# *Development of an Approach for Evaluating the Pavement Rehabilitation Performance using City of Ottawa PMS Data*

Amr Ayed, Ph.D, P.Eng

Amir Abd El Halim, Ph.D, P.Eng

Giannin Viecili, P.Eng

Richard Korczak, P.Eng

(*Stantec Consulting*)

Amjad Ali, P.Eng

Susan O'Connor, P.Eng

(*City of Ottawa*)

Paper prepared for presentation

at innovation in pavement management, engineering and technologies session

of the 2018 Annual Conference of the Transportation Association of Canada

Saskatoon, SK

**Abstract:**

The City of Ottawa rehabilitates its road network through its annual road resurfacing program and integrated road-sewer-watermain reconstruction. The treatment strategies can vary from preservation treatments (i.e., crack sealing, microsurfacing, and thin overlays) to resurfacing (i.e., mill and overlay, pulverize and pave) to reconstruction. The City commissioned Stantec Consulting to perform a Pavement Performance Study. One of the study objectives was to carry out a comprehensive review of the performance /effectiveness of the pavement rehabilitation strategies used by the City. The City uses a computerized Pavement Management System (PMS) as an important tool to manage its road network, especially in the development of its Annual Road Resurfacing Program. The PMS is used for core inventory related to City's entire road network. The system is continually updated with pavement condition data (roughness and surface distress data) collected under an annual program in a manner that condition data for each road is collected on a 3 to 5-year cycle.

Using the information stored in the City's PMS, Stantec reviewed the information to determine the effectiveness of treatments used by the City for the past two decades. Historical condition and construction history information of the sections was used to evaluate the effectiveness of each treatment. Two different approaches, benefit increase and effectiveness area, were utilized to evaluate the effectiveness of the City's treatments. The effectiveness of a treatment can be defined as the difference in area between the post-treatment performance curve and the do-nothing curve over time. The "jump" in pavement condition after a maintenance treatment can be called the benefit increase, which is measured in the units of a performance index. Statistical analysis was carried out to compare between different treatments and identify best strategies that can be adopted by the City for future maintenance programs. The treatment effectiveness area approach was further utilized to compare between different types of asphalt mix (Marshall mix vs. Superpave). In addition, it was used to assess the effect of pavement cross section on the pavement performance.

## 1.0 INTRODUCTION

The City of Ottawa (the City) retained Stantec Consulting Ltd. (Stantec) to conduct a pavement performance study that included a comprehensive review of the performance/effectiveness of the pavement rehabilitation strategies used. The City maintains a road network of approximately 5,900 centreline-km or 14,900 lane-km. The pavement types include flexible (high class bituminous), flexible (low class bituminous), flexible (Regional), Portland Cement Concrete (PCC), composite (Hot Mix Asphalt, HMA, over PCC base) and gravel. This network needs to be managed cost-effectively to provide a desirable level of service to the stakeholders.

An important tool in the management of the City’s road network is a computerized PMS. especially in developing its Annual Road Resurfacing Program. The PMS is used for core inventory related to City’s entire road network. The system is continuously updated with pavement condition data (roughness and surface distress data) collected in an annual program so that condition data for each road is collected on a 3-5-year cycle.

The City rehabilitates its road network through its Annual Road Resurfacing Program and integrated Road-Sewer-Watermain reconstruction. The treatment strategies vary from preservation treatments (i.e., crack sealing, microsurfacing, and thin overlays) to resurfacing (i.e., mill and overlay, pulverize and pave) and reconstruction. When establishing annual resurfacing programs, various renewal options are considered to optimize the life cycle of the roadways. the treatments investigated are presented in Table 1.

Data was collected related to the historical pavement condition data, work history and analysis data from the system to perform a review for completeness. Using this information, a master database was created by combining several of the tables and/or fields from the data provided. The master database was created by combining multiple data sources and cross-referenced to create an environment where the treatment effectiveness could be assessed. the basis of this analysis was Historical condition and construction history for each pavement section.

