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# The Roles of Applied Performance Indicators in Network Pavement Management – Canadian Experience

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**Abstract:** This paper discusses pavement evaluation indicators and deterioration trends observed from Canadian highways. The primary objectives are twofold: 1) technical and economic analyses of the performance indicators applied in pavement rehabilitation programming at network level, 2) assessment of the performance models used in the current pavement management systems. The technical method of carrying out this study is to use the long-term performance data to verify individual pavement deterioration trends. The main findings resulting from the study include the impacts of changing prediction models on pavement preservation programming, the needs for standardizing performance criteria and, relationships between performance criteria and rehabilitation program.

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***Key words***: *Evaluation method; Pavement management; Performance index; Prediction models; Road maintenance.*

## Introduction

The Ministry of Transportation of Ontario currently has about 18,000 kilometres of provincial highways consisting of about 4,000 km of freeways, 4,500 km of collectors, and 10,000 km of other roads. Most of the highways are paved with asphalt concrete or are treated with asphalt surface layer. To meet the requirements of pavement management in terms of database structure and information management, these roads are broken down into 1800 sections based on regional jurisdiction, pavement structure/materials, traffic and environmental factors, etc. At present, the Ministry invests about $300 million annually to ensure that the highway network is maintained above the levels of serviceability required for each classified highway, as shown in Table 1. The serviceability is assessed and ranked by means of Riding Comfort Index (RCI) or International Roughness Index (IRI), Distress Manifestation Index (DMI) and their combination Pavement Condition Index (PCI). Both RCI and DMI range from 0 to 10, while PCI ranges from 0 to 100; new pavements are often rated at 95, and old pavements requiring resurfacing at 45 to 55 [1, 2].

The IRI is obtained from measured longitudinal road profiles that reflect pavement riding quality or roughness, which is calculated to yield an index with units of slope (mm/m or m/km) [3]. While the IRI has an open-ended scale in Ontario, it typically ranges from 0 (mm/m) to 4 (mm/m), where 0 implies an absolute perfect road. Roughness is an important pavement performance indicator because it not only affects ride quality but also affects vehicle delay costs, fuel consumption and maintenance costs [4].

The DMI addresses pavement surface distresses such as cracks, distortion, and defects. DMI is scaled from 0 to 10, with 0 representing the worst condition and 10 representing perfect condition of a pavement section. In the MTO PMS, a number of individual distresses are identified and then combined with consideration of their weighting factors in the evaluation of pavement surface condition. The DMI is used to aggregate the effects of individual distresses present on a given pavement section, and it is defined in Eq. (1):

$$DMI = 10 \times \frac{DMI_{Max} - \sum_{i=1}^{n} W_i ( s_i + d_i )}{DMI_{Max}} \tag{1}$$

where,

$i$ = distress type.

$W_i$ = weighting factor, ranging from 0.5 to 3.0, is a weighted attribution to overall pavement surface condition of a road section. These weighting factors were reviewed and modified regularly by a MTO work group consisting of all regional representatives [5].

$s_i$ = severity of distress expressed on a 5-point scale, ranging from 0.5 to 4.0.

$d_i$ = density of distress occurrence expressed on a 5-point scale, ranging 0.5 to 4.0.

$DMI_{max}$ = the maximum value of an aggregated pavement distresses, defined by pavement type (208, 196, 216 and 180 are for AC, PCC, COM and ST, respectively).

The PCI is an overall evaluation of pavement serviceability and it is calculated from IRI and DMI through their functional relationship described in Eq. (2) below:

$$PCI = a + b \times DMI - c \times IRI \tag{2}$$

where, $a$, $b$, and $c$ are the coefficients that are developed through regression analysis for each of the individual pavement types.

In Eq. (2), PCI values change from 0 and 100, and DMI are all scaled from 0 to 10, with 10 representing a flawless pavement condition. It should be noted that the regression analysis conducted for developing PCI calculation formulas was based on subjective

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**Table 1.** An Overview of the Ontario Ministry of Transportation's Road Network**.**

| Road Class Versus IRI Measured | | | Pavement Type Versus IRI Measured | | |
|---|---|---|---|---|---|
| Road Class | Length (km) | IRI | Pavement Type | Length (km) | IRI |
| Freeway | 3697 (20%) | 1.4 | Asphalt Concrete | 14,499 (78%) | 1.67 |
| Arterial | 6084 (32.5%) | 1.61 | Composite Pavement | 442 (2%) | 1.71 |
| Collector | 4460 (24%) | 1.94 | Portland Cement | 138 (0.7%) | 2.11 |
| Local | 3980 (21%) | 3.09 | Surface-Treated | 3143 (16.8%) | 3.31 |
| Gravel | 458 (2.5%) | N/A | Gravel Surface | 458 (2.5%) | N/A |

Note: The total length of roads in 2011 was 18,800 km

Pavement Condition Rating (PCR) data collected in the past 15years.

