Final Report

Interlocking Concrete Pavement Life-Cycle Cost Comparison Tools

Task 2 – Typical Pavement Structures
Task 3 – Development of Pavement Performance Models
Task 4 – Construction, Maintenance and Rehabilitation Costs
Task 5a – Development of LCC Elements and Tools
Task 5d – Sensitivity Analysis

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This report uses US Customary units. It is also available in SI units.

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GLOSSARY OF ABBREVIATIONS

AADT	- Average Annual Daily Traffic
AADTT	- Average Annual Daily Truck Traffic
AASHTO	- American Association of State Highway and Transportation Officials
ACPA	- American Concrete Pavement Association
ACP	- Asphalt Concrete Pavement
ASCE	- American Society of Civil Engineers
ASTM	- American Society for Testing Materials
CAC	- Cement Association of Canada
CBR	- California Bering Ratio
FHWA	- U.S. Federal Highway Administration
HMA	- Hot Mix Asphalt
ICP	- Interlocking Concrete Pavement
ICPI	- Interlocking Concrete Pavement Institute
LCC	- Life-Cycle Cost
LCCA	- Life-Cycle Cost Analysis
M&R	- Maintenance and Rehabilitation
M_r	- Resilient Modulus
MR	- Modulus of Rupture
NCHRP	- National Cooperative Highway Research Program (U.S.)
OCI	- Overall Condition Index
PCI	- Pavement Condition Index
PCC	- Portland Cement Concrete
PCR	- Pavement Condition Rating
RMCAO	- Ready Mixed Concrete Pavement Association

Executive Summary

Municipalities seek opportunities to improve the performance of their roadways and more efficiently spend their available budgets. Pavement type selection is one of the more challenging engineering decisions facing roadway administrators. The process includes a variety of engineering factors such as materials and structural performance which must be weighed against the initial and life-cycle costs, as well as, sustainable benefits. The technical part of the evaluation includes an analysis of pavement life-cycle strategies including initial and future costs for construction and maintenance but does not include supplemental costs for engineering and contract administration and traffic control/protection and societal costs such as user delay and environmental impact. Non-economic factors such as roadway geometry, availability of local materials, qualified contractors and construction experience, conservation of materials/energy, stimulation of competition, impact on winter maintenance, light reflectance, safety and comfort can also be factored into the decision process. The evaluation helps to select an alternative consistent with the agency's financial goals, policy decisions, and experience.

This project includes several tasks. Task 1 consisted of a survey of municipal agencies and overview of the barriers and opportunities to more widespread use of interlocking concrete pavement. The results of the survey, barriers and opportunities was reported separately. This report covers Tasks 2, 3, 4, 5a and 5d which included the development of typical pavement structures for interlocking concrete pavement (ICP), asphalt and concrete pavements, the development of life-cycle performance models, construction, maintenance and rehabilitation costs over an analysis period of 50 years, preparation of life-cycle cost tools in the form of MS Excel spreadsheets and a sensitivity analysis including discount rates and the cost of ICP versus asphalt surfaced pavements.

The pavement designs for the interlocking concrete pavements were completed in accordance with the American Society of Civil Engineers (ASCE) *Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways* (ASCE 58-16). The pavement designs for the flexible pavements are based on the procedure outlined in the American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Design of Pavement Structures*. The rigid pavements were designed using the American Concrete Pavement Association (ACPA) StreetPave Structural Design Software for Street and Road Concrete Pavements. A total of 108 individual pavement design sections were prepared for 3 pavement surface types, 3 subgrade support strengths, 4 roadway classifications and 3 initial pavement structural design lives (20, 25 and 30 years).

Municipal pavement performance data was obtained from 3 municipal agencies and analyzed to develop pavement performance models for various pavement surfaces and traffic categories. Based on this analysis, an initial pavement service life of 30 years was selected for the life-cycle cost analysis. Maintenance and rehabilitation plans were developed for each pavement surface type to extend the analysis period to 50 years. The plans included maintenance activities such as crack and joint sealing, replacement of cracked pavers, mill and overlay for asphalt pavements, full-depth repair for concrete pavements and the replacement of worn and cracked pavers, etc.

Detailed life-cycle cost analyses were completed for a discount rate of 4 percent resulting in 32 permutations and combinations of pavements. Examples of the results are included in the report with the detailed results provided in the Appendices. Based on the construction, maintenance and rehabilitation plans and unit rates, the life-cycle cost of the paver surfaced roadways are higher than that of asphalt and concrete surface roadways at a discount rate of 4 percent.

A sensitivity analysis was then completed using discount rates of 1 to 5 percent and a reduction in the unit cost of the pavers of 10, 15 and 20 percent. This resulted in the paver surface pavement having a lower life-cycle cost or a life-cycle cost within 5 percent of the cost of asphalt surfaced roadways for higher roadway traffic categories on all subgrade strength in the 1 to 3 percent discount rate range.

Three MS Excel files allow additional life-cycle cost analyses to be completed. The tools developed for this study can be used in conjunction with local pavement material unit costs and pavement design and maintenance plans to develop appropriate life-cycle cost comparisons to reflect local conditions and to assist in making decisions with respect to pavement type selection.

The pavement design and life-cycle cost analysis presented in this report is considered to be typical for municipal pavements. While every attempt has been made to ensure that HMA, ICP and PCC pavements were treated equally, it should be recognized that specific local factors such as project timing and local experience will often influence the choice of a particular pavement type.

1. Introduction

Life-cycle costing (LCC) has become an essential component of any modern infrastructure design. It has long been realized that maintenance and rehabilitation costs, not just the immediate initial construction costs should be considered when evaluating investment alternatives.

The Federal Highway Administration (FHWA) [1] describes Life-Cycle Cost Analysis (LCCA) as "an analysis technique that builds on the well-founded principles of economic analysis to evaluate the overall long-term economic efficiency between competing alternative investment options." The comparison of life-cycle costs has become standard to not only compare different pavement types, but also evaluate different feasible rehabilitation plans over the service life of a pavement.

The service life of a pavement is defined as the time between initial construction and the time when the pavement reaches a minimum unacceptable level of service. Municipal pavements are typically designed for an initial service life of 20 to 30 years. At the end of the initial service life, some form of rehabilitation action such as removal and resetting of concrete pavers for interlocking concrete pavements (ICP), mill and overlay for flexible asphalt pavements and concrete pavement restoration (CPR) consisting of full or partial depth repairs, load transfer retrofit, etc. is completed.

The actual service life of the initial pavement construction and rehabilitation treatment is dependent on a variety of factors including type and composition of the traffic, timeliness of maintenance treatments, and environmental factors such as climate, temperature and precipitation. To develop comparative cost estimates to determine the whole life cost of different pavement types, it is necessary to know the timing, type and quantities of repairs and their service life.

Life-cycle costing is a technique that quantifies all the costs necessary to construct and maintain a pavement over a set analysis period, typically between 30 and 50 years. Future costs are discounted to today's dollars by using a discount rate which accounts for the effects inflation (future value of money) and interest rates (the cost of money) to determine the net present value of future costs. By comparing the total life-cycle cost of two or more pavement options, it is possible to make informed decisions on the best pavement alternative for a particular application.

Life-cycle costing can be used to benchmark potential pavement options to determine which is the most cost effective. Traditionally, when performing a life-cycle cost analysis comparing pavement surface types, only the capital costs for initial construction and maintenance and rehabilitation costs for each of the pavement types are considered.

Task 1 for this project consisted of a survey of municipal agencies and overview of the barriers and opportunities to more widespread use of interlocking concrete pavement. The results of the survey, barriers and opportunities was reported separately. This report covers Tasks 2, 3, 4, 5a and 5d outlined below:

Task 2 – Development of typical pavement structures for ICP, asphalt and concrete pavements

Task 3 – Development of life-cycle performance models

Task 4 – Assessment of construction, maintenance and rehabilitation costs

Task 5a – Development of LCC elements and tools

Task 5d – Sensitivity analysis

2. Development of Typical Municipal Pavement Designs

The initial design and construction of pavements are critical factors in the life-cycle cost evaluation procedure. A pavement built for its appropriate traffic and environmental conditions will have a reasonable service life while providing a functional, safe platform for the traveling public. The service life of a pavement is established during the initial design considering the subgrade, pavement layer materials and their thicknesses, the anticipated traffic using the roadway, and the budget. This service life can be somewhat variable depending on the environmental and loading conditions.

In terms of municipal roadway pavement types, they are typically categorized as flexible and rigid. While there are many sub-categories within these pavement types the basic features of municipal pavements in North America are as follows:

Flexible (Hot Mix Asphalt Pavement)

- Hot mix asphalt (HMA) surface, variable thickness depending on truck/bus traffic volumes
- Minimum granular base (typically 6 in) for uniform support and construction traffic
- Granular subbase thickness depending on truck/bus traffic volumes and subgrade support

Flexible (Interlocking Concrete Pavement)

- Interlocking concrete paver (ICP) surface (3 ½ in thickness) with joint sand
- Bedding sand layer (1 in)
- Minimum granular base (typically 6 in) for uniform support and construction traffic
- Granular subbase thickness depending on truck/bus traffic volumes and subgrade support

Rigid (Portland Cement Concrete Pavement)

- Portland cement concrete (PCC) surface, variable thickness depending on truck/bus traffic volumes
- Jointed, load transfer dowels used for higher truck/bus traffic volumes
- Minimum granular base (8 in) for uniform support and construction traffic
- Subbase may be used for frost susceptible soils but not typically

A comprehensive matrix of municipal pavement designs was prepared as follows:

- 3 pavement surface types
- 3 subgrade strengths (low, medium and high support)
- 4 roadway classifications and traffic in terms of Average Annual Daily Truck Traffic (AADTT)
- 3 initial design lives (20, 25 and 30 years)

The distribution above results in 108 individual pavement design sections. The pavement designs for the ICPs were completed in accordance with the American Society of Civil Engineers (ASCE) *Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways* (ASCE 58-16) and associated ICPI MS Excel Design Charts [2]. The pavement designs for the HMA pavements are based on the procedure outlined in the American Association of State Highway and Transportation Officials

(AASHTO) *Guide for the Design of Pavement Structures* [3]. The PCC pavements were designed using the American Concrete Pavement Association (ACPA) StreetPave Structural Design Software for Street and Road Concrete Pavements. Pavement design parameters common to all pavement types are provided in Table 2-1. Parameters unique to each pavement type are provided in the following sections.

Table 2-1. Common Design Parameters.

Parameter	Value(s)
Initial Design Life (years)	20, 25 and 30
Traffic (AADTT)	<250, 500, 1,000, 1,500
Reliability (Percent)	80
Standard Deviation Flexible Rigid	 0.45 0.35
Initial Serviceability	4.2
Terminal Serviceability	2.5

2.1 Flexible (HMA) Design Parameters

The design parameters for the hot mix asphalt pavements are as shown in Table 2-2.

Table 2-2. HMA Pavement Design Parameters.

Parameter	Value(s)
Surface Layer Coefficient	0.42
Base Layer Coefficient	0.14
Subbase Layer Coefficient	0.09
Subgrade Modulus (psi)	4,350, 5,800, 7,250

2.2 Flexible (ICP) Design Parameters

The design parameters for the interlocking concrete pavements are as shown in Table 2-3.

Table 2-3. ICP Design Parameters.

Parameter	Value(s)
Paver Plus Bedding Layer Coefficient	0.42
Base Layer Coefficient	0.14
Subbase Layer Coefficient	0.09
Subgrade Modulus (psi)	4,350, 5,800, 7,250

2.3 Rigid (PCC) Design Parameters

The design parameters for the concrete pavements are as shown in Table 2-4.

Table 2-4. PCC Design Parameters.

Parameter	Value(s)
Concrete Flexural Strength (MPa)	4.4
Modulus of Subgrade Reaction (pci)	100, 115, 135
Minimum Granular Base	8 in
<250 AADTT, 30 Year Design	No dowels, slab length = 13 ft, tied shoulder/curb
500-1,500 AADT, 30 Year Design	1.25 in dowel bars, 12 in spacing, slab length = 15 ft, 20 in widened outside slab

2.4 Comparable Pavement Design Matrix

The results of the comparable 30-year initial pavement designs for HMA, ICP and PCC are presented in Table 2-5.

Table 2-5. Comparable Pavement Designs.

			Average Annual Daily Truck Traffic (AADTT) - 30 Year Pavement Design			
			Local	**Minor Collector**		**Major Collector**
			Collector	Collector	Bus Route (Residential)	Collector
			<250	500	1,000	1,500
Subgrade Strength	4,350 psi (CBR=3)	HMA	6.5 in AC 6 in Base 14 in Subbase	6.75 in AC 6 in Base 18 in Subbase	7 in AC 6 in Base 18 in Subbase	7.5 in AC 6 in Base 19 in Subbase
Subgrade Strength	4,350 psi (CBR=3)	ICP	3.15 in Paver 1 in Bedding Sand 6 in Base 21 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 26 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 32 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 34 in Subbase
Subgrade Strength	4,350 psi (CBR=3)	PCC	6.75 in PCC 8 in Base	6.75 in PCC 8 in Base	7 in PCC 8 in Base	7 in PCC 8 in Base
Subgrade Strength	5,800 psi (CBR=4)	HMA	5.25 in AC 6 in Base 12 in Subbase	6 in AC 6 in Base 14 in Subbase	6.5 in AC 6 in Base 18 in Subbase	6.75 in AC 6 in Base 18 in Subbase
Subgrade Strength	5,800 psi (CBR=4)	ICP	3.15 in Paver 1 in Bedding Sand 6 in Base 16 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 21 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 26 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 29 in Subbase
Subgrade Strength	5,800 psi (CBR=4)	PCC	6.75 in PCC 8 in Base	6.75 in PCC 8 in Base	7 in PCC 8 in Base	7 in PCC 8 in Base
Subgrade Strength	7,250 psi (CBR=5)	HMA	5.25 in AC 6 in Base 9 in Subbase	5.25 in AC 6 in Base 14 in Subbase	6 in AC 6 in Base 15 in Subbase	6.5 in AC 6 in Base 16 in Subbase
Subgrade Strength	7,250 psi (CBR=5)	ICP	3.15 in Paver 1 in Bedding Sand 6 in Base 13 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 17 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 22 in Subbase	3.15 in Paver 1 in Bedding Sand 6 in Base 25 in Subbase
Subgrade Strength	7,250 psi (CBR=5)	PCC	6.5 in PCC 8 in Base	6.75 in PCC 8 in Base	6.75 in PCC 8 in Base	7 in PCC 8 in Base
Concrete Slab and Joint Properties			No dowels Slab length = 13 ft Tied shoulder/curb	1.25 in Dowel bars, 12 in spacing Slab length = 15 ft 20 in widened outside slab		

3. Development of Life-Cycle Performance Models

By monitoring and rating pavement performance over its service life using standard pavement management tools such as the pavement condition index (PCI), it is possible to establish typical performance curves for the pavement [5]. The PCI procedure outlined in ASTM D6433-20 *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys* [6] for concrete and hot mix asphalt pavements and ASTM E 2840-19 *Standard Practice for Pavement Condition Index Surveys for Interlocking Concrete Roads and Parking Lots* [7] provide guidance for the condition rating of a pavement on a scale ranging from 0 (non-functional) to 100 (new). While the use of these standards by municipal agencies is common, there are many other pavement condition rating procedures in use throughout North America.

To determine the expected life of a pavement, the measured condition and a minimum acceptable level of service are used. The typical path of deterioration is monitored over the life of the pavement until the pavement reaches the typical terminal level of serviceability.

To generate the deterioration path, several possible techniques can be used. A common statistical technique called regression consists of selecting an appropriate form for modelling pavement condition deterioration over time and using the method of least squares to determine the best fit model. This method calculates the best-fitting line for the observed data by minimizing the sum of the squares of the vertical deviations from each data point to the line. (If a point lies on the fitted line exactly, then its vertical deviation is 0.) The terminal level of serviceability is extrapolated from the downward slope line that characterizes a deteriorating condition over time.

On-going pavement maintenance and rehabilitation costs can reverse the downward slope of the line. Maintenance and rehabilitation (M & R) activities are typically scheduled to occur at various times to improve the serviceability of the pavement. The timing of M & R activities and the cost to perform them are discounted to today's costs, then combined with initial costs to estimate the total life-cycle cost.

3.1 Level of Service

The minimum acceptable level of service is an important decision that must be made by a designer. The maximum state of deterioration that a pavement is expected to reach can greatly change the service life. It many cases the service level of a pavement must be maintained at a high level due to its exposure to various types of use resulting in a long service life. The level of service can be described by condition indicators such as structural capacity, ride quality or visual distress. For most municipal roadways, the visual surface condition of the pavement is typically used because it can represent the other, related factors. With the relatively low operating speed of most low-volume pavements, the impact of other functional performance factors is reduced.

A PCI rating of 60 is recommended as the trigger value for rehabilitation action. Once a pavement's condition deteriorates past this level, substantial repairs throughout a section are likely required to restore the pavement to an excellent condition level. Additional deterioration ratings below 60 generally means that maintenance and rehabilitation costs will substantially increase compared to actions taken at ratings at 60 or above.

3.2 Initial Pavement Design

Initial design and construction costs are typically the largest expense over the life cycle. The initial pavement design of ICP is very dependent on many factors such as traffic level, environment, and materials used. Initial pavement designs for HMA, ICP and PCC pavements are provided in Table 2-5 .

3.3 Agency Performance Models

Pavement management data was solicited from agencies across North America. Data was obtained from the cities of Nashville, Tennessee [14], Niagara Falls, Ontario [15] and Calgary, Alberta [16] to analyze it to determine typical pavement deterioration models for various road design categories and surface types. A brief discussion of the data and attempt at developing performance models is outlined below.

3.3.1 Nashville, Tennessee

Pavement performance data was obtained for local and collector roadways for the City of Nashville, Tennessee. The local roadways consisted of 14,861 road segments for a total length of 1,405 miles. All sections have an HMA asphalt surface. The date of the initial construction or rehabilitation was available for all sections dating back to 1994. The City of Nashville calculates an Overall Condition Index (OCI) which is a combination of surface distress, roughness and mean texture depth. After removing some obvious outliners from the data, a plot of the section OCI versus age is shown in Figure 3-1.

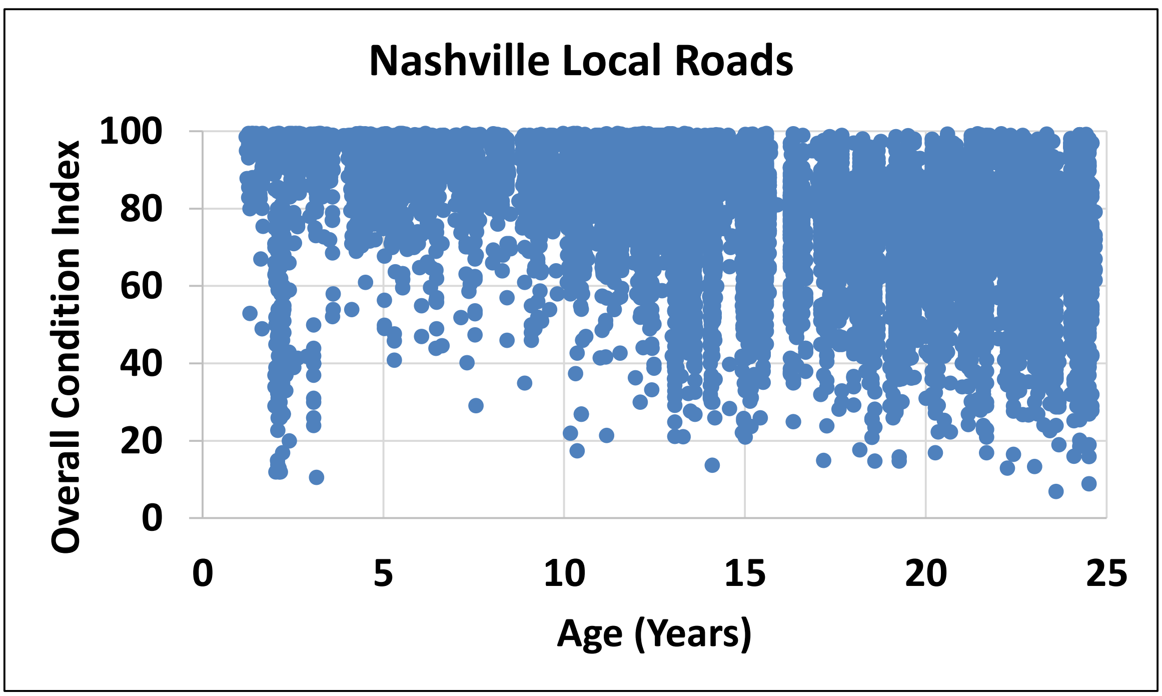


Figure 3-1. OCI versus Age for Nashville Local Roads.

The significant scatter of the OCI versus age data is very typical for Municipal agency pavement management systems. Most agencies are notoriously poor at capturing and screening construction history information. The section weighted average performance model for the Nashville local roads is shown in Figure 3-2. The curve indicates that a terminal OCI will be reached at 25 years of age.

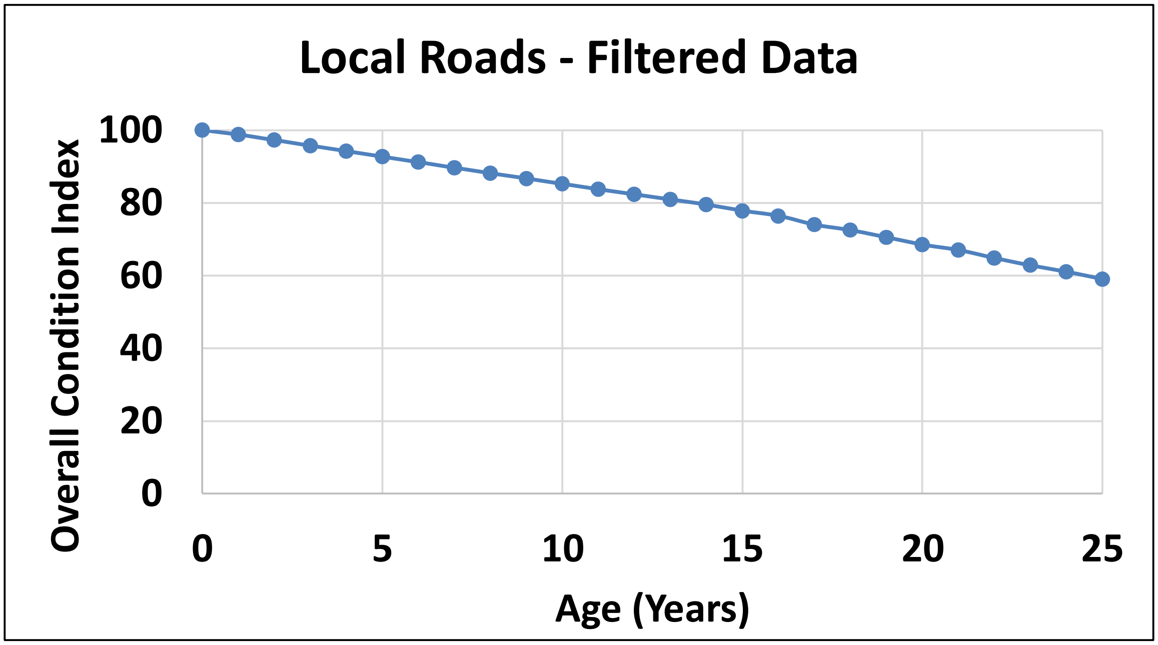


Figure 3-2. Nashville Performance Model for Local Roads.