## Table 1: Treatment Categories

| Type | Sub-type | Strategy |
|---|---|---|
| **Preservation** | Slurry seal / Microsurfacing | Slurry seal on surface treated roads |
| | | Microsurfacing on surface treated roads |
| | | Microsurfacing on hot mix asphalt (HMA) roads |
| | Thin overlay | Overlays 15-20 mm on hot mix asphalt roads |
| | Thin mill and overlay | Mill 15-20 mm and overlay 15-20 mm |
| | | |
| **Resurfacing** | Overlay | 40-50 mm overlay |
| | Mill and overlay | Mill partial depth (40 mm) and overlay 40 mm |
| | | Mill partial depth (50 mm) and overlay 50, 60, 90 mm and above |
| | | Mill full depth and pave 50, 60, 90 mm and above |
| | Hot-in-place recycling | Recycle without overlay |
| | | Recycle and overlay 50 mm and above |
| | | |
| **Major Rehabilitation** | Pulverize and Pave | Pulverize full depth and overlay 50, 60, 90, 110, 120 mm and above, with/without adding granular |
| | Rubblize and Pave | Rubblize existing PCC slab and pave 50 mm and above |
| | Pulverize and Surface treat | Pulverize existing surface treated (low class bitumen) road and apply two coats of surface treatment |
| | Cold-in-place recycling | Recycle partial depth and overlay 50 mm and above |
| | | Recycle full depth and overlay 50 mm and above |
| | | |
| **Reconstruction** | Reconstruction | Excavate and replace with new materials- typically: AC= $90^{+}$ mm, Granular A= $150^{+}$ mm and Granular B= $300^{+}$ mm |
| | | |
| **New Construction** | Capital Growth | New construction of Arterial and Collector roadways, and Transit Busway |
| | Capital Development | New construction of Local and Collector roadways with conventional flexible pavement structures |
| | | New construction of Local and Collector roadways with flexible pavement structures over lightweight fill |

## 2.0 METHODOLOGY

The analysis of the data was completed in three stages. The first stage was to carry out a comprehensive gap analysis to identify incompleteness in the data provided by the city. The second stage was to build an integrated linked database that can be further used in the third stage to retrieve information that will be used to evaluate treatment effectiveness.

A variety of data is available in the PMS including construction history, traffic information and condition history for pavement sections within the network. Treatment history was essential for this analysis to compare the effectiveness for each type. The construction data used included the program type, project type, completion date, material details and thicknesses, location and other site-specific data. This historical construction information was assessed and used to classify the construction activities into categories as outlined in Table 1. Historical records of the Pavement Quality Index (PQI) for each section was used in the analysis to assess the overall performance of rehabilitation strategies.

The existing PMS used by the City was Stantec PMS Version 1.43 and pre-dates the City of Ottawa amalgamation in 2001. Prior to amalgamation, four municipalities (Ottawa, RMOC, Nepean and Gloucester) were using independent Pavement Management Application (PMA's). In 2002, shortly after amalgamation, these four PMA's were harmonized into one consolidated PMA for the newly expanded City of Ottawa. The majority of the information available in the PMS is post 2000, which is likely related to the amalgamation.

### 2.1 GAP ANALYSIS

A gap analysis was performed to review all the available data for completeness. Sections with missing construction/condition dates, unclassified pavement type/construction activities or sections ID's were identified for further examination. Any sections with missing information were eliminated from the study to ensure consistency of the data.

### 2.2 DATABASE DEVELOPMENT

Following the gap analysis of the data, a master database was constructed by combining and linking several of the tables and/or fields. Construction and condition history, section details were aggregated and linked using their unique PMS Asset ID. Hardcoding through Microsoft Excel and using SQL queries in Microsoft Access allowed the data to be reorganized into a dynamic usable format.

General tables were created to monitor section performance over time. Each section has been tied to its construction history activities and PQI condition over time. These tables link the rehabilitation history with its PQI condition data. This was used to assess the pavement condition in relation to the treatment provided. Using this developed database, it was possible to monitor pavement age and condition over time for each treatment. The formation of a dynamic linked database was an essential step in analyzing the treatment effectiveness.

## 2.3 TREATMENT EFFECTIVENESS

The effectiveness of the City's pavement rehabilitation treatments was determined by utilizing the construction history and performance history. Effectiveness of a pavement treatment can be evaluated using several methods. The benefit increase, improved pavement performance, expected service life, area between the performance curve and the threshold are all indicators of effectiveness. Based on available information, literature, industry standard practice and experience, this study used the benefit increase and area under the condition/age curve to determine the effectiveness of the City's pavement treatments. These methods are detailed in the section below.