## Scope and Objectives

The objectives of this ongoing study are to: i) review the pavement performance indicators and their impacts on pavement rehabilitation program and investment analysis, ii) identify the needs for introducing a new technical approach to determining road network preservation strategies with a number of standardized road maintenance and rehabilitation treatments. The study also illustrates the basic steps to analyze the impact of funding strategies on network performance by using an example application of Ontario Pavement Management System.

## Roles of Pavement Performance Indicators

The terms performance measurement and performance management are often used interchangeably in pavement management. However, performance management is a broader term that includes not only performance measurement but also involves the determination of the appropriate level of performance, the reporting of performance information, and the use of that information to assess the actual level of performance against the desired level.

It is essential to distinguish performance measurement from several related concepts. When applied in road management, these performance indicators are used to establish the trigger levels relating to road service standards technically and economically. Pavement performance measurement indicators (such as IRI, RCI, PCI, and DMI used in MTO PMS) perform an important role in not only assessment of current or future road conditions but they also impact economic analyses of long-term maintenance and rehabilitation treatments. Some performance indicators provide road agencies with information on pavement structural condition evaluation, while other performance indicators give a sense of pavement functionality on road safety and serviceability level. Yet, there exist some limitations of these performance indicators, such as localized experience and a subjective decision making process, as well as lack of consistency and international criteria.

The following pavement performance measurement indicators are commonly used by road agencies in their pavement management system:

### Trigger Levels of Categorizing Pavement Conditions

One of the preliminary applications built in the MTO PMS is to allow the user to set up pavement performance categories such as Good, Fair and Poor. The number of pavement performance categories and numeric trigger levels may be customized to comply with the current highway performance evaluation guidelines.

### Performance Indicators with Specific Measures

- International Roughness Index or Riding Comfort Index (IRI/RCI)
- Distress Manifestation Index or Surface Distress Index (DMI/SDI)
- Pavement Condition Index (PCI)
- Pavement Serviceability Index PSI)
- Pavement Quality Index (PQI)
- Structural Adequacy Index or Structural Strength Index (SAI/SSI)
- International Friction Index or Friction Number (IFI/FN)
- Road Safety Index (RSI) is a methodology for the evaluation of road safety. It assesses the actual status of road section and its relationship with road safety. This allows for identifying the specific aspects where road safety can be improved.

Presently, MTO uses PCI as the primary performance indicator, instead of DMI or RCI/IRI, in the whole pavement management process. This process includes acquisition of the data required, evaluation of present and future pavement conditions, trigger level settings associated with determination of maintenance and rehabilitation actions, and multi-year project programming and investment planning. It should be mentioned that the performance trigger levels and corresponding numeric values (i.e., PCI, RCI, IRI and DMI) are defined on the basis on road functional classification (Freeway, Arterial, Collector and Local Road).

Fig. 1 is a screen copy of pavement performance measurement indicators used in MTO PMS. It shows the current pavement condition categories and corresponding individual performance numeric ranges for Arterial highways. This is an effective tool for identifying the pavement condition status and making decisions for which pavement sections are in poor condition in addition to when appropriate rehabilitations should occur.

A quantitative assessment of individual pavement performance indicators provides technical guidance to pavement rehabilitation program and structural design at network level. Table 2 below describes how pavement performance trigger values of minimum acceptable levels are defined in MTO PMS. The trigger values were established and updated regularly through discussion with various technical committees involved in pavement management, agreed with investment planning division, and finally endorsed by senior