The collector roadways consisted of 2,612 road segments for a total length of 318 miles. All sections have an asphalt surface except for 2 sections which have a jointed concrete surface with a total length of 0.6 miles. Construction history information was available for 2,271 sections dating back to 1994. After removing some obvious outliners from the data, a plot of the section OCI versus age is shown in Figure 3-2.

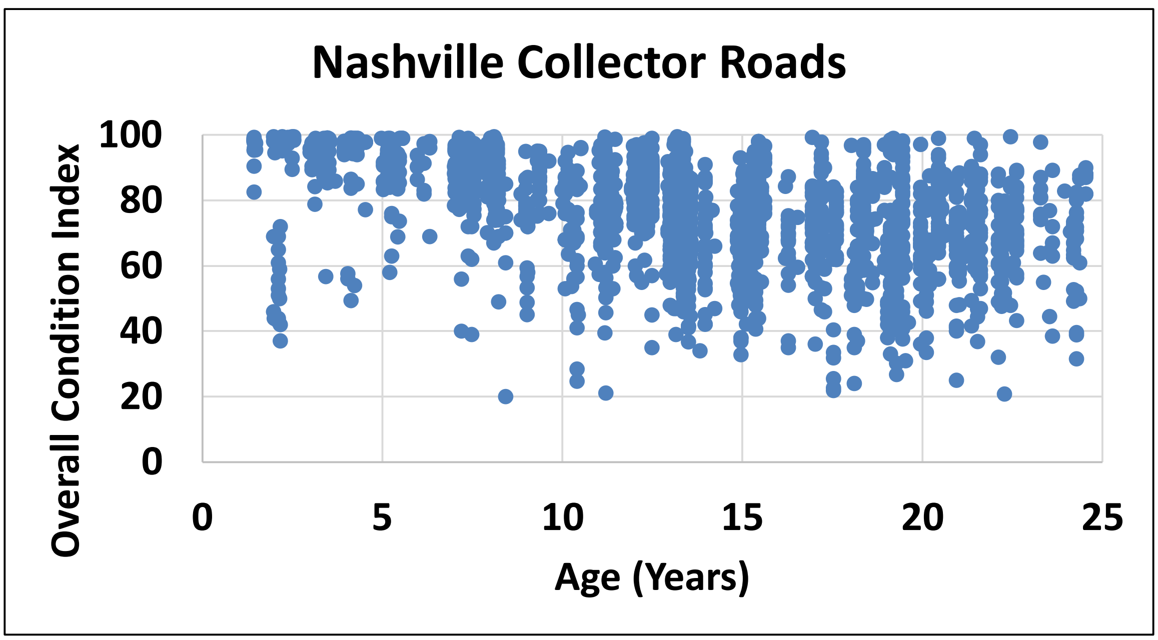


Figure 3-3. OCI versus Age for Nashville Collector Roads.

The section weighted average performance model for the Nashville collector roads is shown in Figure 3-4. The curve indicates that a terminal OCI will be reached at 27 years of age.

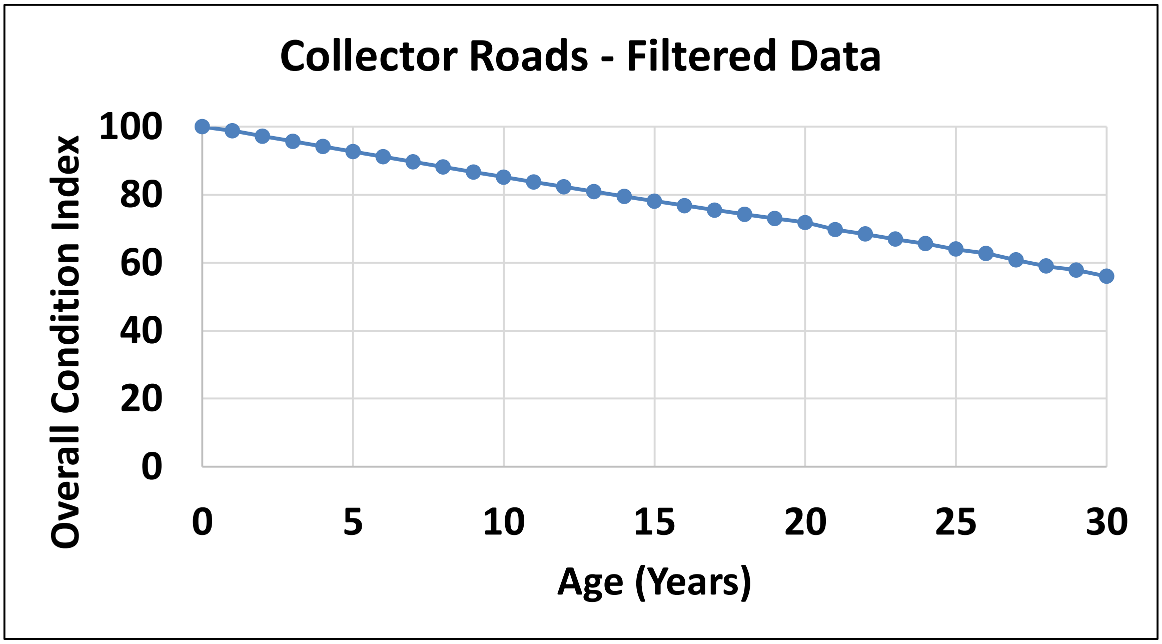


Figure 3-4. Nashville Performance Model for Collector Roads.

Given the lack of ICP and very limited PCC pavements, it was not possible to develop performance models for these categories of pavements.

3.3.2 Niagara Falls, Ontario

Pavement performance data was obtained for local and collector roadways for the City of Niagara Falls, Ontario for 4 pavement management updates completed in 2004, 2005, 2009 and 2016. The roadways consisted of 3,239 road segments for a total length of 406 miles. All sections have an asphalt concrete surface except two sections that are composite pavement with HMA over a PCC base. The date of the initial construction or rehabilitation was available for all sections dating back to 1970. The City of Niagara Falls calculates a Pavement Condition Rating (PCR) developed by the Ontario Ministry of Transportation which is a combination of surface distress and roughness. a plot of the section OCI versus age is shown in Figure 3-5. There is a significant amount of scatter in the PCR versus age plot, because of the lack of accurate construction history for the pavement sections.

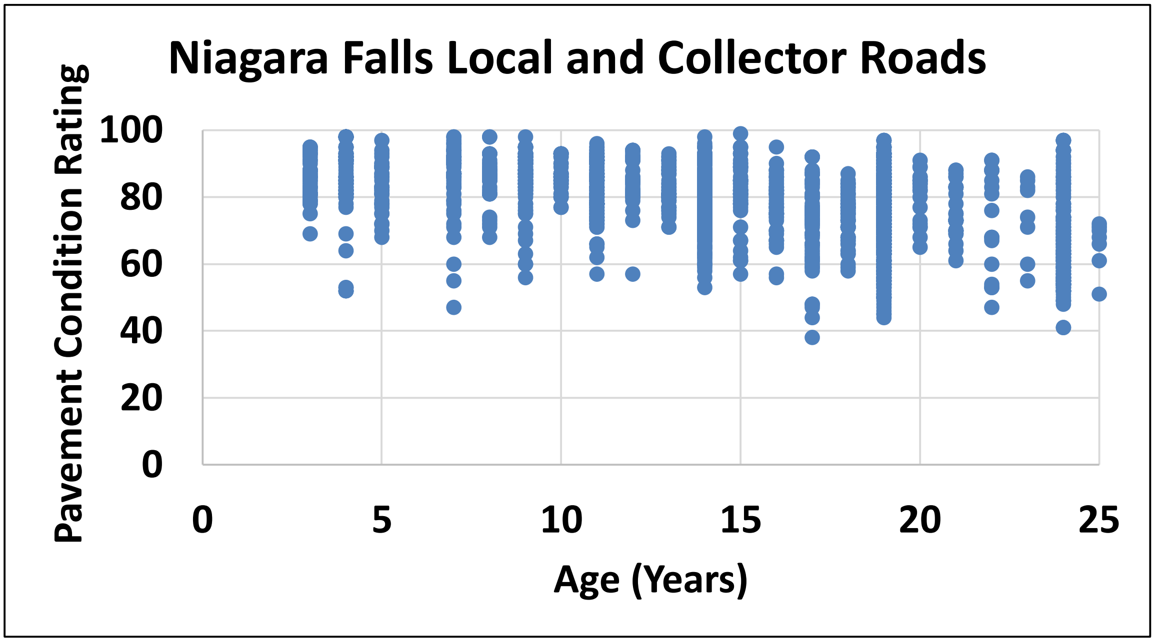


Figure 3-5. PCR versus Age for Niagara Falls Local and Collector Roads.

The section weighted average performance model for the Niagara Falls local and collector roads is shown in Figure 3-6. The curve indicates that a terminal PCR will be reached at 25 years of age.

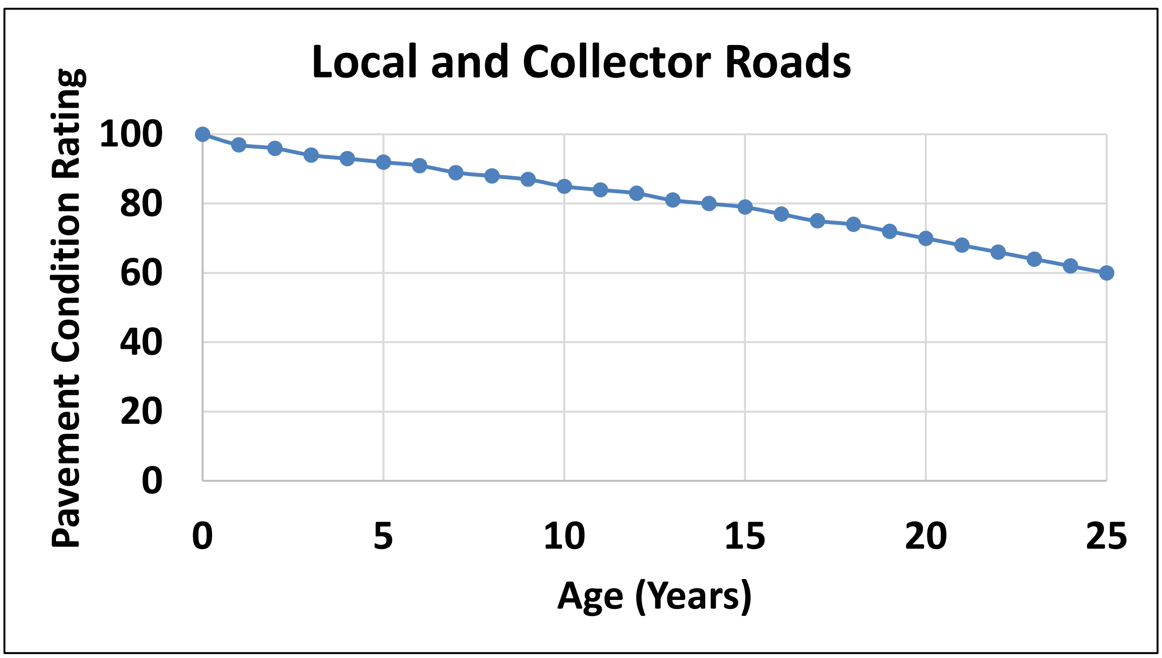


Figure 3-6. Niagara Falls Performance Model for Local and Collector Roads.

Given the lack of ICP and very limited PCC pavements, it was not possible to develop performance models for these categories of pavements.

3.3.3 Calgary, Alberta

Pavement performance data was obtained for local and collector roadways for the City of Calgary, Alberta. The local roadways consisted of 1,681 road segments for a total length of 357 miles. All sections have an asphalt concrete surface. The date of the initial construction or rehabilitation was available for all sections dating back to the 1940s but much of this data is suspected to be inaccurate. For local roadways, the City of Calgary calculates a Pavement Quality Index (PQI) by using a manual survey with approximately 20 percent of the length of local roadways surveyed each year. PQI is calculated on a scale of 0 to 10 but has been adjusted to a 0 to 100 scale like indices used by Nashville and Niagara Falls. After removing some obvious outliners from the data, a plot of the section PQI versus age is shown in Figure 3-7.

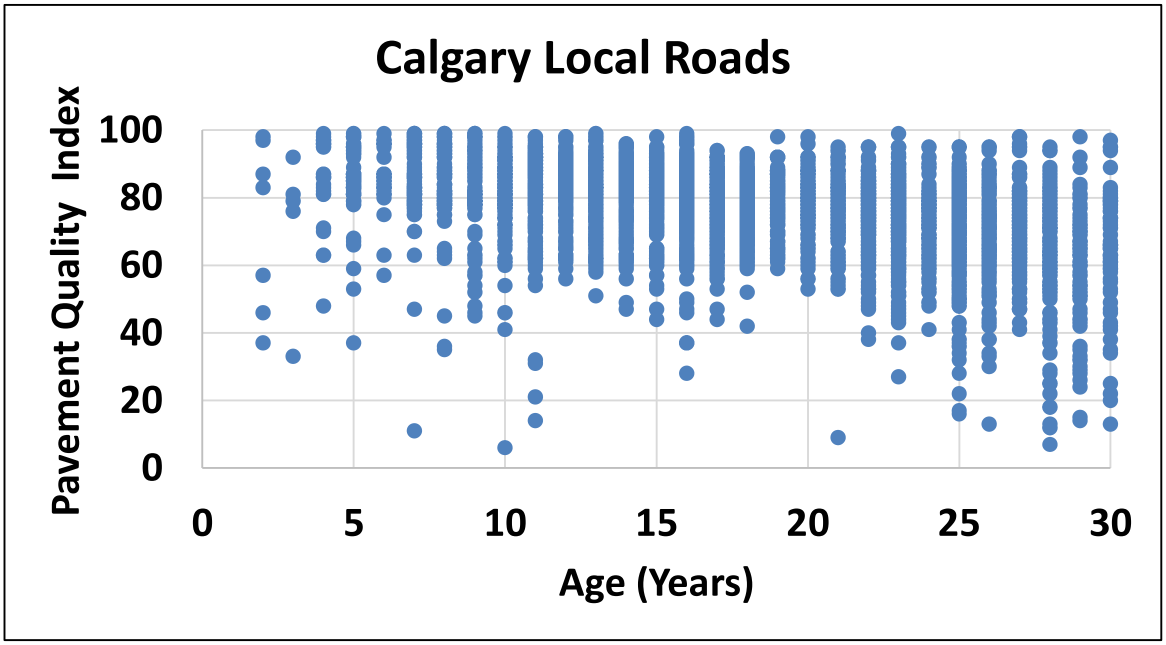


Figure 3-7. PQI versus Age for Calgary Local Roads.

The section weighted average performance model for the Calgary local roads is shown in Figure 3-8. The curve indicates that a terminal PQI will be reached at 25 years of age.

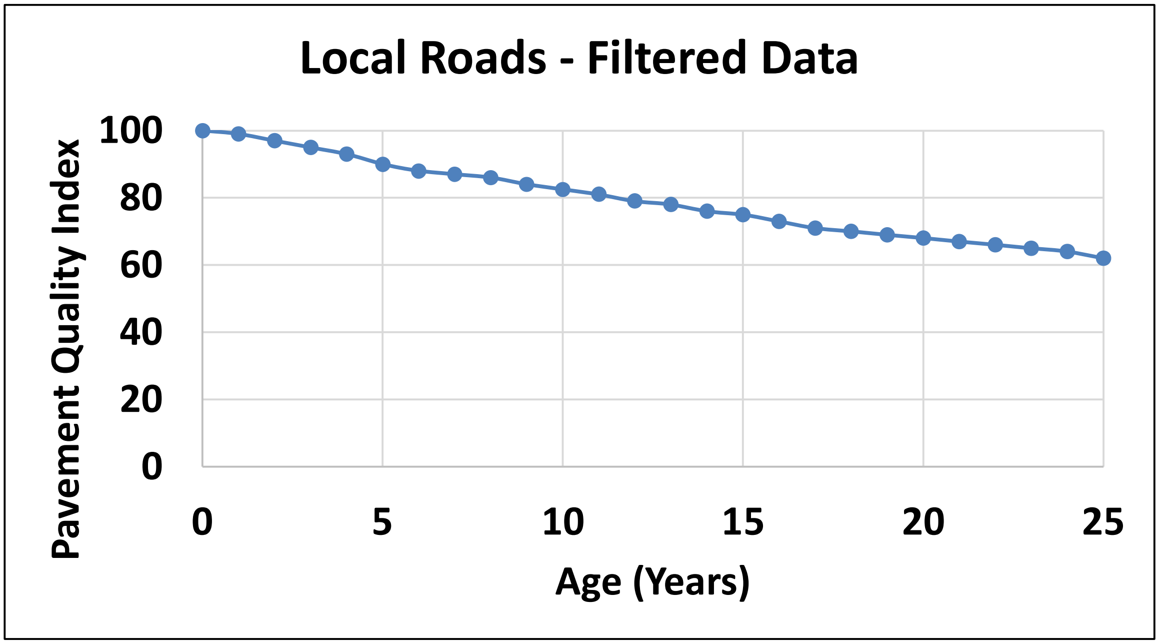


Figure 3-8. Calgary Performance Model for Local Roads.

The collector roadways consisted of 2,160 road segments for a total length of 611 miles. The date of the initial construction or rehabilitation was available for all sections but much of this data is suspected to be inaccurate. After removing some obvious outliners from the data, a plot of the section PQI versus age is shown in Figure 3-9.

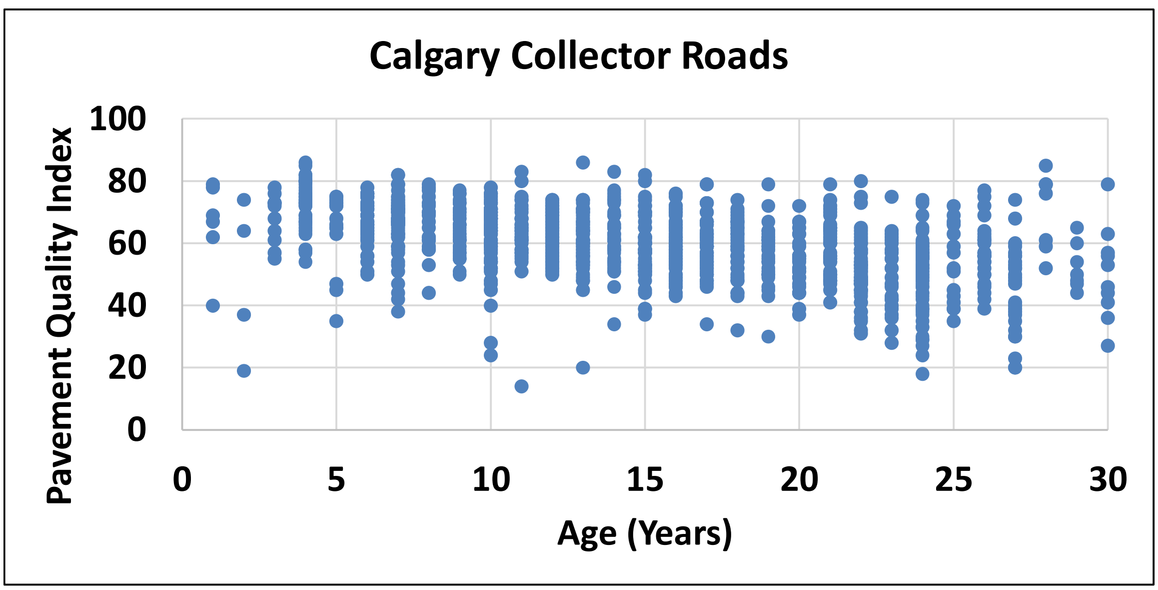


Figure 3-9. OCI versus Age for Calgary Collector Roads.

The section weighted average performance model for the Calgary collector roads is shown in Figure 3-2. The curve indicates that a terminal PQI will be reached at 25 years of age.

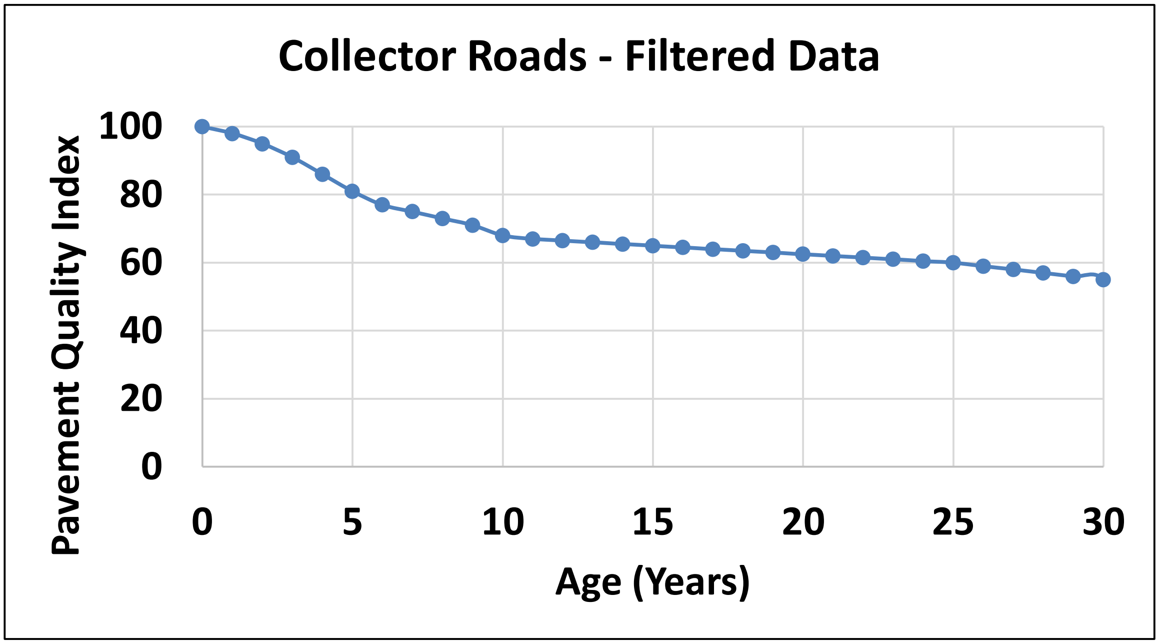


Figure 3-10. Calgary Performance Model for Collector Roads.

Given the lack of ICP and very limited PCC pavements, it was not possible to develop performance models for these categories of pavements.

3.3.4 Interlocking Concrete Pavement

As expected, there is not a significant difference between local and collector roadways as each roadway classification is typically designed to the specific traffic and subgrade conditions. Therefore, it is recommended that an initial service life of 30 years be used for the life-cycle modelling. There was insufficient data available to develop specific initial service life estimates for ICP.

In 2007/2008, ICPI commissioned a study for the life-cycle management of ICP [5]. This study included the field collection of pavement performance data from 83 ICP roadways located in 19 cities across North America. The data was then used to develop a standard practice for pavement condition index surveys for concrete block pavements [8] which eventually was adopted by ASTM International as ASTM E2840 [6]. The PCI versus age data for this study is shown in Figure 3-11.