The database developed was used to identify pavement sections that contained both construction and condition history data. Scenarios with consecutive condition records (immediately after different treatments) were used to calculate treatment effectiveness. Outliers where there was no deterioration trend, or undefinable treatments, were eliminated from the analysis.

The treatment effectiveness was analyzed using the Pavement Quality Index (PQI) stored in the PMS. Two methodologies were explored in this study to evaluate the treatment effectiveness: area under the curve and benefit increase. The two approaches are explained in the following subsection.

### 2.3.1 Area Under Performance Curve Method

The effectiveness of a treatment can be defined as the difference in area between the post-treatment performance curve and the do-nothing curve shown in Figure 1 (1). This method is superior to the others as it takes into consideration the service life of the treatment, pavement condition and quantifies the improvement in pavement performance. Thus, treatments with a lower rate of deterioration are more effective.

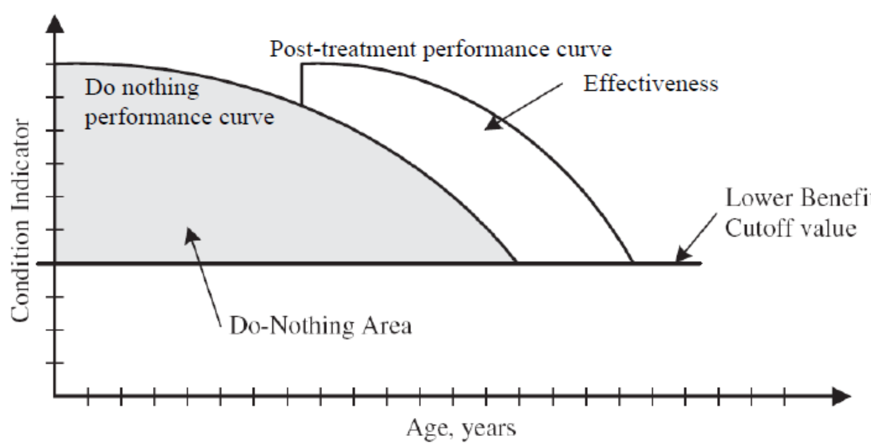


**Figure 1: Conceptual Illustration of the Effectiveness**

The sequential methodology used was as follows:

- *Define Performance Indicators and Benefit Cutoff Values:*
  As previously discussed, the performance indicator used in this study was PQI. A lower benefit cutoff value is the PQI condition when a section will need to receive a rehabilitation activity to maintain

functional performance. The PQI trigger values used are based on the functional class, shown in Table

**Table 2: Ottawa PMS Trigger Levels**

| Road Functional Class | PQI Trigger Level |
|---|---|
| Class 1, Class 2, Arterial, Freeway | 5.0 |
| Collector, Major Collector | 4.5 |
| Local streets, Lanes | 4.0 |

- *Determine Do-nothing and Post-Treatment Performance Relationships:*
  The "do-nothing" performance curve represents what would occur if no maintenance was conducted on the pavement section. The post-treatment performance was defined using recorded historical data after each treatment.
- *Identify Benefit of Treatment:*
  The following formula was used to determine the effectiveness/benefit for each treatment type (2) where all areas are calculated along treatment service life.

$$Area_{Benefit} = Area_{Post\ Treatment} - Area_{Do\ nothing}$$

To provide fair comparison among different treatments, the treatment with the highest PQI effectiveness was used to provide a weighted effectiveness for other treatments. An example is shown in Table 3, where the highest raw PQI effectiveness was 30.7 for reconstruction treatments. To compare these results, other treatments were normalized based on the highest effectiveness (Reconstruction in this case). Accordingly, new normalized effectiveness is calculated for each treatment as shown in Table 3. For example, the normalized effectiveness for major rehabilitations was calculated as follow:

$$Normalized\ PQI\ Effectiveness\ for\ Major\ Rehabilitation\ = \frac{24.8}{33.4} \times 100 = 74$$

**Table 3: Raw and Normalized Effectiveness Example**

| Treatment | Effectiveness | |
|---|---|---|
| | Raw Avg. | Normalized Avg. |
| **Major Rehabilitation** | 24.8 | 74 |
| **Reconstruction** | **33.4** | **100** |
| **New Construction** | 32.5 | 97 |

### 2.3.2 Benefit Increase Method

The benefit increase in pavement condition after a maintenance treatment is also an indication of treatment effectiveness. These values are measured in the units of the performance index. The increase in condition following a treatment is illustrated in Figure 2 below.

