contaminant types could be dry snow, packed snow, slush and ice.
    - The image recognition algorithm could be further improved for better classification accuracy. Conditions that represent specific classification challenges include unusual snow cover, slushy road surfaces, and residual salt.
    - Poor image quality caused by reduced visibility, dirty windshield, and view obstruction is another cause of low system classification quality. Some of the issues such as dirty camera lance and windshield can be addressed by the vehicle operator while others such as heavy precipitation, drifting snow and snow squalls requires improvement in image processing.

RECOMMENDATIONS

- A more extensive pilot study should be carried out in future to obtain additional data on the robustness and reliability of the smartphone based RSC monitoring system. In addition to further evaluate the condition monitoring performance of the system, the future effort should also test out data communication between AVL-Genius and TRIP system and integration of the system to MTO's maintenance performance management process (e.g., generation of patrol reports, bare pavement reports and performance statistics).

- It is expected that the AVL-Genius will be further developed to include additional features such as night-time operations, detection of dry salt and removal of glare effects. As a result, the system needs to be further evaluated in the field on the performance of these new functions. Further research is also needed on several important issues related to field data collection, such as optimal sampling interval, identification of hotspots, and optimal sampling frequency (patrolling frequency).

- One of the main attractions of a smartphone based condition monitoring system is its scalability as a crowdsourcing solution. The system can be installed on any smartphones and operated on any vehicles. As a result, there is a possibility of obtaining RSC information from the traveling public for much more extensive and denser coverage of the road network. This potential should be explored in future effort.

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Appendix A

A1: Winter Patrol Records - MTO

Ontario **Winter Patrol Record** Yard Location: AMC oversite Page # ____________ of __________

Date: MON. FEB. 24/14
Patrolled by: S. ARNOLD
Shift Start: Time 13:54 Mileage 119314
Shift End: Time 15:50 Mileage

Hwy. Closure Information

Hwy	Time Closed	Time Opened

Patrol Route

Highway	Time	From	To	Time	Air Temperature	Pavement Temperature	Clear	Partly Cloudy	Overcast	Rain (L, M, H)	Snow (L, M, H)	Freezing Rain	Fog (L, M, H)	Visibility (G, F, P)	Wind (L, M, S)	Wind Direction	Bare and Dry	Bare and Wet	Track Bare	Center Bare	Snow Covered	Snow Packed	Drifted Sections	Icy Sections	Frost	Slushy	Patrolling	Plowing	Sanding	Salting	Snow Blowing (hwy)
6	13:55	OWEN SOUND	MT. FOREST	14:45	-10				✓					G	M	W		✓	✓		✓		✓								
6	14:55	MT. FOREST	OWEN SOUND	15:45	-10				✓					G	M	W		✓	✓		✓		✓					✓			

Weather Conditions: Clear to Wind Direction. Highway Conditions: Bare and Dry to Slushy. Operations: Patrolling to Snow Blowing (hwy).

Comments:

OWEN SOUND – MT. FOREST
- SOME DRIFTED SECTIONS
- NO OPERATIONS NOTICED.

MT. FOREST → O.S
PLOW SBL 1 KM N/ MT. FOREST
- PLOW DOWN 15:00
PLOW SBL N/ DORNOCH
- PLOW DOWN 15:24

* VIAESYS WEB-CAM RECORDING
- PLOW S/CHATSWORTH SBL 15:34
- DRIFTING CAUSING SOME SNOW COVERED SECTIONS

SA
Patroller's Signature:

Visibility reported as **G**ood, **F**air or **P**oor Rain, Snow or Fog reported as **L**ight, **M**oderate or **H**eavy Wind reported as **L**ight, **M**oderate or **S**trong

A2: Winter Patrol Records - IMOS

Owen Sound Highway Maintenance Limited

Winter Patrol Record

Yard Location: CHATSWORTH 24

Page # 1 of 2

Date: MAR. 4 / 2014
Patrolled by: TIM DRAPER
Shift Start: 7:00
Shift End: 19:00

Hwy. Closure Information

Hwy	Time Closed	Time Opened

Highway	Time	From	To	Time	Air Temperature	Pavement Temperature	Clear	Partly Cloudy	Overcast	Rain (L, M, H)	Snow (L, M, H)	Freezing Rain	Fog (L, M, H)	Visibility (G, F, P)	Wind (L, M, S)	Wind Direction	Bare and Dry	Bare and Wet	Track Bare	Center Bare	Snow Covered	Snow Packed	Drifted Sections	Icy Sections	Frost	Slushy	Plowing	Sanding	Salting	Snow Blowing (hwy)
#6	8:00	DURHAM	MOUNT FOREST	8:25	-15	-14			✓		L			G	L	SW	✓	✓											SPOT ✓	
#6	8:25	MOUNT FOREST	DURHAM	8:50	-14	-13			✓		L			G	L	SW	✓	✓											SPOT ✓	
	9:05	DURHAM.	FLESHERTON	9:30																										
#10	9:30	FLESHERTON	DUNDALK	9:45	-14	-14			✓		L			G-F	L	S-W		✓	✓		✓								✓	
#10	9:45	DUNDALK	CHATSWORTH	10:30	-13	-10			✓		L			G-F	L	S-W		✓	✓	✓	✓								✓	
#6	10:45	CHATSWORTH	OWEN SOUND	11:00	-12	-9			✓		L			G-F	L	S-W		✓	✓	✓	✓								✓	
#26	11:00	OWEN SOUND	MEAFORD	11:30	-11	-10			✓		L			G-F	L	S-W		✓	✓	✓	✓								✓	
#26	12:10	MEAFORD	COLLINGWOOD	12:50	-8	-7			✓		L			G-F	L	S-W		✓	✓		✓								✓	
#26	12:50	COLLINGWOOD	MEAFORD	13:15	-9	-6			✓		L			G-F	L	S-W		✓	✓		✓								✓	
#26	13:20	MEAFORD	OWEN SOUND	13:45	-11	-9			✓		L			G-F	L	S-W		✓	✓		✓								✓	
#6	13:45	OWEN SOUND	CHATSWORTH	14:10	-11	-10			✓		L			G-F	L	S-W		✓	✓		✓								✓	
#6	14:45	CHATSWORTH	OWENSOUND	15:00	-9	-8			✓		L			G-F	L	S-W		✓	✓		✓								✓	
#26	15:00	OWEN SOUND	IRISH BLOCK RD, HWY 26	15:30	-8	-9			✓		L			G-F	L	S-W		✓	✓		✓								✓	
#26	15:30	IRISH BLOCK RD AND HWY 26	OWEN SOUND	15:50	-9	-10			✓		L			G-F	L	S-W		✓	✓		✓								✓	
#6	15:50	OWEN SOUND	CHATSWORTH	16:05	-9	-10			✓		L			G-F	L	S-W		✓	✓		✓								✓	

