IMPACTS OF USING ALTERNATIVE PERFORMANCE INDICIES ON ROAD ASSET VALUE ASSESSMENT

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ABSTRACT: This paper presents a study on impact of using alternative pavement performance indicators on pavement condition assessment and valuation at network level road management. The main objective of the study was to explore all individual performance indicators used in Ontario provincial pavement management system in terms of their functional roles in the decision process of determining pavement network preservation strategies. In addition, analysis of pavement asset valuation against pavement age with different deterioration models was conducted to establish the relationship between pavement asset valuation and the main factors affecting pavement asset values. The main findings from the analysis results indicate that large variations can be caused if different performance indicators are used in pavement condition assessment and valuation. The study concluded that selection or use of appropriate performance indicator(s) is the most essential to assessment of pavement performance and asset valuation in pavement management. Therefore, there is a need to define functional roles and engineering criteria of the selected performance indicators in asset management.

KEY WORDS: Pavement, Asset, Valuation, Performance, Indicator, Impact

1. INTRODUCTION

Asset management is generally defined as a process of combining financial, economic, engineering, management and other practices applied to physical assets with the objective of providing the required level of services in the most cost effective manner. Road asset management deals with the whole life cycle process of managing road infrastructure networks, including design, construction, materials engineering, operation, maintenance and rehabilitation, reconstruction and decommission [1]. The key elements of road asset management include asset inventory, condition and expected service life, investment strategies and engineering standards for asset maintenance and rehabilitation, performance measures and prediction models, funding allocation priorities.

Road asset management activities include acquisition of asset management information and data collection systems, development of asset condition assessment technologies, development of maintenance and rehabilitation policies and procedures, life cycle costing analysis, analysis of asset replacement and rehabilitation strategies. Asset value of a road network can be quantitatively measured in monetary values through several commonly used accounting methods [2]. Managing road assets needs to calculate valuation of each asset component based on either original investment cost or replacement cost.

Ministry of Transportation of Ontario (MTO) has recently applied the principle of asset management to reporting pavement condition assessment of the provincial highway network, including road asset inventory registers, performance measures and key indices, present and future asset valuations. In the process of calculating present or future valuation of a road network, the first step is to define its scope, which may range from a large road network to a small road segment. The second step is to define all layers of road asset components or registers.
that cover a partial or whole asset value of a road network, such as pavements, foundations, bridges, structures, culverts, traffic signs and signals, pavement markings, safety facilities [3, 4].

From a management accounting viewpoint, valuation of various fixed road asset components can be calculated by a number of accounting methods, including replacement cost, written down replacement cost, standard costs and average cost [5, 6]. Among the several commonly used management accounting methods, replacement cost or written down replacement cost of an asset is the most acceptable by public agencies in their infrastructure management reporting systems.

The written down replacement cost of an asset is its current replacement cost less accumulated depreciation, while the replacement cost is the cost of replacing it with a substantially identical new asset. Accumulated depreciation is the total amount of depreciation charged to an asset from when it was first recognized. The standard replacement costs are usually associated with road agency costs, including material cost, construction equipment cost, labor and administration costs. The average cost is computed by dividing the total replacement costs for a same classified maintenance or rehabilitation treatments available from past construction costs. A list of commonly used road asset valuation accounting methods, together with their data requirements is summarized in Table 1.

Table 1. List of methods used in road asset valuation

<table>
<thead>
<tr>
<th>Method</th>
<th>Initial Construction Cost $</th>
<th>Service Life and Depreciation Rate</th>
<th>Maintenance and Repairing Cost $</th>
<th>Performance Measures and Indicators</th>
<th>Current and Predicted Future Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Book Value</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Market Value by Replacement</td>
<td></td>
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<td></td>
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<tr>
<td>Market Value by Written Down Replacement</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Standard Cost</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Cost</td>
<td>X</td>
<td>X</td>
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</tbody>
</table>

This paper presents a few key performance indicators and their prediction models used in the current Pavement Management System at Ministry of Transportation of Ontario (MTO PMS). One of the main functions built in MTO PMS is the asset valuation analysis tool, which makes it possible to provide justification for a specific budget request on the basis of average cost information. Moreover, the valuation analysis tool can be applied to present assessment of pavement conditions and provide decision makers with pavement asset valuations with different rehabilitation programs at network level.

While performance indicators deal with evaluation of pavement structural and functional performance from different perspectives of road serviceability level, they can also be are used to relate current and future pavement asset values in conjunction with a number of influential factors such as service life, traffic, and pavement structural and environmental conditions.