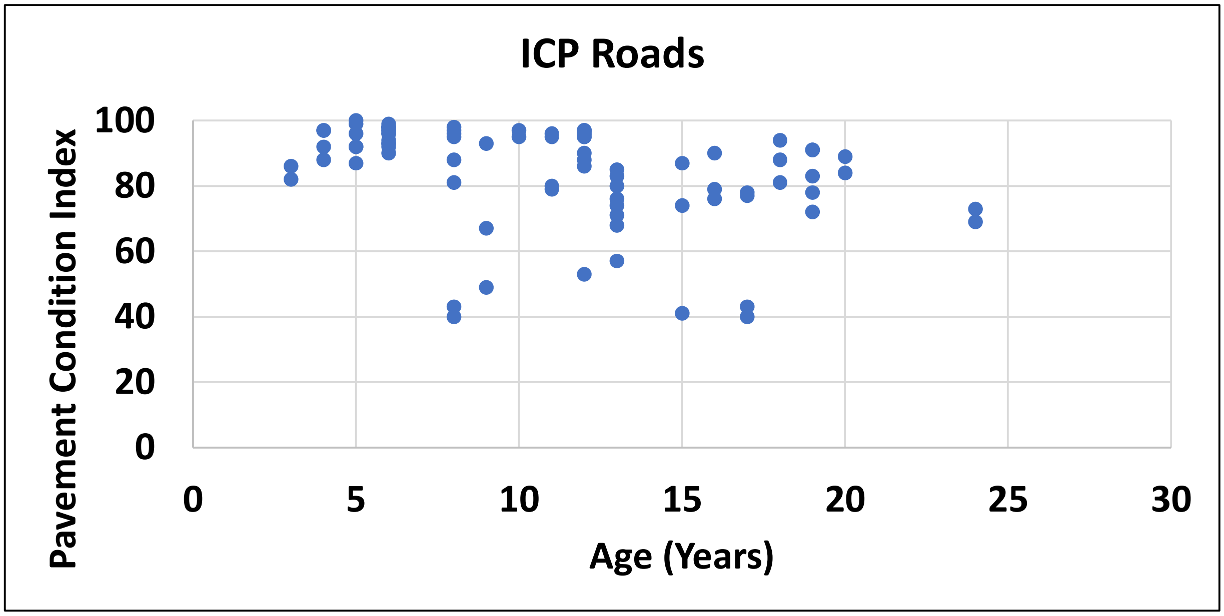


Figure 3-11. PCI versus Age for Interlocking Concrete Pavements.

Using a typical minimum serviceability trigger value PCI of 60, this data would indicate a typical ICP service life of 20 years. It was noted that the variability increases significantly after 8 years into the service life. The data also shows a group of pavement sections with relatively low PCI values (between 40 and 60) which do not seem to be grouped with the remainder of the pavement sections. If these sections (outliers) are removed from the population, the performance curve (Figure 3-12) would cross the PCI of 60 trigger value at about 31 years.

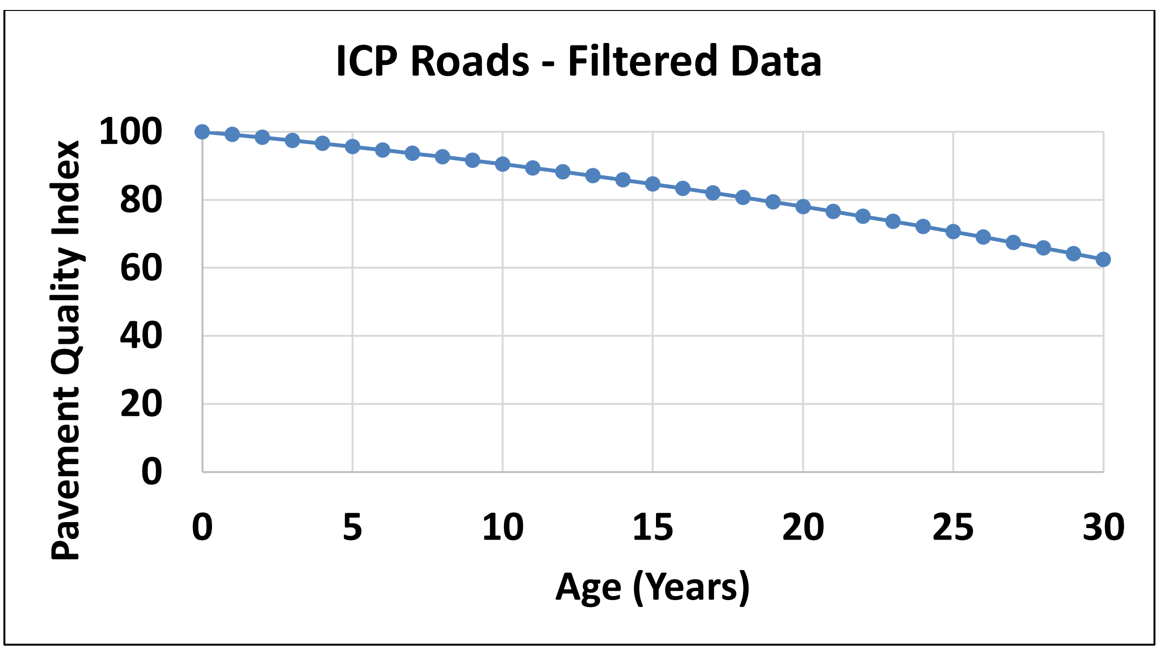


Figure 3-12. ICPI Performance Model for ICP.

Given the variable and limited data sample for ICP, it is recommended that the initial service life be established at 30 years for this project.

3.3.5 Concrete Pavement

There have been numerous studies on the life-cycle cost analysis from the U.S. Federal Highway Administration [9] and various State and Provincial Highway departments [10-13]. Most studies focus on heavily trafficked highway pavements. Highway agencies have different methods of determining the condition of pavements and in defining the initial pavement design life. A study completed by ARA for the Ontario Ready Mixed Concrete Association (RMCAO) and Cement Association of Canada (CAC) was completed specifically for life-cycle cost comparisons between flexible and rigid pavement types for municipal applications [14]. This study was based on pavement structures determined by using the Mechanistic-Empirical Design Guide and the AASHTOWare Pavement ME design software. The initial design life recommended is 30 years for rigid pavements.

3.4 Maintenance and Rehabilitation Plans

When selecting a pavement alternative, it is important to understand the expected pavement performance and costs for the entire life cycle of the pavement. The overall costs and value need to be determined over many years to effectively consider the different options in terms of pavement type, design life, and future rehabilitation. Life-cycle cost analysis (LCCA) has been used for many years to help make decisions regarding pavement type as well as selecting pavement preservation options.

In a typical LCCA, two or more alternate choices are available for an initial pavement design or cross-section. Based on the initial pavement designs, the expected maintenance and rehabilitation over the design life are then determined and incorporated into a single, inflation adjusted, cost in order to evaluate and compare the different options in a fair and consistent manner.

At the end of the initial service life, some form of rehabilitation, such as a mill and overlay for a flexible pavement, replacement of worn or cracked pavers for ICP and slab repairs and possible diamond grinding for smoothness and surface friction restoration for a rigid pavement, is usually required. An analysis period of 50 years was used for this project to include the initial service life as well as at least one major rehabilitation activity.

The maintenance and rehabilitation plans provided were developed for municipal roadways with speeds between 30 and 50 miles/hr. The maintenance and rehabilitation plans for state and provincial highways tend to be more frequent than for municipal roadways due to differences in posted speed and the higher focus on pavement smoothness for the faster moving vehicles. The recommended municipal maintenance and rehabilitation plans have been established to provide a reasonable level of service throughout the asset life.

3.4.1 HMA Pavement

Hot mix asphalt pavements have been commonly used by municipalities due to their history of use and experience with maintenance and rehabilitation. HMA pavements typically deteriorate faster than ICP and PCC pavements and require a more extensive maintenance schedule to maintain an acceptable level of service.

The recommend maintenance and rehabilitation schedules for HMA pavements are outlined in Table 3-1 and Table 3-2. These plans use a combination of preventive maintenance and rehabilitation to ensure a cost-effective preservation plan. The maintenance and rehabilitation quantities provided are for a 2-lane 1 mile length roadway and will need to be adjusted for different section lengths.

Table 3-1. Flexible Pavement Preservation Plan (AADTT <250-500).

Expected Year	Activity Description	Quantity (per 2 lane 1 mile of road)
10	Rout and seal	400 ft
10	Spot repairs, mill 1.5 in/patch 1.5 in	2 %
20	Mill HMA	1.5 in
20	Resurface with HMA surface course	1.5 in
25	Rout and seal	800 ft
30	Spot repairs, 1.5 in/patch 1.5 in	5 %
35	Mill HMA	1.5 in
35	Full depth asphalt base repair	5 %
35	Resurface with HMA surface course	1.5 in
40	Rout and seal	800 ft
43	Spot repairs, 1.5 in/patch 1.5 in	5 %
48	Mill HMA	1.5 in
48	Resurface with HMA surface course	1.5 in

Table 3-2. Flexible Pavement Preservation Plan (AADTT 1,000-1,500).

Expected Year	Activity Description	Quantity (per 2 lane 1 mile of road)
10	Rout and seal	400 ft
10	Spot repairs, mill 1.5 in/patch 1.5 in	2 %
15	Spot repairs, mill 1.5 in/patch 1.5 in	10 %
20	Mill HMA	1.5 in
20	Mill and resurface with HMA surface course	1.5 in
25	Rout and seal	800 ft
30	Spot repairs, 1.5 in/patch 1.5 in	5 %
35	Mill HMA	1.5 in
35	Full depth asphalt base repair	10 %
35	Resurface with HMA surface course	1.5 in
40	Rout and seal	800 ft
43	Spot repairs, 1.5 in/patch 1.5 in	5 %
48	Mill HMA	3.5 in
48	Resurface with HMA binder course	2.0 in
48	Resurface with HMA surface course	1.5 in

3.4.2 Interlocking Concrete Pavement

ICPs have been used by municipalities intermittently across North America. Usage of ICP for municipal pavements is typically based on development requirements for a high quality appearance in specific areas of the city attracting tourist and retail type activities.

The recommend maintenance and rehabilitation schedules for ICP pavements are outlined in Table 3-3 and Table 3-4. These plans use a combination of preventive maintenance and rehabilitation to ensure a cost-effective preservation plan. The maintenance and rehabilitation quantities provided are for a 1-mile length of 2-lane roadway and will need to be adjusted for different section lengths.

Table 3-3. Interlocking Concrete Pavement Preservation Plan (AADTT <250-500).

Expected Year	Activity Description	Quantity (per 2 lane 1 mile of road)
10	Replace Cracked Pavers	2 %
20	Replace Worn/Rutted Pavers (wheelpath)	5 %
30	Replace Cracked Pavers	2 %
40	Replace Worn/Rutted Pavers (wheelpath)	5 %

Table 3-4. Interlocking Concrete Pavement Preservation Plan (AADTT 1,000-1,500).

Expected Year	Activity Description	Quantity (per 2 lane 1 mile of road)
8	Replace Cracked Pavers	2 %
18	Replace Worn/Rutted Pavers (wheelpath)	5 %
28	Replace Cracked Pavers	2 %
38	Replace Worn/Rutted Pavers (wheelpath)	5 %
48	Replace Cracked Pavers	3 %

3.4.3 Concrete Pavement

Concrete pavements have been used by municipalities intermittently across North America often depending on local pricing, availability of aggregates local contractors capable of placing concrete pavements. The recommended maintenance and rehabilitation schedules for PCC pavements are outlined in Table 3-5 and Table 3-6. These plans use a combination of preventive maintenance and rehabilitation to ensure a cost-effective preservation plan. The maintenance and rehabilitation quantities provided are for a 1 mile length of 2-lane roadway and will need to be adjusted for different section lengths.

Table 3-5. Concrete Pavement Preservation Plan (AADTT <250-500).

Expected Year	Activity Description	Quantity (per 2 lane 1 mile of road)
12	Reseal joints	10 %
25	Partial depth PCC repair	2 %
25	Full depth PCC repair	5 %
25	Reseal joints	20 %
40	Partial depth PCC repair	5 %
40	Full depth PCC repair	10 %
40	Reseal joints	20 %

Table 3-6. Concrete Pavement Preservation Plan (AADTT 1,000-1,500).

Expected Year	Activity Description	Quantity (per 1mile of road)
12	Reseal joints	20 %
25	Partial depth PCC repair	5 %
25	Full depth PCC repair	10 %
25	Reseal joints	25 %
40	Partial depth PCC repair	5 %
40	Full depth PCC repair	15 %
40	Reseal joints	25 %

3.5 Pavement Construction, Maintenance and Rehabilitation Costs

One of the key components for evaluating total costs over the pavement life cycle is estimating construction, maintenance and rehabilitation costs. This is typically accomplished by reviewing initial construction costs and the potential activities throughout the service life of a pavement, their frequency and costs.

Unit costs for construction, maintenance and rehabilitation are provided for each pavement type. The unit costs were developed from Nashville, Niagara Falls and Calgary as well as bid information from U.S. and Canadian municipalities. Adjustments due to inflation were made to adjust for current (2020) dollars. The unit costs represent the whole cost to complete the maintenance and rehabilitation activity, including labor, equipment and materials. These costs should be adjusted as necessary for local prices and experience when using the LCCA tools provided for specific projects. Initial construction unit costs for the three pavement types are provided in Table 3-7.

Table 3-7. Initial Pavement Construction Unit Costs.

Pavement Layer	Description	Unit Cost ($)
HMA	Surface course asphalt (ton)	110.00
	Binder course asphalt (ton)	105.00
ICP	3.125 in pavers, 1 in bedding sand (ft^2) machine laid	6.00
PCC	6.5 in PCC, no dowels (ft^2)	4.20
	6.75 in PCC, no dowels (ft^2)	4.30
	6.75 in PCC, 1.25 in dowels (ft^2)	4.85
	7.0 in PCC, 1.25 in dowels (ft^2)	5.00
Base	Granular base (ton)	18.20
Subbase	Granular subbase (ton)	13.65

Maintenance and rehabilitation costs are provided in Table 3-8.

Table 3-8. Maintenance and Rehabilitation Costs.

Maintenance and Rehabilitation Treatment	Unit Cost ($)
Rout and seal asphalt (ft)	1.50
Spot repairs, mill and patch (ft^2)	3.25
Full depth asphalt base repair, % area (ft^2)	4.20
Mill HMA (ton)	16.35
Resurface with surface course asphalt (ton)	110.00
Resurface with binder course asphalt (ton)	105.00
Replace cracked pavers (ft^2)	6.00
Replace worn/rutted pavers (ft^2)	11.15
Reseal concrete joints (ft)	1.10
Partial depth PCC repair (ft^2)	13.95
Full depth PCC repair (ft^2)	9.30

Each unit cost can vary significantly depending on location, size of the project, manual or machine assisted installation, availability of materials and contractors, etc.

4. Life-Cycle Costs

The key benefit of life-cycle cost analysis is the ability to compare multiple pavement structures with different initial cross-sections and hence different maintenance strategies. To ensure a fair comparison of different options, life cycle costs are typically evaluated in terms of their Net Present Worth (NPW). The present worth represents the cost of a future activity in terms of today's dollars. The initial costs and on-going costs are then combined to evaluate the total project present worth.

When evaluating the life-cycle cost, it is typically understood that there is a margin of error due to possible differences in quantities, unit costs, and pavement performance over the service life. Comparisons with marginal differences in cost may require further investigation into other factors to determine the optimal pavement type.

4.1 Calculations of Net Present Value

The costs distributed over the pavement are typically translated into a Net Present Value (NPV). The NPV represents the today's total cost expenditures made in the future. Such expenditures account for the interest minus inflation rate (in percent) expressed as the discount rate. The NPV of all activities each occurring in the future are summed to estimate the total maintenance and rehabilitation cost. This summation of activities is expressed as:

$$Total\ M\&R\ Cost\ = \sum_i \left(\frac{(M\&R\ Cost_i)}{(1 + Discount\ Rate)^{Age}}\right)$$

The discount rate typically reflects the social discount rate for public sector projects and is dependent on many factors such as current economic environment, market risk, and many other potential factors. It often reflects the difference between the prevailing (market) loan interest rate and the inflation rate. A typical discount rate used by municipal agencies is in the order of 3 to 5 percent. The initial LCCA analysis has been completed for a discount rate of 4 percent.

4.2 Residual Value

To ensure fair comparison of the alternatives, residual value of any unused rehabilitation activity at the end of the analysis period must be included in the LCCA. The residual value is estimated by the straight-line depreciation of the last capital activity cost. The prorated life method is used in the LCCA procedure to estimate the residual value. The recoverable cost is estimated by dividing the remaining life of the last rehabilitation treatment, by the expected life of the treatment.

$$Residual\ Value = M\&R\ Cost\ \left(\frac{Service\ Life - Activity\ Age}{Service\ Life}\right)$$

To determine the residual value, the last major rehabilitation activity is used. Based on the year of implementation of the last rehabilitation, the expected service life (from the Unit Costs table) and the activity cost, a proportion of the initial cost is estimated. This residual value at the end of the design period is then converted (discounted) to a net present value. That net present value is then subtracted from the other costs.

4.3 Life-cycle Cost

The total cost to construct and maintain each design option is the outcome from an LCCA. To accomplish this, the sum of all costs using an equivalent NPV is calculated for each option. The total cost for each option is thus calculated as:

$$LCC = Initial\ Cost + Total\ M\&R\ Cost - Residual\ Value$$

This value for each design option can be compared with other design options to determine which is has the lowest cost over the life of the pavement.

4.4 Example LCCA Calculations

An example LCCA for a minor collector bus route roadway (AADTT = 1,000) on the low strength subgrade is shown in Table 4-1 through Table 4-3 for each pavement type. This example shows the reduced cost of future maintenance and rehabilitation activities due to discounting, as well as the relatively low cost of the maintenance and rehabilitation compared to the initial construction. The comparison of the costs shown in Table 4-4 and in Figure 4-1 illustrates the relative difference between the pavement types.

The analysis shows that for a discount rate of 4 percent and the base case costs, the life-cycle cost of the paver surfaced roadways are always higher than that of the asphalt by 15 to 22 percent and for the concrete surface roadways by 37 to 50 percent.

The detailed LCCA results for a discount rate of 4 percent, an initial pavement design of 30 years, for the low, medium and high strength subgrade categories and 4 roadway classifications are provided in Appendix A.

Separate LCCA Microsoft Excel spreadsheets for each of 3 subgrade strength categories are available for use and customization to represent local municipal pricing, discount rates and maintenance plans.

Table 4-1 Example LCCA for a Minor Collector Bus Route HMA Pavement (AADTT = 1,000).

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	5.5	4,325	$ 105.00	$ 454,087
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	18	11,505	$ 13.65	$ 157,045
	Total Initial Cost				**$ 827,789**

Pavement Maintenance and Rehabilitation Action Plan.

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1,300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	2	2,534	$ 3.25	$ 8,237	$ 5,564
15	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	10	12,672	$ 3.25	$ 41,184	$ 22,868
20	Mill HMA, in (ton)	1.5	1,199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1,208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2,600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6,336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1,199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft^2)	10	12,672	$ 4.20	$ 53,222	$ 13,487
35	Resurface with HMA Surface, in (ton)	1.5	1,208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2,600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6,336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	3.5	2,797	$ 16.35	$ 45,728	$ 6,960
48	Resurface with HMA Binder, in (ton)	2	1,573	$ 105.00	$ 165,122	$ 25,131
48	Resurface with HMA Surface, in (ton)	1.5	1,208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 286,456	$ 40,308
Total Maintenance and Rehabilitation Cost					**$ 515,857**	**$ 175,924**

Table 4-2 Example LCCA for a Minor Collector Bus Route ICP Pavement (AADTT = 1,000).

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	32	20,454	$ 13.65	$ 279,192
	Total Initial Cost				**$ 1,123,272**

Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost	Net present worth
8	Replace cracked pavers, % area (ft2)	2	2,534	$ 6.00	$ 15,206	$ 11,111
18	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6,336	$ 11.15	$ 70,646	$ 34,873
28	Replace cracked pavers, % area (ft2)	2	2,534	$ 6.00	$ 15,206	$ 5,071
38	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6,336	$ 11.15	$ 70,646	$ 15,916
48	Replace cracked pavers, % area (ft2)	3	3,802	$ 6.00	$ 22,810	$ 3,472
50	Residual value				$ 4,562	-$ 642
Total Maintenance and Rehabilitation Cost					**$ 176,268**	**$ 67,613**

Table 4-3 Example LCCA for a Minor Collector Bus Route PCC Pavement (AADTT = 1,000).

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	7.0 in PCC pavement, 1.25 in dowels (ft^2)	7	126,720	$ 5.00	$ 633,600
Base	Granular Base, in (ton)	8	6,136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 745,280**

Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	20	1,690	$ 1.10	$ 1,859	$ 1,161
25	Partial depth PCC repair, % area (ft^2)	5	6,336	$ 13.95	$ 88,387	$ 33,156
25	Full depth PCC repair, % area (ft^2)	10	12,672	$ 9.30	$ 117,850	$ 44,207
25	Reseal joints, % length (ft)	25	2,112	$ 1.10	$ 2,323	$ 871
40	Partial depth PCC repair, % area (ft^2)	5	6,336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft^2)	15	19,008	$ 9.30	$ 176,774	$ 36,820
40	Reseal joints, % length (ft)	25	2,112	$ 1.10	$ 2,323	$ 484
50	Residual Value				$ 89,162	$ 12,546
Total Maintenance and Rehabilitation Cost					**$ 388,742**	**$ 122,563**

Table 4-4. Summary of Initial and Life-Cycle Cost for All Roadway Classifications. Low Subgrade Strength

Item	Local Collector		
	250 HMA	250 ICP	250 PCC
Initial Cost	$ 751,609	$ 1,027,300	$ 656,576
M&R Cost (Discounted)	$ 139,631	$ 61,918	$ 70,470
Total Cost	$ 891,240	$ 1,089,218	$ 727,046
LCC Difference to ICP	**-22%**		**-50%**

Item	Minor Collector		
	500 HMA	500 ICP	500 PCC
Initial Cost	$ 807,149	$ 1,070,924	$ 726,272
M&R Cost (Discounted)	$ 139,631	$ 61,918	$ 73,908
Total Cost	$ 946,779	$ 1,132,842	$ 800,180
LCC Difference to ICP	**-20%**		**-42%**

Item	Minor Collector Bus Route		
	1,000 HMA	1,000 ICP	1,000 PCC
Initial Cost	$ 827,789	$ 1,123,272	$ 745,280
M&R Cost (Discounted)	$ 175,924	$ 67,613	$ 122,563
Total Cost	$ 1,003,713	$ 1,190,885	$ 867,844
LCC Difference to ICP	**-19%**		**-37%**

Item	Major Collector		
	1,500 HMA	1,500 ICP	1,500 PCC
Initial Cost	$ 877,794	$ 1,140,722	$ 745,280
M&R Cost (Discounted)	$ 173,385	$ 67,613	$ 122,563
Total Cost	$ 1,051,180	$ 1,208,335	$ 867,844
LCC Difference to ICP	**-15%**		**-39%**

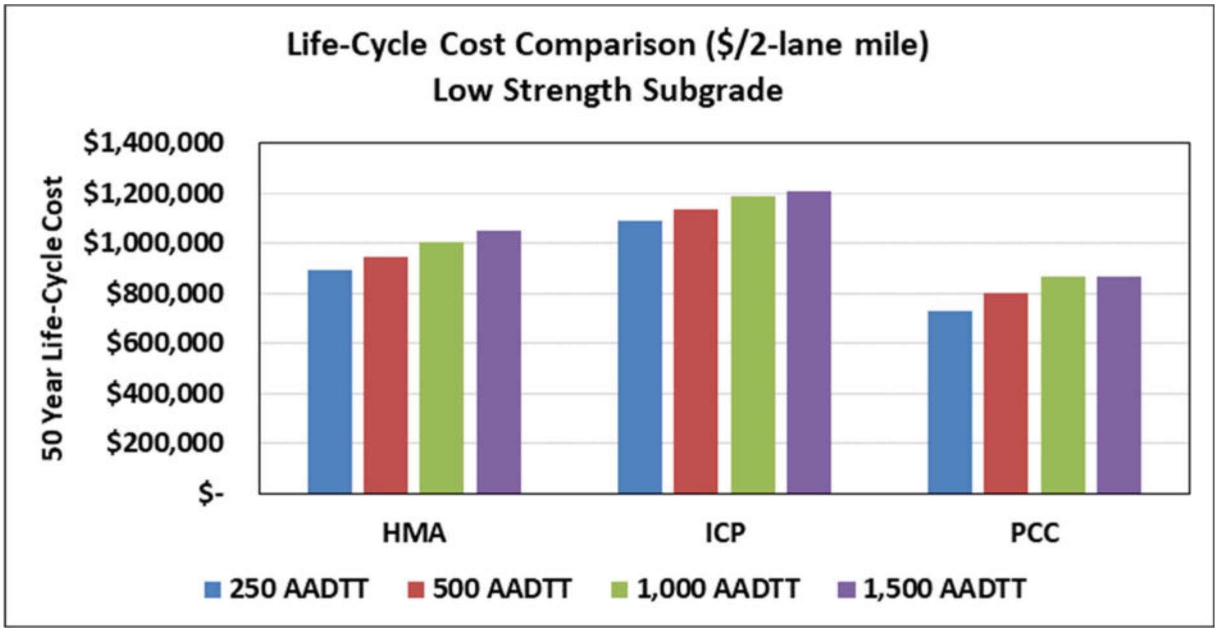


Figure 4-1. Example LCCA Comparison of Costs for a Minor Collector Bus Route.

