Smart Pavement Rehabilitation Decisions using Concise Pavement Condition Data

The Ontario Ministry of Transportation (MTO) invests over $2 Billion annually in its capital construction program. This includes a significant portion invested in highway pavement structures. Smart investment decisions rely on the availability of relevant data and the knowledgeable interpretation of information. At MTO, pavement condition evaluations have been the fundamental element in providing information for developing the most cost-effective pavement rehabilitation strategies and the basis for the MTO pavement management system.

In the past, pavement data collection was carried out using manual pavement surveys. These were inspections that were conducted manually on each highway by ministry staff documenting pavement conditions. Moving to automated pavement data collection has been a gradual process and MTO adopted new pavement distress detection technologies as they were being developed. The integration of these technologies is an example of MTO’s efforts to collect reliable data using innovative state-of-the-art tools.

Automatic Road Analyzer (ARAN) Overview

The use of automated pavement condition data has supplemented manual collection of pavement data since the ministry acquired its first Automatic Road ANalyzer (ARAN) in the mid-1980s. Early ARAN systems were limited by the availability of computing power and storage and the ARAN operated solely as a high speed inertial profiler. Over the last few years, detection technologies related to pavement distress data collection and data interpretation have become increasingly more sophisticated. The quantity and quality of data generated by each successive MTO ARAN has led to a progressive shift and reliance on automated systems. Advances in automated detection of pavement distresses and the capability to process, categorize and report automated pavement condition data is enabling the ministry to shift from manual to semi-automated assessment of pavement performance.

At MTO, pavement condition data collected by the ARAN is used primarily for assessment of the overall health of Ontario’s highway network and for asset management purposes. On an annual basis, the ARAN 9000 unit, owned and operated by MTO, collects over 18,000 km of network level data in support of the ministry’s pavement and asset management program. The ARAN also collects over 9,000 km of continuous video logging imagery.

The MTO ARAN 9000 is equipped with state-of-the-art components that provide the capability for calibrated and repeatable measurement of several pavement distress parameters such as roughness, rutting, and crack measurement. Assessment tools are being developed and refined on a continual basis. The ARAN’s adaptive
platform allows MTO to introduce additional pavement condition assessment parameters over time. Pavement distress data collected by the MTO ARAN is recorded and processed using Fugro Roadware Pave3D system software. The system is comprised of subsystems configured to measure, record and provide continuous output for multiple streams of data. Subsystems include a high speed inertial profiler that measures pavement roughness and Pavemetrics Laser Crack Measurement System (LCMS) to capture rutting, crack and macrotexture data. Two high definition cameras provide video logging images, all supported by GPS/DMI/POS LV inertial referencing systems. Visible features mounted on the ARAN 9000 vehicle are highlighted in Figure 1.

Distance Measuring Instrument (DMI)
Mounted on the rear wheel of the ARAN vehicle, the Distance Measuring Instrument (DMI) allows the ARAN to collect data while travelling at varying speeds without loss of data integrity. DMI is a pulse-based system that uses an optical shaft encoder to generate 10,000 pulses per wheel revolution. In addition to providing linear distance measurement, the data is relied on by all of the other ARAN sub-systems.

Inertial Reference System (Smart Geometrics or POS LV™)
An inertial referencing system measures roll, pitch, velocity and vehicle positioning. The ARAN is equipped with a Position and Orientation System for Land Vehicles (POS LV™), and an Aided Inertial Navigation System (AINS) comprised of gyroscopes, accelerometers and software. Together with GPS and DMI, the POS LV provides critical data that is used to determine longitudinal and transverse profiles, pavement crossfall (transverse sloping of a roadway toward the shoulder), vertical profile or grade and horizontal alignment of the roadway.

MTO ARAN Digital Systems for Global Referencing and Positioning
Global Positioning System (GPS)
The ARAN 9000 operates at speeds between 12.5 and 100 km/h. In order for collected data to be referenced reliably it is important that systems are in place to ensure accuracy in location and spatial orientation.

The ARAN is equipped with a Global Positioning System that provides location coordinates of roadway features to an accuracy of 5 m when operating. Gaps in data will occasionally occur when satellite contact is lost or lacking; for example, when travelling under bridges or in remote locations. These gaps are addressed by additional instrumentation that improves accuracy of post-processed data to within 1 m.
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High Definition Video Logging
The ARAN is fitted with two high definition overhead cameras that provide continuous video logging. One camera records the front view and the second camera is set at 90° and collects right-facing images. The total field of view is 145° and, along with the Global Positioning System, provides viewers with images of other roadway features and their location to an accuracy of 1 m.

