Life Cycle Cost Analyses Comparing Segmental (Interlocking Concrete) Pavements to Other Pavement Structures using a Detailed Project Example

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Abstract

Life Cycle Cost Analysis (LCCA) is an important tool to evaluate the overall long-term economic efficiency between competing alternative investment options. The LCCA can assist transportation agencies and officials in their decision-making process to select a pavement type fora certain location. In a literature review only, a few studies were found to incorporate a systematic economic comparison between Segmental Pavements, also known as Interlocking Concrete Pavements (ICP), conventional Asphalt Concrete (AC) and Portland Cement Concrete (PCC) pavements. The purpose of this paper is to present an approach for comparing ICP with conventional pavements, demonstrated through a case study of an in-service ICP.

It is generally understood that the initial construction costs of ICP are higher than traditional AC and PCC pavements. However, the maintenance costs of ICP are lower than AC and PCC. To evaluate the three pavement types a 50-year LCCA was completed for comparable ICP, AC and PCC pavements. The evaluation included an analysis of pavement life-cycle strategies, including construction and future maintenance costs.

Comparable designs for ICP, AC, and PCC pavements were developed for a sample project for a neighborhood connector road in an Ontario municipality. LCC analyses were created for those design scenarios. Unit costs were obtained through a variety of sources, including an ICP survey conducted in 2021/2022, contractors/suppliers, and input from a municipality with a recent ICP project. A sensitivity analysis was performed to investigate the effects of different discount rates and installation costs in the LCCA.

The results confirmed that the maintenance costs of ICP are lower than the maintenance costs of AC and PCC in all cases. The Life Cycle Cost (LCC) of ICP is higher due to the higher ICP construction costs. The sensitivity analysis on discount rates showed that lower discount rates tend to benefit ICP LCC in comparison to PCC, while higher discount rates tend to benefit AC and PCC LCC.

The ICP installation costs varied from $110 to $325 per square metre (sq. m.) based on the Ontario survey data. When the ICP installation cost is $110 per sq. m., ICP LCC is similar to AC. In the $153 to $325 price range, ICP LCC is higher than AC. Comparing the ICP and PCC Pavements, when the paver installation cost was set between $110 and $153 per sq. m., the ICP LCC was lower than PCC. At $196, ICP and PCC LCCs are the same. As the paver installation cost increases from $216 to $325 per sq. m., the ICP LCC becomes higher than PCC.

LCCA is one tool to help jurisdictions decide on a project design, however, there are other factors to consider in the decision-making process, such as, traffic, soils, material availability, construction, maintenance, aesthetics, and environment.

1 Introduction

The Federal Highway Administration (FHWA) defines Life Cycle Cost Analysis (LCCA) as a technique to evaluate the overall long-term economic efficiency between competing alternative investment options. It incorporates initial and discounted costs over the life of alternative investments. It attempts to identify the best value, that is, the lowest long-term cost that satisfies the performance objective, for investment expenditures (Federal Highway Administration (FHWA), 2002). LCCA is an effective engineering tool known to assist in:

- The selection of cost-effective pavement designs for new or existing infrastructure;
- Calculating the best return on capital investment for the client faced with budgetary restrictions;
- Investigating different or future maintenance, rehabilitation, and/or reconstruction strategies on total project costs; and
- Providing transparency of the project selection process to all levels of government and the public.

To compare the LCC of interlocking concrete pavement (ICP) to conventional asphalt concrete (AC) pavement and Portland cement concrete (PCC) pavement, a case study was used. The case study consisted of a neighborhood connector road currently in service in an Ontario municipality (herein referred to as Municipality). The authors are not aware of any alternative pavement designs considered prior to the design and construction of the ICP case study road. For the purpose of the LCCA comparison, equivalent designs for AC and PCC have been developed based on available data for the case study road.

A sensitivity analysis was performed on two factors: (1) the effect of different discount rates in the LCCA, and (2) the effect of various ICP installation costs in the LCCA.

In general, the evaluation showed that ICP initial construction costs are higher than AC and PCC pavements, with lower maintenance costs. It was also observed that ICP Life Cycle Costs (LCCs) are more competitive in scenarios of discount rates lower than 4%.

Research that incorporates a systematic economic comparison between ICP, AC, and PCC pavements are scarce in the literature. In response to this gap, a 50-year LCCA of ICP, AC and PCC pavements was developed. The evaluation included construction and maintenance life-cycle strategies. The three main steps of the study were to:

(1) Develop comparable pavement structures for ICP, AC, and PCC pavements,
(2) Prepare a life-cycle cost tool (i.e., Excel spreadsheet), and
(3) Conduct a sensitivity analyses, varying discount rates and ICP construction costs.

2 Pavement Design

The neighborhood connector road used for the case study is used to access shopping, dining, as well as public events, and supports a high traffic flow. The ICP pavement is comprised of 80 mm precast concrete pavers, 25 mm sand bedding, 150 mm Cement Treated Base (CTB), 300 mm Granular A, underlain by the subgrade soil, as presented in Figure 2.1.