5. Life-Cycle Cost Sensitivity Analysis

A sensitivity analysis was completed for 5 discount rates, and 4 traffic levels for HMA, ICP and PCC pavement surfaces.

5.1 Summary LCCA Calculations

The life-cycle cost for the 4 traffic levels, 3 subgrade strength categories for each pavement surface type was calculated. The life-cycle cost summaries along with the average life-cycle cost for the traffic categories and low strength subgrade is shown in Table 5-1 and on Figure 5-1.

Table 5-1. Life-Cycle Cost Summary ($/2-Lane mile)
Low Strength Subgrade

Discount Rate	Traffic Category				Average	Percent Compared to ICP
	Local Collector	Minor	Minor Bus	Major Collector		
Hot Mix Asphalt						
1	$ 1,063,920	$ 1,119,459	$ 1,216,077	$ 1,265,039	$ 1,166,124	-10
2	$ 988,179	$ 1,043,719	$ 1,122,979	$ 1,171,219	$ 1,081,524	-15
3	$ 932,507	$ 988,047	$ 1,054,507	$ 1,102,269	$ 1,019,333	-19
4	$ 891,240	$ 946,779	$ 1,003,713	$ 1,051,180	$ 973,228	-22
5	$ 860,383	$ 915,922	$ 965,686	$ 1,012,994	$ 938,746	-24
Interlocking Concrete Pavers						
1	$ 1,157,696	$ 1,201,320	$ 1,259,063	$ 1,276,512	$ 1,223,648	
2	$ 1,127,708	$ 1,171,331	$ 1,229,431	$ 1,246,881	$ 1,193,838	
3	$ 1,105,652	$ 1,149,276	$ 1,207,437	$ 1,224,886	$ 1,171,813	
4	$ 1,089,218	$ 1,132,842	$ 1,190,885	$ 1,208,335	$ 1,155,320	
5	$ 1,076,815	$ 1,120,439	$ 1,178,260	$ 1,195,710	$ 1,142,806	
Portland Cement Concrete						
1	$ 830,442	$ 906,994	$ 1,035,002	$ 1,035,002	$ 951,860	-17
2	$ 784,763	$ 859,858	$ 961,885	$ 961,885	$ 892,098	-20
3	$ 751,415	$ 825,402	$ 907,854	$ 907,854	$ 848,131	-22
4	$ 727,046	$ 800,180	$ 867,844	$ 867,844	$ 815,729	-24
5	$ 709,190	$ 781,668	$ 838,124	$ 838,124	$ 791,777	-26

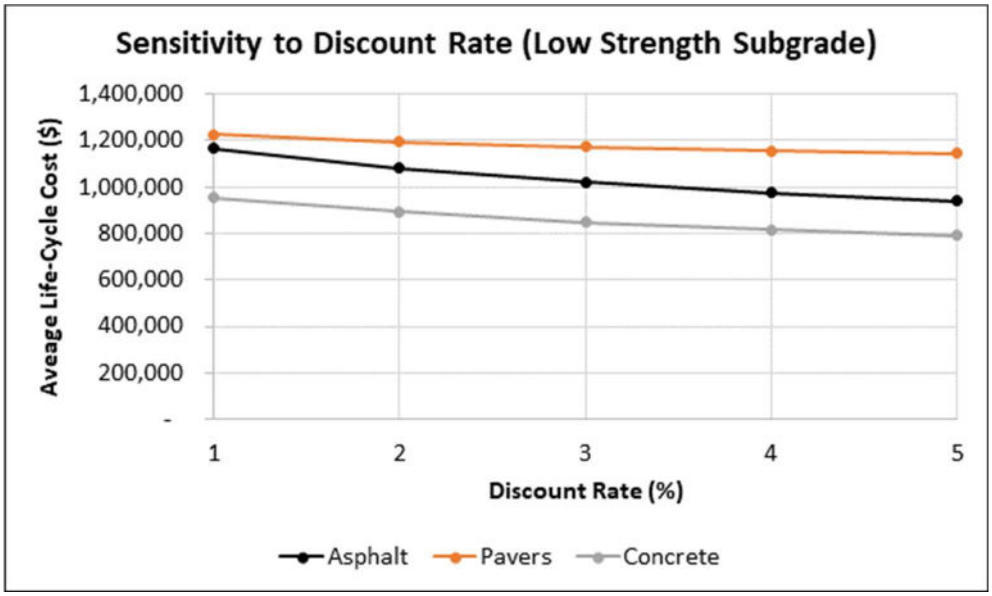


Figure 5-1. AADTT Average Life-Cycle Cost versus Discount Rate (Low Strength Subgrade).

From the figure, it can be seen that the concrete pavement surface pavement has the lowest overall life-cycle cost for all discount rates of 1 through 5 percent. The paver surface pavement life-cycle cost is within 5 percent of the asphalt surface pavement at a discount rate of 1 percent.

The life-cycle cost summaries along with the average life-cycle cost for the traffic categories and medium strength subgrade is shown in Table 5-2 and plotted in Figure 5-2.

Table 5-2. Life-Cycle Cost Summary ($/2-Lane mile)
Medium Strength Subgrade

Discount Rate	Traffic Category				Average	Percent Compared to ICP
	Local Collector	Minor	Minor Bus	Major Collector		
Hot Mix Asphalt						
1	$ 943,269	$ 1,022,639	$ 1,174,797	$ 1,194,394	$ 1,083,775	-10
2	$ 867,528	$ 946,899	$ 1,081,698	$ 1,100,573	$ 999,175	-15
3	$ 811,856	$ 891,227	$ 1,013,226	$ 1,031,623	$ 936,983	-19
4	$ 770,589	$ 849,959	$ 962,432	$ 980,534	$ 890,879	-22
5	$ 739,732	$ 819,102	$ 924,406	$ 942,349	$ 856,397	-24
Interlocking Concrete Pavers						
1	$ 1,114,072	$ 1,157,696	$ 1,206,714	$ 1,232,889	$ 1,177,843	
2	$ 1,084,084	$ 1,127,708	$ 1,177,083	$ 1,203,257	$ 1,148,033	
3	$ 1,062,028	$ 1,105,652	$ 1,155,088	$ 1,181,262	$ 1,126,008	
4	$ 1,045,595	$ 1,089,218	$ 1,138,537	$ 1,164,711	$ 1,109,515	
5	$ 1,033,191	$ 1,076,815	$ 1,125,912	$ 1,152,086	$ 1,097,001	
Portland Cement Concrete						
1	$ 830,442	$ 906,994	$ 1,035,002	$ 1,035,002	$ 951,860	-17
2	$ 784,763	$ 859,858	$ 961,885	$ 961,885	$ 892,098	-20
3	$ 751,415	$ 825,402	$ 907,854	$ 907,854	$ 848,131	-22
4	$ 727,046	$ 800,180	$ 867,844	$ 867,844	$ 815,729	-24
5	$ 709,190	$ 781,668	$ 838,124	$ 838,124	$ 791,777	-26

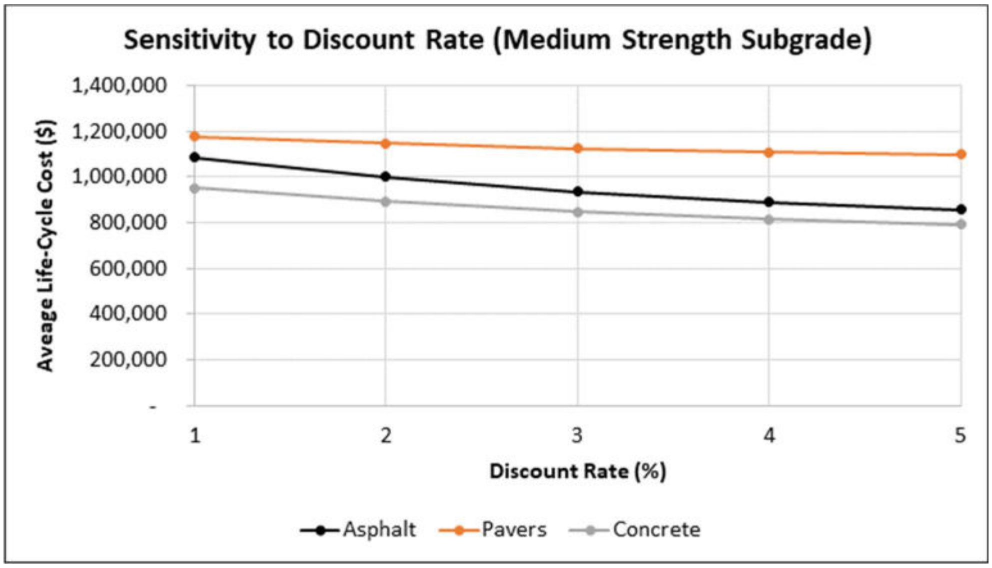


Figure 5-2. AADTT Average Life-Cycle Cost versus Discount Rate (Medium Strength Subgrade).

From the figure, it can be seen that the concrete pavement surface pavement has the lowest overall life-cycle cost for all discount rates of 1 through 5 percent. The paver surface pavement has the highest life-cycle cost for all discount rates.

The average life-cycle cost for the traffic categories and high strength subgrade is shown in Table 5-3 and on Figure 5-3.

Table 5-3. Life-Cycle Cost Summary ($/2-Lane mile)
High Strength Subgrade

Discount Rate	Traffic Category				Average	Percent Compared to ICP
	Local Collector	Minor	Minor Bus	Major Collector		
Hot Mix Asphalt						
1	$ 917,094	$ 960,718	$ 1,107,342	$ 1,156,304	$ 1,035,365	-10
2	$ 841,354	$ 884,978	$ 1,014,243	$ 1,062,484	$ 950,765	-15
3	$ 785,682	$ 829,306	$ 945,771	$ 993,533	$ 888,573	-19
4	$ 744,415	$ 788,039	$ 894,977	$ 942,444	$ 842,469	-22
5	$ 713,558	$ 757,181	$ 856,951	$ 904,259	$ 807,987	-24
Interlocking Concrete Pavers						
1	$ 1,087,898	$ 1,122,797	$ 1,171,815	$ 1,197,990	$ 1,145,125	
2	$ 1,057,910	$ 1,092,809	$ 1,142,184	$ 1,168,358	$ 1,115,315	
3	$ 1,035,854	$ 1,070,753	$ 1,120,189	$ 1,146,363	$ 1,093,290	
4	$ 1,019,420	$ 1,054,319	$ 1,103,938	$ 1,129,812	$ 1,076,872	
5	$ 1,007,017	$ 1,041,916	$ 1,091,013	$ 1,117,187	$ 1,064,283	
Portland Cement Concrete						
1	$ 830,442	$ 906,994	$ 1,035,002	$ 1,035,002	$ 951,860	-17
2	$ 784,763	$ 859,858	$ 961,885	$ 961,885	$ 892,098	-20
3	$ 751,415	$ 825,402	$ 907,854	$ 907,854	$ 848,131	-22
4	$ 727,046	$ 800,180	$ 867,844	$ 867,844	$ 815,729	-24
5	$ 709,190	$ 781,668	$ 838,124	$ 838,124	$ 791,777	-26

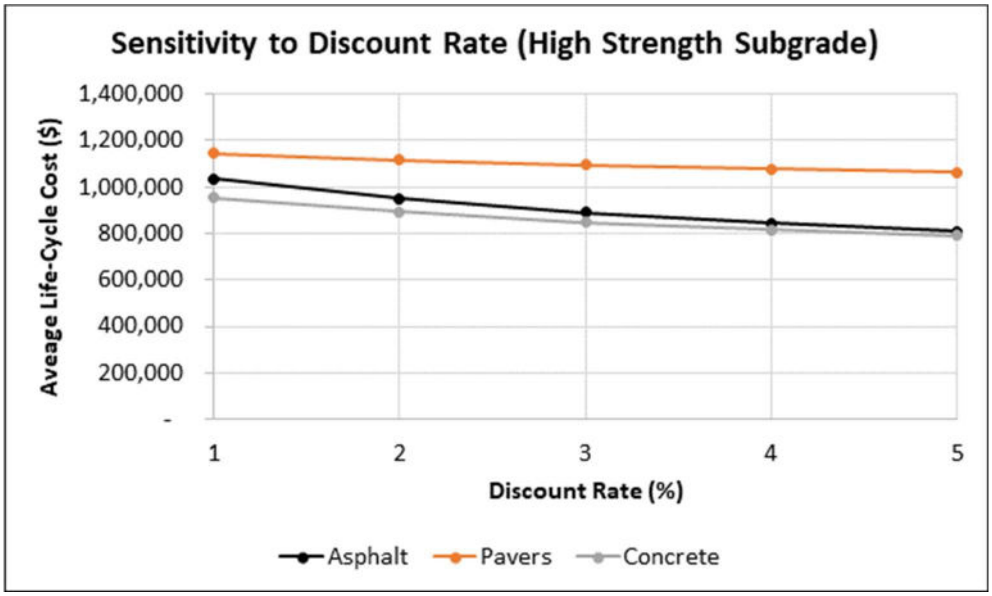


Figure 5-3. AADTT Average Life-Cycle Cost versus Discount Rate (High Strength Subgrade).

From the figure, it can be seen that the concrete pavement surface pavement has the lowest overall life-cycle cost for all discount rates of 1 through 5 percent. The asphalt pavement surface is competitive with the concrete pavement surface at discount rates of 4 and 5 percent. The paver surface pavement has the highest life-cycle cost for all discount rates.

5.2 Example of Detailed LCCA Comparisons

The analysis in Section 5.1 compared the average life-cycle cost for all traffic categories with the discount rates varying from 1 to 5 percent. In this section, an example analysis is provided comparing the life-cycle cost of pavers versus asphalt for each traffic category and discount rate for the low strength subgrade category. The detailed results are shown visually for the base costs case in Table 5-4. Combinations of discount rate and traffic categories are green for cases where the paver surface pavement has a lower life-cycle cost than and asphalt surface pavement and yellow if the costs are within 5 percent of each other. Many State and Provincial Highway agency life-cycle cost policies consider the alternatives to be equal if the life-cycle costs are within 5 percent of each of other and base their final decision on the best alternative based on the construction bid costs.

Table 5-4. Life-Cycle Cost of Pavers versus Asphalt (Base Cost Case)
Low Strength Subgrade

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt

The example above shows that the life-cycle cost of the paver surface pavement is less than that of the asphalt surface pavement for major collector roadways and a discount rate of 1 percent. The life-cycle cost of the paver surface pavement is within 5 percent of the asphalt surface pavement for minor collector bus routes and average of all traffic categories for at a discount rate of 1 percent and for the major collector traffic category at a discount rate of 2 percent.

The analysis was repeated above was repeated including a reduction in the cost of the pavers by 10, 15 and 20 percent. The costs used in the analysis are provided in Table 5-5.

Table 5-5. Paver Cost Sensitivity Analysis

Paver Cost Reduction (%)	US (ft^2)
0	$ 6.00
10	$ 5.45
15	$ 5.15
20	$ 4.85

Figure 5-4 and Table 5-6 show the results of the analysis for a 10 percent reduction in the unit cost of pavers.

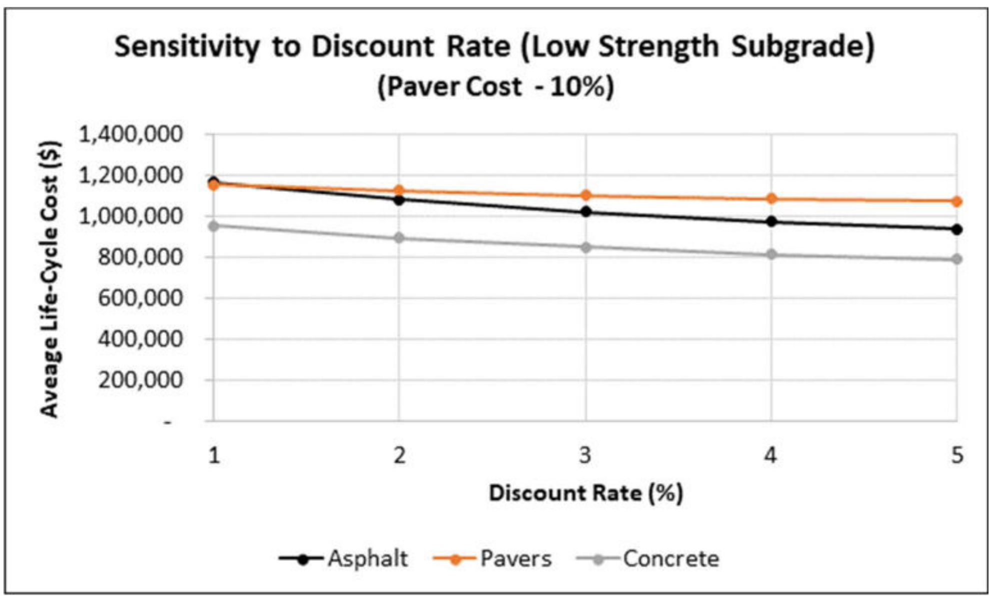


Figure 5-4. AADT Average Life-Cycle Cost versus Discount Rate (Paver Unit Rate Reduced by 10%)

Table 5-6. Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -10%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt

The paver surfaced pavement has a lower life-cycle cost than an asphalt surfaced pavement at a 1 percent discount rate and is within 5 percent for 4 traffic categories at a discount rate of 2 percent.

Figure 5-5 and Table 5-7 show the results of the analysis for a 15 percent reduction in the unit cost of pavers.

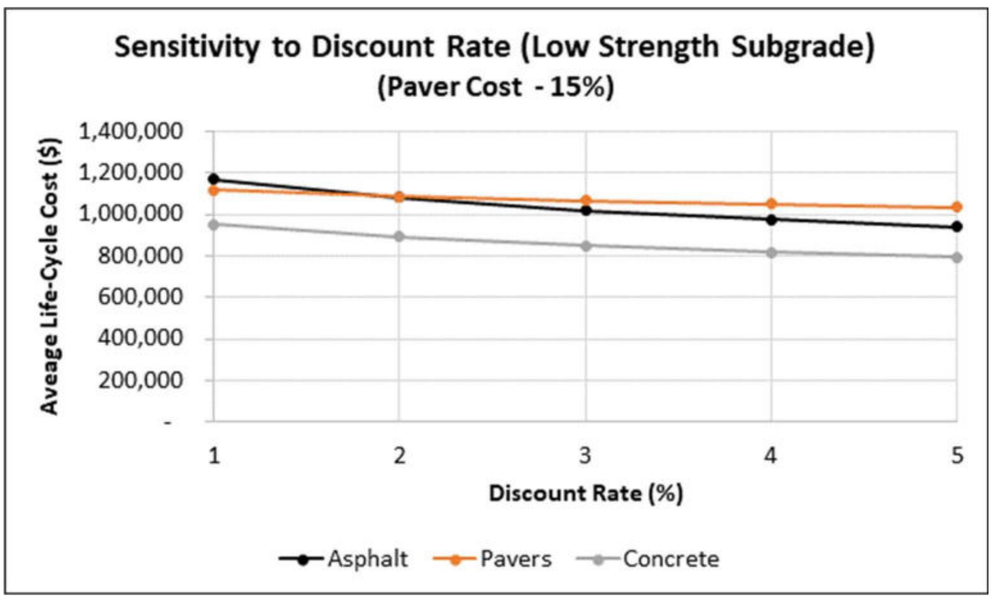


Figure 5-5. AADT Average Life-Cycle Cost versus Discount Rate (Paver Unit Rate Reduced by 15%)

Table 5-7. Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -15%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt

For a paver cost of 15 percent lower than the base cost, the ICP pavement has a lower life-cycle cost on average and for two categories of traffic at the 1 and 2 percent discount rates as well as for the major collector for a discount rate of 3 percent. The paver surface pavement life-cycle cost is also within 5 percent of the asphalt surface pavement for several other categories.

Figure 5-6 and Table 5-8 show the results of the analysis for a 20 percent reduction in the unit cost of pavers.

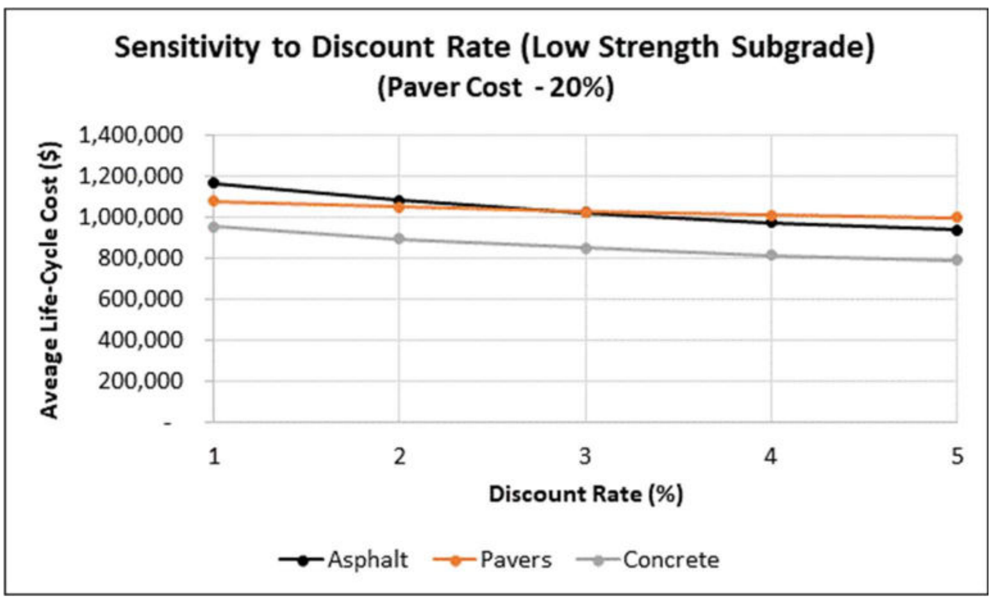


Figure 5-6. AADT Average Life-Cycle Cost versus Discount Rate (Paver Unit Rate Reduced by 20%)

Table 5-8. Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -20%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt

Paver LCC within 5 % of Asphalt

For a paver cost of 20 percent lower than the base cost, the ICP pavement has a lower life-cycle cost on average and for several categories of traffic at the 1 to 4 percent discount rates as well as being within 5 percent of the cost for an asphalt surface pavement for several other traffic categories.