2. MULTIPLE ROLES OF PERFORMANCE INDICATORS IN MTO PM

The terms performance management and individual performance indicators are often used by many road agencies in their road assessment systems to report road network service levels and expected performance targets given annual investment allocations. When applied in MTO PMS, performance indicators are used to perform not only assessment of pavement functional and structural conditions, but also valuation of categorized road pavements based on their performance trends or serviceability levels. 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.
The key performance indicators used in MTO PMS include International Roughness Index (IRI), Riding Comfort Index (RCI), Distress Manifestation Index (DMI), and Pavement Condition Index (PCI). Each of the indicators has an important role in not only assessment of specific pavement functional or structural condition, but also in economic analysis of pavement maintenance and rehabilitation strategies and allocation of investments. When applied in road asset management, these performance indicators are used to establish the trigger levels relating to road service standards technically and economically. For more than 30 years, the ministry has been collecting pavement condition information for feeding MTO PMS applications on all provincial highways at network level.

2.1 Key Performance Indicators in MTO PMS

The IRI used in MTO PMS is calculated from measured longitudinal profile along a road that reflects pavement riding quality. While the IRI has an open-ended scale in Ontario, it typically ranges from 0 (m/km) to 4 (m/km), where zero implies an absolute perfect road. Since its introduction in 1986, The IRI has become the most commonly used pavement performance index for all most all pavement management systems in the world. The IRI value of a pavement section provides information of its riding serviceability level and vehicle operation cost.

The RCI in MTO PMS is converted from a corresponding IRI value through a statistic relationship between the two indices. To obtain RCI value for a pavement section, a transfer function between RCI and IRI has been established through regression analysis. The RCI is scaled from 0 to 10, where 0 represents the worst riding condition of a pavement section and 10 implies an excellent riding condition.

The DMI in MTO PMS addresses pavement surface conditions such as distortion, cracks and defects. The DMI is scaled from 0 to 10, with 0 representing the worst condition and 10 representing perfect condition of a pavement section. The DMI reflects not only the assessment of distressed pavement surface condition in terms of severity and density, but also reflects road safety of a pavement section. These distresses fall into three categories: surface defects, surface deformation, and surface cracks.

The PCI in MTO PMS is an overall performance indicator for individual pavement management sections. The PCI scale is 0-100, with scores 95-100 representing new constructed pavement conditions.

2.2 Trigger Levels for Pavement Condition Categories

The MTO PMS application allows user to design and set up pavement performance categories such as Very Good, Good, Fair and Poor. The number of pavement performance categories and numeric trigger levels can be customized to comply with the current highway performance evaluation guidelines. It should be mentioned that the performance trigger levels and corresponding numeric values developed for MTO PMS applications vary between pavement types and road functional classes, such as freeway, arterial and local roads.

Figure 1 is a screen copy of pavement performance indicators used in MTO PMS. It shows the current pavement condition categories and corresponding individual performance numeric ranges for Arterial highways. For future pavement conditions, accurate prediction of pavement deterioration is crucial to ensure that pavement rehabilitation or reconstruction strategies can be programmed for the purpose of preserving the provincial highway network. The MTO PMS is an effective tool for pavement management engineers and investment planners to identify pavement sections that need for repairing or rehabilitation programming.

The optimal performance indicators and thresholds should be defined on the basis of pavement type, road functional class category and regional economic development standards. For example, freeways have the highest priority and therefore their trigger values for rehabilitation are generally higher.
A quantitative assessment of individual performance indicators provides guidance regarding present and future needs in road pavement design and maintenance at network level. In Figure 1, the button Rehab Trigger Values provides options for determining pavement rehabilitation trigger values that define a Poor condition or minimum acceptable level for each road class and pavement type. The trigger values are established and updated through discussions with highway engineers and managers, involved in pavement management and investment planning. By specifying limits and acceptance values (e.g. minimum acceptable levels, threshold values) for individual performance indicators, minimum standards can be established for both planned and existing road pavements.

2.3 Trigger Levels for Preservation and Rehabilitation Actions

The key performance indicators (PCI, IRI and DMI) are also used in determining action needs for pavement rehabilitation treatments, which is processed through the decision trees built in MTO PMS. Generally, any individual performance indicators may be applied to the process that optimizes multiple rehabilitation treatments for all pavement sections in the road network. These performance indicators include IRI trigger values for pavement overlays, DMI trigger values for crack routing and sealing treatments, PCI trigger levels for major rehabilitation or re-construction actions. Furthermore, these individual performance indicators should be related to road safety, riding comfort, structural and functional performance levels expected from road users.

