Long-Term Monitoring of Low-Volume Road Performance in Ontario

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ABSTRACT

This paper discusses the long-term pavement performance observed on Ontario's low-volume roads. These low-volume roads, which carry fewer than 1,000 vehicles per day, comprise some 3,715 center-line kilometers in length, about 20 per cent of the total Ontario provincial road network. The long-term monitoring of pavement performance trends on these low-volume roads spans twenty years, and includes performance measures of pavement roughness, distress and overall pavement condition. Most of the observed pavement sections have been rehabilitated or re-constructed several times since 1985. The main objectives of this paper are to: 1) review the pavement rehabilitation and maintenance treatments applied on Ontario provincial highways over the last twenty years, focusing on observed pavement performance records of individual treatments versus age, construction costs and predicted performance curves, 2) analyze pavement life-cycle costs and overall long-term performance of the typical pavement structures used in the past, and 3) compare the pavement performance curves of specific pavement maintenance and rehabilitation (M&R) treatments applied to these low-volume roads. The paper starts with an introduction to the pavement rehabilitation and re-construction activities that are commonly used for low-volume roads in Ontario, which are listed in the Ministry's pavement management system (PMS/2). It then discusses typical pavement M&R treatments, historical performance records and predicted performance trends, addressing the best practices in rehabilitating low-volume roads in Ontario. Finally, some preliminary findings and conclusions based on the long-term pavement performance observations and economic analyses are presented in the paper.

INTRODUCTION

Low-volume roads, which carry fewer than 1,000 vehicles per day, comprise some 3,715 centre-line kilometers or about 20 per cent of the total Ontario provincial road network. For over 20-years, the Ministry of Transportation Ontario (MTO) has carried out long-term monitoring of pavement performance trends on these low-volume roads using performance measures for pavement roughness, distress and overall pavement condition.

Recently, the Ministry carried out a review of the pavement rehabilitation and maintenance treatments applied on Ontario provincial highways over the last twenty years, focusing on observed pavement performance records. Most of the observed pavement sections have been rehabilitated or re-constructed several times since 1985. The review looked at individual treatments versus age, construction costs and predicted performance curves, analyzing pavement life-cycle costs and overall long-term performance of the typical pavement treatments. It also compared the pavement performance curves of specific pavement maintenance and rehabilitation (M&R) treatments applied to low-volume roads.

This paper discusses the long-term pavement performance observed on Ontario's low-volume roads. The paper begins with an introduction to the pavement rehabilitation and re-construction activities that are commonly used for low-volume roads in Ontario, then discusses typical pavement M&R treatments. Historical performance records, predicted performance trends and life-cycle costing analyses are used to highlight the best practices in rehabilitating low-volume roads in Ontario.

PAVEMENT REHABILITATION AND RECONSTRUCTION

Table 1 below lists all the major pavement rehabilitation and re-construction activities that have been commonly used on low-volume roads in Ontario over the last 30 years.

Table 1: List of Ontario Pavement Rehabilitation and Reconstruction Treatments

Activity Code	Activity Description
101	Hot Mix Overlay 1
102	Mill and Hot Mix Overlay 1
103	Hot Mix Overlay 2
104	Mill and Hot Mix Overlay 2
106	Full Depth Reclamation (FDR) and Hot Mix Overlay 1
107	Full Depth Reclamation (FDR) and Hot Mix Overlay 2
152	Cold-in-Place Recycling and Hot Mix Overlay 1
153	Cold-in-Place Recycling and Hot Mix Overlay 2
304	Reconstruction (Unspecified)
402	Reconstruction to AC
403	Reconstruction to ST
401	Single Surface Treatment

These pavement rehabilitation activities or treatments have been programmed through expert knowledge-based procedures into the decision trees developed for the Ministry's pavement management system (PMS/2). These PMS/2 applications include determination of multi-year investments and budget allocations needed for maintaining and improving road performance at the network level, economic analysis of alternative pavement maintenance and rehabilitation treatments for the entire network, and prediction of future network performance under budget constraints [1]. It should be noted that some routine maintenance treatments, such as rout and crack-sealing, chip-sealing, micro-surfacing and hot mix patching, are not listed in Table 1. These maintenance treatments were not taken into consideration in this study due to the lack of data regarding these activities.

Historic performance data from the PMS/2 database was collected for 133 pavement sections, all having a current Annual Average Daily Traffic (AADT) of 1000 or less. As illustrated in **Figure 1**, the typical pavement structures for low-volume roads in Ontario are:

Typical Structure 1: 40mm hot mix HL4 Surface + 40mm hot mix HL4 Binder + 150mm Granular A Base + 650mm Granular B Sub-base;

Typical Structure 2: 50mm hot mix HL4 Surface + 150mm Granular A Base + 700mm Granular B Sub-base;

Typical Structure 3: Surface Treatment + 100mm Granular A Base + 700mm Granular B Sub-base.

Table 2 presents a summary of the categorized pavement sections with low-volume traffic. It should be noted that surface treated pavement accounts for 40% of the sections in this study.

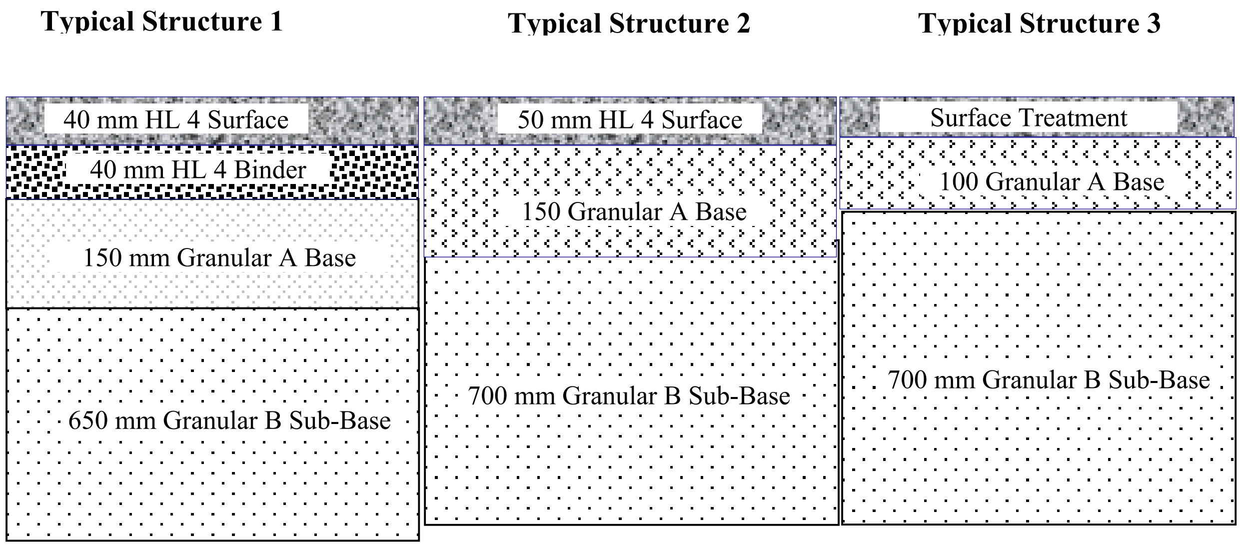

Figure 1 Typical Pavement Structures Used in Ontario for Low-volume Roads

Table 2: Summary of Low-Volume Road Sections by Category

Function Class	**# of Sections**	**Center-Line Length (km)**	**Percentage by Section**	**Percentage by Length**
Arterial	13	309.54	9.8%	13.7%
Collector	43	936.28	32.3%	41.4%
Local Roads	77	1014.51	57.9%	44.9%
Pavement Type				
Hot Mix Asphalt	71	1359.7	53.4%	60.2%
Surface Treatment	62	899.70	46.6%	39.8%
Type of Rehabilitation Activity				
Hot Mix Overlay 1 (Activity 101)	7	161.17	5.3%	7.1%
Mill and Hot Mix Overlay 1 (Activity 102)	2	38.29	1.5%	1.7%
Hot Mix Overlay 2 (Activity 103)	5	55.4	3.8%	2.5%
Full Depth Reclamation and Hot Mix Overlay 1 (Activity 106)	25	361.28	18.8%	16.0%
Full Depth Reclamation and Hot Mix Overlay 2 (Activity 107)	16	375.13	12%	16.6%
Cold-in-place Recycling and Hot Mix Overlay 1 (Activity 152)	1	15.2	0.8%	0.7%
Cold-in-place Recycling and Hot Mix Overlay 2 (Activity 153)	1	36.3	0.8%	1.6%
Reconstruction (Activity 304)	12	185.14	9.0%	8.2%
Reconstruction to AC (Activity 402)	8	227.82	6.0%	10.1%
Reconstruction to ST (Activity 403)	7	73.03	5.3%	3.2%
Surface Treatment (Activity 401)	49	731.58	36.8%	32.4%
Total	***133***	***2260.33***	***100%***	***100%***

Although the PMS/2 database contains 3,715 center-line kilometres of low-volume traffic sections, some of them did not have sufficient performance information. Therefore, the total length of pavement sections analyzed in this study was 2,260 center-line kilometres. Contained in these 133 sections are three functional classes: Arterial Roads, Collectors, and Local Roads. There are only two pavement types grouped from these sections: Hot Mix Asphalt (HMA) and Surface Treatment (ST). Each pavement type was further categorized into several construction and rehabilitation activities so that comparison of observed versus predicted pavement performance of each individual construction activity could be analyzed by this study.