Comments: SNOW BLOWER WORKING ON HWY. #26 FROM OWEN SOUND TO MEAFORD

Visibility reported as Good, Fair or Poor   Rain, Snow or Fog reported as Light, Moderate or Heavy   Wind reported as Light, Moderate or Strong

A3: Winter Patrol Records – R&WIS

Ontario

Ministry of Transportation
London Traffic Operations Centre
659 Exeter Road
London, Ontario N6E 1L3
Telephone: (519) 873-4223
Facsimile: (519) 873-4443

Ministère des Transports
Le Centre des Opérations de London
659, chemin Exeter
London, Ontario N6E 1L3
Téléphone: (519) 873-4223
Télécopieur: (519) 873-4443

Report Information

Report Time: 03:00 09:00 13:00 (15:00) 21:00

Special Report Time: ______

Date: SAT, MAR 22/14

Operator: L'COLLINS

Road and Weather Information Sheet

NORTH

Time Entered into RCS: ______

Precipitation Conditions

AN - No Precipitation
Rain - Rain [L-M-H]
Fr Rain - Freezing Rain [L-M-H]
Snow - Snow [L-M-H]
Ice Pel - Ice Pellets [L-M-H]
Mix - Mix (Rain/Snow) [L-M-H]

Atmospheric Conditions

Temp - Air Temperature [Reported in °Celcius]
Wind - Wind Direction [8 point compass]
Speed - Wind Speed [Light - Moderate - Strong]
Vis - Visibility [Good - Fair - Poor]
Sky - Cloud Condition [Clear - Partly Cloudy - Overcast]
Fog - Fog [L-M-H]
Drift - Drifting [Y / N]

Road Conditions

RB - Roads Bare and Dry
WET - Roads Bare and Wet
PSC - Partly Snow Covered
RSC - Snow Covered
PSP - Partly Snow Packed
RSP - Snow Packed
PIC - Partly Ice Covered
RI - Roads Ice Covered

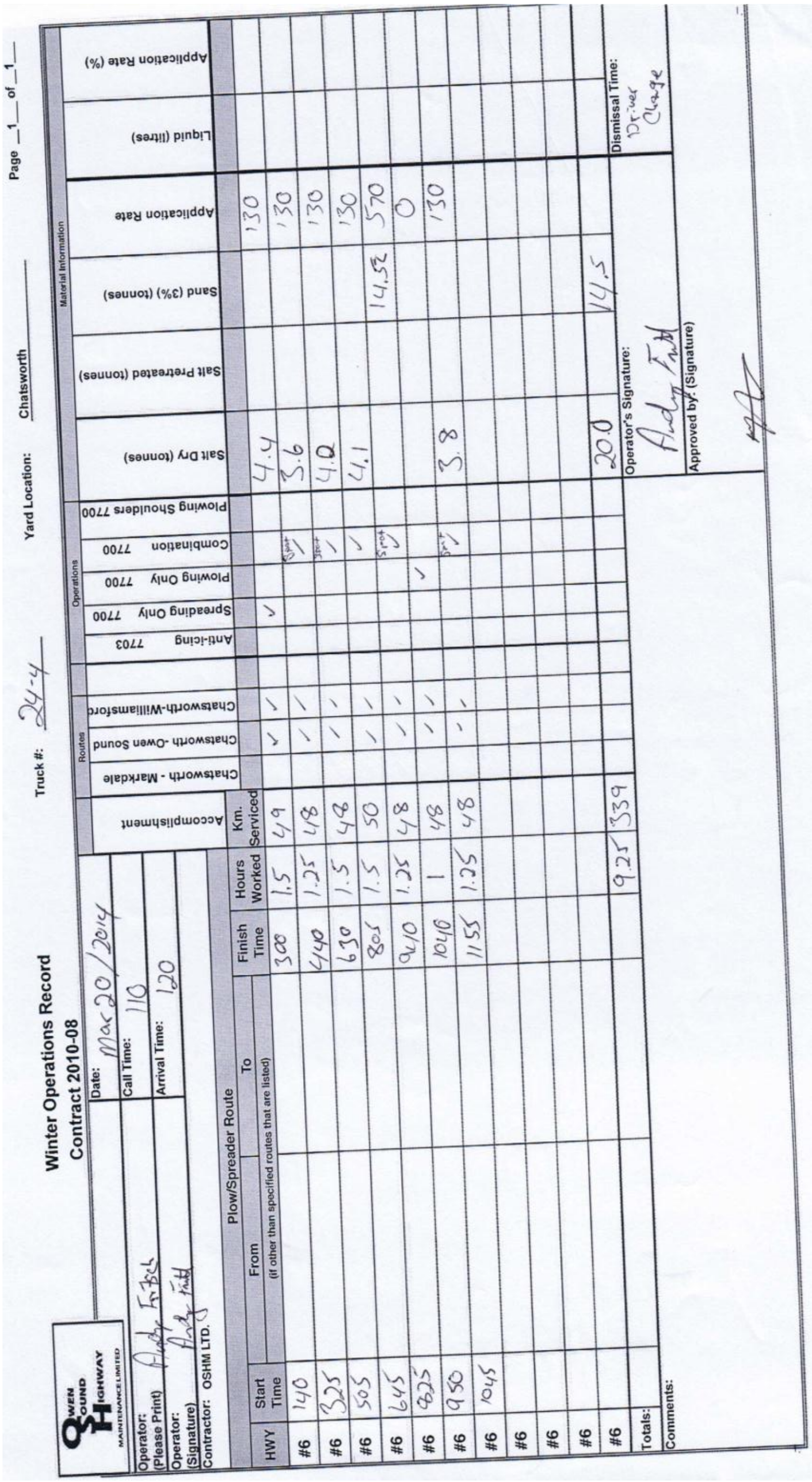
Maintenance Operations

PAT - Patrolling
OP - Plowing
OSA - Sanding
OSG - Salting
DLA - Anti-Icing
CU - Clean Up