The detailed LCCA comparisons for all traffic categories, subgrade strengths and traffic categories in Appendix B.

6. Summary

This LCCA study compared four road classes (e.g., local collector, minor collector, minor collector bus route, major collector) on HMA, PCC and ICP structures receiving corresponding average annual daily truck traffic for each class on three soil subgrade strengths. The analysis period was 50 years for all pavements. When using 4 percent as the typical discount rate, ICP had the highest net present value cost. PCC consistently had the lowest with asphalt landing between ICP and PCC.

The study showed that ICP is 15 to 37 percent more expensive than asphalt pavement when using a common current discount rate of 4 percent. At the time of this writing, asphalt prices are lower in part due to lack of demand of higher petroleum distillates such as kerosene, diesel and gasoline. Higher demand for these increases prices as well as draws more lighter fractions out of each barrel of oil. This happened in 2011-12 when gasoline was over $4 per U.S. gallon. Demand for gasoline impinged on the manufacturing of asphalt. Lack of asphalt supplies and high prices were further aggravated by limited asphalt industry production capacity.

Compared to the U.S., asphalt is taxed heavily in the UK and Europe in an effort to support (subsidize) public transit and other programs. In addition, there is a 1000+ year tradition of segmental paving in Europe that perpetuates ICP use. ICP awareness and experience is very limited in the much younger New World. Segmental paving is further hindered here by the reasons provided in the Task 1 survey results: lack of a trained workforce, lack of design, construction and maintenance experience, and then from previous bad experiences. All of these are accompanied by high ICP initial costs. Hence, this study was initiated to more thoroughly review life cycle costs via sensitivity analyses.

Such analyses were conducted with the installed price of concrete pavers, jointing and bedding sands reduced by 10, 15 and 20%, i.e. from a base rate of $6 down to $4.85/ft^2. In addition, these LCCAs modeled present values using discount rates of 1, 2, 3, 4 and 5 percent for the four road classes over three subgrade strengths (low = CBR=3; medium = CBR=4 and high=CBR=5).

For ICP with no cost reductions applied, the PCC pavement had the lowest overall life-cycle cost for discount rates of 1 through 5 percent. PCC pavements typically have lower life-cycle costs for higher volume traffic pavements with low strength subgrade.

ICP had the highest overall life-cycle cost for all discount rates with the exception of the major collector traffic category at a discount rate of 1 percent for the low strength subgrade. ICP present values were within 5 percent of the life-cycle cost of the HMA pavement for two lower road categories at a 1 percent discount rate. This analysis was modeled over low-strength subgrade which typically requires thick and more expensive base/subbase layer combinations or stabilized base layers compared to analyses conducted on higher strength subgrades. This reduction in thickness also reduces excavation costs. In general, ICP has lower present value costs for low discount rate values for higher traffic roadways on low strength subgrades. This suggests that ICP on weak subgrades may be more cost-effective with stabilized bases to reduce thick, unstablized aggregate layers.

For a 10 percent reduction in paver installation costs, ICP on a high-strength subgrade had a lower life-cycle cost than HMA at a 1 percent discount rate. The life-cycle costs or present value is within 5 percent for two traffic categories, minor bus collector route and major collector, at a discount rate of 2 percent.

For a 15 percent reduction in paver installation costs, ICP starts to become cost competitive with HMA for all levels of subgrade support and traffic at discount rates of 1 to 2 percent.

For a 20 percent reduction in paver installation costs, ICP has a lower present value cost for discount rates of up to 4 percent within all traffic categories with the exception of local collectors. In general, as the discount rate rises, all three pavement types start to have competitive present value costs.

The tools developed for this study can be used in conjunction with local pavement material unit costs and pavement design and maintenance plans to develop appropriate life-cycle cost comparisons to reflect local conditions and to assist in making decisions with respect to pavement type selection.

Besides life-cycle costs, pavement selection includes engineering factors such as availability and quality of materials, construction expertise and structural performance. These factors must be weighed against the initial and life-cycle costs, as well as, sustainable benefits. This LCCA does not include supplemental costs for engineering and contract administration and traffic control/protection and societal costs such as user delays and environmental impacts. In addition, other factors such as roadway geometry, qualified contractors and construction experience, conservation of materials/ energy, stimulation of competition, impact on winter maintenance, light reflectance, safety and comfort can also be factored into the decision process. All of these factors with LCCAs are given weight in selecting pavements consistent with the agency's financial goals, policy decisions, project timing, experience and familiarity with pavement types.

The pavement design and life-cycle cost analysis presented in this report is considered to be typical for municipal pavements. The decision to use life-cycle cost analysis and evaluate sustainable benefits including non-economic factors as part of the pavement type selection process provides government agencies with better knowledge of the true cost of a roadway rather than just considering the initial cost of the pavement.

7. References

1. Walls, James III and Michael R. Smith. *Life-Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin*. FHWA Report FHWA-SA-98-079, September 1998.
2. ASCE 58-16. Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways, American Society of Civil Engineers, Reston, Virginia, 2016.
3. AASHTO. American Association of State Highway and Transportation Officials Guide for the Design of Pavement Structures, Washington D.C., 1993.
4. ACPA. American Concrete Pavement Association StreetPave Structural Design Software for Street and Road Concrete Pavements, Rosemont, Illinois.
5. Interlocking Concrete Pavement Institute, Life-Cycle Cost Management of Interlocking Concrete Block Pavements - Methodology Report, Washington, D.C., August 2008.
6. ASTM International. ASTM E2840 Standard Practice for Pavement Condition Surveys for Interlocking Concrete Roads and Parking Lots, West Conshohocken, Pennsylvania, 2020.
7. ASTM International. ASTM D6433 Standard Practice for Roads and Parking Lots Pavement Condition Surveys, West Conshohocken, Pennsylvania, 2020.
8. Interlocking Concrete Pavement Institute. Standard Practice for Pavement Condition Index Surveys for Concrete Block Pavement, Washington, D.C., December 2007.
9. FHWA. U.S. Department of Transportation, Federal Highway Administration. Life-Cycle Cost Analysis in Pavement Design – In Search of Better Investment Decisions, Washington, D.C., Publication No. FHWA-SA-98-079.
10. ARA. Ministry of Transportation of Ontario Life-Cycle Cost: 2006 Update. Toronto, ON: Applied Research Associates, Inc., 2006.
11. NCHRP. Guide for Pavement Type Selection Report 703, National Cooperative Highway Research Program, Washington, D.C., 2011.
12. ODOT. Pavement Design Manual, Office of Pavement Engineering, Ohio Department of Transportation, Columbus, Ohio, 2015.
13. RMCAO and CAC. Ready Mixed Concrete Association of Ontario and the Cement Association of Canada. Methodology for the Development of Equivalent Pavement Structure Design Matrix for Municipal Roadways, Toronto, Canada 2011.
14. Nashville. Long Range Paving Plan. Metro Nashville Public Works, Nashville, Tennessee, 2020. www.mpw.nashville.gov/IMS/Paving/MasterPlan.aspx.
15. ARA. City of Niagara Falls Road Needs and Structural Assessment. Applied Research Associates, Inc., Toronto, Ontario, 2016.
16. Stantec. City of Calgary 2017 HPMA Present Status & Network Needs Report. Stantec Consulting Ltd. Waterloo, Ontario, 2018.

Appendix A

Life-Cycle Cost Details

Typical Pavement Designs for Municipal Roadways

		Average Annual Daily Truck Traffic (AADTT) - 30 Year Pavement Design			
		Local	Minor Arterial		Major Collector
		Collector	Collector	Bus Route (Residential)	Collector
Subgrade Strength		250	500	1,000	1,500
4,350 psi (CBR = 3)	HMA	1.5 in AC Surface	1.5 in AC Surface	1.5 in AC Surface	1.5 in AC Surface
		5 in AC Base	5.25 in AC Base	5.5 in AC Base	6 in AC Base
		6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase
		14 in Granular Subbase	18 in Granular Subbase	18 in Granular Subbase	19 in Granular Subbase
	ICP	3.15 in Paver	3.15 in Paver	3.15 in Paver	3.15 in Paver
		1 in Bedding Sand	1 in Bedding Sand	1 in Bedding Sand	1 in Bedding Sand
		6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase
		21 in Granular Subbase	26 in Granular Subbase	32 in Granular Subbase	34 in Granular Subbase
	PCC	6.75 in PCC	6.75 in PCC	7 in PCC	7 in PCC
		8 in Granular Subbase	8 in Granular Subbase	8 in Granular Subbase	8 in Granular Subbase
5,800 psi (CBR = 4)	HMA	1.5 in AC Surface	1.5 in AC Surface	1.5 in AC Surface	1.5 in AC Surface
		3.75 in AC Base	4.5 in AC Base	5 in AC Base	5.25 in AC Base
		6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase
		12 in Granular Subbase	14 in Granular Subbase	18 in Granular Subbase	18 in Granular Subbase
	ICP	3.15 in Paver	3.15 in Paver	3.15 in Paver	3.15 in Paver
		1 in Bedding Sand	1 in Bedding Sand	1 in Bedding Sand	1 in Bedding Sand
		6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase
		16 in Granular Subbase	21 in Granular Subbase	26 in Granular Subbase	29 in Granular Subbase
	PCC	6.75 in PCC	6.75 in PCC	7 in PCC	7 in PCC
		8 in Granular Subbase	8 in Granular Subbase	8 in Granular Subbase	8 in Granular Subbase
7,250 psi (CBR = 5)	HMA	1.5 in AC Surface	1.5 in AC Surface	1.5 in AC Surface	1.5 in AC Surface
		3.75 in AC Base	3.75 in AC Base	4.5 in AC Base	5 in AC Base
		6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase
		9 in Granular Subbase	14 in Granular Subbase	15 in Granular Subbase	16 in Granular Subbase
	ICP	3.15 in Paver	3.15 in Paver	3.15 in Paver	3.15 in Paver
		1 in Bedding Sand	1 in Bedding Sand	1 in Bedding Sand	1 in Bedding Sand
		6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase	6 in Granular Subbase
		13 in Granular Subbase	17 in Granular Subbase	22 in Granular Subbase	25 in Granular Subbase
	PCC	6.5 in PCC	6.75 in PCC	6.75 in PCC	7 in PCC
		8 in Granular Subbase	8 in Granular Subbase	8 in Granular Subbase	8 in Granular Subbase
		No Dowels	1.25 in Dowels	1.25 in Dowels	1.25 in Dowels
		13 ft Slab Length	15 ft Slab Length	15 ft Slab Length	15 ft Slab Length
		Tied Shoulder/Curb	Tied Shoulder/Curb	Tied Shoulder/Curb	Tied Shoulder/Curb

Notes:

- Subgrade levels are based on three common subgrade materials in North America
- - Low Strength (4,350 psi) - Low Plasticity Clay Subgrade
  - Medium Strength (5,800 psi) - Low Plasticity Silt Subgrade
  - High Strength (7,250 psi) - Sandy Silt Subgrade

Unit Costs

Discount Rate (%) 4.0
Analysis Period (years) 50

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Unit costs	Conversion Factor	Unit
HMA	HMA Surface Course, in (ton)	$110.00	6.356	lbs/ft²/in
	HMA Binder Course, in (ton)	$105.00	6.205	lbs/ft²/in
ICP	3.15 in ICP + 1 in Bedding Sand (ft^2)	$6.00		
PCC	6.5 in PCC pavement, no dowels (ft²)	$4.20	-	-
	6.75 in PCC pavement, no dowels (ft²)	$4.30	-	-
	6.75 in PCC pavement, 1.25 in dowels (ft²)	$4.85	-	-
	7.0 in PCC pavement, 1.25 in dowels (ft²)	$5.00	-	-
Base	Granular Base, in (ton)	$18.20	6.053	lbs/ft²/in
Subbase	Granular Subbase, in (ton)	$13.65	5.044	lbs/ft²/in

Pavement Preservation Treatments

Description of maintenance and rehabilitation treatments	Unit costs	Conversion Factor	Unit
Rout and seal, ft/mile (ft)	$1.50	-	-
Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	$3.25	-	-
Full depth asphalt base repair, % area (ft²)	$4.20	-	-
Mill HMA, in (ton)	$16.35	6.306	lbs/ft²/in
Resurface with HMA Surface, in (ton)	$110.00	6.356	lbs/ft²/in
Resurface with HMA Binder, in (ton)	$105.00	6.205	lbs/ft²/in
Replace cracked pavers, % area (ft^2)	$6.00		
Replace worn/rutted pavers wheelpath, %area (ft^2)	$11.15		
Reseal joints, % length (ft)	$1.10	-	-
Partial depth PCC repair, % area (ft²)	$13.95	-	-
Full depth PCC repair, % area (ft²)	$9.30	-	-

Appendix A-1 – Low Strength Subgrade

Typical Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

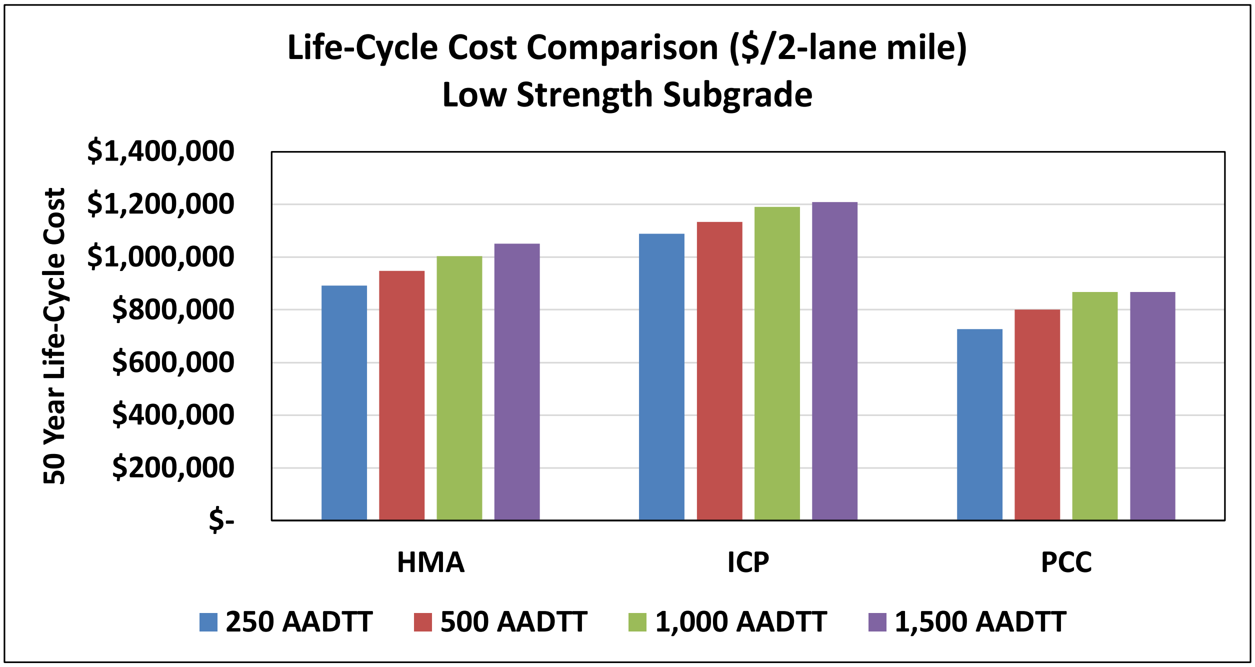
Listed by 30 Year AADTT and Pavement Type for Low Strength Subgrade

Item	Local Collector		
	250 HMA	**250 ICP**	**250 PCC**
Initial Cost	$ 751,609	$ 1,027,300	$ 656,576
M&R Cost (Discounted)	$ 139,631	$ 61,918	$ 70,470
Total Cost	$ 891,240	$ 1,089,218	$ 727,046
LCC Difference to ICP	**-22%**		**-50%**

Item	Minor Collector		
	500 HMA	**500 ICP**	**500 PCC**
Initial Cost	$ 807,149	$ 1,070,924	$ 726,272
M&R Cost (Discounted)	$ 139,631	$ 61,918	$ 73,908
Total Cost	$ 946,779	$ 1,132,842	$ 800,180
LCC Difference to ICP	**-20%**		**-42%**

Item	Minor Collector Bus Route		
	1,000 HMA	**1,000 ICP**	**1,000 PCC**
Initial Cost	$ 827,789	$ 1,123,272	$ 745,280
M&R Cost (Discounted)	$ 175,924	$ 67,613	$ 122,563
Total Cost	$ 1,003,713	$ 1,190,885	$ 867,844
LCC Difference to ICP	**-19%**		**-37%**

Item	Major Collector		
	1,500 HMA	**1,500 ICP**	**1,500 PCC**
Initial Cost	$ 877,794	$ 1,140,722	$ 745,280
M&R Cost (Discounted)	$ 173,385	$ 67,613	$ 122,563
Total Cost	$ 1,051,180	$ 1,208,335	$ 867,844
LCC Difference to ICP	**-15%**		**-39%**


Life-Cycle Cost Comparison ($/2-lane mile)
Low Strength Subgrade
50 Year Life-Cycle Cost
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$-
HMA
ICP
PCC
250 AADTT
500 AADTT
1,000 AADTT
1,500 AADTT

Road Class **Municipal Local Collector HMA**
AADTT **250**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
5 in AC Base
6 in Granular Subbase
14 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	5	3,931	$ 105.00	$ 412,806
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	14	8,948	$ 13.65	$ 122,146
	Total Initial Cost				**$ 751,609**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	5	6336	$ 4.20	$ 26,611	$ 6,744
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 2,983
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 127,078	$ 17,882
	Total M&R Cost				**$ 416,186**	**$ 139,631**

Road Class **Municipal Local Collector ICP**
AADTT **250**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
1 in Bedding Sand
6 in Granular Subbase
21 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	21	13,423	$ 13.65	$ 183,220
	Total Initial Cost				**$ 1,027,300**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 10,273
20	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 32,242
30	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 4,688
40	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 14,715
50	Residual value				$ -	$ -
	Total M&R Cost				**$ 171,706**	**$ 61,918**

Road Class **Municipal Local Collector PCC**
AADTT **250**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
6.75	in PCC
8	in Granular Subbase
No	Dowels
13	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	6.75 in PCC pavement, no dowels (ft²)	6.75	126720	$ 4.30	$ 544,896
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 656,576**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Reseal joints, % length (ft)	10	975	$ 1.10	$ 1,072	$ 670
25	Partial depth PCC repair, % area (ft²)	2	2534	$ 13.95	$ 35,355	$ 13,262
25	Full depth PCC repair, % area (ft²)	5	6336	$ 9.30	$ 58,925	$ 22,104
25	Reseal joints, % length (ft)	20	1950	$ 1.10	$ 2,144	$ 804
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 24,547
40	Reseal joints, % length (ft)	20	1950	$ 1.10	$ 2,144	$ 447
50	Residual Value				$ 69,460	$ 9,774
	Total M&R Cost				**$ 236,417**	**$ 70,470**

Road Class **Municipal Minor Arterial Collector HMA**
AADTT **500**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
5.25 in AC Base
6 in Granular Subbase
18 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	5.25	4,128	$ 105.00	$ 433,447
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	18	11,505	$ 13.65	$ 157,045
	Total Initial Cost				**$ 807,149**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	5	6336	$ 4.20	$ 26,611	$ 6,744
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 2,983
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 127,078	$ 17,882
	Total M&R Cost				**$ 416,186**	**$ 139,631**

Road Class	**Municipal Local Collector ICP**
AADTT	**500**
Subgrade	**4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
1 in Bedding Sand
6 in Granular Subbase
26 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	26	16,619	$ 13.65	$ 226,843
	Total Initial Cost				**$ 1,070,924**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 10,273
20	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 32,242
30	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 4,688
40	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 14,715
50	Residual value				$ -	$ -
	Total M&R Cost				**$ 171,706**	**$ 61,918**

Road Class **Municipal Minor Arterial Collector PCC**
AADTT **500**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
6.75	in PCC
8	in Granular Subbase
1.25	in Dowels
4.5	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	6.75 in PCC pavement, 1.25 in dowels (ft²)	6.75	126720	$ 4.85	$ 614,592
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 726,272**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Reseal joints, % length (ft)	10	2816	$ 1.10	$ 3,098	$ 1,935
25	Partial depth PCC repair, % area (ft²)	2	2534	$ 13.95	$ 35,355	$ 13,262
25	Full depth PCC repair, % area (ft²)	5	6336	$ 9.30	$ 58,925	$ 22,104
25	Reseal joints, % length (ft)	20	5632	$ 1.10	$ 6,195	$ 2,324
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 24,547
40	Reseal joints, % length (ft)	20	5632	$ 1.10	$ 6,195	$ 1,290
50	Residual Value				$ 70,811	$ 9,964
	Total M&R Cost				**$ 245,194**	**$ 73,908**

Road Class **Municipal Minor Arterial Bus Route (Residential) HMA**
AADTT **1000**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
5.5 in AC Base
6 in Granular Subbase
18 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	5.5	4,325	$ 105.00	$ 454,087
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	18	11,505	$ 13.65	$ 157,045
	Total Initial Cost				**$ 827,789**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
15	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	10	12672	$ 3.25	$ 41,184	$ 22,868
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	10	12672	$ 4.20	$ 53,222	$ 13,487
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	3.5	2797	$ 16.35	$ 45,728	$ 6,960
48	Resurface with HMA Binder, in (ton)	2	1573	$ 105.00	$ 165,122	$ 25,131
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 286,456	$ 40,308
	Total M&R Cost				**$ 515,857**	**$ 175,924**

Road Class **Municipal Minor Arterial Bus Route (Residential) ICP**
AADTT **1000**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
1 in Bedding Sand
6 in Granular Subbase
32 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	32	20,454	$ 13.65	$ 279,192
	Total Initial Cost				**$ 1,123,272**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 11,111
18	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 34,873
28	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 5,071
38	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 15,916
48	Replace cracked pavers, % area (ft2)	3	3802	$ 6.00	$ 22,810	$ 3,472
50	Residual value				-$ 4,562	-$ 642
	Total M&R Cost				**$ 176,268**	**$ 67,613**

Road Class	**Municipal Minor Arterial Bus Route (Residential) PCC**
AADTT	**1000**
Subgrade	**4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
7	in PCC
8	in Granular Subbase
1.25	in Dowels
15	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	7.0 in PCC pavement, 1.25 in dowels (ft²)	7	126720	$ 5.00	$ 633,600
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 745,280**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	20	1690	$ 1.10	$ 1,859	$ 1,161
25	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 33,156
25	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 44,207
25	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 871
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	15	19008	$ 9.30	$ 176,774	$ 36,820
40	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 484
50	Residual Value				$ 89,162	$ 12,546
	Total M&R Cost				**$ 388,742**	**$ 122,563**