MTO ARAN Digital Systems for Pavement Distress Data Collection and Identification
RoLine Laser Profilometer
Longitudinal profile of the roadway is measured using a RoLine Laser inertial profiler. Lasers and accelerometers are mounted over each wheel path capturing profile data that is used to calculate International Roughness Index (IRI). The laser footprint spans 100 mm as shown in Figure 3 and data is collected every 25 mm. Roughness measurement is carried out in accordance with ASTM Standard E1926. The RoLine profilometer meets the requirements of a Class 1 profiling device under ASTM E950-09.
Laser Crack Measurement System (LCMS)

Two units that house high-speed cameras, custom optics and laser line projectors are mounted at the back of the ARAN vehicle (Figure 4a). The sensors capture two and three dimensional digital images that, in combination, provide high-resolution 3D profiles of the road. Together the sensors cover a full pavement width (4 m) collecting transverse profile data at 1mm intervals across the pavement width every 5mm along the pavement in the longitudinal direction.

Figure 4a: Laser Crack Measurement System (LCMS) mounted at the top rear of van

Figure 4b: Laser Crack Measurement System (LCMS), close up

Figure 5a: LCMS Crack Detection

Figure 5b: LCMS Crack Rating
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When LCMS data is processed the images of a lane of pavement appear as shown in Figure 5a. The software provides 3D definition of cracks that appear at the pavement surface and, when rating parameters are applied, cracks are highlighted based on their severity, red being the most severe. (Figure 5b).

iVision – Provincial Imagery and Pavement Condition Viewer

A significant volume of data, in the order of 25 terabytes annually, is generated by the Pave3D system, the data processing software. Multiple streams of data are uploaded, processed and analysed using iVision software, a proprietary desktop application. The ministry’s Pavements Group perform quality checks on the uploaded data and run the data through pavement distress detection and characterization algorithms. Once post-processing is complete, the data is made available to MTO staff on a user-friendly, web-based viewing platform known as iVision Provincial Imagery and Pavement Condition Viewer.

iVision allows synchronized viewing of right-of-way imagery, pavement imagery and pavement condition data. Figure 6 shows one of the viewing options that can be created by the user. The example identifies the site by its location, provides front and right view images from the ARAN’s two high definition cameras, as well as a laser imaging of the pavement surface. Video logging images provide continuous viewing along a pavement section.

iVision best highlights the features and capability of the MTO ARAN 9000. The data collected and displayed is relevant and accessible to MTO staff.

As an assessment tool, the ARAN 9000 provides valuable information not only about the condition of MTO’s pavement but other roadside assets as well. The data collected improves the ability of MTO to monitor performance and to make informed and timely decisions about proposed pavement rehabilitation strategies.

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Figure 6: iVision Viewer Image
Innovative Fish Passage

First of Its Kind for the Ministry of Transportation

The Ontario Ministry of Transportation (MTO) has installed a replacement culvert on Highway 21, northeast of Southampton, at Craig Street, within Saugeen First Nation #29. The culvert replacement included an innovative fish ladder which promotes improved fish passage through the culvert. This new liner, featuring Duguay-Hannaford fish baffles, is the first of its kind for the ministry.

The outdated Craig Street culvert was assessed in poor condition, requiring replacement. It was also perched above the stream bed and on a steep incline at an approximately seven per cent grade. Perched culverts are often the result of erosion and can lead to the fragmentation of aquatic connectivity for streams and rivers, resulting in restricted movement of fish further upstream.

Fish ladders have long been a popular solution used to address the challenges of perched culverts. They enable fish to leap up a series of low steps within a culvert or a dam as they migrate through their environment. Some fish baffle designs host sharp baffle edges and excessive turbulence which can injure or even kill fish, especially those that are exhausted from swimming against the combined forces of gravity and flowing water. The velocity of water flowing through the ladder has to be great enough to attract the fish to the culvert, but not so strong that it washes fish back downstream.