Patrol / Highways			Precipitation Conditions						Atmospheric Conditions										Road Conditions								Maintenance Operations					
			AN	Rain	Fr Rain	Snow	Ice Pel	Mix	Temp	Wind		Visibility	Sky			Fog	Drifting	Roads Bare		Snow Covered		Snow Packed		Ice		PAT	OP	OSA	OSG	DLA	CU
Patrol Name	Patrol #	HWYS	No Precip	L-M-H	L-M-H	L-M-H	L-M-H	L-M-H	°C	Direction	Speed	G-F-P	Clear	Partly Cloudy	Overcast	L-M-H	Y / N	RB Bare/Dry	WET Bare/Wet	PSC Partly	RSC Covered	PSP Partly	RSP Packed	PIC Partly	RI Covered	Patrolling	Plowing	Sanding	Salting	Anti-icing	Clean Up
Mitchell East	21	23	✓						-1	NW	L	G			✓		Y	✓	✓	✓	✓					✓	✓		✓		
		7															Y	✓	✓	✓						✓	✓		✓		
		8															N	✓								✓					
Mitchell West	22	21	✓						0	NW	L	G		✓			N	✓								✓					✓
		4																													
		8																													
Shelburne	23	6	✓						-1	N	L	G			✓		Y		✓	✓						✓	✓		✓		
(Orangeville to Shelburne)	23A	10&10/89																								✓					
(Shelburne to Dundalk)	23B	10															N	✓								✓					
	23	89																	✓	✓						✓	✓		✓		
Chatsworth	24	10	✓						-2	NW	L-M	G			✓		Y			✓						✓	✓		✓		
		26															N	✓		~~D~~						✓					
		6 & 6/10																		✓						✓	✓		✓		
Kincardine	25	21	✓						0	NW	L	G			✓		N	✓	✓							✓					✓
		9																								✓					
Clavering	26	21	✓						-1	NW	L-M	G		✓				✓	✓							✓					
		6																													

Page 3 of 3

A4: Winter Operations Records



Owen Sound Highway Maintenance Limited

Winter Operations Record
Contract 2010-08

Truck #: 24-4   Yard Location: Chatsworth   Page 1 of 1

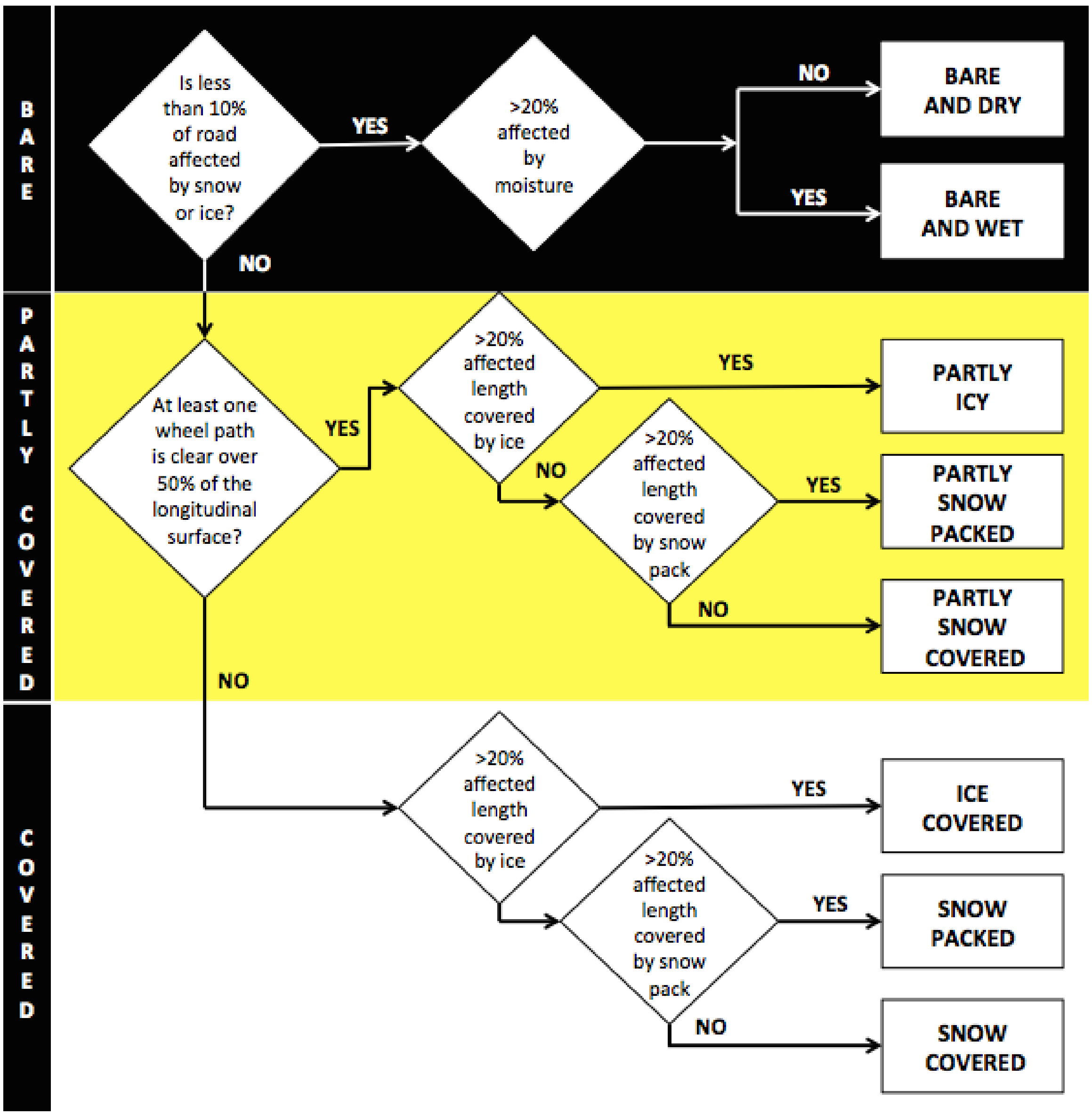
Date: Mar 20/2014
Call Time: 110
Arrival Time: 120
Operator: (Please Print) Andy Fritsch
Operator: (Signature) Andy Fritsch
Contractor: OSHM LTD.

HWY	Start Time	From (if other than specified routes that are listed)	To	Finish Time	Hours Worked	Km. Serviced	Chatsworth - Markdale	Chatsworth -Owen Sound	Chatsworth-Williamsford	Anti-icing 7703	Spreading Only 7700	Plowing Only 7700	Combination 7700	Plowing Shoulders 7700	Salt Dry (tonnes)	Salt Pretreated (tonnes)	Sand (3%) (tonnes)	Application Rate	Liquid (litres)	Application Rate (%)
#6	140			300	1.5	49		✓	✓		✓				4.4			130		
#6	325			440	1.25	48		✓	✓				Spot ✓		3.6			130		
#6	505			630	1.5	48		✓	✓				Spot ✓		4.0			130		
#6	645			805	1.5	50		✓	✓				✓		4.1			130		
#6	825			940	1.25	48		✓	✓				Spot ✓				14.52	570		
#6	950			1040	1	48		✓	✓			✓						0		
#6	1045			1155	1.25	48		✓	✓				Spot ✓		3.8			130		
#6																				
#6																				
#6																				
#6																				
Totals:					9.25	339									20.0		14.5			

Comments:

Operator's Signature: Andy Fritsch
Dismissal Time: Driver Change
Approved by: (Signature)