Trigger values are suggested for key condition levels at which a pavement is generally considered in need of structural improvement. Similarly, trigger values are suggested for key condition levels at which a pavement is generally considered in need of functional improvement. The MTO PMS allows for other data to be collected and entered into the system, including unit costs for all preservation treatments programmed by decision trees.

Pavement rehabilitation is defined as a structural or functional enhancement of a pavement, which produces a substantial extension in service life by improving pavement riding quality or surface conditions. Pavement preservation activities, in contrast, are those treatments that preserve pavement condition, safety, and ride quality, without increasing structure thickness and therefore aid a pavement in achieving its design life.
3. IMPACT ANALYSIS OF INDIVIDUAL PERFORMANCE INDICATORS

The MTO PMS currently uses PCI as one of the key performance indicators in the process of pavement management at both regional and provincial network levels. This includes performance evaluation technologies, engineering criteria, assessment of current and future pavement conditions in terms of performance distributions, application of performance prediction models, selection of optimal preservation and rehabilitation treatments, and analysis of all regional multi-year investment plans with performance targets or/and budget constraints. All other performance trigger values (DMI, RCI and IRI) are used as secondary performance indicators or as reference only.

Figure 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 length of Ontario’s provincial highway network was 41198 lane-km. It is obviously that variations in the categories of Good and Fair conditions assessed by the three different indicators are significant, specifically the DMI versus PCI and RCI. In addition, it is evident that there is a large amount of variation in terms of the percentage of Poor condition screened by each of the performance indicators. It is also apparent that DMI varies the most from the other two performance indicators.

PCI is calculated from measured or predicted IRI and DMI values by means of their functional relationship, which has brought some issues and concerns about data accuracy and consistency. In view of IRI and DMI data collection and evaluation procedures, DMI is currently obtained manually or subjectively by pavement evaluators who could bring significant variation and inconsistency issues, which are considered as challenges to many road agencies in the world. However, this can be resolved through automation of data collection and evaluation processes. Moreover, it is practical and straightforward to have a clear relationship between PCI and IRI and DMI. The current estimation of PCI, with 70% values contributed from IRI and 30% from DMI, should be scrutinized through reviewing a reasonable amount of historic data in addition to performing a proper statistical analysis.

For network level analysis, what is the most 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, selecting rehabilitation programs and investment plans at a network level. On the other hand, city or municipal road agencies normally use DMI in developing pavement preservation
programs at the project level. Depending on the level of pavement management being considered and what pavement performance issues are being addressed, alternative performance indicators may be applied to compare with the analysis results.

Figure 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. Again, variability of DMI from PCI and RCI is considerable.

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.

4. IMPACTS OF CHANGING PERFORMANCE TRIGGER LEVELS

The impact of changing performance trigger levels on pavement condition assessment and asset valuation was tested by increasing or decreasing PCI by two units and RCI by half a unit. The results of changing PCI trigger levels for MTO Western Regional road network were observed as shown in Figure 4. Since asset value is directly related to pavement condition, asset value of the road network analyzed is, therefore, changed proportionally. 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 roads is in the Collector functional class by 0.2% (5 CL km) when PCI is increased by 4 units.
The impacts on changing percentage of poor condition pavements as a result of decreasing the PCI trigger value were also analyzed. The lower the PCI trigger level, the lower the amount of Poor pavement condition sections. Similarly, 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.

Figure 5 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 and budgeting. 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 14.9% (364 CL km). Lastly, an increase of RCI trigger values by 0.5 units marginally increases the amount of Poor condition roads by 12.8% (314 CL km). The largest increase in the percentage of Poor condition roads is in the Freeway functional class by 9.1% (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 2% (49 CL km) when RCI is increased by 1 unit.

The impacts of lowering RCI trigger levels on changing percentage of poor condition pavement sections were also analyzed 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 4.9% (121 CL km). Unlike the movement for PCI 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. This is simply because there are no roads within Ontario that are damaged enough to have such a low RCI. The largest decrease in the percentage of poor condition pavements is in the Freeway functional class by 5.8% (118 CL km) when RCI is decreased by 2 units.
condition roads is in the Collector functional class by 2.5% (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 0.4% (10 CL km) when RCI is decreased by 1 unit.

![Figure 5. Sensitivity to increasing RCI trigger levels for western region](image)

5. IMPACTS OF ALTERNATIVE PERFORMANCE INDICATORS ON ASSET VALUATION

5.1 Impact Analysis of Performance Indicators
Valuing and depreciating road infrastructure assets are interrelated processes, and both of them can be converted into monetary terms based on assessment of road conditions or performance index values. For example, it may be appropriate to apply pre-defined depreciation rate to assets that are subject to traffic loading, traffic volume and environmental conditions. Therefore, adopting an appropriate and consistent method for valuing or depreciating assets is the most important to report the value of the road infrastructure in financial statements.