Road Class	**Municipal Major Collector HMA**
AADTT	**1500**
Subgrade	**4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
6 in AC Base
6 in Granular Subbase
19 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	6	4,718	$ 105.00	$ 495,367
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	19	12,144	$ 13.65	$ 165,770
	Total Initial Cost				**$ 877,794**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
18	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	10	12672	$ 3.25	$ 41,184	$ 20,330
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	10	12672	$ 4.20	$ 53,222	$ 13,487
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	3.5	2797	$ 16.35	$ 45,728	$ 6,960
48	Resurface with HMA Binder, in (ton)	2	1573	$ 105.00	$ 165,122	$ 25,131
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 286,456	$ 40,308
	Total M&R Cost				**$ 515,857**	**$ 173,385**

Road Class **Municipal Major Collector ICP**
AADTT **1500**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
3.15	in Paver
1	in Bedding Sand
6	in Granular Subbase
34	in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	34	21,732	$ 13.65	$ 296,641
	Total Initial Cost				**$ 1,140,722**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 11,111
18	Replace worn/rutted pavers wheelpath, %area (ft2	5	6336	$ 11.15	$ 70,646	$ 34,873
28	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 5,071
38	Replace worn/rutted pavers wheelpath, %area (ft2	5	6336	$ 11.15	$ 70,646	$ 15,916
48	Replace cracked pavers, % area (ft2)	3	3802	$ 6.00	$ 22,810	$ 3,472
50	Residual value				-$ 4,562	-$ 642
	Total M&R Cost				**$ 176,268**	**$ 67,613**

Road Class **Municipal Major Collector PCC**
AADTT **1500**
Subgrade **4,350 psi (CBR = 3)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
7	in PCC
8	in Granular Subbase
1.25	in Dowels
15	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	7.0 in PCC pavement, 1.25 in dowels (ft²)	7	126720	$ 5.00	$ 633,600
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 745,280**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Reseal joints, % length (ft)	20	1690	$ 1.10	$ 1,859	$ 1,161
25	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 33,156
25	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 44,207
25	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 871
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	15	19008	$ 9.30	$ 176,774	$ 36,820
40	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 484
50	Residual Value				$ 89,162	$ 12,546
	Total M&R Cost				**$ 388,742**	**$ 122,563**

Appendix A-2 – Medium Strength Subgrade

Typical Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

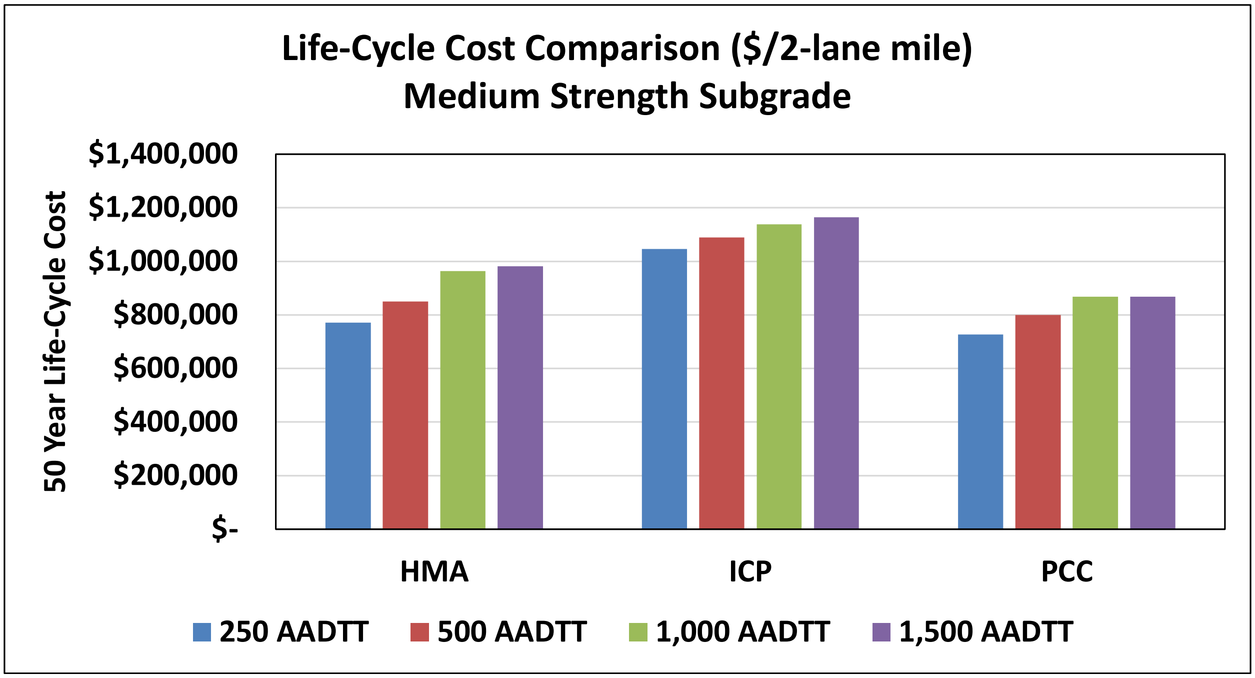
.isted by 30 Year AADTT and Pavement Type for Medium Strength Subgrade

Item	Local Collector		
	250 HMA	**250 ICP**	**250 PCC**
Initial Cost	$ 630,958	$ 983,676	$ 656,576
M&R Cost (Discounted)	$ 139,631	$ 61,918	$ 70,470
Total Cost	$ 770,589	$ 1,045,595	$ 727,046
LCC Difference to ICP	**-36%**		**-44%**

Item	Minor Collector		
	500 HMA	**500 ICP**	**500 PCC**
Initial Cost	$ 710,329	$ 1,027,300	$ 726,272
M&R Cost (Discounted)	$ 139,631	$ 61,918	$ 73,908
Total Cost	$ 849,959	$ 1,089,218	$ 800,180
LCC Difference to ICP	**-28%**		**-36%**

Item	Minor Collector Bus Route		
	1,000 HMA	**1,000 ICP**	**1,000 PCC**
Initial Cost	$ 786,508	$ 1,070,924	$ 745,280
M&R Cost (Discounted)	$ 175,924	$ 67,613	$ 122,563
Total Cost	$ 962,432	$ 1,138,537	$ 867,844
LCC Difference to ICP	**-18%**		**-31%**

Item	Major Collector		
	1,500 HMA	**1,500 ICP**	**1,500 PCC**
Initial Cost	$ 807,149	$ 1,097,098	$ 745,280
M&R Cost (Discounted)	$ 173,385	$ 67,613	$ 122,563
Total Cost	$ 980,534	$ 1,164,711	$ 867,844
LCC Difference to ICP	**-19%**		**-34%**



Life-Cycle Cost Comparison ($/2-lane mile)
Medium Strength Subgrade
50 Year Life-Cycle Cost
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$-
HMA
ICP
PCC
250 AADTT
500 AADTT
1,000 AADTT
1,500 AADTT

Road Class	**Municipal Local Collector HMA**
AADTT	**250**
Subgrade	**5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
3.75 in AC Base
6 in Granular Subbase
12 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	3.75	2,949	$ 105.00	$ 309,605
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	12	7,670	$ 13.65	$ 104,697
	Total Initial Cost				**$ 630,958**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	5	6336	$ 4.20	$ 26,611	$ 6,744
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 2,983
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 127,078	$ 17,882
	Total M&R Cost				**$ 416,186**	**$ 139,631**

Road Class	**Municipal Local Collector ICP**
AADTT	**250**
Subgrade	**5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
1 in Bedding Sand
6 in Granular Subbase
16 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	16	10,227	$ 13.65	$ 139,596
	Total Initial Cost				**$ 983,676**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 10,273
20	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 32,242
30	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 4,688
40	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 14,715
50	Residual value				$ -	$ -
	Total M&R Cost				**$ 171,706**	**$ 61,918**

Road Class **Municipal Local Collector PCC**
AADTT **250**
Subgrade **5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
6.75	in PCC
8	in Granular Subbase
No	Dowels
13	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	6.75 in PCC pavement, no dowels (ft²)	6.75	126720	$ 4.30	$ 544,896
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 656,576**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	10	975	$ 1.10	$ 1,072	$ 670
25	Partial depth PCC repair, % area (ft²)	2	2534	$ 13.95	$ 35,355	$ 13,262
25	Full depth PCC repair, % area (ft²)	5	6336	$ 9.30	$ 58,925	$ 22,104
25	Reseal joints, % length (ft)	20	1950	$ 1.10	$ 2,144	$ 804
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 24,547
40	Reseal joints, % length (ft)	20	1950	$ 1.10	$ 2,144	$ 447
50	Residual Value				$ 69,460	$ 9,774
	Total M&R Cost				**$ 236,417**	**$ 70,470**

Road Class	**Municipal Minor Arterial Collector HMA**
AADTT	**500**
Subgrade	**5,800 psi (CBR = 4)**

All quantities and costs are for one mile km of 2-lane roadway

Pavement Design
1.5 in AC Surface
4.5 in AC Base
6 in Granular Subbase
14 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	4.5	3,538	$ 105.00	$ 371,526
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	14	8,948	$ 13.65	$ 122,146
	Total Initial Cost				**$ 710,329**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	2	2534	$ 3.25	$ 8,237	$ 5,564
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft^2)	5	6336	$ 4.20	$ 26,611	$ 6,744
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 2,983
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 127,078	$ 17,882
	Total M&R Cost				**$ 416,186**	**$ 139,631**

Road Class	**Municipal Local Collector ICP**
AADTT	**500**
Subgrade	**5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
1 in Bedding Sand
6 in Granular Subbase
21 in Granular Subbase

Geometric Design

Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	21	13,423	$ 13.65	$ 183,220
	Total Initial Cost				**$ 1,027,300**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 10,273
20	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 32,242
30	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 4,688
40	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 14,715
50	Residual value				$ -	$ -
	Total M&R Cost				**$ 171,706**	**$ 61,918**

Road Class **Municipal Minor Arterial Collector PCC**
AADTT **500**
Subgrade **5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
6.75	in PCC
8	in Granular Subbase
1.25	in Dowels
4.5	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	6.75 in PCC pavement, 1.25 in dowels (ft²)	6.75	126720	$ 4.85	$ 614,592
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 726,272**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	10	2816	$ 1.10	$ 3,098	$ 1,935
25	Partial depth PCC repair, % area (ft²)	2	2534	$ 13.95	$ 35,355	$ 13,262
25	Full depth PCC repair, % area (ft²)	5	6336	$ 9.30	$ 58,925	$ 22,104
25	Reseal joints, % length (ft)	20	5632	$ 1.10	$ 6,195	$ 2,324
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 24,547
40	Reseal joints, % length (ft)	20	5632	$ 1.10	$ 6,195	$ 1,290
50	Residual Value				$ 70,811	$ 9,964
	Total M&R Cost				**$ 245,194**	**$ 73,908**

Road Class **Municipal Minor Arterial Bus Route (Residential) HMA**
AADTT **1000**
Subgrade **5,800 psi (CBR = 4)**

AAll quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
5 in AC Base
6 in Granular Subbase
18 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	5	3,931	$ 105.00	$ 412,806
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	18	11,505	$ 13.65	$ 157,045
	Total Initial Cost				**$ 786,508**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
15	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	10	12672	$ 3.25	$ 41,184	$ 22,868
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	10	12672	$ 4.20	$ 53,222	$ 13,487
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	3.5	2797	$ 16.35	$ 45,728	$ 6,960
48	Resurface with HMA Binder, in (ton)	2	1573	$ 105.00	$ 165,122	$ 25,131
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 286,456	$ 40,308
	Total M&R Cost				**$ 515,857**	**$ 175,924**

Road Class **Municipal Minor Arterial Bus Route (Residential) ICP**
AADTT **1000**
Subgrade **5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
0 in Bedding Sand
6 in Granular Subbase
26 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	3.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	26	16,619	$ 13.65	$ 226,843
	Total Initial Cost				**$ 1,070,924**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 11,111
18	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 34,873
28	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 5,071
38	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 15,916
48	Replace cracked pavers, % area (ft2)	3	3802	$ 6.00	$ 22,810	$ 3,472
50	Residual value				-$ 4,562	-$ 642
	Total M&R Cost				**$ 176,268**	**$ 67,613**

Road Class **Municipal Minor Arterial Bus Route (Residential) PCC**
AADTT **1000**
Subgrade **5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
7 in PCC
8 in Granular Subbase
1.25 in Dowels
15 ft Slab Length
Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	7.0 in PCC pavement, 1.25 in dowels (ft²)	180	126720	$ 5.00	$ 633,600
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 745,280**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	20	1690	$ 1.10	$ 1,859	$ 1,161
25	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 33,156
25	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 44,207
25	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 871
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	15	19008	$ 9.30	$ 176,774	$ 36,820
40	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 484
50	Residual Value				$ 89,162	$ 12,546
	Total M&R Cost				**$ 388,742**	**$ 122,563**

Road Class	**Municipal Major Collector HMA**
AADTT	**1500**
Subgrade	**5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
5.25 in AC Base
6 in Granular Subbase
18 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	5.25	4,128	$ 105.00	$ 433,447
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	18	11,505	$ 13.65	$ 157,045
	Total Initial Cost				**$ 807,149**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	2	2534	$ 3.25	$ 8,237	$ 5,564
18	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	10	12672	$ 3.25	$ 41,184	$ 20,330
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft^2)	10	12672	$ 4.20	$ 53,222	$ 13,487
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	3.5	2797	$ 16.35	$ 45,728	$ 6,960
48	Resurface with HMA Binder, in (ton)	2	1573	$ 105.00	$ 165,122	$ 25,131
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 286,456	$ 40,308
	Total M&R Cost				**$ 515,857**	**$ 173,385**

Road Class	**Municipal Major Collector ICP**
AADTT	**1500**
Subgrade	**5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
3.15	in Paver
1	in Bedding Sand
6	in Granular Subbase
29	in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	29	18,536	$ 13.65	$ 253,018
	Total Initial Cost				**$ 1,097,098**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 11,111
18	Replace worn/rutted pavers wheelpath, %area (ft2	5	6336	$ 11.15	$ 70,646	$ 34,873
28	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 5,071
38	Replace worn/rutted pavers wheelpath, %area (ft2	5	6336	$ 11.15	$ 70,646	$ 15,916
48	Replace cracked pavers, % area (ft2)	3	3802	$ 6.00	$ 22,810	$ 3,472
50	Residual value				-$ 4,562	-$ 642
	Total M&R Cost				**$ 176,268**	**$ 67,613**

Road Class	**Municipal Major Collector PCC**
AADTT	**1500**
Subgrade	**5,800 psi (CBR = 4)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
7	in PCC
8	in Granular Subbase
1.25	in Dowels
15	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	7.0 in PCC pavement, 1.25 in dowels (ft²)	7	126720	$ 5.00	$ 633,600
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 745,280**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	20	1690	$ 1.10	$ 1,859	$ 1,161
25	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 33,156
25	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 44,207
25	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 871
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	15	19008	$ 9.30	$ 176,774	$ 36,820
40	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 484
50	Residual Value				$ 89,162	$ 12,546
	Total M&R Cost				**$ 388,742**	**$ 122,563**

Appendix A-3 – High Strength Subgrade

Typical Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

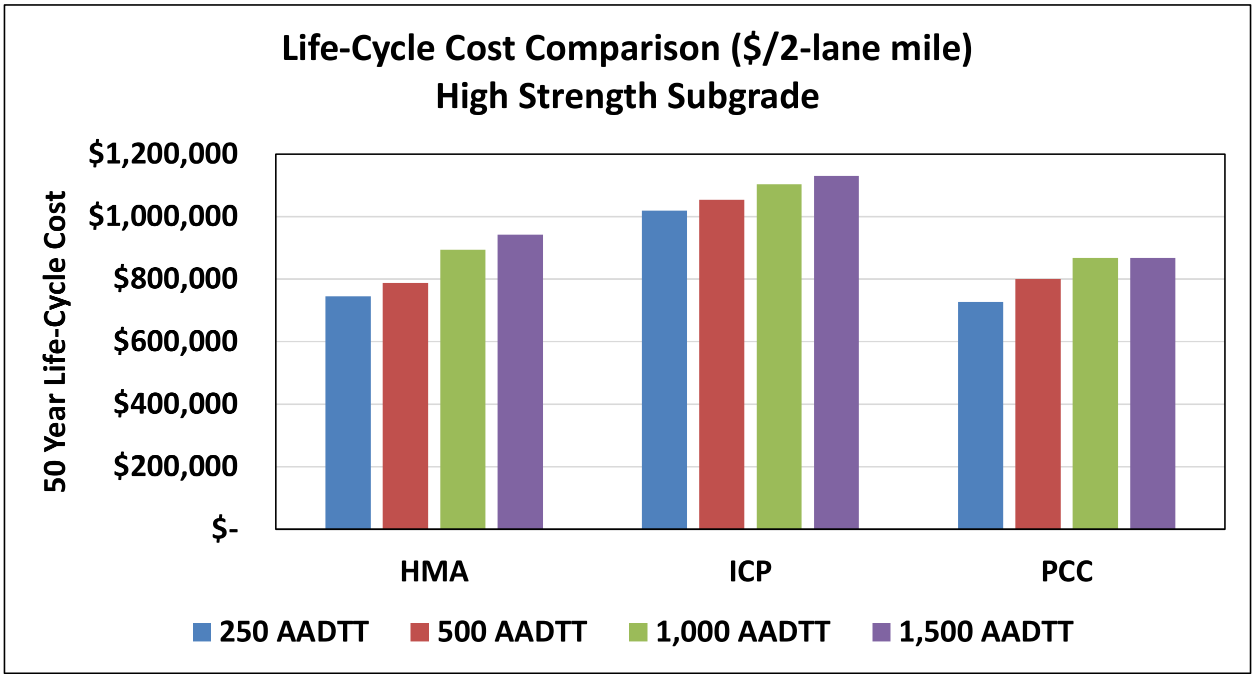
Listed by 30 Year AADTT and Pavement Type for High Strength Subgrade

Item	Local Collector		
	250 HMA	250 ICP	250 PCC
Initial Cost	$ 604,784	$ 957,502	$ 656,576
M&R Cost (Discounted)	$ 139,631	$ 61,918	$ 70,470
Total Cost	$ 744,415	$ 1,019,420	$ 727,046
LCC Difference to ICP	**-37%**		**-40%**

Item	Minor Collector		
	500 HMA	500 ICP	500 PCC
Initial Cost	$ 648,408	$ 992,401	$ 726,272
M&R Cost (Discounted)	$ 139,631	$ 61,918	$ 73,908
Total Cost	$ 788,039	$ 1,054,319	$ 800,180
LCC Difference to ICP	**-34%**		**-32%**

Item	Minor Collector Bus Route		
	1,000 HMA	1,000 ICP	1,000 PCC
Initial Cost	$ 719,054	$ 1,036,025	$ 745,280
M&R Cost (Discounted)	$ 175,924	$ 67,613	$ 122,563
Total Cost	$ 894,977	$ 1,103,638	$ 867,844
LCC Difference to ICP	**-23%**		**-27%**

Item	Major Collector		
	1,500 HMA	1,500 ICP	1,500 PCC
Initial Cost	$ 769,059	$ 1,062,199	$ 745,280
M&R Cost (Discounted)	$ 173,385	$ 67,613	$ 122,563
Total Cost	$ 942,444	$ 1,129,812	$ 867,844
LCC Difference to ICP	**-20%**		**-30%**


Life-Cycle Cost Comparison ($/2-lane mile)
High Strength Subgrade
50 Year Life-Cycle Cost
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$-
HMA
ICP
PCC
250 AADTT
500 AADTT
1,000 AADTT
1,500 AADTT

Road Class **Municipal Local Collector HMA**
AADTT **250**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
3.75 in AC Base
6 in Granular Subbase
9 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	3.75	2,949	$ 105.00	$ 309,605
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	9	5,753	$ 13.65	$ 78,523
	Total Initial Cost				**$ 604,784**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	2	2534	$ 3.25	$ 8,237	$ 5,564
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft^2)	5	6336	$ 4.20	$ 26,611	$ 6,744
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 2,983
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 127,078	$ 17,882
	Total M&R Cost				**$ 416,186**	**$ 139,631**

Road Class **Municipal Local Collector ICP**
AADTT **250**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
1 in Bedding Sand
6 in Granular Subbase
13 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	13	8,309	$ 13.65	$ 113,422
	Total Initial Cost				**$ 957,502**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 10,273
20	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 32,242
30	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 4,688
40	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 14,715
50	Residual value				$ -	$ -
	Total M&R Cost				**$ 171,706**	**$ 61,918**

Road Class **Municipal Local Collector PCC**
AADTT **250**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
6.5	in PCC
8	in Granular Subbase
No	Dowels
13	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	6.75 in PCC pavement, no dowels (ft²)	6.5	126720	$ 4.30	$ 544,896
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 656,576**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	10	975	$ 1.10	$ 1,072	$ 670
25	Partial depth PCC repair, % area (ft²)	2	2534	$ 13.95	$ 35,355	$ 13,262
25	Full depth PCC repair, % area (ft²)	5	6336	$ 9.30	$ 58,925	$ 22,104
25	Reseal joints, % length (ft)	20	1950	$ 1.10	$ 2,144	$ 804
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 24,547
40	Reseal joints, % length (ft)	20	1950	$ 1.10	$ 2,144	$ 447
50	Residual Value				$ 69,460	$ 9,774
	Total M&R Cost				**$ 236,417**	**$ 70,470**

Road Class	**Municipal Minor Arterial Collector HMA**
AADTT	**500**
Subgrade	**7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
3.75 in AC Base
6 in Granular Subbase
14 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	3.75	2,949	$ 105.00	$ 309,605
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	14	8,948	$ 13.65	$ 122,146
	Total Initial Cost				**$ 648,408**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	5	6336	$ 4.20	$ 26,611	$ 6,744
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 2,983
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 127,078	$ 17,882
	Total M&R Cost				**$ 416,186**	**$ 139,631**

Road Class **Municipal Local Collector ICP**
AADTT **500**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
1 in Bedding Sand
6 in Granular Subbase
17 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	17	10,866	$ 13.65	$ 148,321
	Total Initial Cost				**$ 992,401**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 10,273
20	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 32,242
30	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 4,688
40	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 14,715
50	Residual value				$ -	$ -
	Total M&R Cost				**$ 171,706**	**$ 61,918**

Road Class **Municipal Minor Arterial Collector PCC**
AADTT **500**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
6.75 in PCC
8 in Granular Subbase
1.25 in Dowels
4.5 ft Slab Length
Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	6.75 in PCC pavement, 1.25 in dowels (ft²)	6.75	126720	$ 4.85	$ 614,592
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 726,272**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	10	2816	$ 1.10	$ 3,098	$ 1,935
25	Partial depth PCC repair, % area (ft²)	2	2534	$ 13.95	$ 35,355	$ 13,262
25	Full depth PCC repair, % area (ft²)	5	6336	$ 9.30	$ 58,925	$ 22,104
25	Reseal joints, % length (ft)	20	5632	$ 1.10	$ 6,195	$ 2,324
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 24,547
40	Reseal joints, % length (ft)	20	5632	$ 1.10	$ 6,195	$ 1,290
50	Residual Value				$ 70,811	$ 9,964
	Total M&R Cost				**$ 245,194**	**$ 73,908**