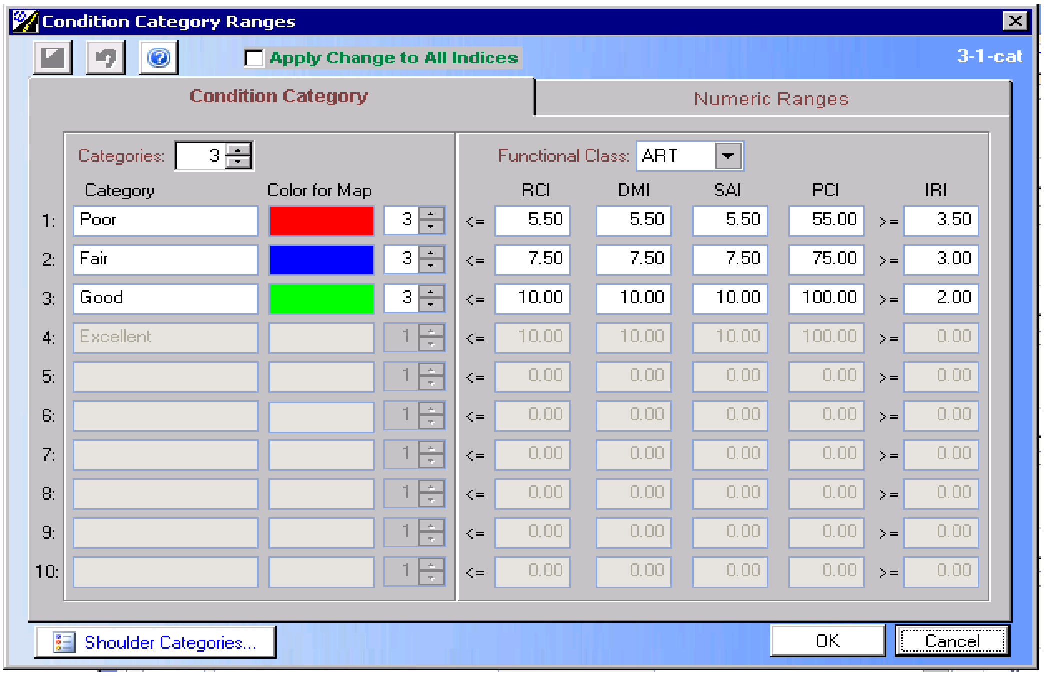


**Fig. 1.** Pavement Performance Categories and Trigger Value Settings.

**Table 2.** Performance Indicators and Their Trigger Values for Poor Condition.

| Road Class by Function | Performance Measurement Indicators in MTO PMS RCI | DMI | IRI | PCI |
|---|---|---|---|---|
| Local | 5 | 5 | 3.5 | 45 |
| Collector | 5.5 | 5.5 | 2.5 | 50 |
| Arterial | 6 | 6 | 2 | 55 |
| Freeway | 7 | 7 | 1.5 | 65 |

management. By specifying limits and acceptance values (e.g. minimum acceptable levels, threshold values, etc.) for individual performance indicators, minimum standards can be established for both planned and existing road pavements.

Optimal performance indicators and thresholds for different functional highways should be defined on the basis of regional economic development levels. Furthermore, these individual performance indicators should be related to road safety, riding comfort, structural performance, and environmental performance, required by road users from different perspectives [6].

## Trigger Levels for Preservation and Rehabilitation Treatments

Performance indicators are also involved in determining action needs for preservation and rehabilitation treatments that are programmed in decision trees of MTO PMS. Generally, any individual or combined performance indicators may be applied to the process of determining preventive and major rehabilitation treatments. These performance indicators include IRI trigger values for pavement overlay, DMI trigger values for crack routing and sealing treatment, PCI trigger levels for major rehabilitation or re-construction action, etc. Hence, pavement performance trigger values play a crucial role in analyzing when and what treatment actions need to be implemented in the future.

Pavement rehabilitation is defined as a structural or functional enhancement of a pavement, which produces a substantial extension in service life by substantially improving pavement condition and ride quality.

The trigger value refers to a pavement condition at which a pavement session is generally considered in need of either structural improvement or functional improvement. The MTO PMS also allows for other data collected and entered into the system, including unit costs for all preservation and rehabilitation treatments programmed by decision trees.

## Impacts of Using Alternative Performance Indicators

Currently, MTO PMS uses PCI as the primary performance indicator in the process of pavement management at both regional and provincial network levels. This includes performance evaluation programs, prediction of pavement conditions, performance prediction models, optimal preservation and rehabilitation treatments, and analysis of all regional multi-year investment plans given performance targets. All other performance trigger values (DMI, RCI and IRI) are used as secondary performance indicators or as reference only.