PAVEMENT PERFORMANCE EVALUATION METHODS

In PMS/2, the serviceability of pavement sections is measured using three performance indices. The first is the Ride Condition Index (RCI), which is an objective measure of ride quality of the road in terms of roughness experienced when travelling on it. RCI ranges from 0 to 10 (10 meaning perfect condition) and is a function of International Roughness Index (IRI), which is collected by high speed automated inertial profilers. The second criterion is a measure of pavement distress and is a value given on the Distress Manifestation Index (DMI) scale. Like RCI, DMI ranges from 0 to 10, with 10 referring to new, distress-free pavement. However, unlike RCI, DMI is a subjective assessment given by regional Pavement Design Evaluation Officer with the aid of a special evaluation program called Pavement Distress Data Collection (PDDC) and is not measured mechanically. The final performance measure is the Pavement Condition Index or PCI. PCI is a direct function of DMI and RCI and is a measure of overall pavement condition. PCI values fall between 0 and 100 with a higher number referring to a better condition.

On a network level, PMS/2 uses PCI values to determine when, where and what major maintenance and rehabilitation is needed for each pavement section in the road network through the use of trigger or threshold values. For example, for all roads classified as Freeways, if a PCI value is between 65 and 75, the road is considered to be in 'Fair' condition, and if a PCI value of less than 65 is calculated, the road is seen to be in 'Poor' condition. Anything higher than 75 and that section is considered to be in 'Good' condition. These three measurements, RCI, DMI and PCI are taken and stored within the PMS/2 database and used for assessment of pavement performance and various analysis scenarios. The current PMS/2 database contains 20 years of static and dynamic pavement performance information from 1985 to 2005, which was used in this study.

HISTORICAL PAVEMENT PERFORMANCE

The actual historical performance records of the typical pavement rehabilitation activities applied on low volume roads in Ontario are presented in the following section. These activities or treatments are also incorporated into the rehabilitation and preventive maintenance analysis functions of the PMS/2 application. Comparisons of the predicted performance curves, using PMS/2 models, with the actual observed historical performance records over the last 20 years for several rehabilitation activities are also discussed in the following section.

One Lift Hot Mix Overlay (Activity 101)

There were a total of 7 instances where a 1 lift HMA Overlay treatment was performed on low-volume sections, which is equivalent to a section length of 161.17 km. The average performance in terms of RCI (Ride Comfort Index), DMI (Distress Management Index) and PCI (Pavement Condition Index) was taken and compared to the performance prediction models used in PMS/2. Note the average observed performance curve was taken to be a second-degree polynomial with the R^2 displayed on each graph.

The predicted pavement performance trends by PMS2 were generated with a Granular Base Equivalency (GBE) value of GBE between 500 and 750 and an Equivalent Single Axle Load (ESAL) value of less than 5000 per year. The other model parameters, such as Environment and Subgrade strength, were left as default values. **Figures 2-5** display the comparison between the observed values and prediction models. Comments on each of the observed and predicted performance plots are listed in **Table 3.**

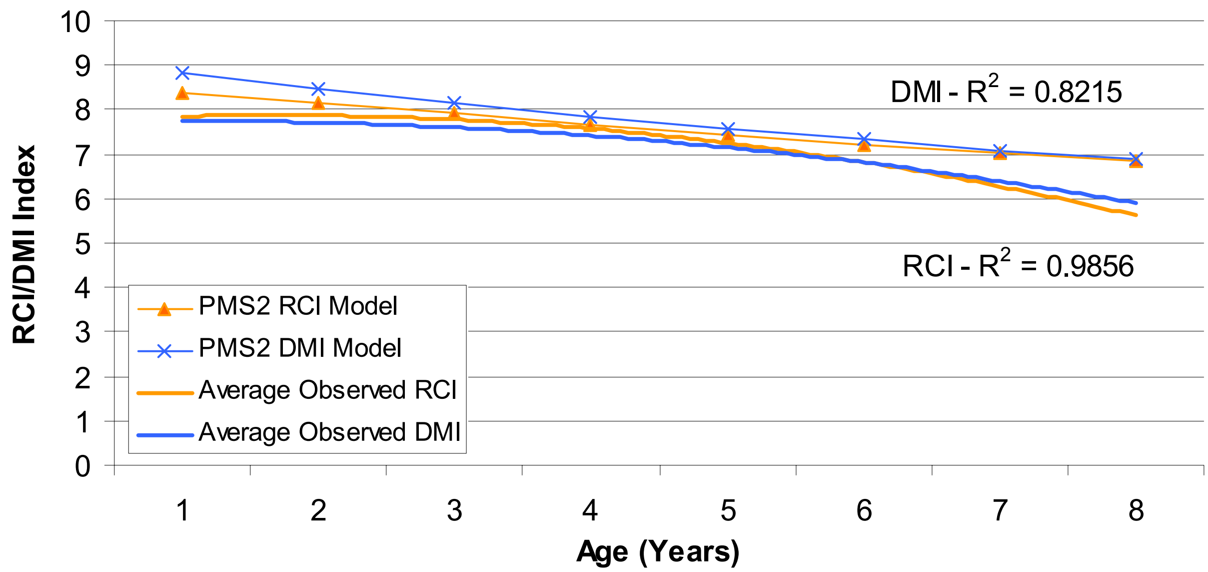

Figure 2 Comparison of Observed Versus Predicted RCI and DMI Performance of 1 lift Hot Mix Overlay (Activity 101) on Arterials

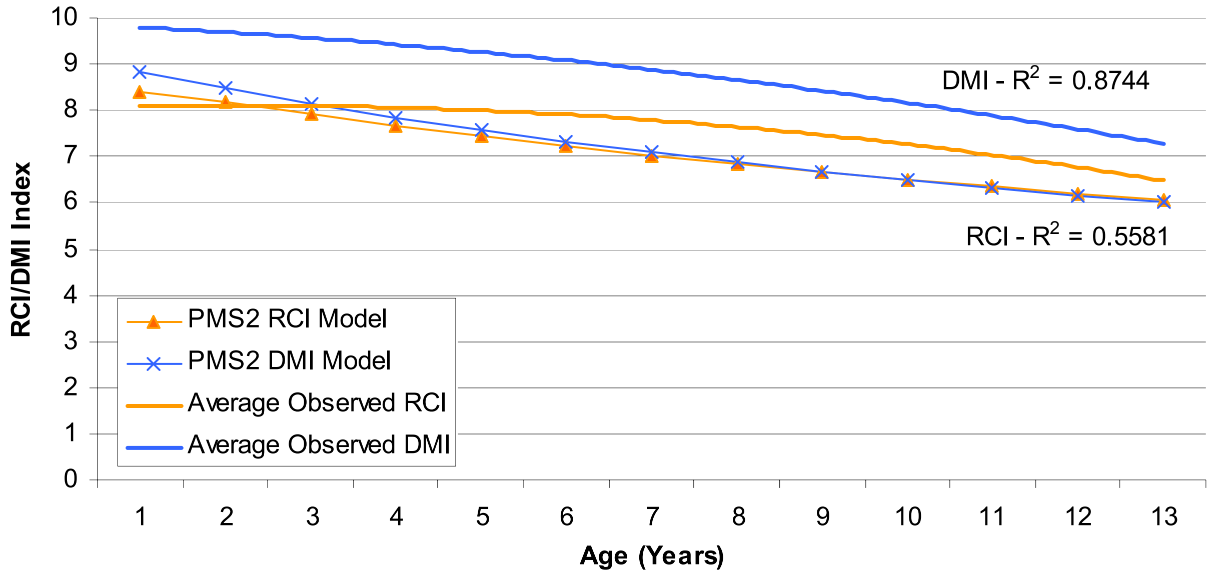

Figure 3 Comparison of Observed Versus Predicted RCI and DMI Performance of 1 Lift Hot Mix Overlay (Activity 101) on Collectors