Road Class **Municipal Minor Arterial Bus Route (Residential) HMA**
AADTT **1000**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
4.5 in AC Base
6 in Granular Subbase
15 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	4.5	3,538	$ 105.00	$ 371,526
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	15	9,588	$ 13.65	$ 130,871
	Total Initial Cost				**$ 719,054**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
15	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	10	12672	$ 3.25	$ 41,184	$ 22,868
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	10	12672	$ 4.20	$ 53,222	$ 13,487
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	3.5	2797	$ 16.35	$ 45,728	$ 6,960
48	Resurface with HMA Binder, in (ton)	2	1573	$ 105.00	$ 165,122	$ 25,131
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 286,456	$ 40,308
	Total M&R Cost				**$ 515,857**	**$ 175,924**

Road Class **Municipal Minor Arterial Bus Route (Residential) ICP**
AADTT **1000**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
3.15 in Paver
1 in Bedding Sand
6 in Granular Subbase
22 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	22	14,062	$ 13.65	$ 191,944
	Total Initial Cost				**$ 1,036,025**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 11,111
18	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 34,873
28	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 5,071
38	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 15,916
48	Replace cracked pavers, % area (ft2)	3	3802	$ 6.00	$ 22,810	$ 3,472
50	Residual value				-$ 4,562	-$ 642
	Total M&R Cost				**$ 176,268**	**$ 67,613**

Road Class	**Municipal Minor Arterial Bus Route (Residential) PCC**
AADTT	**1000**
Subgrade	**7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
6.75	in PCC
8	in Granular Subbase
1.25	in Dowels
15	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	7.0 in PCC pavement, 1.25 in dowels (ft²)	6.75	126720	$ 5.00	$ 633,600
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 745,280**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % length (ft)	20	1690	$ 1.10	$ 1,859	$ 1,161
25	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 33,156
25	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 44,207
25	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 871
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	15	19008	$ 9.30	$ 176,774	$ 36,820
40	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 484
50	Residual Value				$ 89,162	$ 12,546
	Total M&R Cost				**$ 388,742**	**$ 122,563**

Road Class **Municipal Major Collector HMA**
AADTT **1500**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design
1.5 in AC Surface
5 in AC Base
6 in Granular Subbase
16 in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	HMA Surface Course, in (ton)	1.5	1,208	$ 110.00	$ 132,896
Binder	HMA Binder Course, in (ton)	5	3,931	$ 105.00	$ 412,806
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	16	10,227	$ 13.65	$ 139,596
	Total Initial Cost				**$ 769,059**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, ft/mile (ft)	1300	1300	$ 1.50	$ 1,950	$ 1,317
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	2	2534	$ 3.25	$ 8,237	$ 5,564
18	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	10	12672	$ 3.25	$ 41,184	$ 20,330
20	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 8,944
20	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 60,652
25	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 1,463
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 6,349
35	Mill HMA, in (ton)	1.5	1199	$ 16.35	$ 19,598	$ 4,966
35	Full depth asphalt base repair, % area (ft²)	10	12672	$ 4.20	$ 53,222	$ 13,487
35	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 33,678
40	Rout and seal, ft/mile (ft)	2600	2600	$ 1.50	$ 3,900	$ 812
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft²)	5	6336	$ 3.25	$ 20,592	$ 3,813
48	Mill HMA, in (ton)	3.5	2797	$ 16.35	$ 45,728	$ 6,960
48	Resurface with HMA Binder, in (ton)	2	1573	$ 105.00	$ 165,122	$ 25,131
48	Resurface with HMA Surface, in (ton)	1.5	1208	$ 110.00	$ 132,896	$ 20,226
50	Residual value				$ 286,456	$ 40,308
	Total M&R Cost				**$ 515,857**	**$ 173,385**

Road Class **Municipal Major Collector ICP**
AADTT **1500**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
3.15	in Paver
1	in Bedding Sand
6	in Granular Subbase
25	in Granular Subbase

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per mile	Price per unit of quantity	Cost
Surface	3.15 in ICP + 1 in Bedding Sand (ft2)	4.15	126,720	$ 6.00	$ 760,320
Base	Granular Base, in (ton)	6	4,602	$ 18.20	$ 83,760
Subbase	Granular Subbase, in (ton)	25	15,979	$ 13.65	$ 218,119
	Total Initial Cost				**$ 1,062,199**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 11,111
18	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 34,873
28	Replace cracked pavers, % area (ft2)	2	2534	$ 6.00	$ 15,206	$ 5,071
38	Replace worn/rutted pavers wheelpath, %area (ft2)	5	6336	$ 11.15	$ 70,646	$ 15,916
48	Replace cracked pavers, % area (ft2)	3	3802	$ 6.00	$ 22,810	$ 3,472
50	Residual value				-$ 4,562	-$ 642
	Total M&R Cost				**$ 176,268**	**$ 67,613**

Road Class **Municipal Major Collector PCC**
AADTT **1500**
Subgrade **7,250 psi (CBR = 5)**

All quantities and costs are for one mile of 2-lane roadway

Pavement Design	
7	in PCC
8	in Granular Subbase
1.25	in Dowels
15	ft Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, ft	24.0
Total width of paved shoulders, ft	N/A
Total width of subject road, ft	24.0
Length of section, ft	5280

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per mile**	**Price per unit of quantity**	**Cost**
Surface	7.0 in PCC pavement, 1.25 in dowels (ft²)	7	126720	$ 5.00	$ 633,600
Base	Granular Base, in (ton)	8	6136	$ 18.20	$ 111,680
	Total Initial Cost				**$ 745,280**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Reseal joints, % length (ft)	20	1690	$ 1.10	$ 1,859	$ 1,161
25	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 33,156
25	Full depth PCC repair, % area (ft²)	10	12672	$ 9.30	$ 117,850	$ 44,207
25	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 871
40	Partial depth PCC repair, % area (ft²)	5	6336	$ 13.95	$ 88,387	$ 18,410
40	Full depth PCC repair, % area (ft²)	15	19008	$ 9.30	$ 176,774	$ 36,820
40	Reseal joints, % length (ft)	25	2112	$ 1.10	$ 2,323	$ 484
50	Residual Value				$ 89,162	$ 12,546
	Total M&R Cost				**$ 388,742**	**$ 122,563**

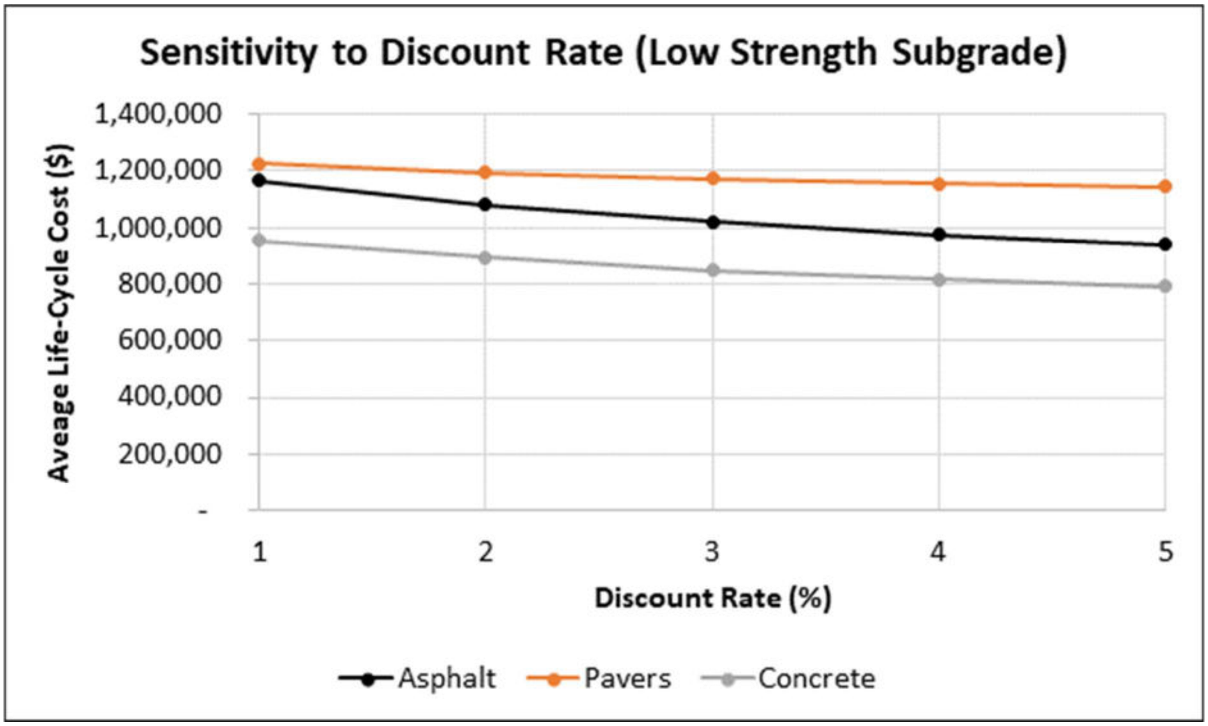
Appendix B

Life-Cycle Cost Sensitivity Analysis

Appendix B-1 – Low Strength Subgrade

Life-Cycle Cost Summary – US Customary Units, ($/2-Lane mile)
Low Strength Subgrade

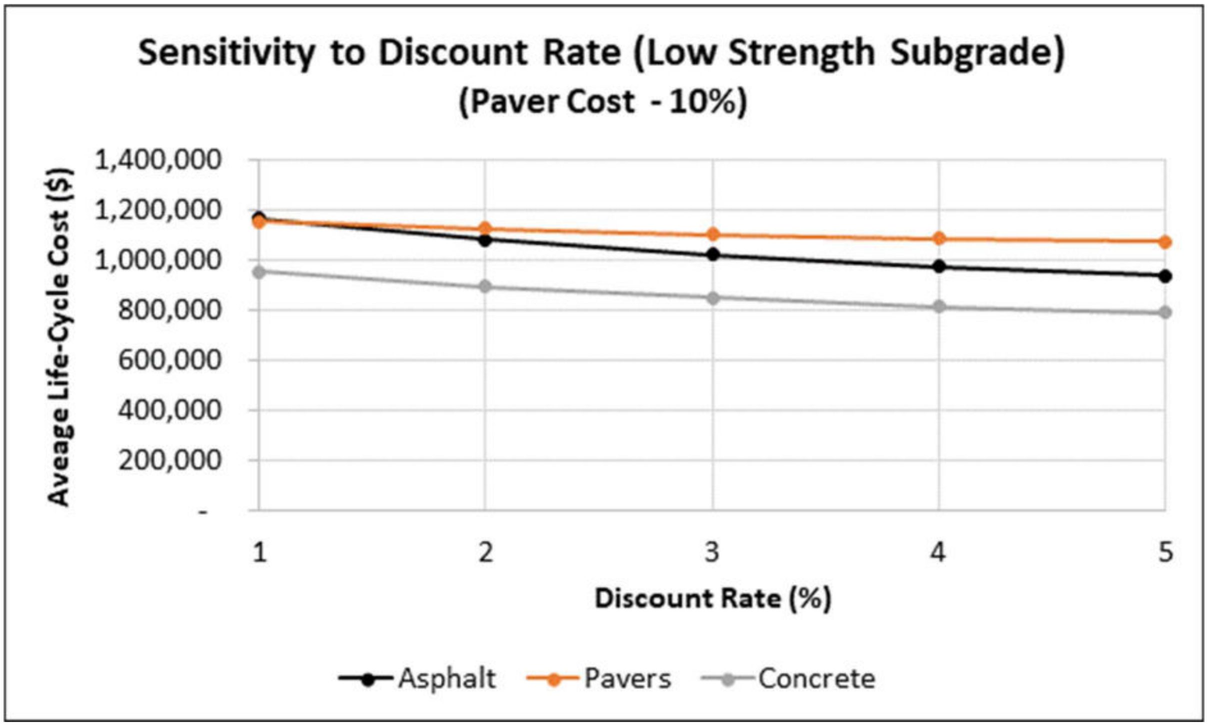
Discount Rate	Traffic Category				Average	Percent Compared to ICP
	Local Collector	Minor	Minor Bus	Major Collector		
Hot Mix Asphalt						
1	$ 1,063,920	$ 1,119,459	$ 1,216,077	$ 1,265,039	$ 1,166,124	-10
2	$ 988,179	$ 1,043,719	$ 1,122,979	$ 1,171,219	$ 1,081,524	-15
3	$ 932,507	$ 988,047	$ 1,054,507	$ 1,102,269	$ 1,019,333	-19
4	$ 891,240	$ 946,779	$ 1,003,713	$ 1,051,180	$ 973,228	-22
5	$ 860,383	$ 915,922	$ 965,686	$ 1,012,994	$ 938,746	-24
Interlocking Concrete Pavers						
1	$ 1,157,696	$ 1,201,320	$ 1,259,063	$ 1,276,512	$ 1,223,648	$ 1,157,696
2	$ 1,127,708	$ 1,171,331	$ 1,229,431	$ 1,246,881	$ 1,193,838	$ 1,127,708
3	$ 1,105,652	$ 1,149,276	$ 1,207,437	$ 1,224,886	$ 1,171,813	$ 1,105,652
4	$ 1,089,218	$ 1,132,842	$ 1,190,885	$ 1,208,335	$ 1,155,320	$ 1,089,218
5	$ 1,076,815	$ 1,120,439	$ 1,178,260	$ 1,195,710	$ 1,142,806	$ 1,076,815
Portland Cement Concrete						
1	$ 830,442	$ 906,994	$ 1,035,002	$ 1,035,002	$ 951,860	-17
2	$ 784,763	$ 859,858	$ 961,885	$ 961,885	$ 892,098	-20
3	$ 751,415	$ 825,402	$ 907,854	$ 907,854	$ 848,131	-22
4	$ 727,046	$ 800,180	$ 867,844	$ 867,844	$ 815,729	-24
5	$ 709,190	$ 781,668	$ 838,124	$ 838,124	$ 791,777	-26



Life-Cycle Cost of Pavers versus Asphalt (Base Case)
Low Strength Subgrade

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

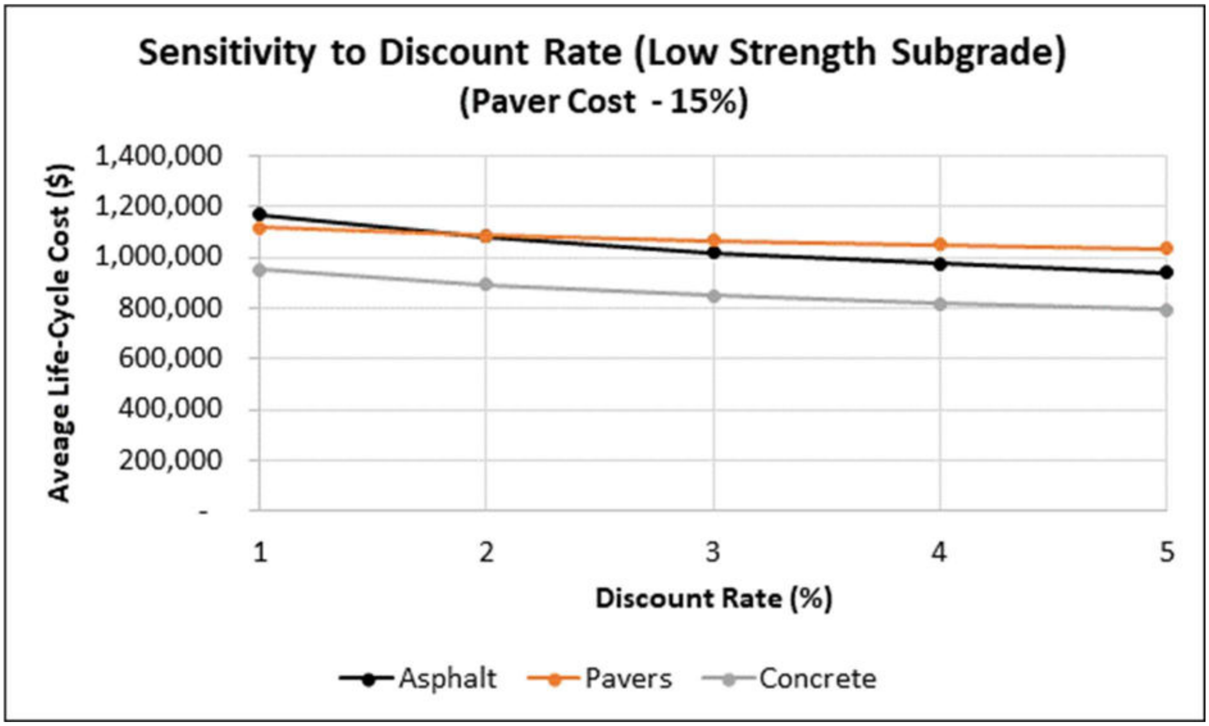
Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -10%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

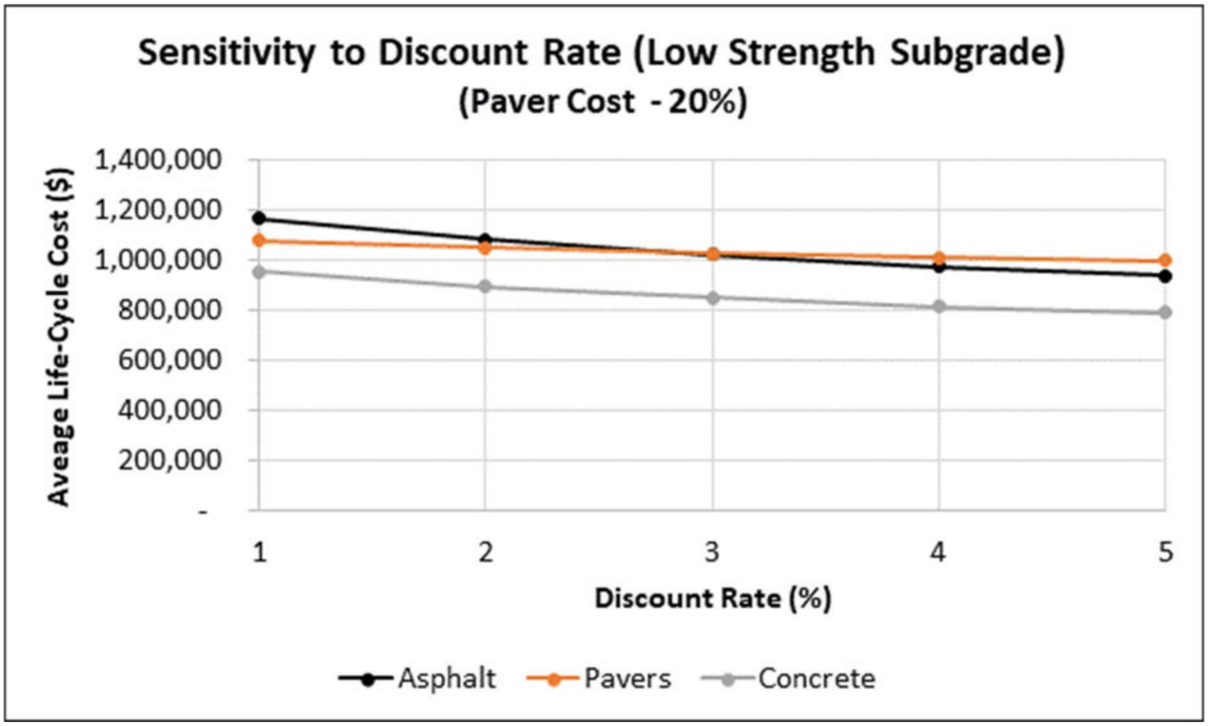
Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -15%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -20%)

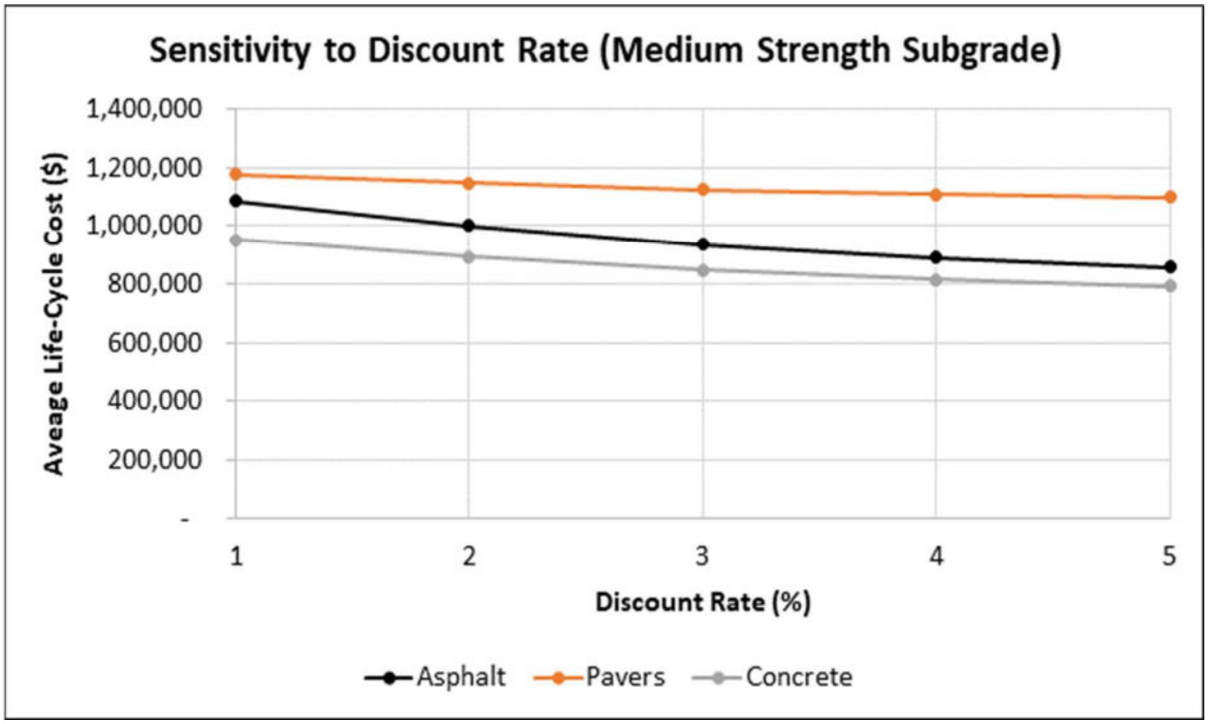
Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt
Paver LCC within 5 % of Asphalt

Appendix B-2 – Medium Strength Subgrade

Life-Cycle Cost Summary – US Customary Units, ($/2-Lane mile)
Medium Strength Subgrade