Appendix B: TAC RSC Classification Scheme



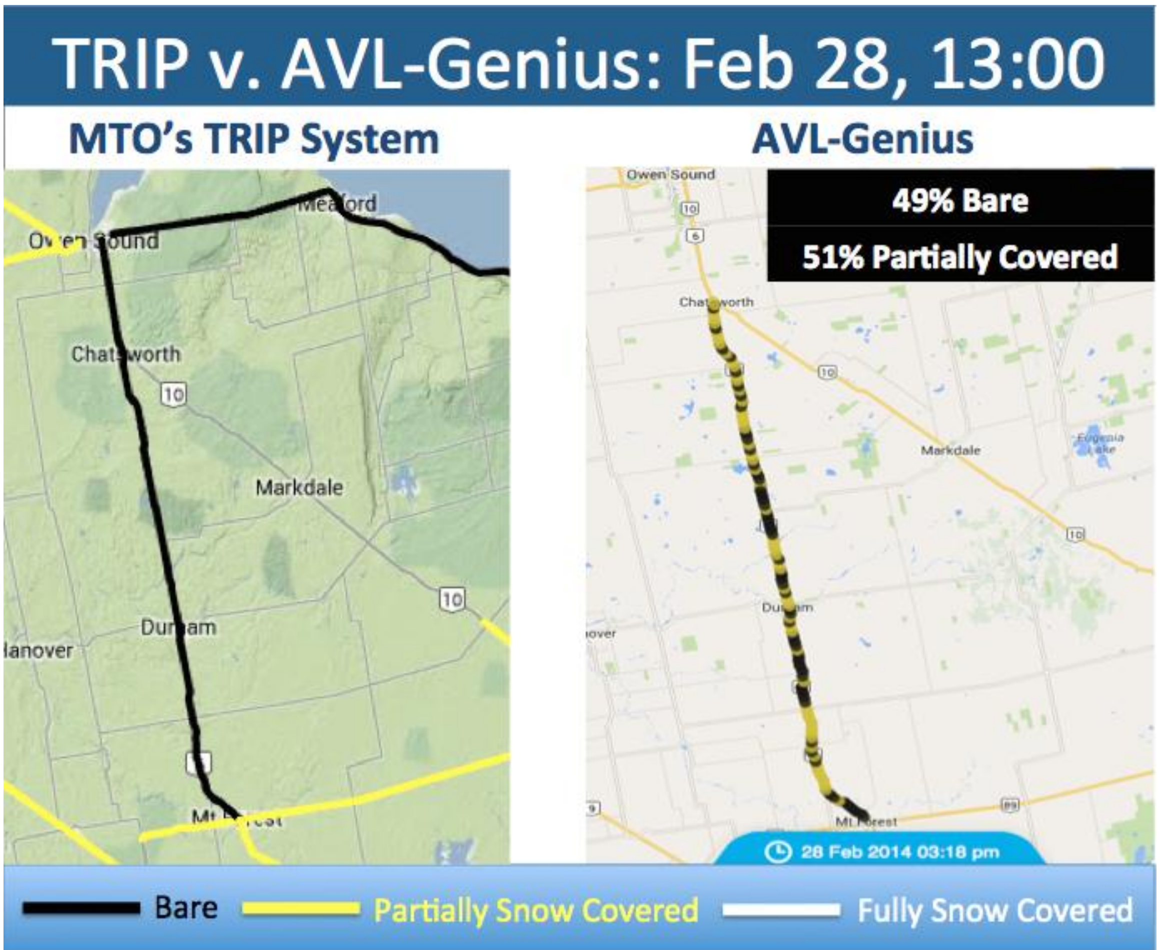
Appendix C: Image Classification Accuracy

Date	Device Name	Matching	Non-Matching	Automatic Classification Accuracy
2014-02-24	IMOS Device 1	20	17	54%
2014-02-24	IMOS Device 4	356	166	68%
2014-02-24	MTO Device 1	227	42	84%
2014-02-24	MTO Device 2	199	78	72%
2014-02-25	IMOS Device 1	15	19	44%
2014-02-25	IMOS Device 4	532	140	79%
2014-02-25	MTO Device 1	249	8	97%
2014-02-25	MTO Device 2	150	109	58%
2014-02-26	IMOS Device 4	504	346	59%
2014-02-26	MTO Device 1	200	53	79%
2014-02-26	MTO Device 2	93	196	32%
2014-02-27	IMOS Device 4	473	191	71%
2014-02-27	MTO Device 1	213	70	75%
2014-02-28	IMOS Device 1	52	56	48%
2014-02-28	IMOS Device 4	400	326	55%
2014-02-28	MTO Device 1	25	9	74%
2014-02-28	MTO Device 2	55	80	41%
2014-03-01	IMOS Device 4	479	180	73%
2014-03-04	IMOS Device 1	47	12	80%
2014-03-04	IMOS Device 4	569	310	65%
2014-03-04	MTO Device 2	231	37	86%