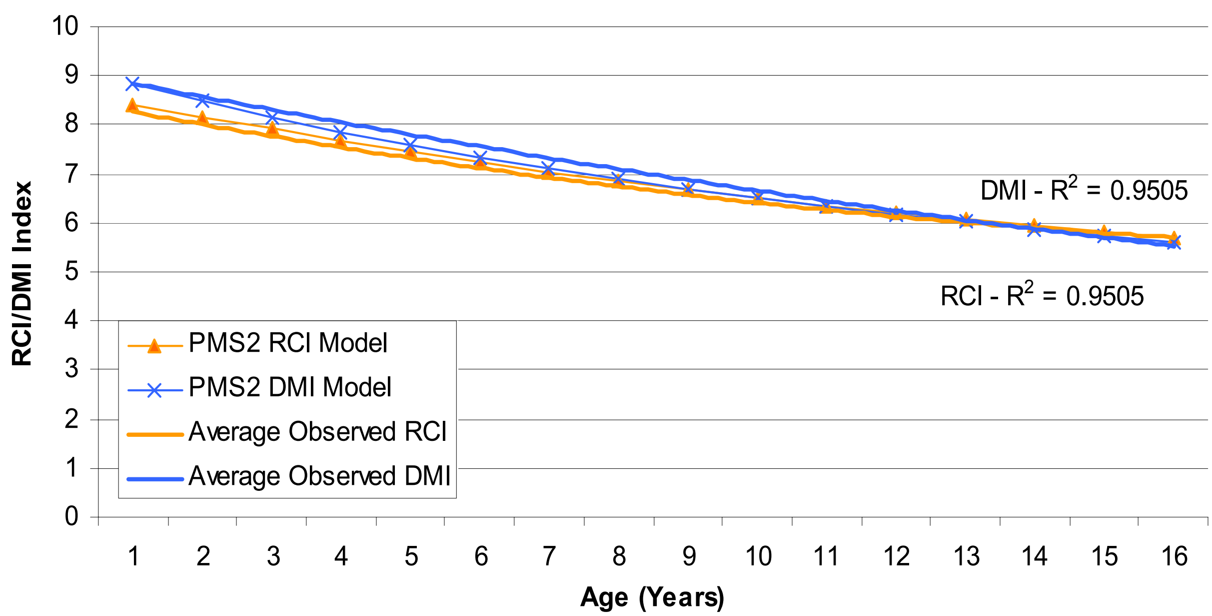

Figure 4 Comparison of Observed Versus Predicted RCI and DMI Performance of 1 Lift Hot Mix Overlay (Activity 101) on Local Roads

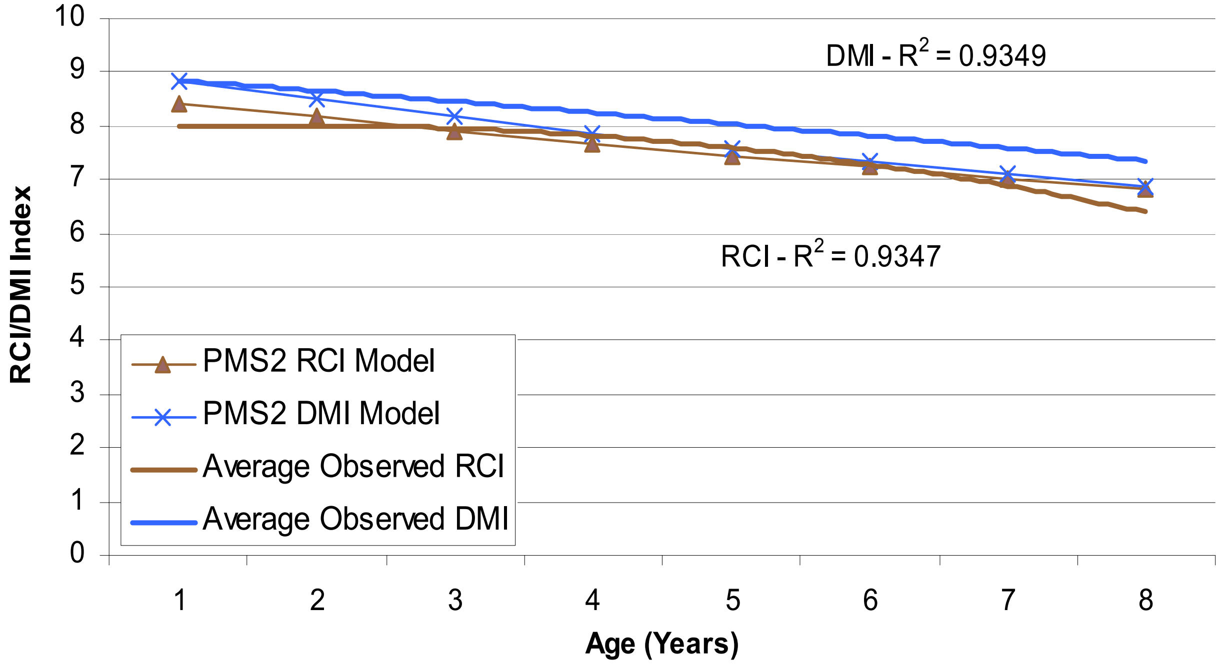

Figure 5 Comparison of Observed Versus Predicted RCI and DMI Performance of 1-Lift Hot Mix Overlay (Activity 101) on All Low-Volume Roads

Table 3: Comments on Observed versus Predicted RCI, DMI and PCI for Activity 101

Item	Figure No.	Comments
RCI and DMI Performance on Arterial Roads	2	Both models predict values too high; should use lower initial RCI and DMI values; After 6 years, the observed rate of deterioration was higher than the current PMS2 model
RCI and DMI Performance on Collector Roads	3	RCI model has fairly accurate values, but the shape of the curve does not match due to poor regression with small sample size DMI model predicts low values; initial value should be closer to 10
RCI and DMI Performance on Local Roads	4	Both DMI and RCI models appear to be in good agreement with observed performance
RCI and DMI Performance on All Low-Volume Roads	5	RCI model predicts fairly accurate values; shape of curve is dissimilar because of low RCI in first year of construction DMI model predicts a slightly higher rate of deterioration; should be reduced for PMS2 models

Two Lift Hot Mix Overlay (Activity 103)

There were a total of 5 instances where a 2 Lift Hot Mix Overlay (Activity 103) treatment was performed on low-volume sections. Of these 5, 2 were on collector roads and 3 were on local roads, with a combined length of 55.4 km.

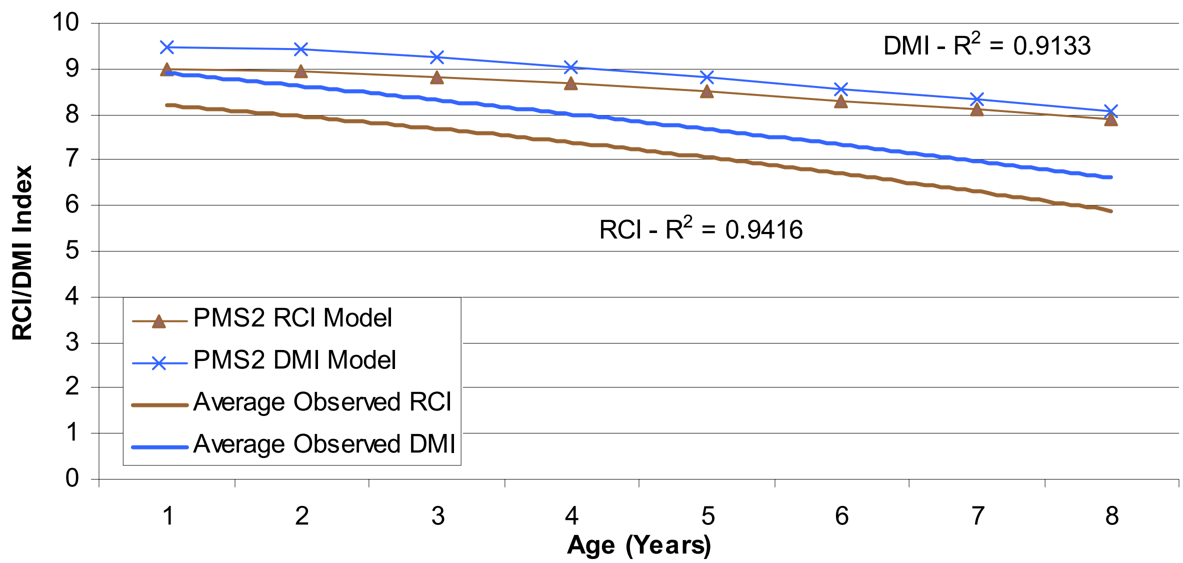

Figure 6 Comparison of Observed Versus Predicted RCI and DMI Performance of 2 Lift Hot Mix Overlay (Activity 103) on All Collector Roads