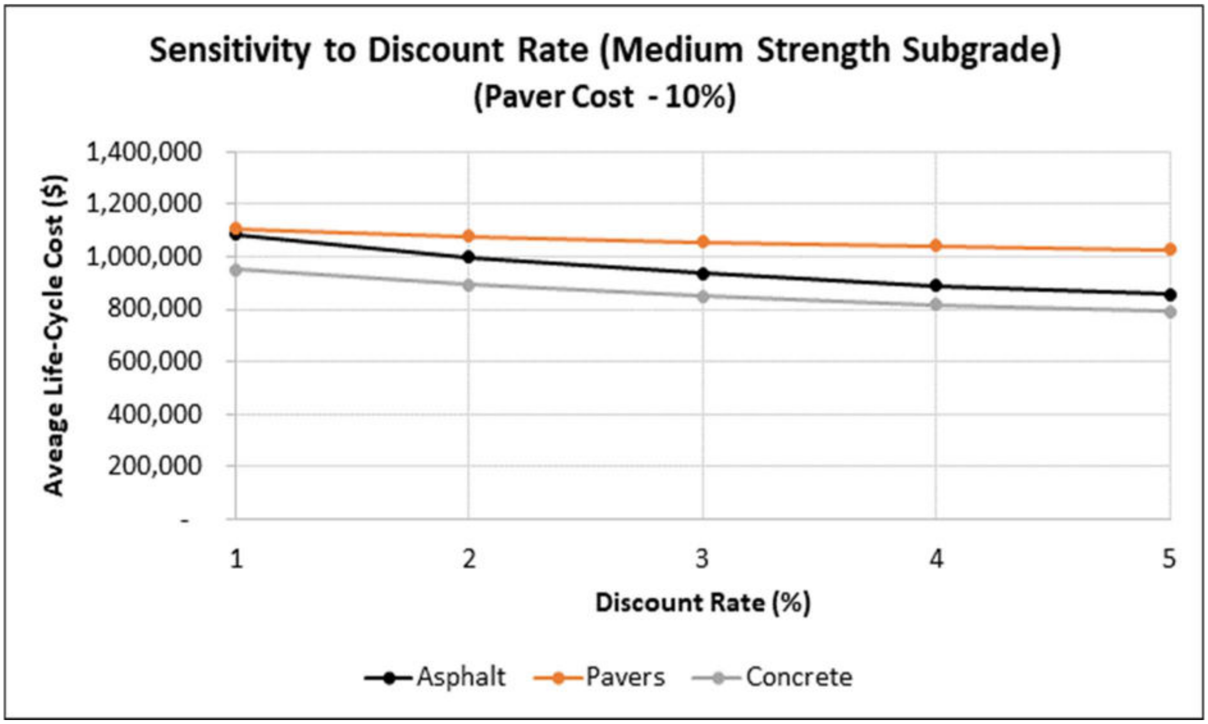
Discount Rate	Traffic Category				Average	Percent Compared to ICP
	Local Collector	Minor	Minor Bus	Major Collector		
Hot Mix Asphalt						
1	$ 943,269	$ 1,022,639	$ 1,174,797	$ 1,194,394	$ 1,083,775	-10
2	$ 867,528	$ 946,899	$ 1,081,698	$ 1,100,573	$ 999,175	-15
3	$ 811,856	$ 891,227	$ 1,013,226	$ 1,031,623	$ 936,983	-19
4	$ 770,589	$ 849,959	$ 962,432	$ 980,534	$ 890,879	-22
5	$ 739,732	$ 819,102	$ 924,406	$ 942,349	$ 856,397	-24
Interlocking Concrete Pavers						
1	$ 1,114,072	$ 1,157,696	$ 1,206,714	$ 1,232,889	$ 1,177,843	
2	$ 1,084,084	$ 1,127,708	$ 1,177,083	$ 1,203,257	$ 1,148,033	
3	$ 1,062,028	$ 1,105,652	$ 1,155,088	$ 1,181,262	$ 1,126,008	
4	$ 1,045,595	$ 1,089,218	$ 1,138,537	$ 1,164,711	$ 1,109,515	
5	$ 1,033,191	$ 1,076,815	$ 1,125,912	$ 1,152,086	$ 1,097,001	
Portland Cement Concrete						
1	$ 830,442	$ 906,994	$ 1,035,002	$ 1,035,002	$ 951,860	-17
2	$ 784,763	$ 859,858	$ 961,885	$ 961,885	$ 892,098	-20
3	$ 751,415	$ 825,402	$ 907,854	$ 907,854	$ 848,131	-22
4	$ 727,046	$ 800,180	$ 867,844	$ 867,844	$ 815,729	-24
5	$ 709,190	$ 781,668	$ 838,124	$ 838,124	$ 791,777	-26



Life-Cycle Cost of Pavers versus Asphalt (Base Case)
Medium Strength Subgrade

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

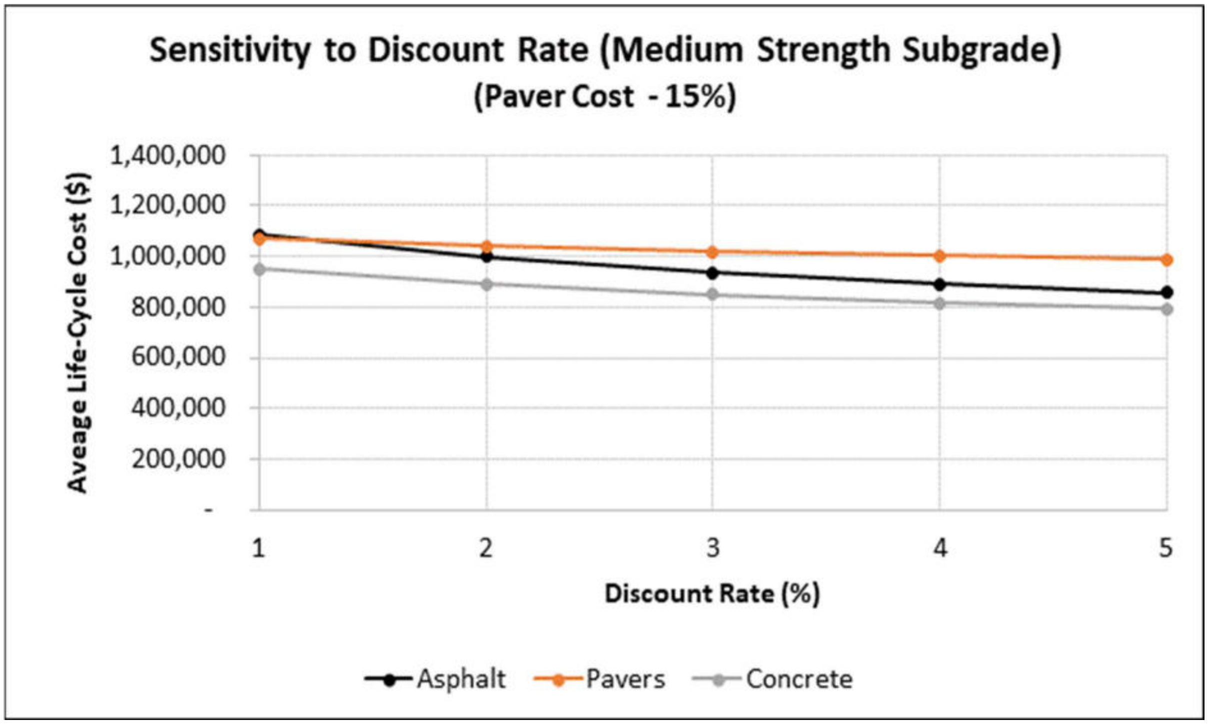
Legend:	Paver LCC < Asphalt	
	Paver LCC within 5% of Asphalt	



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -10%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

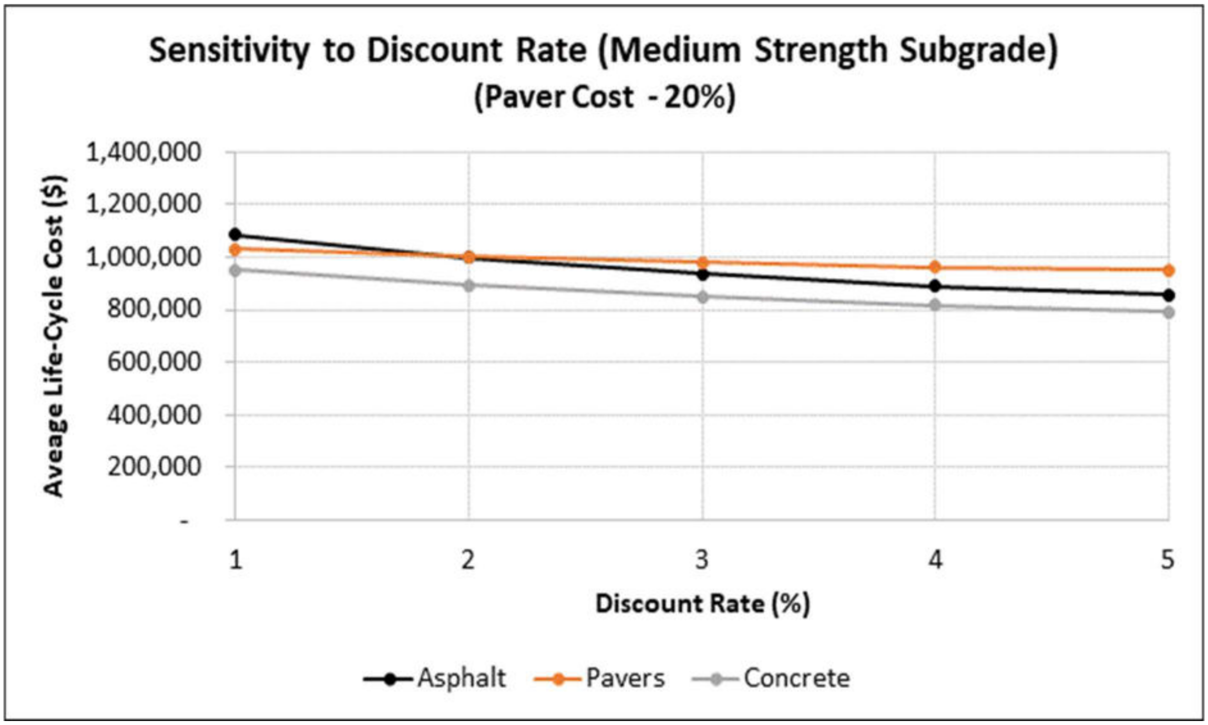
Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -15%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -20%)

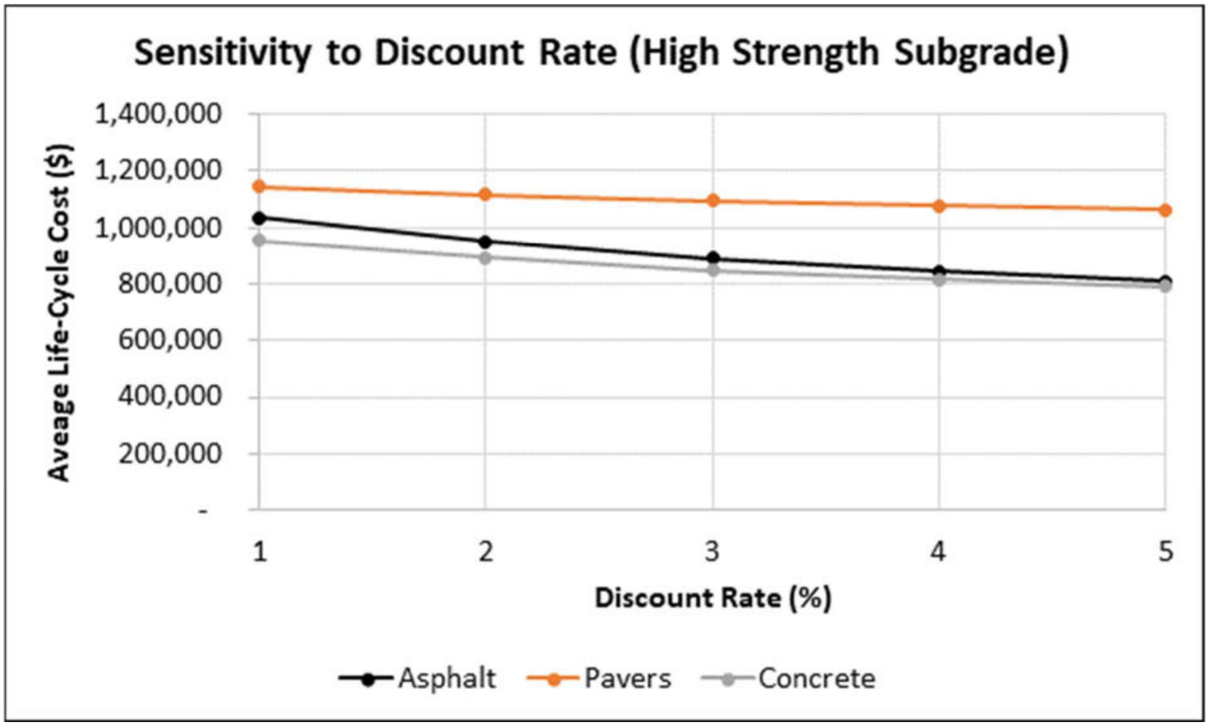
Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt (green)
Paver LCC within 5 % of Asphalt (yellow)

Appendix B-3 – High Strength Subgrade

Life-Cycle Cost Summary – US Customary Units, ($/2-Lane mile)
High Strength Subgrade

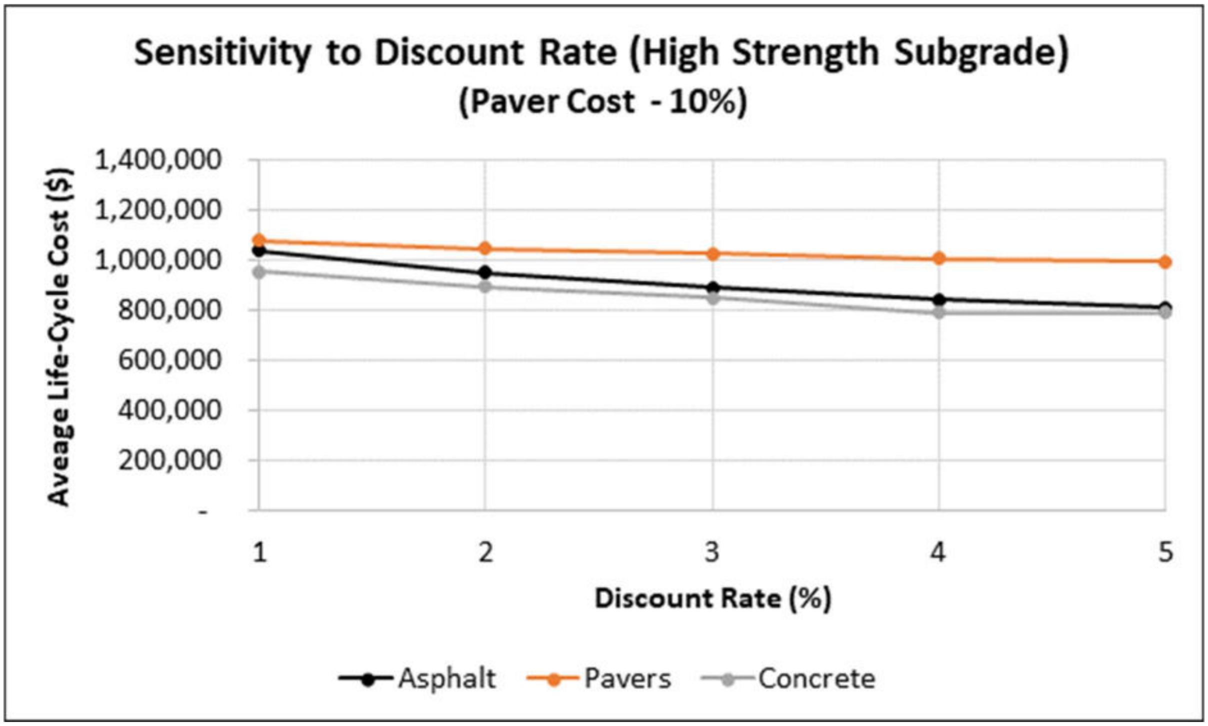
Discount Rate	Traffic Category				Average	Percent Compared to ICP
	Local Collector	Minor	Minor Bus	Major Collector		
Hot Mix Asphalt						
1	$ 917,094	$ 960,718	$ 1,107,342	$ 1,156,304	$ 1,035,365	-10
2	$ 841,354	$ 884,978	$ 1,014,243	$ 1,062,484	$ 950,765	-15
3	$ 785,682	$ 829,306	$ 945,771	$ 993,533	$ 888,573	-19
4	$ 744,415	$ 788,039	$ 894,977	$ 942,444	$ 842,469	-22
5	$ 713,558	$ 757,181	$ 856,951	$ 904,259	$ 807,987	-24
Interlocking Concrete Pavers						
1	$ 1,087,898	$ 1,122,797	$ 1,171,815	$ 1,197,990	$ 1,145,125	
2	$ 1,057,910	$ 1,092,809	$ 1,142,184	$ 1,168,358	$ 1,115,315	
3	$ 1,035,854	$ 1,070,753	$ 1,120,189	$ 1,146,363	$ 1,093,290	
4	$ 1,019,420	$ 1,054,319	$ 1,103,938	$ 1,129,812	$ 1,076,872	
5	$ 1,007,017	$ 1,041,916	$ 1,091,013	$ 1,117,187	$ 1,064,283	
Portland Cement Concrete						
1	$ 830,442	$ 906,994	$ 1,035,002	$ 1,035,002	$ 951,860	-17
2	$ 784,763	$ 859,858	$ 961,885	$ 961,885	$ 892,098	-20
3	$ 751,415	$ 825,402	$ 907,854	$ 907,854	$ 848,131	-22
4	$ 727,046	$ 800,180	$ 867,844	$ 867,844	$ 815,729	-24
5	$ 709,190	$ 781,668	$ 838,124	$ 838,124	$ 791,777	-26



Life-Cycle Cost of Pavers versus Asphalt (Base Case)
High Strength Subgrade

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

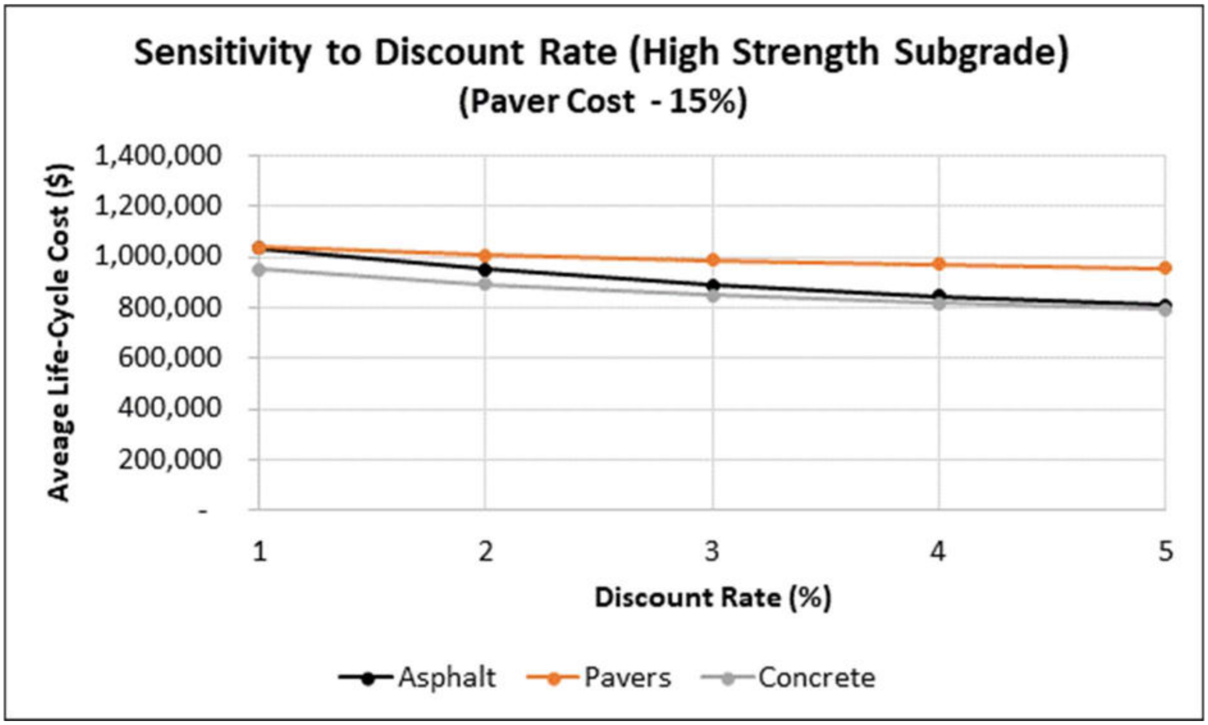
Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -10%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

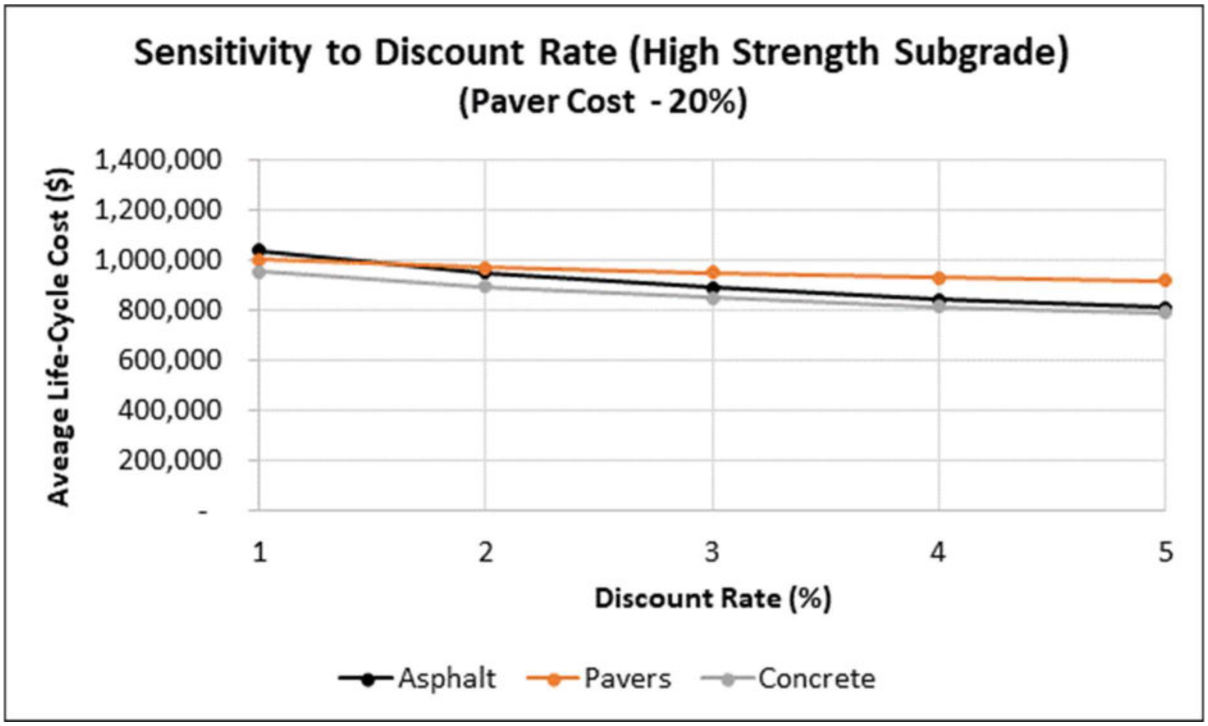
Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -15%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt
Paver LCC within 5% of Asphalt



Life-Cycle Cost of Pavers versus Asphalt (Paver Cost -20%)

Discount Rate (%)	Local Collector	Minor Collector	Minor Collector Bus Route	Major Collector	Average
1					
2					
3					
4					
5					

Legend: Paver LCC < Asphalt
Paver LCC within 5 % of Asphalt