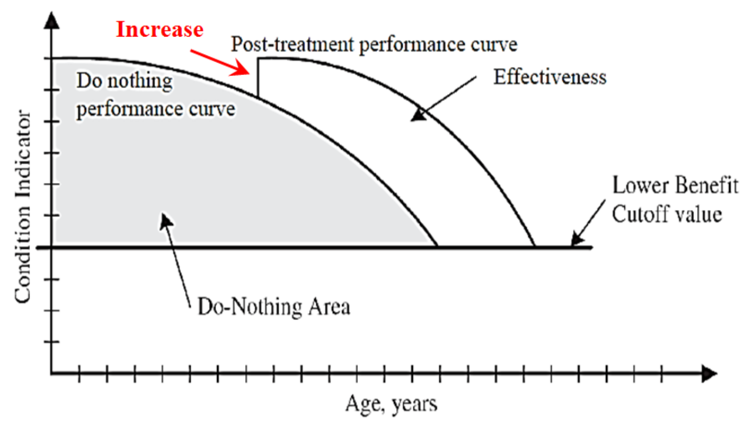


**Figure 2: Benefit Increase in Condition Following Treatment[1]**

This increase was calculated for each treatment type and strategy based on historical condition data.

## 3.0 ANALYSIS RESULTS

The results were summarized at three levels. The first level where treatments were all grouped into five major categories. The raw and normalized effectiveness as well as the increase in condition following the treatment type are presented in Table 4. The data was normalized based on the treatment with the highest effectiveness (Reconstruction).

At the second level, the treatments were grouped into sub-types. The raw and normalized effectiveness as well as the increase in condition following the treatment sub-type are presented Table 5. The data was normalized based on Capital Development effectiveness and Capital Growth benefit increase values.

The third level is the most detailed breakdown of treatments. The raw and normalized effectiveness as well as the increase in condition following the treatment strategy are presented Table 6 below. The data was normalized based on Capital Development effectiveness and Mill and Overlay benefit increase values. The analysis of the data at the third level provides a methodology for the city to assess deficiencies and needs at strategic as well as project level stages. As expected, Reconstruction and New construction treatments provided the most cost-effective alternatives. These treatments provide the best alternatives at network level analysis and budgeting stage. Other alternatives such as Mill and Overlay showed significant improvement in treatment effectiveness which indicates that in some cases a Resurfacing strategy could provide a similar or better improvement to pavement condition than the Major Rehabilitation or Reconstruction strategies. Within preservation treatments, Thin Overlays showed the highest effectiveness. Within Resurfacing, Hot-in-place Recycling yielded the highest effectiveness, however the sample size was very small and may not be representative. In the Major Rehabilitation treatment type, Pulverize and Surface Treat had the highest effectiveness.

**Table 4: Effectiveness and Benefit Increase by Treatment Type**

| Type | Treatment Effectiveness | | | | | | Benefit Increase | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Avg | StDev | Count | Normalized Avg | Min | Max | Avg | StDev | Count |
| **Preservation** | 4.8 | 41.5 | 21.1 | 4.5 | 276 | 63 | 0.02 | 6.3 | 1.2 | 0.9 | 276 |
| **Resurfacing** | 4.1 | 47.5 | 21.8 | 6.4 | 788 | 65 | 0.04 | 6.5 | 2.1 | 1.4 | 788 |
| **Major Rehabilitation** | 14.5 | 42.6 | 24.8 | 4.4 | 134 | 74 | 0.10 | 6.5 | 2.1 | 1.2 | 134 |
| **Reconstruction** | 3.5 | 64.0 | **33.4** | 13.8 | 190 | 100 | 0.01 | 6.6 | **2.9** | 1.7 | 190 |
| **New Construction** | 5.5 | 62.2 | 32.5 | 14.5 | 130 | 97 | - | - | - | - | - |