Figure 6 presents the observed versus predicted DMI and RCI values for 2 lift HMA Overlay treatment applied to all low-volume roads. It appears that both DMI and RCI have a higher initial value compared to the observed values. The initial value of RCI should be 8.5 and the rate of deterioration in the PMS2 model should be increased to improve prediction accuracy. Similarly, the DMI prediction model also gives values too high; initial DMI value should be around 9.0.

Considering the few instances of this activity that were observed on local roads, the observed performance of RCI and DMI appear lower than those predicted by the PMS/2 models. More data should be analyzed from this category before any further conclusions are made.

Full Depth Reclamation (FDR) and 1 Lift HMA Overlay (Activity 106)

There were a total of 25 instances where FDR plus 1 lift HMA Overlay treatment was performed on low-volume sections. Of these 25 sections, 1 belonged to the arterial class, 14 to collector roads and 10 to local roads, with a total length of 361.28 km (16% by length of all low-volume traffic roads used in this study). **Figure 7** displays the comparison between the observed PCI values with those predicted using the prediction models of PMS2 for Activity 106 applied to Collector roads. **Figure 8** presents the comparison between the observed PCI values with those predicted using the prediction models of PMS2 for Activity 106 applied to Local roads. **Figure 9** displays the comparison between the observed PCI values with those predicted by the PMS2 prediction models for Activity 106 applied to all low-volume roads. Summaries of the comments on these comparisons are listed in **Table 5.** It should be noted that the RCI value did not increase significantly in the first year after construction for this activity, especially in the case of the collector roads and local roads. It is a possibility that the pavement in these sections was not stable at the time the first measurement was taken. This would result in a lower initial value for the RCI curve and would skew the results.

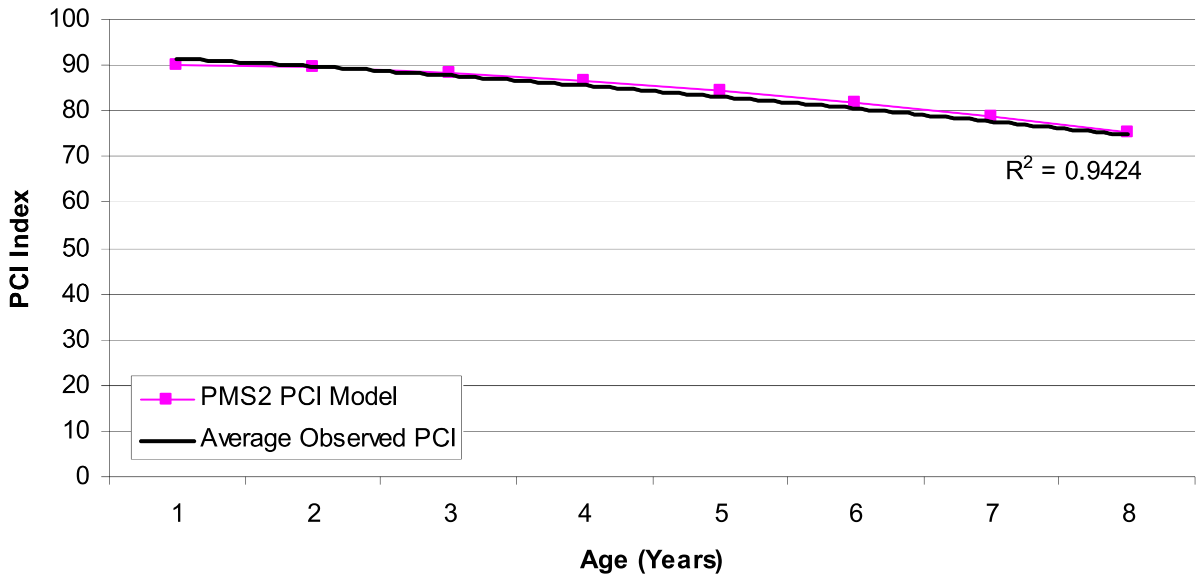

Figure 7 Comparison of the Observed Versus Predicted PCI Values for Activity 106 Applied to Collector Roads

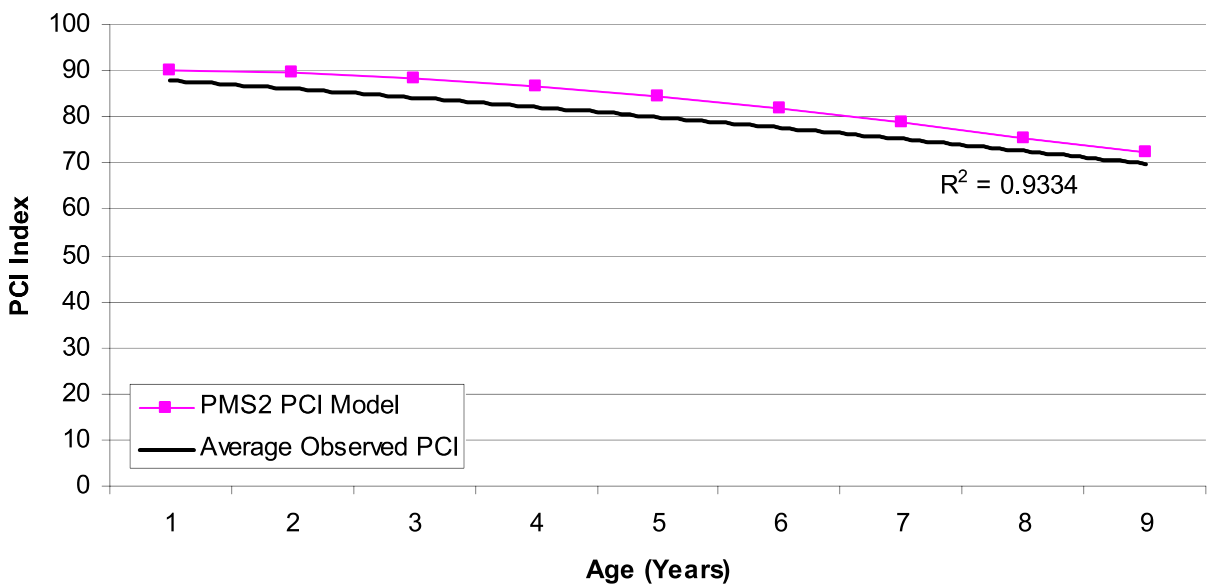

Figure 8 Comparison of the Observed Versus Predicted PCI Values for Activity 106 Applied to Local Roads