The Corrugated Steel Pipe Institute (CSPI), in collaboration with the Universite de Sherbrooke, has developed a fish passage liner to meet fish migration challenges. After four years of development, the ministry’s Craig Street culvert replacement project presented a piloting opportunity for the new design.

“The inefficiencies of current fish ladder designs and the dangers they pose to fish were the principal reasons why we wanted to design a better, affordable, portable or permanent solution for safe fish passage at vertical barriers such as perched culverts,” says Jason Duguay, Civil Engineering PhD candidate at the Universite de Sherbrooke.

Fish ladder being attached to smooth steel casing pipe. (Photo courtesy of CSPI)

Inlet at the original Craig Street culvert.
Innovative Fish Passage:
First of Its Kind for the Ministry of Transportation, continued

Termed the Duguay-Hannaford baffle, the fish ladder consists of a lower (primary) and a higher (secondary) passageway to accommodate passage for as many kinds of fish as possible over a wide range of seasonal water flow rates. The primary and secondary passageways alternate on each side of the successive baffles. The passageways are separated by an arch which protrudes from the water surface under all but the highest flow rates.

Water moves through the primary passageway just above the secondary passageway of the next downstream baffle. This design promotes velocity decrease through the pools between the baffles resulting in improved passage for fish. The primary passage is also wider, allowing more water to flow through, giving fish a larger passage to jump through. The secondary passage serves as an alternative slot during high flow rates, not only for fish, but also for debris.

The key technical refinement of this fish baffle design, by Environmental Scientist, Ken Hannaford, is the use of more natural alternating curved forms rather than angular ones. By sequentially alternating the baffles on either side of the pipe, water velocities are relegated, reducing overall turbulence in each pool of the fish ladder. The corrugated walls of the pipe also help to reduce flow velocities.

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During the development of the liner, water simulations were numerically evaluated for barrier velocities, turbulence and maximum vertical drop between pools to ensure that the new design could develop spatial distributions of water similar to those of other designs recommended by the Department of Fisheries and Oceans Canada. The elevated centre arch in the new baffle design creates pool depths, minimizing the volumetric dissipative power in the pools at higher flow rates. Numerical results showed that velocities at the passageways support critical swim speeds for a wide range of North American fish species, including: Brown Trout and Cutthroat,
Innovative Fish Passage:
First of Its Kind for the Ministry of Transportation, continued

Sockeye, Coho and Chinook Salmon species. The presence of adequate refuge zones (calmer areas of water between the baffles for fish to rest as they move up the culvert) was also assessed. The fish ladder simulations were tested at typical seasonal flow rates.

For the pilot project, CSPI incorporated the ministry’s design requirements into an innovative solution for the Highway 21/Craig Street site conditions. A new steel pipe culvert was installed adjacent to the original culvert at approximately a seven per cent grade, using a trenchless method (jack and bore), beneath the highway. The fish passage liner was installed inside the new steel pipe culvert, enabling fish to access the watercourse upstream. In addition, favourable fish habitat features were incorporated into the stream at the upstream and downstream ends of the new culvert, including fish pools and riffles.

Noticeable habitat improvements have been observed since the installation of the new culvert. Fish surveys were completed on May 6, 2016, and results indicate that fish are migrating upstream of the culvert. Two Rainbow Trout and five Creek Chub were found upstream during the survey. Prior to the culvert replacement, no fish could migrate upstream due to the barrier imposed by the original culvert. Additional monitoring will take place in the summer, and again in spring and summer 2017.

Plantings and site restoration to complete the project began in spring 2016 and are taking place in two phases. MTO is currently pursuing a post-construction landscaping opportunity where members of the Saugeen First Nation community will help to restore the site after construction by planting native trees, shrubs and grasses to enhance the area surrounding the Craig Street culvert.

MTO is meeting its obligations under the Environmental Assessment Act by balancing environmental protection with transportation engineering considerations. This project is an example of how environmental protection principles which enhance the natural environment can be successfully implemented within highway improvement projects.

The replacement of the Craig Street culvert was a unique project due to its steep perched grade. The ministry will consider using the innovative Duguay-Hannaford fish baffle in future similar scenarios, based on the success of this project and the positive effect on habitat.

The Highway 21 culvert replacement, completed in December 2015, was presented in detail at the 2016 Canadian Society of Civil Engineers (CSCE) Conference in London, Ontario, June 1-4.

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