Since PCI is not a directly measurable performance indicator but is calculated on the basis of IRI and DMI values by use of their functional relationship, it has brought some concerns about data accuracy and consistency. Reviewing IRI and DMI data collection and evaluation procedures, DMI is currently obtained by subjective method that could bring significant variation and inconsistency issues. However, this can be resolved by using new technologies ensuring data collection and evaluation processes are made a completely objective process. Moreover, it is practical and straightforward to have a clear relationship between PCI and IRI and DMI.

What is the most reasonable and practical performance indicator in terms of effective collection of pavement condition data and performance evaluation methods? Some road agencies use IRI for pavement data collection, performance evaluation, and selecting rehabilitation programs at a network level. However, municipal road agencies tend to use DMI in developing pavement preservation programs at the project level.

Fig. 2 presents pavement performance distribution in three condition categories (Good, Fair and Poor) measured by PCI, RCI and DMI performance indicators. Based on the survey in 2010, the total lane-kilometres of Ontario's provincial highway network was 41, 000 km. Obviously, the variations assessed by the three different indicators are significant in the categories of Good and Fair conditions, specifically the DMI versus PCI and RCI. In addition, it is evident in the Poor category that there is a large amount of variation in terms of the percentage of Poor condition pavements screened by the three performance indicators. It is also apparent that DMI varies the most from the other two performance indicators.

Fig. 3 represents Ontario's Western regional road network performance distribution at its trigger level for all functional classes. The performance distribution is shown as a percentage of regional roads in Poor condition evaluated by three individual performance indicators. The information presented in this worksheet was pulled from the MTO PMS system. The figure shows that the percentage of pavement in Poor condition varies substantially regardless of functional road class. Specifically, the variation in Arterial functional class is significant between all performance indicators.

Overall, the largest variation is in the Arterial functional class with a 3.1% variation from PCI and RCI and a 1.7% difference from RCI to DMI. Performance indicators in the Collector functional class also differ dramatically as there is more than a 2.8% difference between PCI and RCI with DMI. Only the Freeway class gives some consistency when it comes to measuring pavements in Poor condition with the biggest variation being 0.9% between PCI and RCI.

## Sensitivity of Changing Performance Trigger Levels

The sensitivity of changing performance trigger values was tested by increasing or decreasing PCI by two units and RCI by half a unit. The effects of changing trigger levels can be seen through movements in Poor condition regional roads as a percentage of all Western region roads which total 2453 centerline (CL) kilometres.

Fig. 4 illustrates the effects of increasing PCI trigger values. Consistent with the data presented below, an increase in PCI trigger levels also increases the amount of sections that fall below the trigger level. Increasing trigger levels can have significant effects on investment planning and budgeting, ultimately directing more costs towards rehabilitating the additional Poor condition roads. Increasing PCI trigger levels by 4 units yields the largest marginal increase in Poor condition roads at 4.5% (111 CL km). Increasing PCI trigger levels by 2 units and 6 units generate marginal increases of Poor condition roads by 3.6% (89 CL km) and 2.8% (68 CL km) respectively. The largest increase in the percentage of Poor condition roads is in the Freeway functional class by 2.8% (70 CL km) when PCI is increased by 4 units. The smallest increase in the percentage of Poor condition is Collector class by 0.2% (5 CL km) when PCI is increased by 4 units.