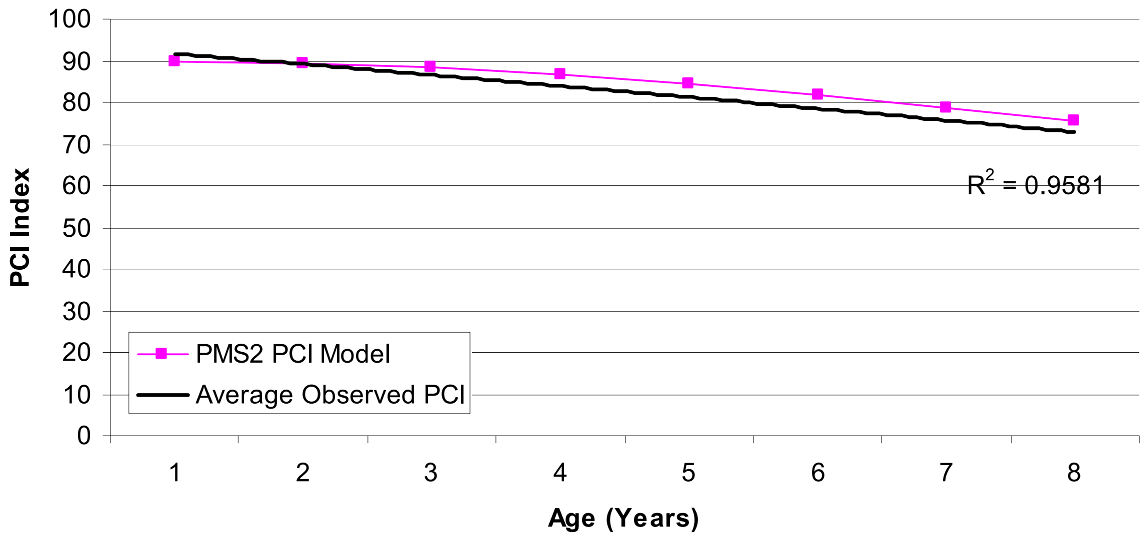

Figure 9 Comparison of the Observed Versus Predicted PCI Values for Activity 106 Applied to All Low-Volume Roads

Table 5: Comments on Comparison of Models and Observed Values for Activity 106

Item	Figure No.	Comments
PCI Performance on Collector Roads	7	The predicted performance of FDR and 1 lift HMA Overlay treatment for Collectors appears to be in agreement with the observed performance
PCI Performance on Local Roads	8	The predicted performance is very close to the observed performance; the initial PCI value used for the prediction model in PMS2 should be lowered to 85
PCI Performance on All Low-Volume Traffic Roads	9	The PCI prediction model compares favourably with the observed performance reviewed in this study

Full Depth Reclamation and 2 Lift HMA Overlay (Activity 107)

There were a total of 16 recorded FDR plus 2 Lift HMA Overlay treatments within the low-volume roads of the network, 8 of which belonged to the arterial class, 7 to collector roads and 1 to local roads. The total length of these 16 sections was 375.13 km, or roughly 16.6% by length of all low-volume traffic roads used in this study. **Table 6** lists the comments comparing the observed versus predicted performance of the FDR plus 2 lift HMA Overlay applied to all low-volume roads**.**

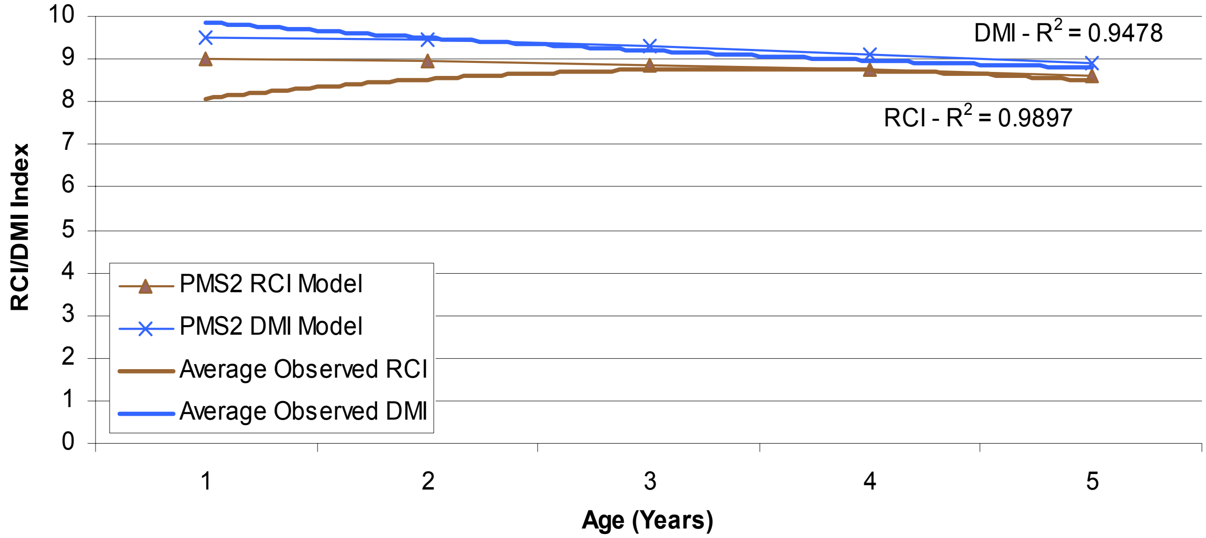

Figure 10 **Comparison of Observed versus Predicted RCI and DMI Performance of Activity 107Applied to All Low-volume Roads**

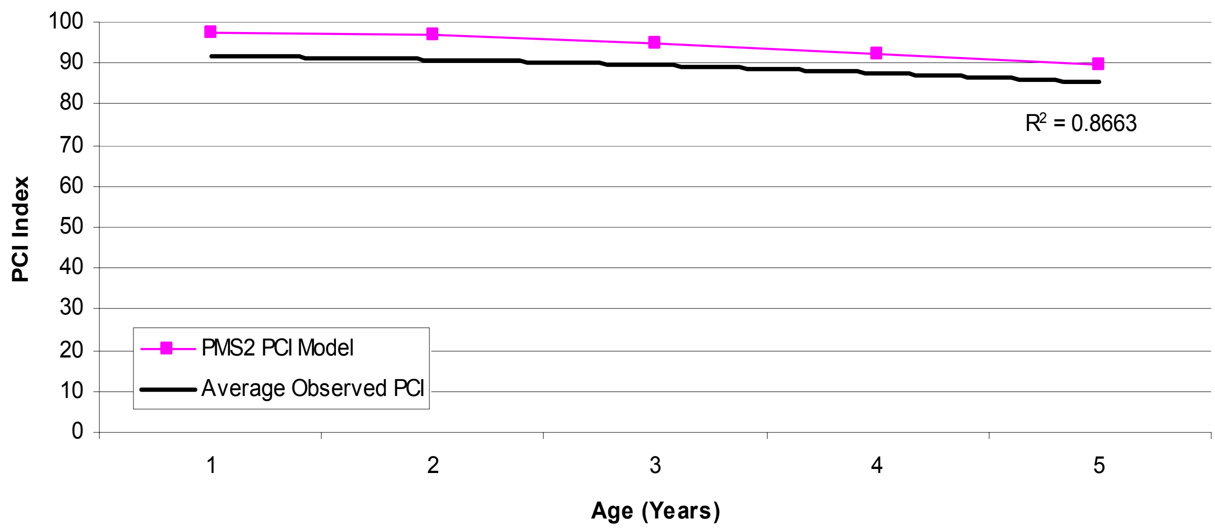

Figure 11 **Comparison of Observed Versus Predicted PCI Performance of Activity 107 Applied on All Low-volume Roads**

Figure 10 presents the observed and predicted RCI and DMI performance curves for Full Depth Reclamation plus 2 lift HMA Overlay treatment, while **Figure 11** presents the observed and predicted PCI performance curves for the same treatment.

Table 6: Comments on Observed Versus Predicted RCI, DMI and PCI for Activity 107

Item	# of Figure	Comments on Observed Versus Predicted Pavement Performance Values
RCI and DMI Performance on All Low-volume Roads	10	Both models fairly accurate; The RCI model is slightly inaccurate due to a low initial RCI value in the first year after construction; since this is a 2-lift treatment, it is possible that the initial RCI value was taken on the binder course.
PCI Performance on All Low-volume Roads	11	PCI Model predicts values too high but deterioration rate is good; initial value should be lowered to approximately 90

Surface Treatment (Activity 401)

There were a total of 49 instances where Surface Treatment was performed on low-density sections. The total length of these sections was 731.58 km, which is equivalent to 32.4% of all roads used in this study. Of these 49 sections, 7 were collector roads and 42 were local roads. Comments on comparisons of the observed versus predicted performance of pavement structures with Single Surface Treatment are listed in **Table 7.**