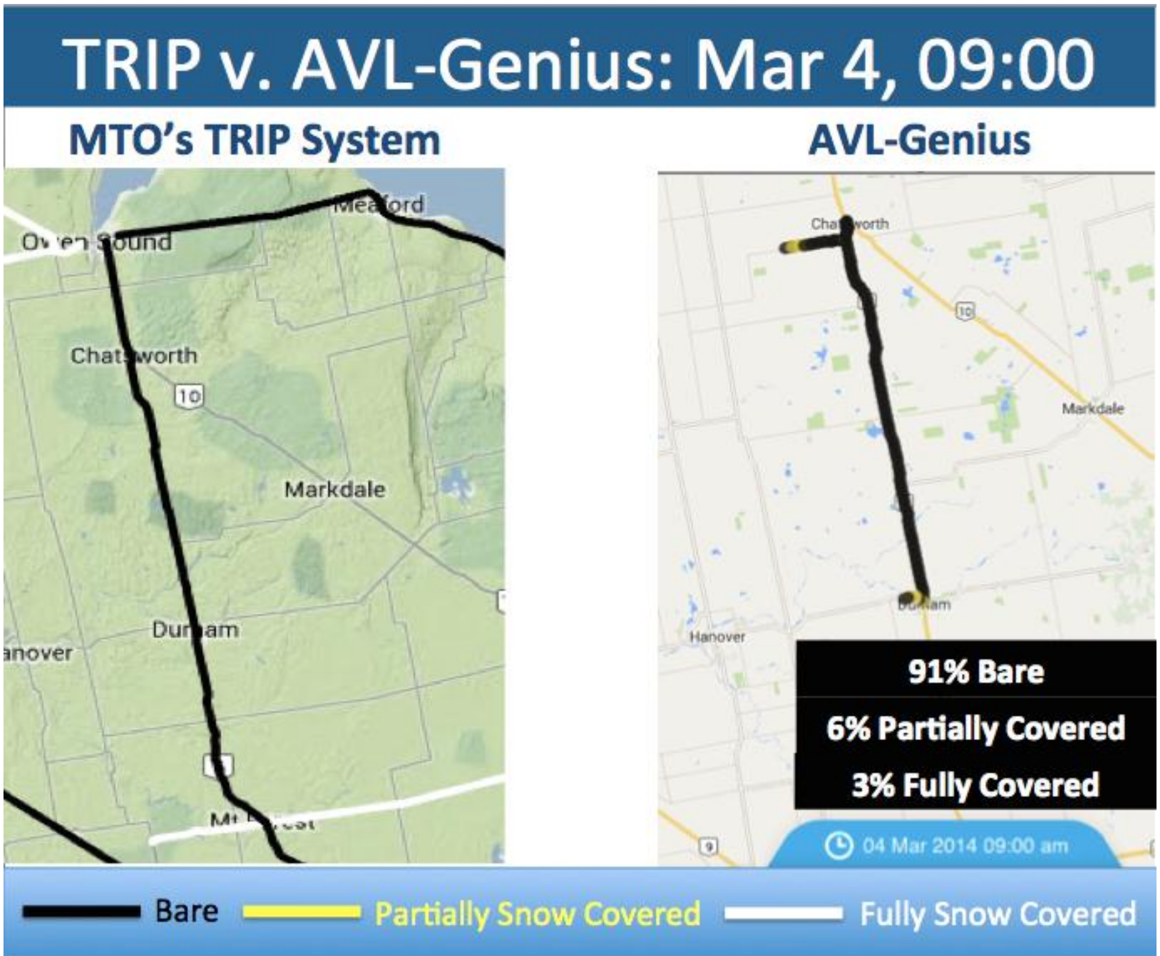
Date	Device Name	Matching	Non-Matching	Automatic Classification Accuracy
2014-03-05	IMOS Device 4	363	181	67%
2014-03-05	MTO Device 1	250	13	95%
2014-03-10	IMOS Device 4	286	32	90%
2014-03-10	MTO Device 1	213	37	85%
2014-03-12	IMOS Device 1	0	7	0%
2014-03-12	IMOS Device 4	147	103	59%
2014-03-13	IMOS Device 1	66	117	36%
2014-03-13	IMOS Device 4	36	20	64%
2014-03-13	MTO Device 1	165	99	63%
2014-03-14	IMOS Device 4	278	128	68%
2014-03-14	MTO Device 1	179	81	69%
2014-03-15	IMOS Device 4	364	319	53%
2014-03-16	IMOS Device 4	42	45	48%
2014-03-19	MTO Device 1	183	84	69%
2014-03-20	IMOS Device 4	286	85	77%
2014-03-20	MTO Device 1	175	118	60%
2014-03-21	IMOS Device 4	345	56	86%
2014-03-21	MTO Device 1	202	59	77%
2014-03-22	IMOS Device 4	622	99	86%
2014-03-23	IMOS Device 4	477	69	87%
2014-03-25	IMOS Device 4	243	34	88%
2014-03-25	MTO Device 1	225	44	84%
2014-03-26	IMOS Device 4	371	44	89%
2014-03-27	IMOS Device 4	705	21	97%

Date	Device Name	Matching	Non-Matching	Automatic Classification Accuracy
2014-03-27	MTO Device 1	231	26	90%
2014-03-27	MTO Device 2	42	0	100%
2014-04-02	IMOS Device 4	383	105	78%
2014-04-02	MTO Device 1	149	105	59%
	TOTAL	12117	4576	73%

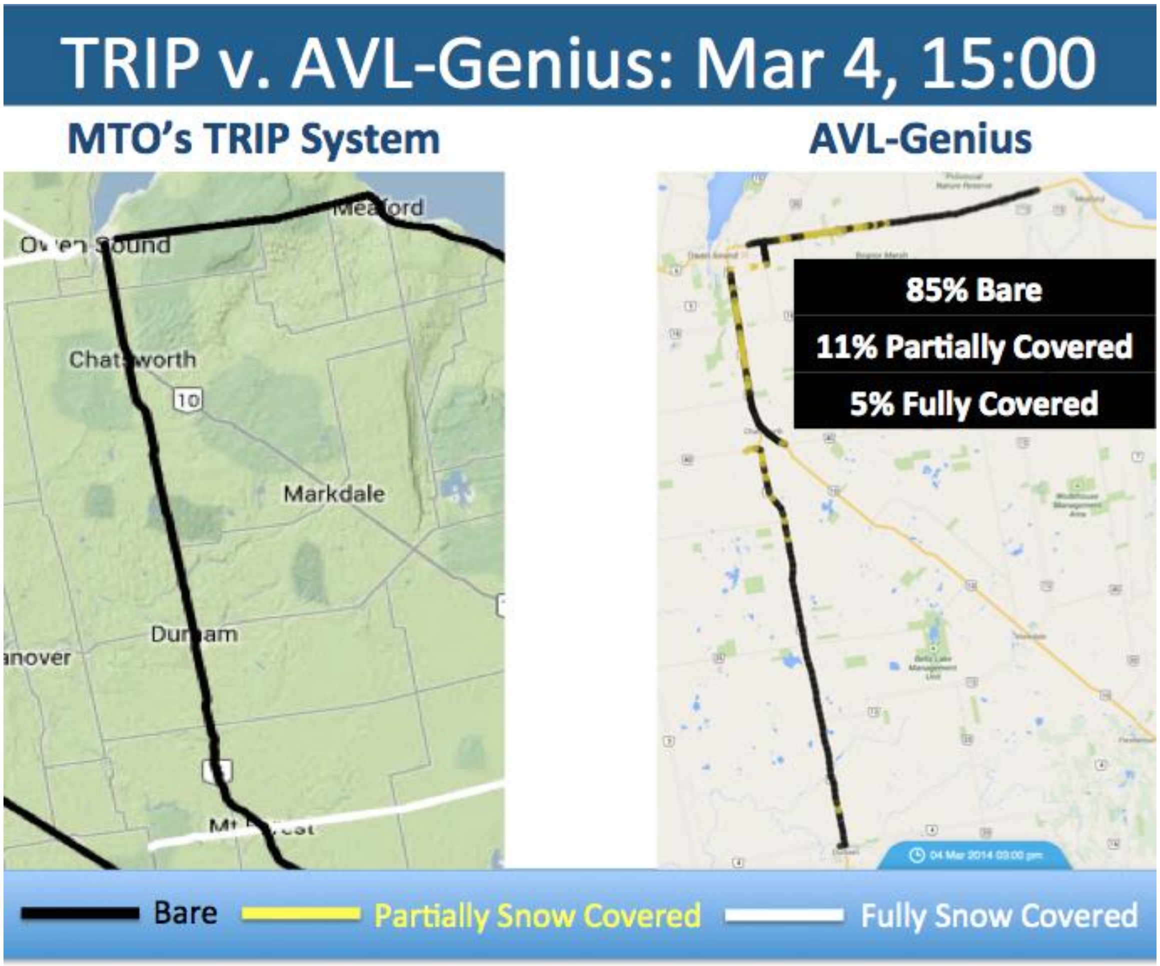
Appendix D: Comparison between MTO's TRIP System and AVL-Genius