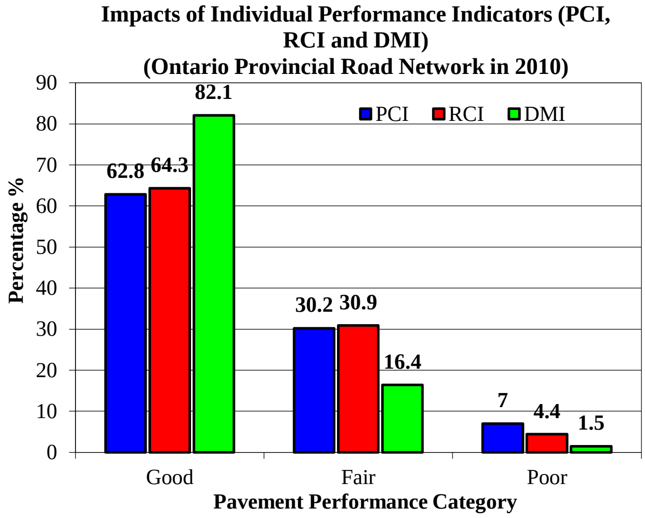


**Fig. 2.** Performance Distributions Scanned by Individual Performance Indicators.

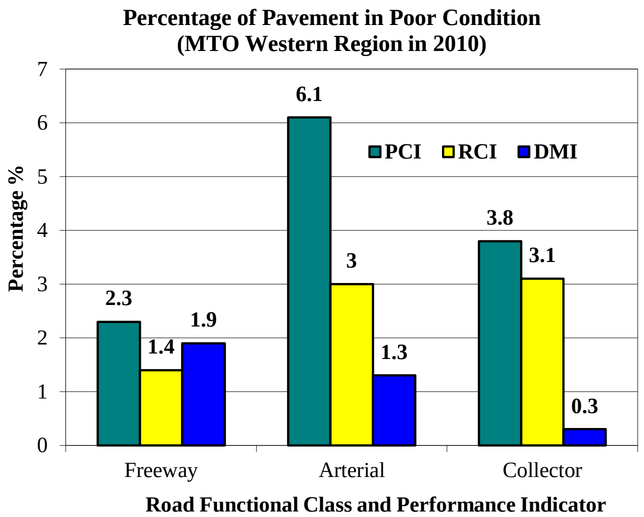


**Fig. 3.** Pavement Condition Scanned by Individual Performance Indicators.

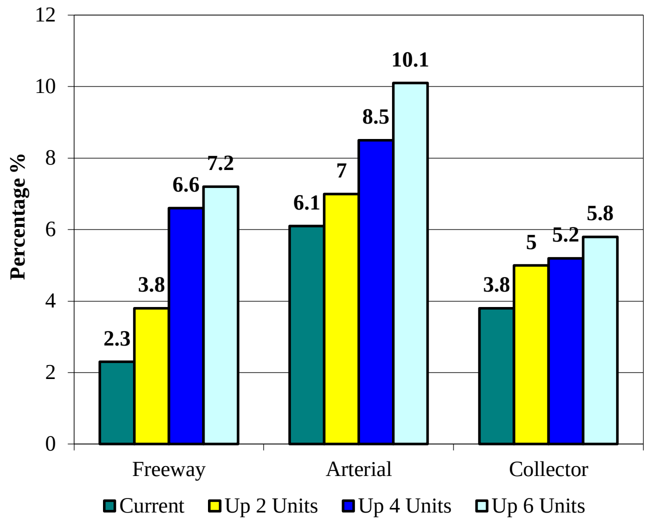


**Fig. 4.** Sensitivity to Increasing PCI Trigger Levels (Western Region).

Fig. 5 shows how percentage of Poor condition pavements changes as a result of decreasing the PCI trigger value. The lower the PCI trigger level, the lower the amount of Poor pavement condition sections. Again, the biggest effect is a decrease in PCI trigger levels by 4 units, which marginally decreases the overall amount of Poor condition roads by 6.1% (151 CL km). A decrease in PCI trigger values by 2 units and 6 units results in an marginal decrease of Poor condition roads by 1.8% (43 CL km) and 1.6% (40 CL km) respectively. For freeways, decreasing PCI past 6 units has no effect on the percentage of Poor condition roads. Arterial roads have the biggest movements when it comes to decreasing PCI trigger levels. The largest decrease in the percentage of Poor condition roads is in the Arterial functional class by 2.5% (62 CL km) when PCI is decreased by 4 units. The smallest decrease in the percentage of Poor condition roads is in the Freeway functional class by 0.8% (18 CL km) when PCI is decreased by 2 units.

Fig. 6 presents the effects of increasing RCI trigger levels for Western region. Consistent with the interval increases in PCI, the amount of Poor condition roads grow in response to the incremental increases of 0.5 units. The most significant change in the total amount of Poor condition roads is when RCI is increased by one unit. Similar to changing PCI trigger levels, a change in RCI trigger levels also will affect investment planning. Increasing RCI levels will increase the amount of Poor condition roads which increases the amount of rehabilitations performed to maintain road levels at good or fair conditions. Again, the largest marginal increase occurs at the second interval increase with 17.8% (436 CL km) when increasing RCI by 1 unit.