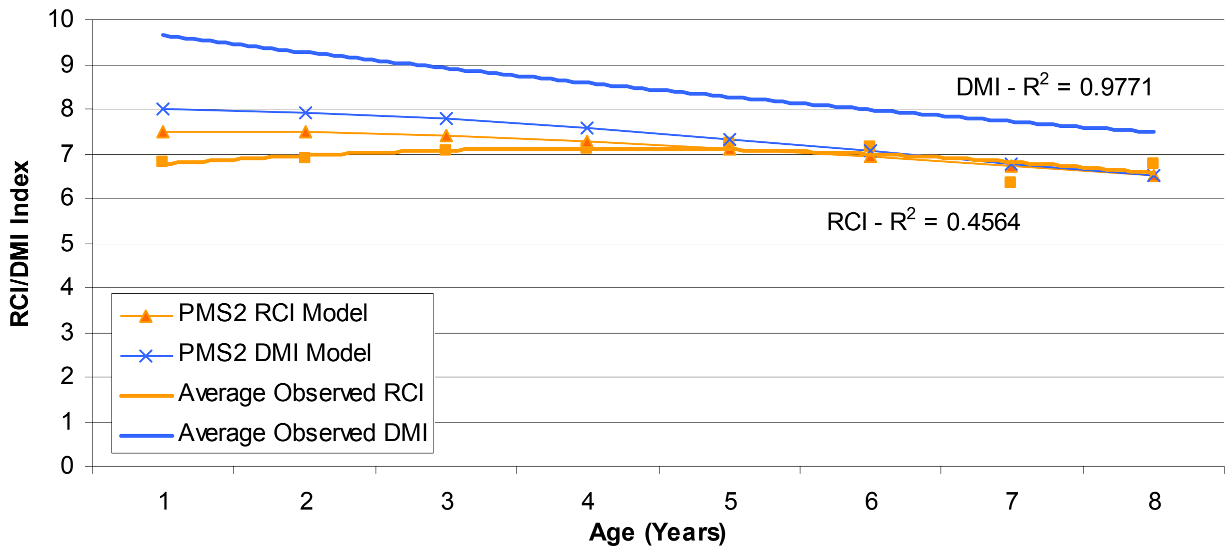

Figure 12 Comparison of Observed Versus Predicted RCI/DMI Performance of Activity 401 Applied on All Low-Volume Roads

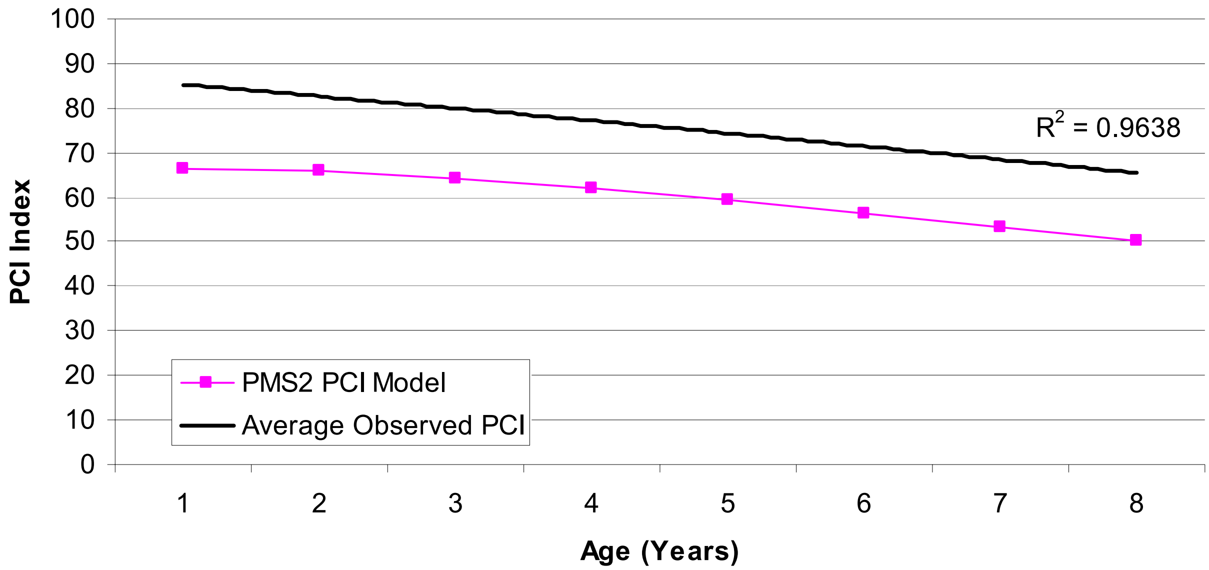

Figure 13 Comparison of Observed Versus Predicted PCI Performance of Activity 401 Applied on All Low-Volume Roads

Table 7 Comments on Observed Versus Predicted RCI, DMI and PCI Performance of Activity 401 Applied on all Low-Volume Roads

Item	# of Figure	Comments
RCI and DMI Performance on All Low-volume Roads	12	RCI model fairly accurate; initial value should be approximately 7. DMI model does not compare well to the observed DMI; the initial value should be close to 9.
PCI Performance on All Low-volume Roads	13	The PCI Model does not compare well to the observed PCI curve; the model predicts values significantly lower than observed; the initial value should be approximately 85. The comparison of the prediction model to observed performance of single surface treatments highlights to difficulties rating distresses and ride of short-lived surface treated surfaces. The model is predicting performance of a single surface treatment, however, in reality these single surface treatments are over existing surface treatments.

LIFE-CYCLE COST ANALYSES

Life Cycle Costing (LCC) is an economic analysis technique that is used to calculate initial construction costs of a pavement and convert future rehabilitation and maintenance costs over the analysis period into present day dollars [2]. The main function of LCCA is to evaluate the cost of particular initial, maintenance and rehabilitation activities versus its performance over the life of the pavement. Different combinations of M&R activities may prove to uphold the same level of road performance but at difference costs.

Figure 14 below is an example of historical performance of a Northern Ontario road section over 20 years. The scatter plot shows the observed PCI for each year and the line plot is the PMS/2 predicted performance. The vertical line shows the time when M&R treatments should be completed. As soon as the performance of the section reached below the PCI rehabilitation trigger value, in this case is 50 for the Arterial function class, M&R will be performed at the beginning of the next year. In this case, a Mill and 2 lift Hot Mix Overlay treatment (Activity 104) was performed in 1986, and when the condition of the pavement deteriorated to the rehabilitation trigger value of PCI = 50, a FDR and 2 lift Hot Mix Overlay treatment (Activity 107) was performed in 1996.

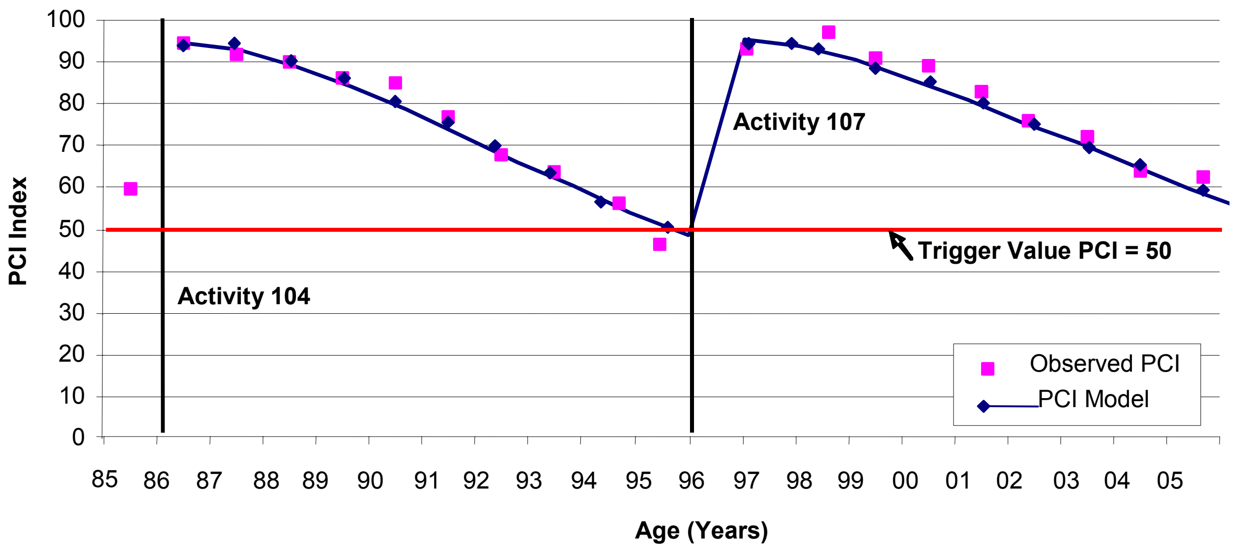

Figure 14 An Example of Historical Performance of a Road Section

Using the PMS/2 models to predict the performance of various treatments, it is possible to predict the costs associated with maintaining a road section above its trigger value in the long-term. By varying what combination of treatments are used, the most cost-effective method of keeping the pavement in good condition can be determined.