**Table 5: Effectiveness and Benefit Increase by Sub-Type**

| Type | Sub-type | Treatment Effectiveness | | | | | Benefit Increase | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Avg | StDev | Normalized Avg | Min | Max | Avg | StDev |
| **Preservation** | Slurry seal/Microsurface | 4.8 | 32.0 | 21.1 | 4.3 | 60 | 0.02 | 4.4 | 1.1 | 0.7 |
| | Thin Overlay | 6.2 | 41.5 | 21.3 | 6.7 | 60 | 0.05 | 6.3 | 2.0 | 1.0 |
| | Thin mill and overlay | 13.6 | 20.4 | 17.0 | 2.2 | 48 | 0.22 | 4.0 | **3.0** | 1.0 |
| **Resurfacing** | Overlay | 5.1 | 40.5 | 22.8 | 6.1 | 65 | 0.10 | 6.5 | 1.5 | 1.1 |
| | Mill and overlay | 4.1 | 47.5 | 21.2 | 6.5 | 60 | 0.04 | 6.5 | **2.8** | 1.4 |
| | Hot-in-place recycling | 27.3 | 27.3 | **27.3** | 0.0 | 77 | 1.36 | 1.4 | 1.4 | 0.0 |
| **Major Rehabilitation** | Pulverize and Pave | 17.6 | 42.6 | 25.5 | 5.5 | 72 | 0.50 | 6.5 | 2.8 | 1.5 |
| | Rubblize and Pave | 14.5 | 27.3 | 22.6 | 2.6 | 64 | 0.75 | 3.4 | 1.9 | 0.6 |
| | Pulverize and Surface treat | 27.4 | 30.1 | **29.6** | 1.0 | 84 | 0.70 | 1.7 | 1.6 | 0.4 |
| | Cold-in-place recycling | 19.9 | 30.6 | 25.7 | 3.9 | 73 | 0.10 | 4.3 | 1.5 | 1.2 |
| **Reconstruction** | Reconstruction | 3.5 | 64.0 | 33.4 | 13.8 | 94 | 0.01 | 6.6 | 2.9 | 1.7 |
| **New Construction** | Capital Growth (City Projects) | 6.4 | 54.1 | 26.0 | 8.9 | 74 | - | - | - | - |
| | Capital Development | 5.5 | 62.2 | **35.3** | 15.5 | 100 | - | - | - | - |

**Table 6: Effectiveness and Benefit Increase by Strategy**

| Strategy | Treatment Increase | | | | | Benefit Increase | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Avg | StDev | Normalized Avg | Min | Max | Avg | StDev |
| Slurry seal on surface treated roads | 18.2 | 31.4 | 24.2 | 4.0 | 69 | 0.60 | 1.5 | 1.0 | 0.2 |
| Microsurfacing on surface treated roads | 20.9 | 27.9 | 26.3 | 2.4 | 75 | 0.73 | 1.0 | 0.9 | 0.1 |
| Microsurfacing on hot mix asphalt (HMA) roads | 4.8 | 25.7 | 20.0 | 3.3 | 57 | 0.02 | 4.4 | 1.1 | 0.7 |
| Overlays15-20 mm on hot mix asphalt roads | 15.0 | 41.5 | 25.4 | 7.5 | 72 | 0.05 | 6.3 | 2.2 | 2.0 |
| Mill 15-20 mm and overlay 15-20 mm | 13.6 | 20.4 | 17.0 | 2.2 | 48 | 0.22 | 4.0 | 3.0 | 1.0 |
| Overlay/Thin Mill and overlay | 6.2 | 32.1 | 20.8 | 6.5 | 59 | 0.66 | 3.2 | 2.0 | 0.8 |
| 40-50 mm overlay | 5.1 | 40.5 | 22.8 | 6.1 | 65 | 0.10 | 6.5 | 1.5 | 1.1 |
| Mill partial depth (40 mm) and overlay 40 mm | 4.1 | 47.5 | 22.1 | 8.5 | 63 | 0.10 | 6.2 | 2.8 | 1.6 |
| Mill partial depth (50 mm) and overlay 50, 60, 90 mm and above | 4.5 | 42.5 | 21.0 | 5.6 | 60 | 0.04 | 6.5 | 2.7 | 1.3 |
| Mill and overlay (Partial Depth) | 11.3 | 22.8 | 16.0 | 3.8 | 45 | 1.30 | 3.4 | 2.6 | 0.6 |
| Mill full depth and pave 50, 60, 90 mm and above | 13.7 | 33.9 | 20.4 | 11.7 | 58 | 2.96 | 4.2 | **3.8** | 0.7 |
| Mill and Overlay | 12.9 | 32.5 | 20.5 | 4.5 | 58 | 0.80 | 3.0 | 2.1 | 0.6 |
| Recycle without overlay | 27.3 | 27.3 | 27.3 | 0.0 | 77 | 1.36 | 1.4 | 1.4 | 0.0 |
| Pulverize full depth and overlay 50, 60, 90, 110, 120 mm and above, with/without adding granular | 17.6 | 42.6 | 25.5 | 5.5 | 72 | 0.50 | 6.5 | 2.8 | 1.5 |
| Rubblize existing PCC slab and pave 50 mm and above | 14.5 | 27.3 | 22.6 | 2.6 | 64 | 0.75 | 3.4 | 1.9 | 0.6 |
| Pulverize existing surface treated (low class bitumen) road and apply two coats of surface treatment | 27.4 | 30.1 | 29.6 | 1.0 | 84 | 0.70 | 1.7 | 1.6 | 0.4 |
| Recycle partial depth and overlay 50 mm and above | 20.4 | 29.7 | 22.3 | 2.4 | 63 | 0.10 | 1.8 | 0.5 | 0.4 |
| Recycle full depth and overlay 50 mm and above | 19.9 | 19.9 | 19.9 | - | 56 | 0.14 | 0.1 | 0.1 | - |
| Cold-in-place recycling | 23.6 | 30.6 | 28.2 | 2.5 | 80 | 0.78 | 4.3 | 2.3 | 0.9 |
| Excavate and replace with new materials- typically: AC= 90+ mm, Granular A= 150+ mm and Granular B= 300+ mm | 3.5 | 64.0 | 33.4 | 13.8 | 94 | 0.01 | 6.6 | 2.9 | 1.7 |
| New construction of Arterial and Collector roadways, and Transit Busway | 8.8 | 54.1 | 26.9 | 7.7 | 76 | - | - | - | - |
| New construction of Local and Collector roadways with conventional flexible pavement structures, or with flexible pavement structures over lightweight fill | 5.5 | 62.2 | **35.3** | 15.5 | 100 | - | - | - | - |
| Capital Growth or Development | 6.4 | 45.0 | 21.7 | 13.2 | 61 | - | - | - | - |

## 4.0 RESULTS COMPARIOSN

The treatment effectiveness results were further utilized to compare performance among different mix designs and pavement cross sections. Analysis of Variance (ANOVA) was used in this study to determine if there was a significant difference in performance for Urban and Rural Cross-sections, and Superpave and Marshall Mix sections.

### 4.1 EFFECT OF MIX DESIGN ON THE PERFORMANCE OF A TREATMENT STRATEGY

Two of the most common asphalt mixes used are Superpave (SP) and Marshall Mix (MM). As opposed to other methods, the Superpave mix design method considers traffic and climate. Differences between the two methods are highlighted below.

Several studies were done on the performance of the mixes designed to Superpave and Marshall methods. A study by Watson et al., performed in Alabama on 25 pavement sections showed that both mixes performed well over a 4-year period. It was found that the durability of the Superpave mixtures could be improved by increasing asphalt content (3). Another study by Asi, performed in Jordan using laboratory testing of prepared samples from both methods found the Superpave mixes have superior results (4). Additionally, a study in Thailand by Jitsangiam et al., considered the performance of Superpave and Marshall asphalt mix designs using experimental laboratory analysis and found Superpave superior (5). In Malaysia, Ahmad et al. found the same results and tests showed SP designed mixtures are more resistant to rutting and moisture damage (6). In Taiwan, a similar study by Wang et al. found Superpave mixtures were more resistant to permanent deformation (7).

In this study, sections were identified based on the surface type using a Marshall Mix or Superpave mix design. The effectiveness of these mixes over time was compared.

#### 4.1.1 Study Results

The effect of using Marshall Mix and Superpave mixes on treatment effectiveness was evaluated, the P-Values calculated from the T-tests are presented below in Table 7. The results of the T-test performed to determine the variation of Effectiveness when using Marshall Mix and Superpave mixes illustrates that Marshall Mix designed pavement sections have statistically significant higher effectiveness values at a 95% confidence level. However, it should be noted that the difference in effectiveness between the mix types is very small as indicated by the p-values greater than zero, but less than 0.05.

**Table 7: Results of T-Test for Marshall Mix and Superpave Effectiveness**

| | Raw Superpave PQI Effectiveness | Raw Marshall Mix PQI Effectiveness |
|---|---|---|
| **Mean** | 24.1 | 27.0 |
| **Variance** | 95.3 | 65.2 |
| **Observations** | 155 | 102 |
| **Hypothesized Mean Difference** | 0 | |
| **df** | 255 | |
| **t Stat** | -2.52 | |
| **P(T<=t) one-tail** | 0.01 | |
| **t Critical one-tail** | 1.65 | |
| **P(T<=t) two-tail** | 0.01 | |
| **t Critical two-tail** | 1.97 | |

## 4.2 EFFECT OF PAVEMENT CROSS-SECTION ON THE PERFORMANCE OF A STRATEGY

The pavement design feature that sets urban and rural roads apart is the drainage system. Rural roads are constructed using ditches to collect and remove surface water as opposed to controlled edge drainage in urban roads. The urban drainage systems are typically comprised of curbs and catchbasins. Minimizing the infiltration and allowing a water to drain to an appropriate outlet will extend the life (8). The advantages and disadvantages of urban and rural drainage systems are listed in Table 8 below.

**Table 8: Advantages and Disadvantages of Urban and Rural Drainage Systems in Terms of Pavement Performance (9)**

| **Urban Cross-Section: Curbs and Gutters** | |
|---|---|
| **Advantages** | **Disadvantages** |
| Promote safety for motorists and pedestrians by offering a physical barrier.<br>Protects the road edge and road base from erosion and reduces sod damage from snow ploughing activities.<br>Roads with curbs and gutters can be designed to create low points where excess storm water can be retained. | Slippery conditions on roads due to clogging of catch basins.<br>Water ponding during storms or blockage of inlet by ice or debris can create hydroplaning conditions.<br>Can increase downstream channel erosion. |
| **Rural Cross-Section: Ditch with or without culvert** | |
| **Advantages** | **Disadvantages** |
| Lower peak flows result in some erosion control benefits.<br>During intense storms, water is less likely to pond on surface of the road. | Local flooding during spring snowmelt if there is a culvert blockage.<br>Can be difficult to maintain if side slopes are steep and ditches retain water. |

In this study, the sections were identified being Urban or Rural based on the presence of curbs and subsurface drainage. A comparison of Urban and Rural Cross-section effectiveness is discussed below. It should be noted that this is a general analysis where all treatment types were included.

### 4.2.1 Study Results

The effect of a pavement section using an Urban/Rural cross-section on the treatment effectiveness is shown below in Table 9. Microsurfacing is conducted on both types of roadways in the network. Pulverize and Pave and Full Depth Removal and Pave is typical for Rural roads. Mill and Pave is common for Urban sections in the network.

**Table 9: Treatment Effectiveness of Urban and Rural Sections**

| Treatment Sub Type | Treatment Effectiveness | | | | | |
|---|---|---|---|---|---|---|
| | Type | Min | Max | Avg | StDev | Count |
| Microsurfacing on hot mix asphalt (HMA) roads | Rural | 6.8 | 25.6 | 20.8 | 2.4 | 125 |
| | Urban | 4.8 | 25.7 | 20.0 | 3.3 | 187 |
| Mill partial depth (50 mm) and overlay 50, 60, 90 mm and above | Urban | 4.5 | 42.5 | 21.0 | 5.6 | 266 |
| Mill full depth and pave 50, 60, 90 mm and above | Rural | 13.7 | 33.9 | 20.4 | 11.7 | 3 |
| Pulverize full depth and overlay 50, 60, 90, 110, 120 mm and above, with/without adding granular | | 17.6 | 42.6 | 25.3 | 5.6 | 41 |
| All treatment types | Rural | 4.1 | 56.0 | 24.3 | 7.5 | 529 |
| | Urban | 3.5 | 64.0 | 24.3 | 9.4 | 1534 |

The P-Values calculated from the T-tests evaluating the general difference between the sections classified as Urban and Rural are presented below in Table 10. There was no significant difference found in Effectiveness at a 95% confidence level. Hence, the results of the T-test show that the effectiveness of a treatment is not dependent on the cross section.