The amount of Poor condition roads are very sensitive to RCI trigger level changes of even one unit because RCI is scaled from 0 – 10. The second most sensitive trigger level increase is by 1.5 units, marginally raising the overall level of Poor condition roads by 364 CL km. Lastly, an increase of RCI trigger values by 0.5 units marginally increases the amount of Poor condition roads by 314 CL km. The largest increase in the percentage of Poor condition roads is in the Freeway functional class by 223 CL km when RCI is increased by 1 unit. The smallest increase in the percentage of Poor condition roads is in the Collector functional class by 49 CL km when RCI is increased by 1 unit.

Fig. 7 illustrates the effects of 0.5 incremental decreases of RCI trigger levels on the percentage of Poor condition pavement sections for all functional classes. Lowering RCI by 0.5 units yields a substantial decline in the amount of Poor condition pavements in Western region by 121 CL km. Unlike the movement for RCI and decreases in PCI shown above, lowering RCI trigger values more than 1.5 units from the current trigger level defined in MTO PMS has no effect on the amount of Poor condition roads. The largest decrease in the percentage of Poor condition roads is in the Collector functional class by 61 CL km when RCI is decreased by 0.5 units. The smallest decrease in the percentage of Poor condition roads is in the Freeway functional class by 10 CL km when RCI is decreased by 1 unit.

The following sigmoidal model in Eq. (3) is used to predict RCI and DMI for each individual pavement sections in MTO PMS:

$$P = P_o - 2e^{(a - b \times c^t)} \tag{3}$$

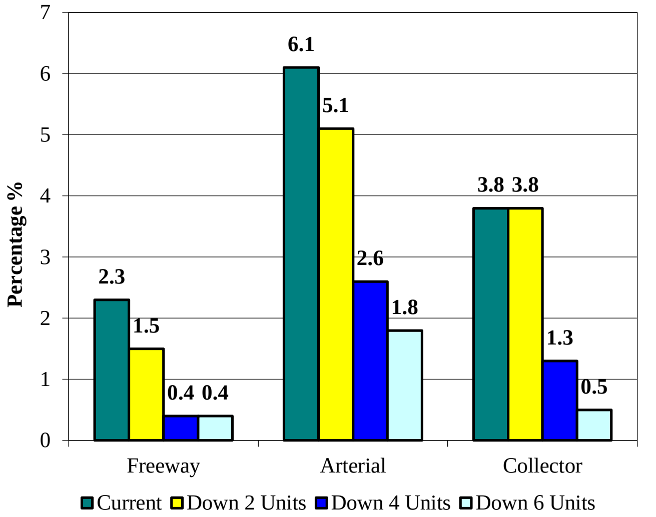


**Fig. 5.** Sensitivity to Decreasing PCI Trigger Levels (Western Region).

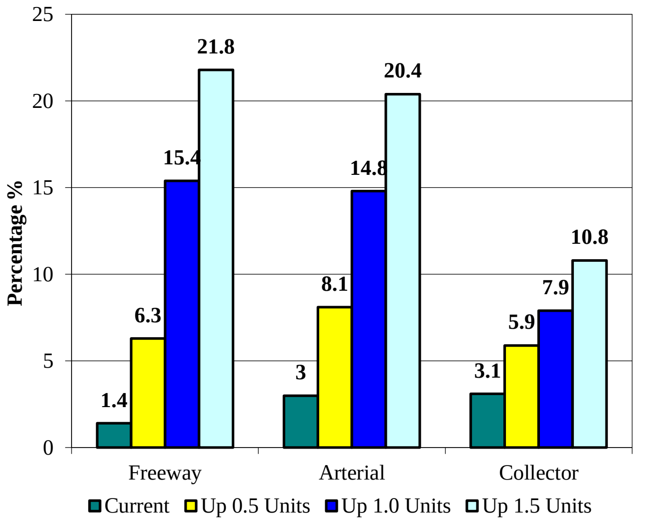


**Fig. 6.** Sensitivity to Increasing RCI Trigger Levels (Western Region).

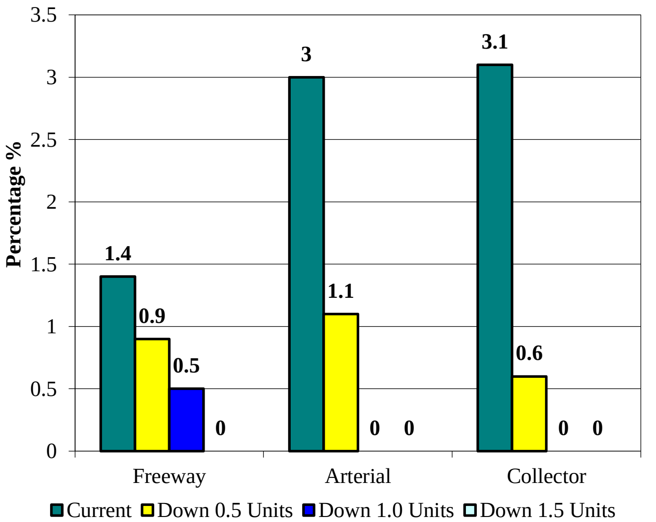


**Fig. 7.** Sensitivity to Decreasing RCI Trigger Level (Western Region).

where:
$P$ = performance index, RCI or DMI
$P_o$ = $P$ at age 0
$t$ = $\log_e(1/Age)$
$a,b,c$ = model coefficients

Pavement performance is also related to existing rehabilitation activities for a pavement section. Upon completion, based on the expected service life span of each treatment, performance improvements and deterioration rates are developed, as well as individual RCI and DMI prediction models are developed for each of these treatments.

## Summary and Conclusions

This paper presents the current practice and experience in dealing with pavement performance indicators and their individual roles in the MTO PMS. Specifically, the paper examined what pavement management outputs are significantly impacted if a different performance indicator is used or performance trigger level is changed. Examples are used to show how pavement performance evaluation results vary with individual performance indicators and trigger levels applied at network level management.

Conclusions are drawn from this study that using alternative pavement performance indicators will have considerable impacts on pavement management processes, such as pavement condition assessments, needs for pavement preservation and rehabilitation treatments at network level.

The historic pavement performance observed from Ontario's provincial highway network has provided good data sources for verifying individual pavement deterioration trends as compared to the outputs from the prediction models used in the MTO PMS system.

At present, the needs required for MTO PMS improvement with respect to selection of pavement performance indicators and prediction models are listed as follows:

- Conduct studies on trigger levels for various functional highways, specifically the most suitable condition assessment trigger levels for each pavement type.
- Establish a reasonable IRI trigger level for each of the performance categories, i.e., Good, Fair and Poor condition.
- Modify the existing PCI relationship with RCI and DMI and create more comprehensive performance models. This is imperative since performance is important to preservation and rehabilitation activities for overall planning and budgeting purposes.
- Continue monitoring the effects of various rehabilitation treatments on pavement performance trends. Perhaps the most significant challenge facing pavement management engineers with respect to performance measurement indicators is developing a better understanding of the pavement condition assessment associated with selecting one performance indicator over another.
- Integrate pavement performance as part of pavement management, focusing on defining pavement failures (e.g., cracking, rutting, ravelling, faulting, etc)
- Introduce a new technical approach to predicting pavement deterioration trends integrated with a number of standardized rehabilitation treatments and their individual treatment effects.
- Examine the long-term historic performance trends of all individual rehabilitation and preservation treatments that are currently used in MTO PMS decision trees, including the 60 standardized rehabilitation treatments built in the decision trees. Although there is no consensus on which measures are most meaningful, it is widely believed that these measures do not adequately reflect the benefits of pavement preservation treatments.

## References


1. Chong, G., Phang, W., and Wrong, G. (1989). Manual for Condition Rating of Flexible Pavements - Distress Manifestation, Report SP-024, R&D Branch, Ministry of Transportation, Ontario, Canada.
2. Chong, G. and Wrong, G. (1995). Manual for Condition Rating of Rigid Pavements, Report SP-026, R&D Branch, Ministry of Transportation, Ontario, Canada.
3. Sayers, M.W. (1990). Profiles of Roughness. *Transportation Research Record*, No. 1260, pp. 106-111.
4. Sayers, M.W., Gillespie, T.D., and Paterson, W.D. (1986). Guidelines for the Conduct and Calibration of Road Roughness Measurements, World Bank Technical Paper No. 46, The World Bank, Washington DC, USA.
5. Li, N., Haas, R., and Michel, H. (1998), Integer Programming of Maintenance and Rehabilitation Treatments for pavement Networks, *Transportation Research Record*, No. 1629, pp. 242-248.
6. Haas, Ralph, 2008. A Perspective on Seven ICMPA. *Proceedings, 7th International Conference on Managing Pavement Assets*, Calgary, Canada.