The cost effectiveness ratio (i.e., CE value) is the total effectiveness calculated within the analysis period and then divided by the total cost (or Net Present Value) of the section. The Cost Effectiveness Ratio of a 2-lane bi-directional section is calculated as follows:

$$CE = \left[\sum_{Yr=1985}^{2005} \{ AADT(Yr) \times 365 \times PCI(Yr) \} \right] \div NPV \qquad \textbf{(Eq. 1)}$$

The average annual daily traffic for the year is multiplied by 365 days and then multiplied by the PCI value for that year. However, the PCI is the difference between the predicted PCI value of each year and the PCI trigger value defined by road function class (i.e. $PCI_{year} - PCI_{trigger\ value}$).

Case Study: Low-Volume Roads Over a 30-year Time Period

As an example, an economic analysis was conducted over a 30-year time period to demonstrate the use of LCCA. All of the performance models, including the initial PCI performance value, were taken from the PMS/2 Index Prediction Models for low ESAL value roads. The cost information for the major rehabilitation activities was also taken from PMS/2 database, and it was assumed that the section in question was 6.5 metres wide and 1 km long.

The section was taken to have an area of 6500 m^2, and it was assumed that a series of preventive maintenance activities would be applied to the pavement section after a major rehabilitation activity. According to historic information and experience, about 3% of the total pavement surface area would require preventive maintenance in every second year after construction of 1 lift HMA Overlay, every third year after construction of mill and 2 lift HMA Overlay, and every forth year after construction of FDR plus 2 lift HMA Overlay. Salvage value [3] was taken into consideration by converting the remaining life of the pavement after 30 years and discounting it from the total cost.

A discount rate of 5.3% was used for the analysis period, and the Average Annual Daily Traffic (AADT) was taken to be 650 in the first year and increased by 1.25% each year thereafter for the study period. Three alternative pavement rehabilitation scenarios for the pavement section are analyzed through life-cycle cost economic comparisons, detailed as follows.

1 Lift Hot Mix Overlay Pavement – Scenario 1

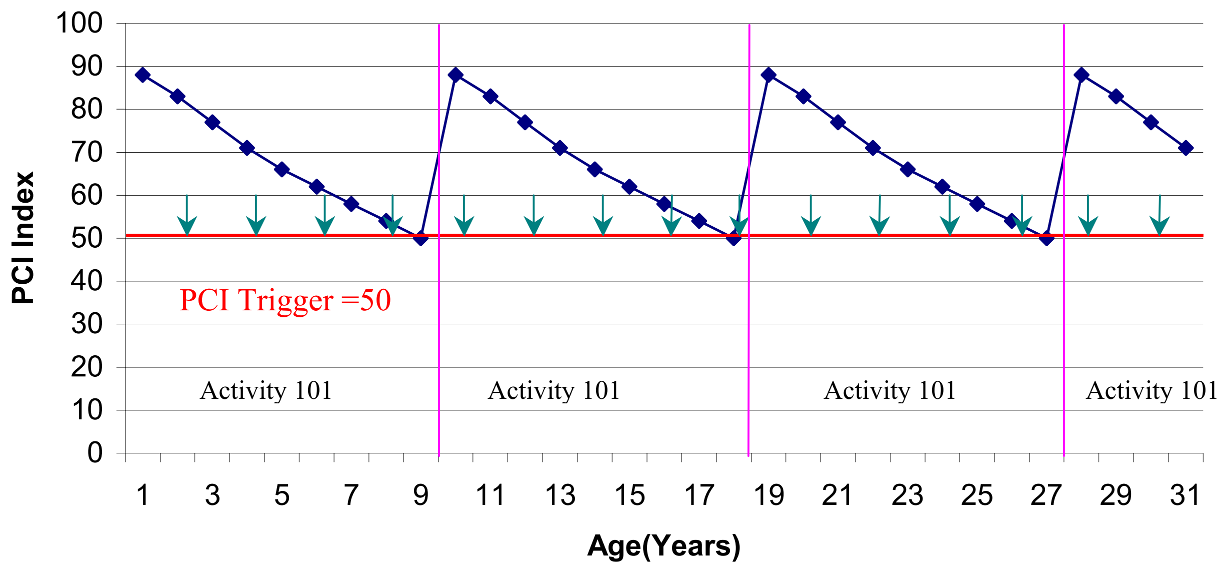

Figure 15 Predicted Pavement Performance Trends for Scenario 1

Figure 15 shows the predicted performance of the 1 km asphalt section over a 30-year time period. The vertical lines indicate when major M&R was completed, which in this case would be a 1 lift HMA Overlay treatment at year 0, 9, 18 and 27. In this scenario, the section has a functional class of Collectors, and thus the PCI rehabilitation trigger value is set at PCI = 50, as indicted by the horizontal red line on the graph above. As soon as the performance of the section reached below the trigger value, M&R was performed at the beginning of the next year.

The unit cost of a 1 lift HMA Overlay treatment (50 mm thick) is $\$15.23/m^2$, which equates to $98,995 per kilometre for this section, with preventive maintenance cost of $2969.85 in every second year after the 1 lift HMA Overlay treatment until the end of analysis period. For the last treatment, only 3 out of 9 years of service life were used in the analysis period, so it was calculated that $65,996.66 would be the salvage value discounted from the total cost. The summation of the Net Present Value (NPV) for this scenario including the application of the interest is as follows:

Total NPV = Initial Cost + NPV of Activity 101 in Year 9 + NPV of Activity 101 in Year 18 + NPV of Activity 101 in Year 27 + NPV of a series of preventive maintenance costs – NPV salvage/Residual

= $98,995 + $98,995(P/F, 5.3%, 9) +$98,995(P/F, 5.3%, 18+ $98 995(P/F, 5.3%, 27) +$2969.85(P/A, 5.3%, every second year) - $65,996.66 (P/F, 5.5%, 30)

= $230,149

The cost effectiveness ratio is calculated by multiplying the AADT and the effective PCI value for each year and then dividing that number by the total cost over the time period in question. For this scenario, the total effectiveness calculated for the analysis period is 170,754,899, and the cost effectiveness ratio is 742

1 Lift HMA Overlay then FDR with 2 Lift HMA Overlay and then 1 Lift HMA Overlay – Scenario 2

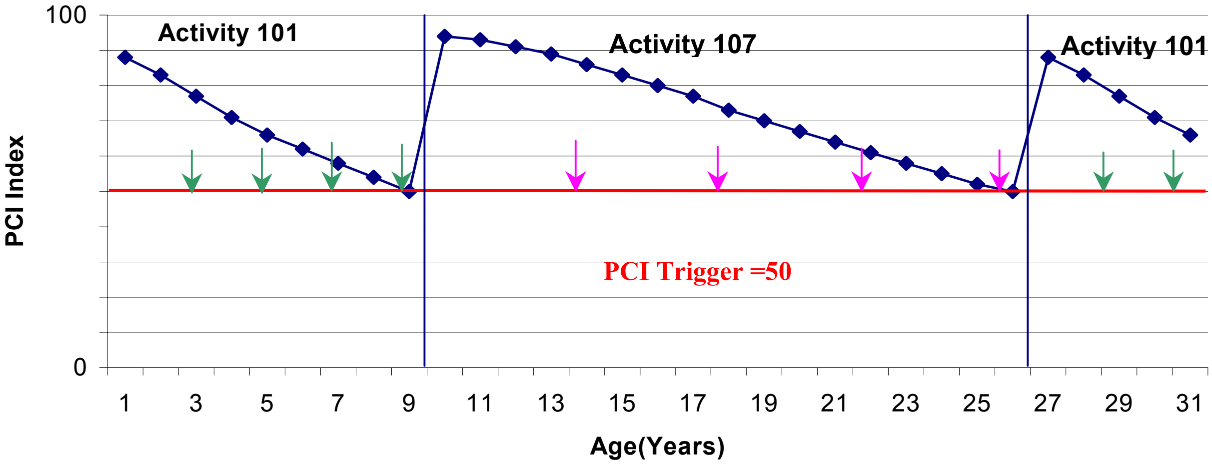

Figure 16 Predicted Pavement Performance Trends for Scenario 2

Figure 16 shows the predicted performance of the same 1 km asphalt section over a 30-year time period, except with a different M&R strategy. Again, the vertical lines indicate when major M&R was completed, in this scenario a single lift HMA overlay in Year 0, followed by FDR with 2 lift HMA overlay in year 9, and a single lift HMA is applied in Year 25. The section is Collectors function class, with a PCI rehabilitation trigger value at PCI = 50.