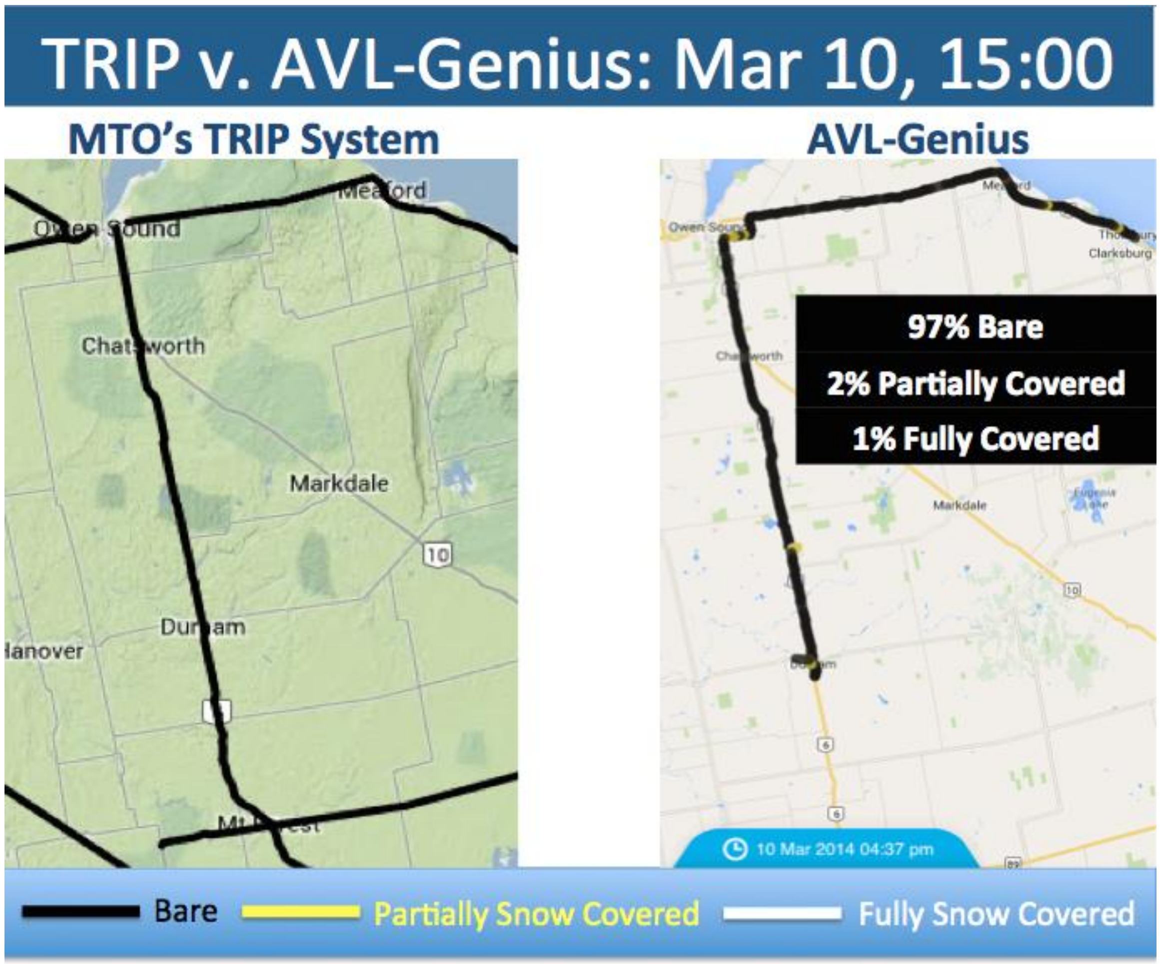
Road and Weather Information Sheet RSC: Partly Snow Covered, Partly Snow Packed, Bare and Wet, Bare and Dry



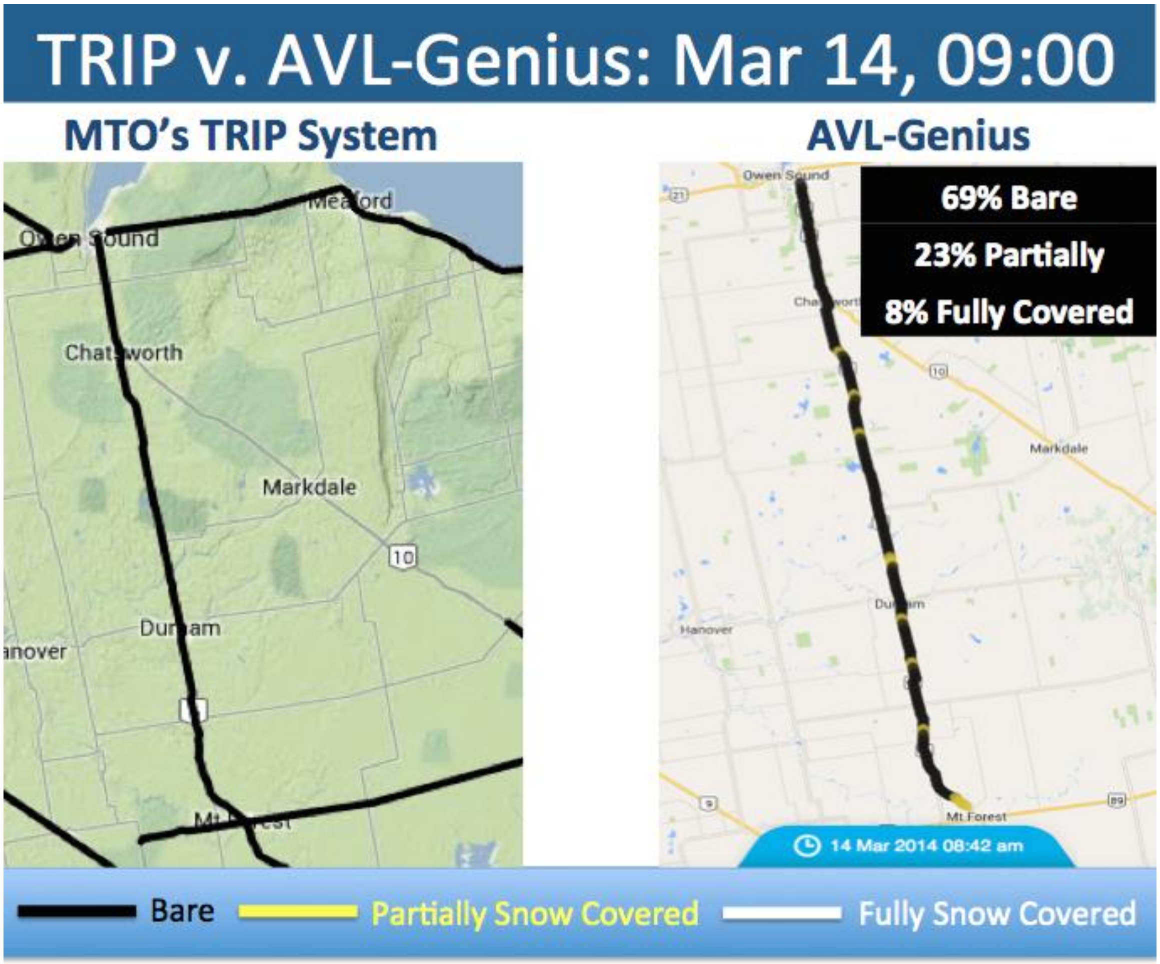
Road and Weather Information Sheet RSC: Partly Snow Covered, Bare and Wet, Bare and Dry