It becomes common in asset management that pavement and bridge network is expressed in capital value or monetary term, which is calculated from the cost of replacing the value or of recovering the existing roads to an as built conditions. The functional relationship between individual road performance indicators and their valuations plays an important role in asset management because one of the main purposes is to enable reporting in monetary terms to reflect the physical conditions of the road network, and to report the effects of different financing strategies.

The current MTO PMS has the functionality to select performance indicator from multiple choices built in the system, set-up performance scanning trigger levels corresponding to pre-defined performance categories, update performance prediction models based on historical data, etc. Based on the above sensitivity analysis results of the impacts of alternative performance indicators (i.e., PCI, RCI or IRI, and DMI) on assessment of pavement conditions, valuation of road assets varies significantly in the same pattern as assessed performance distribution. Depending on which performance indicator is used, calculated valuation of pavement assets in each category of the road network may be largely different from each other, as illustrated in Figure 6. In addition, valuation of road assets estimated for any horizon year is very sensitive to the performance prediction models used in the system. The following examples present some explanations of the impacts of individual performance indicators and their performance models on valuation of pavement assets.
5.2 Performance Models in MTO PMS

The following sigmoidal model is currently applied in MTO PMS to predict RCI and DMI for each classified individual pavement sections:

\[
P = P_o - 2e^{(a - b \times c^t)}
\]  

(1)

Where:
- \(P\) = Road Condition Index, RCI or DMI
- \(P_o\) = \(P\) at age zero
- \(t = \log_e(1/\text{Age})\)
- \(a, b, c\) = model coefficients

Pavement performance is related to existing rehabilitation activities for a pavement section. Upon completion of a specified designed rehabilitation or reconstruction treatment, all coefficients associated with the performance models and deterioration rates can be calculated through regression analysis based on the expected service life span, performance improvements, traffic and environmental information. The models were developed for both RCI and DMI performance indicators.

Impact analysis of changing performance models involves review of historic data and all coefficients recalculated through MTO PMS. The deterioration of pavements is modeled using a mechanical-empirical method. This method takes into consideration previous M&R treatment effects on future deterioration rates of pavement serviceability. Each rehabilitation treatment is defined in terms of structural design, construction criteria, paving materials, and treatment effects on the existing pavement structural and functional performance. The programming produces maintenance planning for each pavement section in the network on the basis of annual cost-effectiveness.

5.3 Asset Valuation VS Performance Evaluation

Effective asset evaluation provides road agencies with helpful information of their asset conditions and projections of asset replacement or rehabilitation costs. The purpose of asset performance evaluation is to identify asset requiring rehabilitation and replacement in the short and medium term and develop asset deterioration models. Figure 7 is a screen copied from MTO PMS, which illustrates how valuation of each
individual road section asset is related exclusively to the current or future pavement condition index (PCI) and replacement cost. The PCI values are mainly based on the performance models applied in the system.

![Section Data Browse -- Subset: All Sections (294 sections)](image)

Figure 7. Road section asset values calculated from PCI and replacement cost relationship

6. CONCLUSIONS

This paper described the current MTO practice in dealing with pavement performance indicators and their individual functional roles in asset valuation associated with assessment of road conditions. Specifically, the paper examined what and how pavement management outputs, in terms of assessment of current or future pavement conditions and valuation of road assets, vary significantly if an alternative performance indicator or condition ranking trigger level is applied to compare the analysis results. A few examples were presented to show pavement performance assessment and corresponding asset valuation at network level calculated by using asset valuation models built in the MTO PMS application.

The impacts of using alternative performance indicators on asset condition assessment can be extended to variation of the needs for multi-year investments in pavement rehabilitation and reconstruction programming, which was illustrated by using a series of scenario and sensitivity analyses. In addition, the paper discussed the key issues with pavement prediction models and asset valuation management accounting methods, focusing on practicality of the individual indicators from a pavement management process viewpoint.

Conclusions from this study indicate that using alternative pavement performance indicators will have considerable impacts on pavement evaluation and maintenance programming analysis results, including assessment of current and future pavement conditions, identifying pavement rehabilitation needs, and calculation of road asset values at network level. The historic pavement performance observed from Ontario’s provincial highway network has provided good data sources and reference materials for the process of verifying individual pavement deterioration trends as compared to the outputs from the prediction models used in the MTO PMS.
system. The paper also indicates need for continuous study on standardizing pavement performance indicators and mitigating their impacts on pavement condition assessment and asset valuation.

REFERENCES:


