Development of a Decision Support Tool for Arterial Roads Rehabilitation in Hamilton

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ABSTRACT

The City of Hamilton is in the process of developing an asset management system in an effort to bring city's infrastructure to grade B+ over ten years period. As one of the city's most valuable assets, the road network demands that the city uses a proactive management approach to maintain the network in a safe and good condition. This paper present a decision support tool that has been implemented for the city of Hamilton to facilitate the selection of the appropriate rehabilitation strategy for city's urban arterial and collector network. The tool is intended to be incorporated later into the asset management system.

Key parameters that are known to highly impact rehabilitation selection such as road functional class, pavement type, traffic volume, and current pavement condition were identified. The combination of these various parameters resulted in a total of 54 scenarios to be evaluated.

Within each scenario, suitable rehabilitation strategies set were identified for further evaluation. A comprehensive life cycle cost analysis based on incremental equivalent uniform annual cost was conducted for all expected rehabilitations within each of the 54 scenarios in order to select the most cost effective rehabilitation strategy. In addition, comparison among competing alternatives within each scenario was demonstrated.

An automated spreadsheet-based decision support tool was implemented in order to assist the City with evaluating competing rehabilitation strategies and selection of the most cost effective strategy. Using the developed life cycle cost analysis tool, city staff can enter project specific parameters and quickly have a print out of the list of feasible treatments along with the corresponding life cycle cost analysis for these treatments.

INTRODUCTION

Over the years, it has been a challenging task for transportation agencies to identify the best practice for selecting the appropriate pavement rehabilitation for deteriorating pavement. State highway agencies are under pressure to mitigate such pavement conditions through maintenance, rehabilitation, and reconstruction work while accelerating construction, minimizing traffic disruption, reducing accident risk, and improving public acceptance.

In the absence of a comprehensive pavement management system, needs will arise for a tool to evaluate different rehabilitation scenarios and assist transportation agencies to take the right decision for future work based on the current condition of the pavement.

Review of current practice showed that various studies were carried out to identify best practice for pavement rehabilitation (4, 5, 6 and 7). In a study carried out through the Second Strategic Highway Research Program (SHRP2) (1) to establish the guidelines for pavement preservation, the study identified the main parameters that affect the selection of a pavement preservation treatment to be:

- Traffic levels;
- Pavement condition;
- Climate/environment;
- Work zone duration restrictions;
- Expected treatment performance; and
- Costs

The purpose of these guidelines is to provide direction to agencies on the selection and use of preservation treatments mainly for high-traffic-volume roadways. The study emphasized that users of these guidelines should be aware that achieving the desired results from pavement preservation is dependent upon many interacting factors, including proper project selection, materials availability and quality, contractor capabilities, construction practices, and ambient conditions at the time of placement.

The guidelines described a process for the selection of feasible treatments by generating a first cut of treatments capable of preserving the pavement structure and preventing or delaying future deterioration and then the list of treatments can be narrowed down through the assessment of the traffic and climatic characteristics Further refining of the list may occur after considering constraints such as available funding, the expected timing and allowable duration of the work, geometrics issues, and traffic control issues. Once a final set of feasible preservation treatments has been identified, a cost-effectiveness analysis should be performed to determine which treatment provides the greatest return for the investment.

Another study conducted in 2004 by Wei and Tighe (2) discussed the efforts of developing preventive maintenance decision trees based on cost-effective analyses for the road network in Ontario, Canada. The primary goal of this study was to compare the cost effectiveness of 15 different HMA preventive maintenance treatments as used under the climatic and traffic conditions specific to the Ontario road network. The research method used for this study was based on determining the cost-effectiveness for each treatment or strategy as the area underneath the performance curve divided by the life-cycle cost of each strategy. Decision trees were then developed for each pavement functional class in the Ontario road network based on an analysis of the pavement data provided by the Ministry of Transportation of Ontario (MTO).

Zhang et al (3) has shown in a study conducted at the University of Texas at Austin that using only three decision variables (Pavement Condition Index (PCI), pavement age, and average daily traffic) with five levels for each will result in a total of 125 (5x5x5=125) M&R alternatives. Such a large number of alternatives are not very practical in implementation. The study suggested reducing the number of levels within the decision variables to reduce the total number of Maintenance and Rehabilitation (M&R) strategies because most cities use 10 to 20 M&R strategies for budgeting and programming. The current study will be demonstrated using 54 alternatives but can be easily expanded to include large number of scenarios due to the fact it was implemented on a spreadsheet platform in addition to provide cost effectiveness analysis among different alternatives.

STUDY OBJECTIVES

The objective of this study is to provide a user friendly tool that can help in assessing the life cost estimate for various treatments alternatives under different conditions in the absence of a comprehensive pavement management system for the City of Hamilton at project level decision making. The initial process starts by develop a framework for the selection of appropriate pavement rehabilitation treatments for the urban arterial and collector network only. Since urban network accounts for approximately 35% of the road lane-km network for the city of Hamilton, therefore, these roads are vital to the long-term viability of the City, as they form the backbone of the City's transportation network and must continue to provide efficient routes for personal and commercial traffic across the City.

The following factors were considered in the treatment selection integrated into decision support tool:

- Current and anticipated traffic volumes,
- Current condition of roads,
- Life cycle costs associated with maintaining roads, and
- Life cycle costs associated with constructing and maintaining roads rehabilitation options.

DATA AGGREGATION

As part of the data gathering task, the following data was provided from the City for the completion of the analysis:

- Complete database of the City's pavement types and functional classes
- Most recent traffic data
- Current maintenance and capital budgets for various pavement types
- Construction costs for all current treatment strategies
- All available pavement condition data for arterial/collector roads

In order to estimate which treatment alternative would be selected for of the urban arterial and collector roads, a decision matrix was developed that considered the following factors, for which the City had available data and were found to highly impact treatment selection:

- Pavement Type
- Functional Class
- Traffic
- Performance Condition

The following subsection explain briefly the findings from the data aggregation

Pavement Type

There are eight pavement types found across the Hamilton road network. These pavement surface types identified along the Urban Arterial and Collector portion of the network include (type and % area of network): Asphalt Concrete (83.18%), Brick (0.21%), Composite (15.10%), Open Graded Cold Mix (OGCM) (0.08%), Portland Cement Concrete (0.35%) and Surface Treated (SRFT) (1.08%) as shown in figure 1. For the purpose of this study, rehabilitation options will be considered only for asphalt concrete and composite pavement types which account for approximately 98.28% of the network.

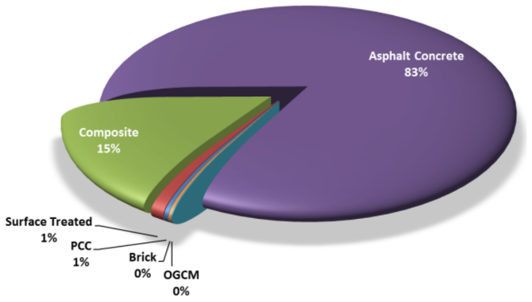


Figure 1: Different Pavement Types within Urban Network

Functional Class

The Urban Arterial and Collector portion of the Hamilton network accounts for approximately 29% of the total road network, including: Urban Arterials Major (32.6%), Urban Arterials Minor (19.8%) and Urban Collectors (47.6%) of total urban network.

Traffic

To further refine the parameters for the framework, various traffic volume levels were established. The City's database was used to review the average annual daily traffic (AADT) and develop the traffic matrix levels: high, medium and low as shown in figure 2. The final AADT thresholds that have been assigned to each traffic levels based on traffic data statistical analysis are as follow:

- High: AADT ≥ 5,000
- Medium: AADT 2,000-5,000
- Low: AADT < 2,000

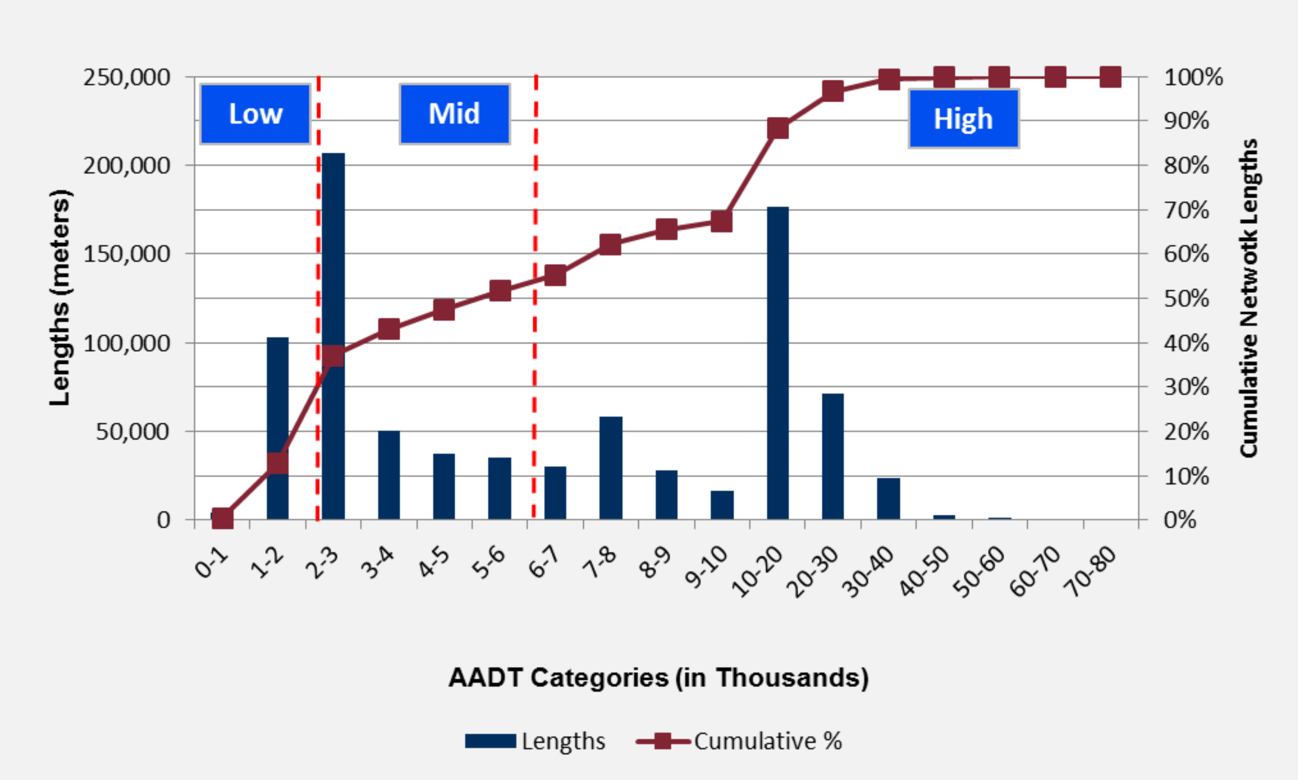


Figure 2: AADT Traffic Pattern for City of Hamilton

Performance Condition

The Overall Condition Index (OCI) of the Urban Arterial and Collector portion of the network was used in the decision matrix to denote the overall condition of the pavement. The OCI data is a measure of the current performance of the pavement with respect to cracking, smoothness and remaining service life. The OCI thresholds that have been recommended by City staff for treatment selection are:

- Good: OCI > 60
- Fair: OCI 30-60
- Poor: OCI < 30

DECISION MAKING FRAMEWORK

Based on the decision factors shown in Figure 3, there are 54 conditions resulting from the combination of two pavement types, three functional classes, three traffic levels, and three performance conditions. Each condition combination in the decision matrix represents a unique condition and has been assigned with possible treatment options from treatment list in table 1. It should be noted that more than one treatment could be applicable to the same condition. The decision making framework process for evaluation of asphalt and composite pavement structures is presented in Figure 4. The first step is to categorize each road under consideration based on the four factors in addition to identify project needs for traffic diversion, next is to identify treatment set for each factor-combination scenarios. Next is to carry out a comprehensive life cycle cost analysis (LCCA) for each scenario. Once LCCA is accomplished, a comparison among possible scenarios is presented graphically with 50-preventative maintenance action needs.

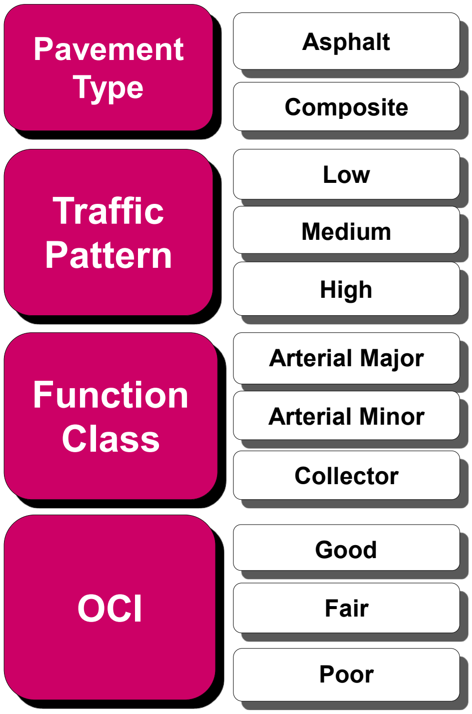


Figure 3: Urban Arterial and Collector Decision Making Factors

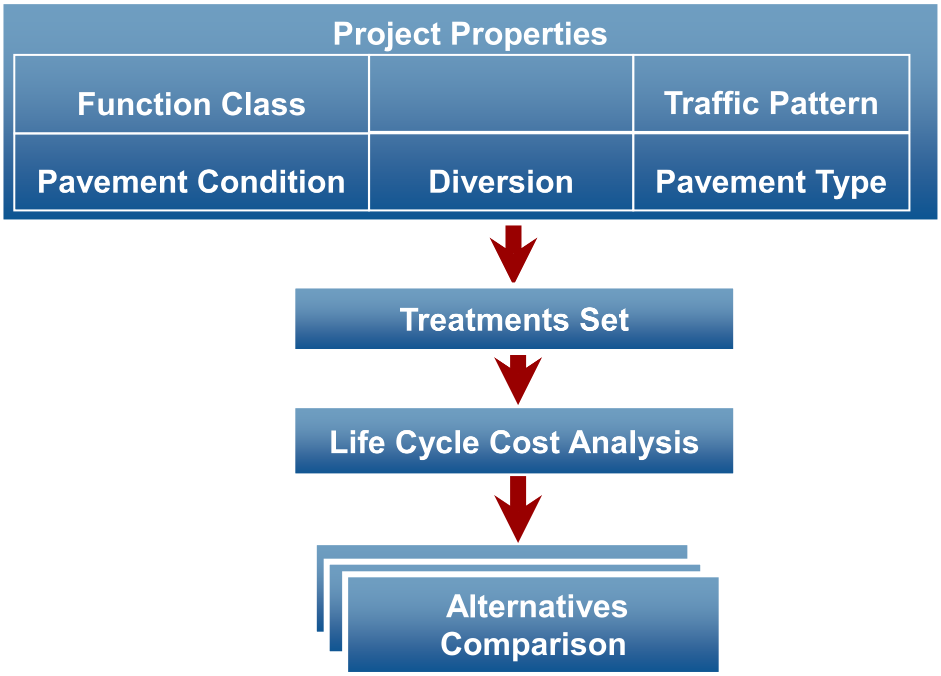
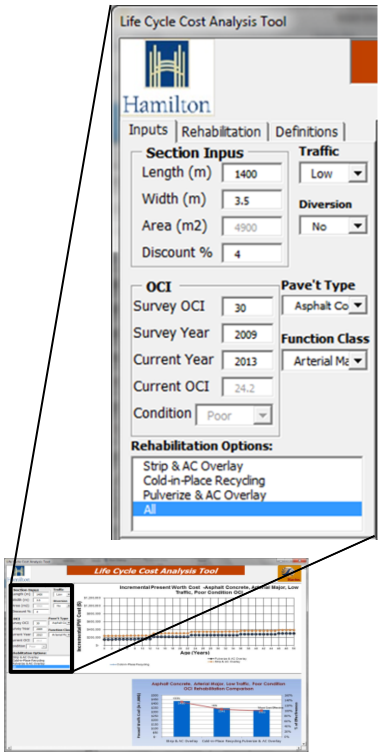


Figure 4: Decision Process Framework for Treatment Selection

Table 1: Treatment List Considered for each Pavement Type

Pavement Type	Activity Code	Activity Description
Asphalt Concrete	1	OGCM (not on Arterials)
	2	Tar & Chip (not on Arterials)
	3	Mill & AC Overlay
	4	Strip & AC Overlay (strip all asphalt)
	5	Cold-in-Place Recycling
	6	Pulverize & AC Overlay
	7	Full Reconstruction - AC
Composite	8	Mill & AC Overlay
	9	Strip & AC Overlay (strip all asphalt)
	10	Strip & Concrete Base Repair & AC Overlay
	11	Full Reconstruction - AC
	12	Full Reconstruction PCC
	13	Mill AC, Rubblize & AC Overlay



Life Cycle Cost Analysis Tool

Hamilton

Inputs | Rehabilitation | Definitions

Section Inpus

Length (m) 1400

Width (m) 3.5

Area (m2) 4900

Discount % 4

Traffic Low

Diversion No

OCI

Survey OCI 30

Survey Year 2009

Current Year 2013

Current OCI 24.2

Condition Poor

Pave't Type Asphalt Co

Function Class Arterial Ma

Rehabilitation Options:

- Strip & AC Overlay
- Cold-in-Place Recycling
- Pulverize & AC Overlay
- All

Figure 5: LCCA Input Parameters within the Decision Support Tool

Figure 5 shows how the decision framework was implemented into the decision support tool. By selecting different factor combinations, treatment alternatives associated with the selected condition are populated in the rehabilitation option box. It should be noted that the decision tool can be used to predict current overall condition index based historical models integrated into the decision tool engine. In addition, the tool can calculate project area based on user inputs and will account for traffic diversion impact for life cycle cost analysis. Once traffic, pavement type, function class and OCI condition are identified, applicable rehabilitation alternatives are populated for particular condition for further evaluation.

LIFE CYCLE COST ANALYSIS

Life cycle cost analysis (LCCA) is a process for evaluating the total economic worth of a project by analyzing initial costs and discounted future costs, including maintenance, rehabilitation, and reconstruction, over the life of a project. The following basic assumptions were considered in the LCCA:

- 50-year analysis period
- Equivalent Annual Uniform Cost (EAUC) were used as the basis for comparison between strategies

The equivalent annual uniform cost (EAUC) is an annuity that is mathematically equivalent to a generally more complicated cash flow. The EAUC is used to calculate the regular annuity, given the present worth and is calculated as follows:

$$EAUC = NPW\frac{i(1+i)^N}{(1+i)^N - 1}$$

Where:

$EAUC$ is the equivalent annual uniform cost

NPW is the total net present worth of the strategy over the analysis period

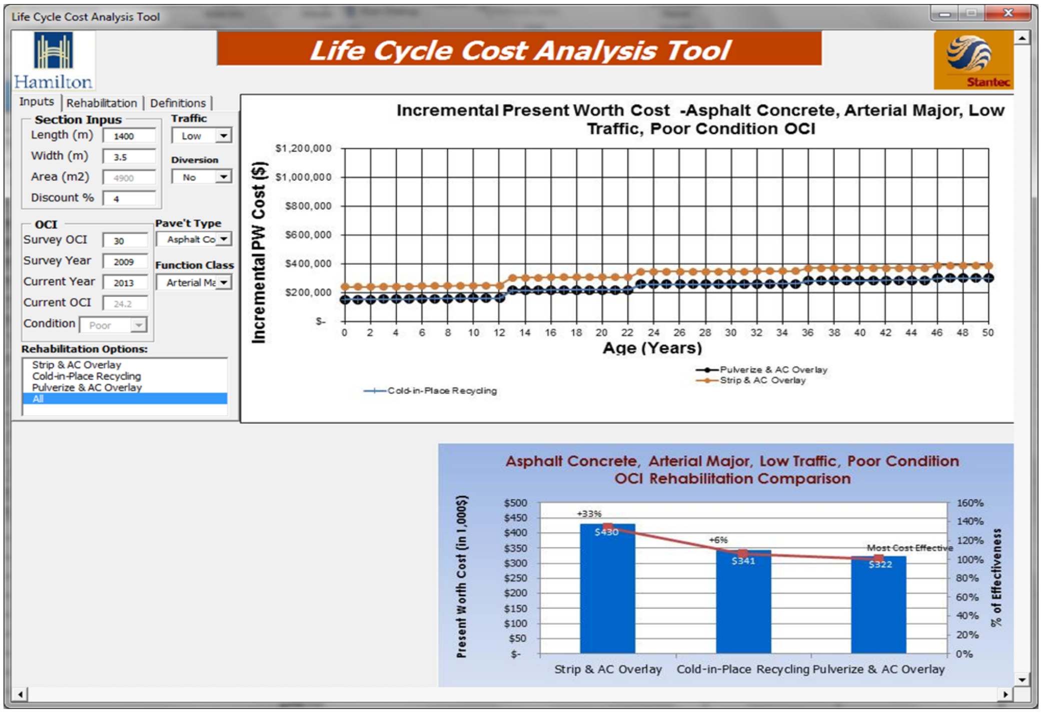
i is the discount rate

N is the analysis period (50 years)

The incremental costs of EAUC are calculated similar to the incremental costs for the present worth. First all the equivalent annual costs are converted to an annual Present Worth cost, then each annual present worth cost is added to the previous annual present worth cost. The user has the flexibility to change discount rate as shown in figure 5.

LCCA RESULTS

Figure 6 shows the Incremental Equivalent Uniform Annual Cost for the low traffic, asphalt pavement type, arterial minor function class and poor OCI condition along the 50-year- period for each case scenario. The presented LCCA result is based on the assumption that LCCA was executed at 4% discount rate for a typical road with 1,400 meter length and 3.5 lane width.
As shown in figure 6, the decision tool has the capability to perform comparison among different alternatives at same condition in addition to plot the marginal effectiveness difference among different treatment alternatives. Such comparison can help to identify the most cost effective strategy for each condition based on the treatment options applicable to each case.



Section Inpus
Length (m): 1400
Width (m): 3.5
Area (m2): 4900
Discount %: 4

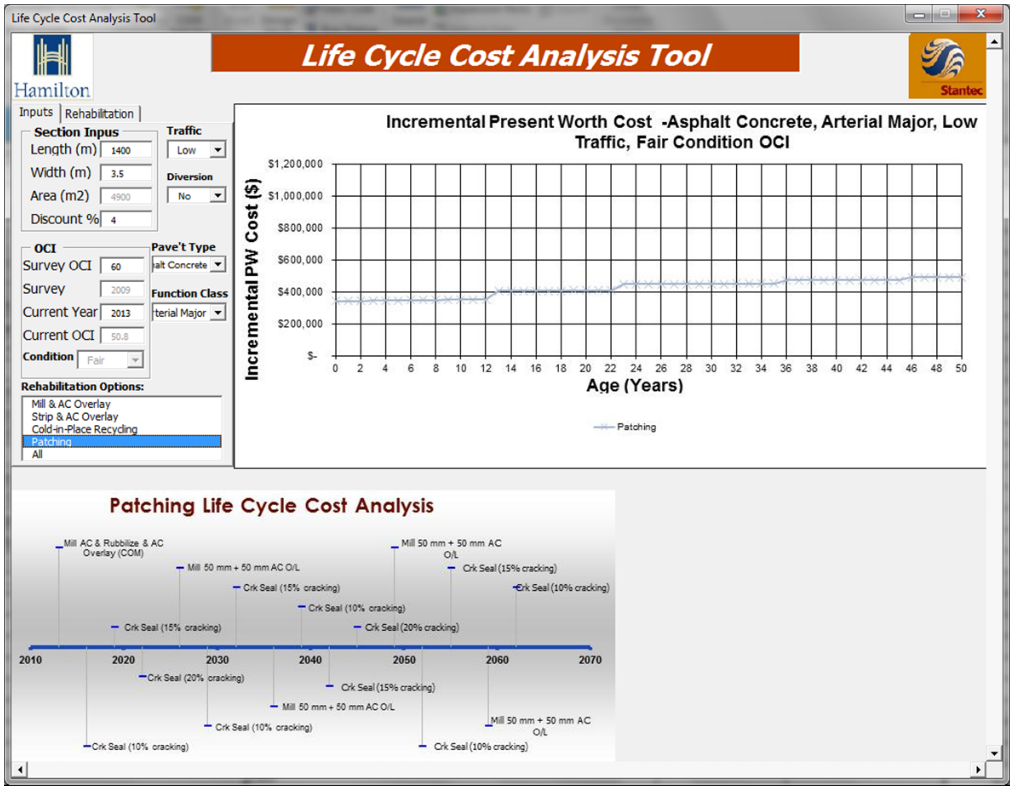
Traffic: Low
Diversion: No

OCI
Survey OCI: 30
Survey Year: 2009
Current Year: 2013
Current OCI: 24.2
Condition: Poor

Pave't Type: Asphalt Co
Function Class: Arterial Ma

Rehabilitation Options:
Strip & AC Overlay
Cold-in-Place Recycling
Pulverize & AC Overlay
All

Figure 6: Decision Support Tool LCCA Results


Life Cycle Cost Analysis Tool

Inputs | Rehabilitation

Section Inpus
Length (m): 1400
Width (m): 3.5
Area (m2): 4900
Discount %: 4

Traffic: Low
Diversion: No

OCI
Survey OCI: 60
Survey: 2009
Current Year: 2013
Current OCI: 50.8
Condition: Fair

Pave't Type: alt Concrete
Function Class: terial Major

Rehabilitation Options:
Mill & AC Overlay
Strip & AC Overlay
Cold-in-Place Recycling
Patching
All

Figure 7: Preventive Maintenance Action for Selected Treatment

The decision support tool has the capability to identify different preventive action for particular treatment along the 50 years analysis period as shown in figure 7. These proposed preventive maintenance actions are stored in the in the decision tool database and can be access and modified according to agency practice as needed. In addition, the decision tool has the capability of adding new treatments, deleting or modifying existing treatments and can be customized to city staff needs.

FUTURE ENHANCEMENTS

The framework developed as a part of this study could be extended to include other functional classifications within the City's roadway network and incorporate additional factors that are known to impact the treatment selection decision such as climatic condition and subgrade condition. The tool can be integrated into city roads network and automated to develop rehabilitation strategies for all city road network and accordingly can be used to establish initial funding needed for the upcoming years at network level. Field testing is always recommended to enhance OCI prediction models and validate economic analysis and conceptual planning. Further evaluation should be carried out by pavement engineers and practitioners to refine available treatments for each scenario in order to select the best applicable treatments based on other conditions and criteria that were not included in the current decision support tool such as drainage and environmental conditions before going into final LCCA stage. Final treatment selection could be simplified by simply selecting the treatment with lowest life cycle cost at the end of 50 years, however, it more cost effective to calculate treatment effectiveness for each treatment and carry out an incremental benefit cost optimization to select the most cost effective alternative especially in cases with more than three alternatives competing within each scenario.

CONCLUSIONS

A study was conducted for City of Hamilton to develop a decision making framework and assist city staff in determining which rehabilitation treatments are the most cost effective for the Urban Arterial and Collector network. The study was carried out on three phases. The first phase of the study reviewed the current practice for selecting the cost effective treatment. The second phase involved developing a decision making framework to identify appropriate rehabilitation treatments for various existing conditions across the City's roadway network. This analysis resulted in identifying traffic (three levels), current pavement conditions (three OCI levels), pavement type (asphalt or composite) and functional classification of the roadway (3 levels) as the main factors to highly impact decision selection. The third phase involved the implementation of a comprehensive life cycle cost analysis, which included the evaluation of 13 rehabilitation strategies for 54 unique combinations of roadway parameters to reflect future capital expenditures.

As part of this study, a decision support tool was programmed on excel platform to encapsulate the developed framework decision scheme and make it available for use by city staff and pavement practitioners on regular maintenance planning activities. The tool incorporates the recommendations and analysis from the LCCA performed during this study to provide the most cost-effective treatment with all flexibility needed to modify project properties such as project geometry, interest rate or adding new treatment for future work . This tool is intended to be used as a high level planning tool at project level and the final decision on construction strategy should be based on detailed engineering analysis and design. The make-up of final decision for pavement structure needs should be assessed in light of load carrying capacity and drainage condition. The advantages of the developed decision support tool are its simplicity in use, its applicability in the absence of a comprehensive pavement management system and providing fair comparison among competing projects at project level. The tool can be enhanced to include other functional classes and other pavement types in addition to include other factors that are known to highly impact treatment selection such as climatic condition and geographical location.

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