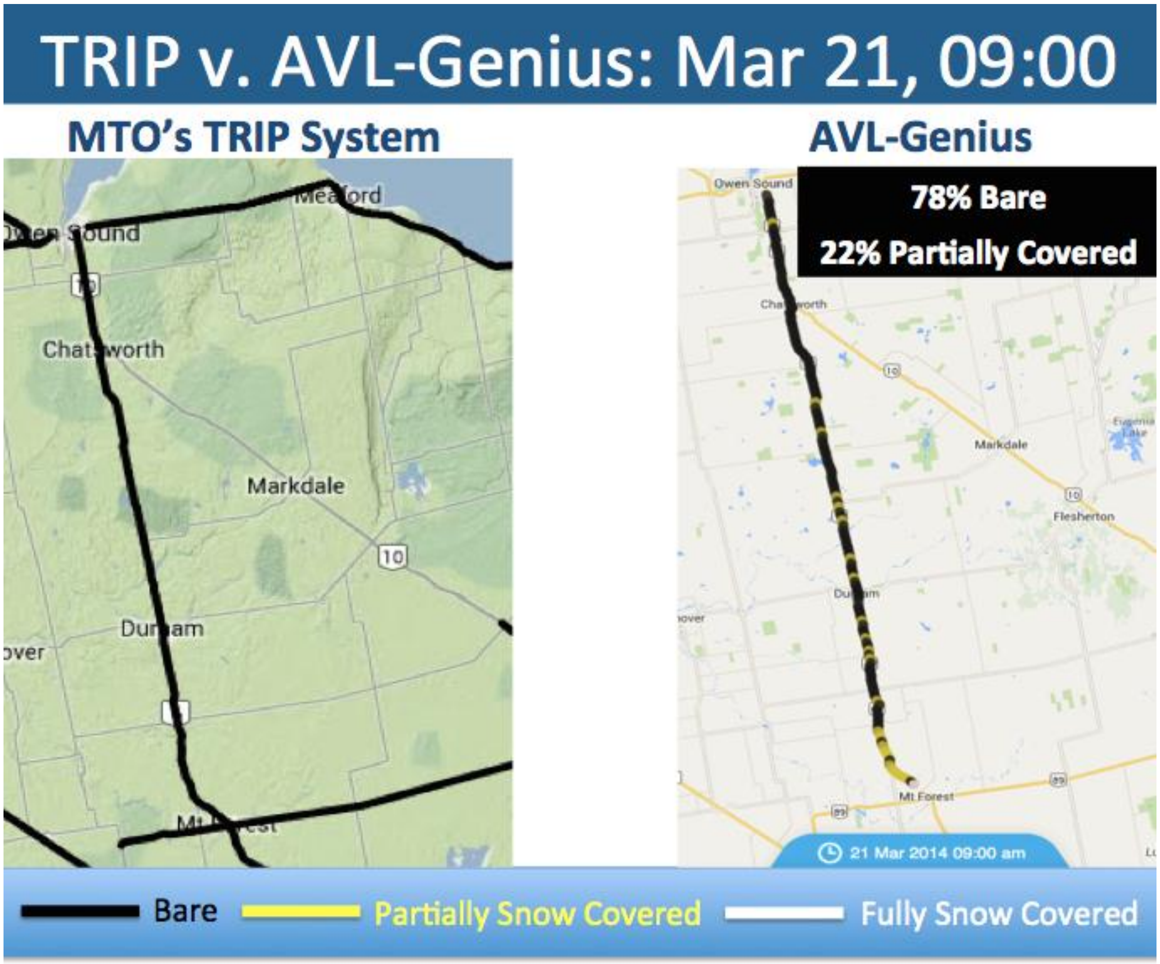
Road and Weather Information Sheet RSC: Partly Snow Covered, Bare and Wet, Bare and Dry



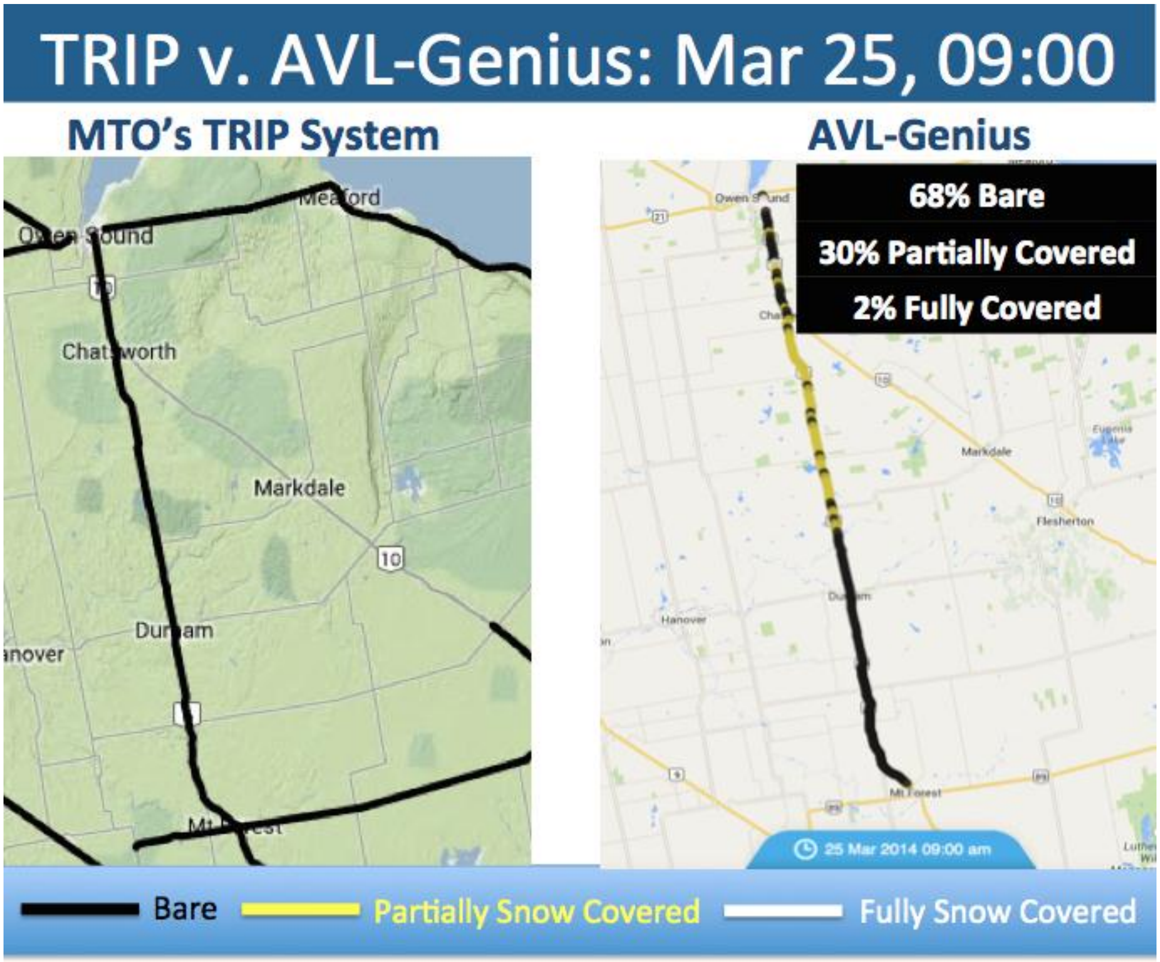
Road and Weather Information Sheet RSC: Bare and Wet, Bare and Dry