The unit cost of a FDR with 2 lift Hot Mix Overlay (80 mm thick) is $27.52/m^2$, which equates to $178,880 per kilometre for this section. For this scenario, a preventive maintenance is treatment applied in every second year after 1 lift HMA Overlay treatment, and the same preventive maintenance is applied in every third year after construction of FDR and 2 lift HMA Overlay. For the last treatment, 5 out of 9 years of its service life were used in the analysis period, so the salvage value is $43,998 discounted from the total cost. The Net Present Value is calculated as follows:

Total NPV = Initial Cost + NPV of Activity 107 in Year 9 + NPV of Activity 101 in Year 25 + NPV of a series of preventive maintenance costs – NPV salvage/Residual
= $98 995 + $178 880(P/F, 5.3%, 9) + $98 995 (P/F, 5.3%, 25) + $2969.85(P/F, 5.3%, a series of preventive maintenance costs) -$43,998 (P/F, 5.3%, 30)
=$243,649

For this scenario, the total effectiveness calculated for the analysis period is 194,905,460. Therefore, the cost effectiveness ratio is found to be 800.

Mill and 2 Lift HMA Overlay then FDR with 2 Lift HMA Overlay – Scenario 3

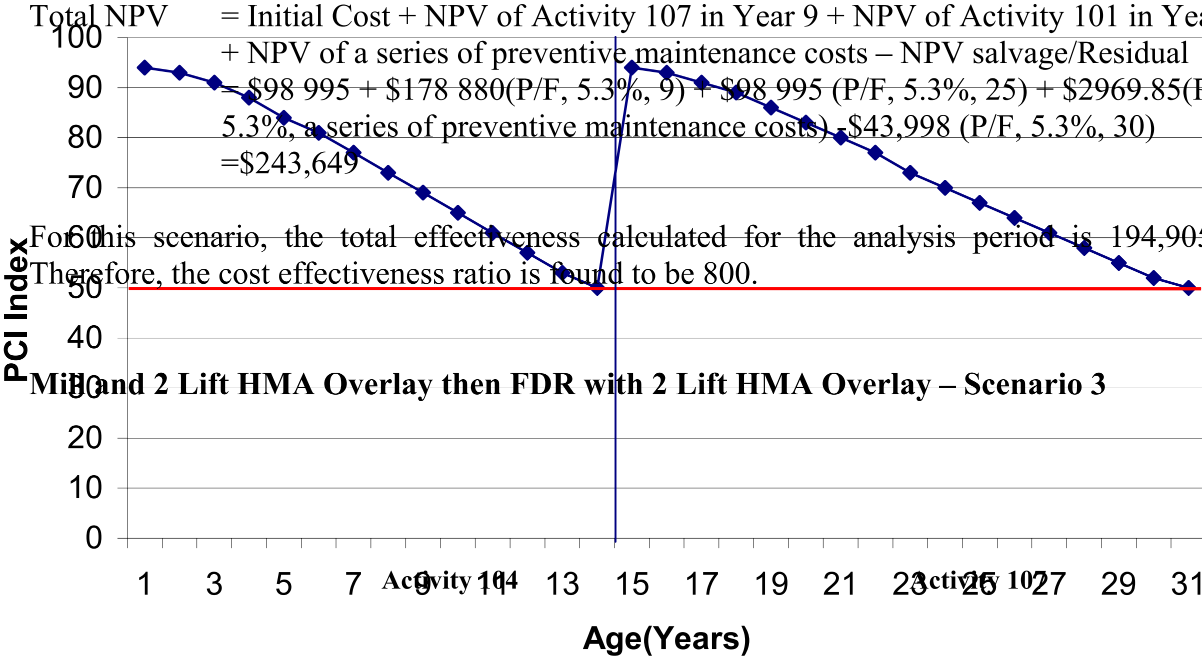

Figure 17 Predicted Pavement Performance Trends for Scenario 3

Figure 17 displays the performance of the third comparison scenario for AC Pavement. The activities are now a mill and 2 lift HMA Overlay treatment at the beginning of year 1, followed by a FDR plus 2 lift HMA Overlay treatment in year 14. The trigger value remains at PCI = 50 for Collector sections. The service life of the two treatments will last 30 years, which is equal to the analysis period. The unit cost of a mill and 2 lift HMA Overlay treatment is $\$25.12/m^2$, which equates to $163,280 per kilometre for this section. For this scenario, a preventive maintenance is treatment applied in every third year after construction of the mill and 2 lift HMA Overlay, and the same preventive maintenance is applied in every forth year after construction of the FDR and 2 lift HMA Overlay. There is no salvage value left by the end of analysis period. The summation of the Net Present Value including the application of the interest is as follows:

Total NPV = Initial Cost + NPV of Activity 107 in Year 14 + NPV of a series of preventive maintenance costs
= $163,280 + $178,880 (P/F, 5.3%, 14) + $2,969.85 (P/F, 5.3%, a series of preventive maintenance costs)
= $261,807

For this scenario, the total effectiveness calculated for the analysis period is 202,011,977, and the cost effectiveness ratio is 772.

COMPARISON OF LIFE-COST ANALYSIS SCENARIOS

Table 8 shows a comparison of the three scenarios above, as well as a breakdown of the costs:

In terms of cost-effectiveness ratio, it appears that Scenario 2 would be the best alternative. The total NPV cost for Scenario 2 alternative is a little more compared to Scenario 1, but the total effectiveness in Scenario 2 is higher than that in Scenario 1. In comparing Scenario 2 to Scenario 3, the total NPV costs are lower but the total effectiveness is similar. In addition, Scenario 2 involves only two major rehabilitation construction activities, while Scenario 1 has four major rehabilitation construction activities, which could cause more road user costs in terms of traffic delay and additional non-agency costs. Although in specific years the strategies will differ in terms of PCI value, overall they all maintain the pavement above the trigger value for 'Poor' condition, and Scenario 2 does this with the greatest cost effectiveness.

It must be noted however that this LCC analysis was quite simplified. Road user costs such as vehicle operating costs, travel time costs, traffic delay costs due to construction, accident costs and discomfort costs were not taken into consideration. Also, the cost information used for both major M&R activities as well as routine annual maintenance were just approximate estimates. The assumption that the AADT would increase by 1.25% per year, as well as any inaccuracies with the PMS/2 performance models, might also alter the results.

Table 8 Summary of AC Pavement LCCA Comparison

Economic Analysis Item	Scenario 1	Scenario 2	Scenario 3
Initial Treatment Cost	$ 98,995	$ 98,995	$163,280
First Rehab. Cost	62,195	112,384	86,808
Second & other M&R Cost	63,625	27,221	0.00
Maintenance Costs	19,351	14,394	11,718
Salvage Value	- 14,017	- 9,345	- 0.00
Net Present Value	$ 230,149	$ 243,649	$ 261,807
Total Effectiveness	170,754,899	194,905,460	202,011,977
Ratio of Cost Effectiveness	742	800	772
Number of Treatments	4	3	2

SUMMARY AND CONCLUSIONS

Many of the PMS2 performance prediction models appeared to match the actual observed performance curves quite well, while a few of them were inaccurate. However, the amount of data available for this study from the PMS/2 database was limited. Specially for the variations between observed pavement conditions right after pavement rehabilitation or reconstruction treatments and the initial values used in the prediction models, more data and investigations are needed to examine the resulting factors, such as construction deficiency, type of construction equipment, performance measuring techniques, etc. Consequently, no PMS/2 performance models should be discarded or modified based solely on this report. Rather, these results should be used only as an indication of what further investigations need to be carried out regarding specific activity performance models. Nonetheless, for the models that do match the observed pattern well, this report may serve as a justification for their continued use.

Based on the worked examples, Life-Cycle Cost Analysis is a tool that is making decisions for selecting the most cost effective maintenance and rehabilitation treatments for low volume pavement section. The analyses mentioned in this report are simplified, but even so they provide adequate demonstration of the use of LCCA to simplify decision-making. With additional data such as user costs and accurate pricing information available, it is evident that LCCA can be put to practical use for low-volume roads and can improve the quality of decisions made regarding maintenance and rehabilitation strategies.

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