**Table 10: Results of T-Test for Urban and Rural Effectiveness**

| | Urban PQI Effectiveness | Rural PQI Effectiveness |
|---|---|---|
| **Mean** | 24.3 | 24.3 |
| **Variance** | 88.3 | 56.9 |
| **Observations** | 1534 | 529 |
| **Hypothesized Mean Difference** | 0 | |
| **df** | 2061 | |
| **t Stat** | 0.04 | |
| **P(T<=t) one-tail** | 0.49 | |
| **t Critical one-tail** | 1.65 | |
| **P(T<=t) two-tail** | 0.97 | |
| **t Critical two-tail** | 1.96 | |

## 5.0 CONCLUSIONS

Using the City's PMS data, two methods were developed to evaluate the effectiveness of treatments used. The following conclusions were drawn based on the available information at the time of analysis.

- The effectiveness results were analyzed on three levels, by Type (5 categories), Sub-Type (13 categories), and Strategy (23 categories). The results are as follows.
  - Treatment Type:
    - Reconstruction had the highest effectiveness as well as the highest benefit increase when comparing treatments by Type.
  - Treatment Sub-Type:
    - When comparing treatments by Sub-Type, New Construction: Capital Development projects had the highest effectiveness.
    - Preservation: Thin Mill and Overlay had the highest benefit increase following treatment.
  - Treatment Strategy:
    - Out of all treatment strategies, New Construction of Local and Collector roadways had the highest effectiveness.
    - Resurfacing: Mill Full Depth and Pave over 50 mm showed the highest benefit increase when compared to all strategies.

- The benefit increase following Mill and Overlay may be larger than other treatments because it removes and replaces the deteriorated top asphalt layers, a significant contributor to the pavement's performance and ride quality.
- It would be expected that Superpave sections perform better due to the additional considerations in design. However, Marshall Mix sections were found to have higher effectiveness values.
- The effectiveness of a treatment is not dependent on its Urban or Rural cross section characteristics.

## 6.0 REFERENCES


1- Peshkin, D., and Zimmerman, K. 2004. ”Optimal Timing of Pavement Preventive Maintenance Treatment Applications”, NCHRP Report 523, Washington, DC: Transportation Research Board of the National Academies.

2- Dong, Q., and Huang, B. 2010. "Cost-Effectiveness Evaluation of Pavement Maintenance Treatments by OPTime", GeoShanghai 2010 International Conference, Paving Materials and Pavement Analysis, Shanghai.

3- Watson, D., Brown, E., and Moore, J. 2005."Comparison of Superpave and Marshall Mix Performance in Alabama" Transportation Research Record: Journal of the Transportation Research Board 1929: 133-40.

4- Asi, Ibrahim M. 2007. "Performance Evaluation of Superpave and Marshall Asphalt Mix Designs to Suite Jordan Climatic and Traffic Conditions", Construction and Building Materials 21.8: 1732-740.

5- Jitsangiam, P., Chindaprasirt, P., and Nikraz, H.2013. "An Evaluation of the Suitability of SUPERPAVE and Marshall Asphalt Mix Designs as They Relate to Thailand’s Climatic Conditions", Construction and Building Materials, 40: 961-70.

6- Ahmad, J., Abdul Rahman, M., Hainin, M., and Hossain, M. 2012. "Comparative Evaluation of Hot-mix Asphalt Design Methods" International Journal of Pavement Engineering, 13.2: 89-97, Web.

7- Wang, J., Kennedy, T., and Mcgennis, R. 2000. "Volumetric and Mechanical Performance Properties of Superpave Mixtures", Journal of Materials in Civil Engineering, 12.3: 238-44.

8- Ministry of Transportation Ontario. 2013. “Pavement Design and Rehabilitation Manual”, Materials Engineering and Research Office, Downsview, ON. p.140.

9- J.F. Sabourin Associates. 2000. “Evaluation of Roadside Ditches and Other Related Stormwater Management Practices”, Final Report, Ottawa.