Road and Weather Information Sheet RSC: Partly Snow Covered, Bare and Wet, Bare and Dry



Road and Weather Information Sheet RSC: Snow Packed, Partly Snow Covered, Partly Snow Packed, Bare and Wet, Bare and Dry



Road and Weather Information Sheet RSC: Partly Snow Covered, Partly Snow Packed, Bare and Wet, Bare and Dry

Appendix E: Classifications by Sample Size

Table 10 - Patrol Reports and Corresponding automatic RSC classification for alternative sample sizes Feb 24; IMOS Device 1

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
08-35 - 09:11	Snow Covered Center Bare Track Bare Drifted Sections Bare and Wet	41	57	3	37	58	5	38	54	8

Table 11 - Patrol Reports and Corresponding automatic RSC classification for alternative sample sizes Feb 28; IMOS Device 4

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
08:20 - 09:00	Track Bare	38	62	0	25	75	0	14	86	0
09:05 - 09:20	Track Bare	21	79	0	12	88	0	4	96	0
11:25 - 12:00	Track Bare	33	61	9	23	71	9	14	79	7
14:05 - 14:25	Bare and Dry Bare and Wet	86	14	0	75	25	0	65	35	0
14:55 - 15:27	Track Bare	53	47	0	39	61	0	26	74	0

Table 12 – Patrol Reports and Corresponding automatic RSC classification for alternative sample sizes Mar 01; IMOS Device 4

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
08:30 - 08:55	Track Bare Snow Covered	15	67	18	21	66	14	11	63	26
12:10 - 12:25	Track Bare Snow Covered Drifted Sections Slushy	81	16	3	80	20	0	90	10	0
15:25 - 15:40	Snow Covered Drifted Sections Bare and Dry Bare and Wet	97	3	0	94	6	0	100	0	0

Table 13 – Patrol Reports and Corresponding automatic RSC classification for alternative sample sizes Mar 10; MTO Device 1

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
08:00 - 08:25	Bare and Dry Bare and Wet	81	19	0	81	19	0	94	6	0
08:25 - 08:50	Bare and Dry Bare and Wet	96	2	2	96	0	4	100	0	0
10:45 - 11:00	Snow Covered Centre Bare Track Bare Bare and Wet	6	91	3	12	88	0	9	82	9
13:45 - 14:10	Bare and Wet Track Bare Snow Covered	85	4	11	88	0	13	87	6	7

Table 13 – Cont'd

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
14:45 - 15:00	Bare and Wet Track Bare Snow Covered	69	31	0	64	36	0	80	20	0
15:50 - 16:05	Bare and Wet Track Bare Snow Covered	50	50	0	53	47	0	70	30	0

Table 14 - Patrol Reports and Corresponding automatic RSC classification for alternative sample sizes Mar 12; IMOS Device 4

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
11:49 - 12:00	Track Bare Partly Snow Covered Snow Covered	4	85	11	0	86	14	0	90	10
14:10 - 14:20	Track Bare Partly Snow Covered Snow Covered Bare and Wet Partly Ice Covered	25	71	4	36	64		30	60	10
14:35 - 15:00	Track Bare Snow Covered Snow Packed Drifted Sections Slushy	6	44	50	9	39	52	9	36	55

Table 14 – Cont'd

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
15:00 - 15:30	Snow Covered Snow Packed Partly Snow Covered Partly Snow Packed	0	66	34	0	64	36	0	63	37
15:37 - 15:48	Partly Snow Covered Partly Ice Covered Snow Covered Snow Packed Bare and Wet	7	72	21	0	86	14	0	80	20

Table 15 - Patrol Reports and Corresponding automatic RSC classification for alternative sample sizes Mar 15; IMOS Device 4

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
08:19 -09:02	Center Bare Track Bare Drifted Sections Slushy Bare and Wet	54	21	24	58	16	26	58	21	21
12:15 - 12:50	Track Bare Drifted Sections Slushy Bare and Wet	27	55	18	19	64	17	38	58	4
12:50 - 13:07	Track Bare Drifted Sections Slushy Bare and Wet	26	55	19	25	50	25	10	50	40

Table 15 – Cont'd

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
15:28 - 15:41	Drifted Sections Slushy Bare and Wet Bare and Dry	46	42	12	50	50	0	33	44	22

Table 16 - Patrol Reports and Corresponding automatic RSC classification for alternative sample sizes Mar 120; IMOS Device 4

Time	Classification	1 in 450m			1 in 900m			1 in 1350m		
	Patrol Reports	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)	Bare (%)	PS (%)	FS (%)
11:04 - 12:30	Snow Covered Center Bare Track Bare Bare and Wet	66	34	0	66	34	0	66	34	0
12:30 - 13:30	Snow Covered Center Bare Track Bare Bare and Wet	83	17	0	85	15	0	82	18	0
17:40 - 18:05	Snow Covered Snow Packed Slushy Drifted Sections Track Bare Bare and Wet	90	10	0	79	21	0	91	19	0