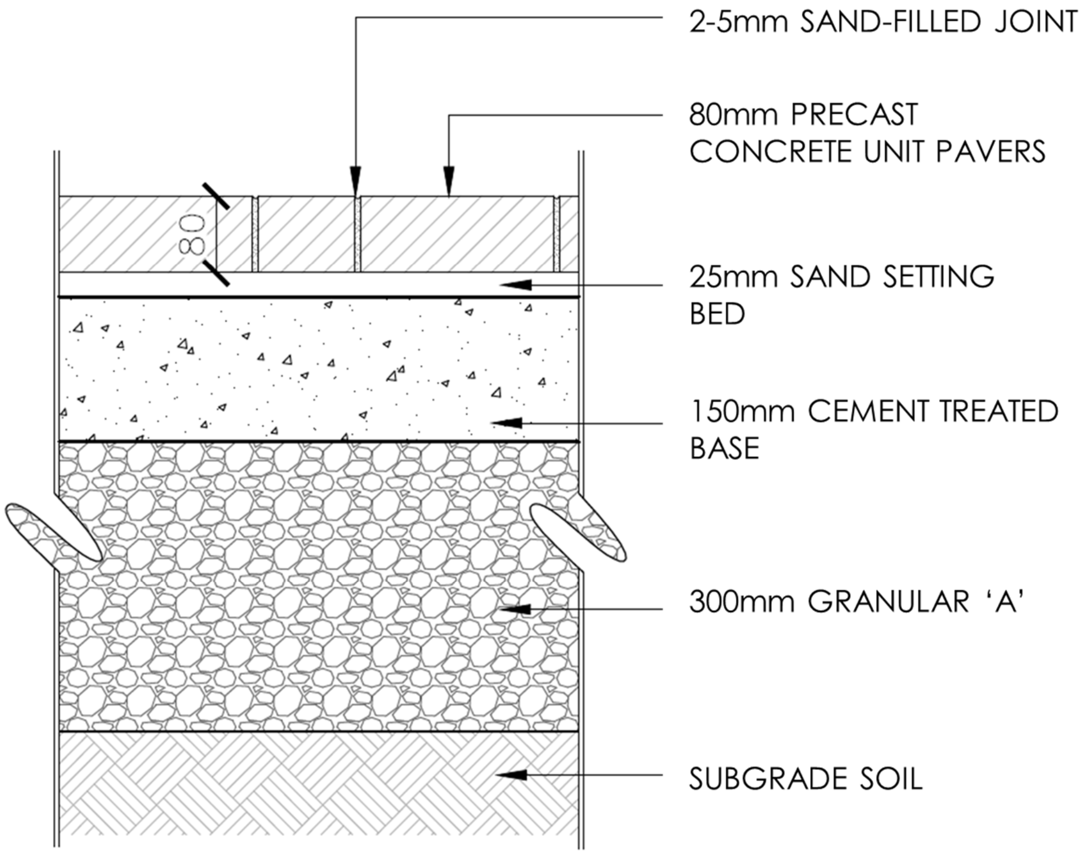

Figure 2.1: ICP Project Details

The structural coefficients of the ICP layer materials are presented in Table 2.1.

Table 2.1: ICP Structural Layer Coefficients

Parameter	Value
Pavers and Bedding Structural Coefficient	0.44
Cement Treated Base Structural Coefficient	0.20
Unbound Dense Graded Base Structural Coefficient	0.14

Considering the thickness of the ICP layer materials, as well as the structural coefficients presented above, the ICP Structural Number (SN) is 118.2 mm.

According to available traffic data, the case study road is a neighborhood connector. The Municipality's design manual notes that all neighborhood connector AC pavements should have at least 130 mm of AC, 150 mm of Granular A, and a layer of Granular B with thicknesses varying from 150 mm for "strong" subgrade soil, to 450 mm for "medium/weak" subgrade soil.

The structural coefficients of the AC pavement layer materials are presented in Table 2.2.

Table 2.2: AC Pavement Layer Structural Coefficients

Parameter	Value
AC Structural Coefficient	0.42
Unbound Dense Graded Base Structural Coefficient	0.14
Unbound Dense Graded Sub-Base Structural Coefficient	0.11

To reach an SN close to 118.2, the equivalent AC pavement could consist of 130 mm of AC, 150 mm of Granular A, 400 mm Granular B. Such structure would be similar to the design proposed in the Municipality's design manual for a "weak/medium" subgrade soil.

The Municipality's design manual does not include a PCC pavement alternative. To design an equivalent PCC pavement the following was used. A subgrade with "weak/medium" stiffness, with a California Bearing Ratio (CBR) 5% (or a subgrade resilient modulus of approximately 40 MPa). The modulus of subgrade reaction, including a granular layer of 200 mm, is 122 (MPa/m), or 450 pci.

The approximate traffic of the case study road was estimated based on the SN of the ICP pavement and the soil stiffness. The traffic was calculated as being $8.7*10^6$ Equivalent Single Axle Loads (ESALs), over a design life of 25 years. The PCC pavement structure was developed based on the design method proposed by AASHTO 93. A print screen of the design process is presented in Figure 2.2.

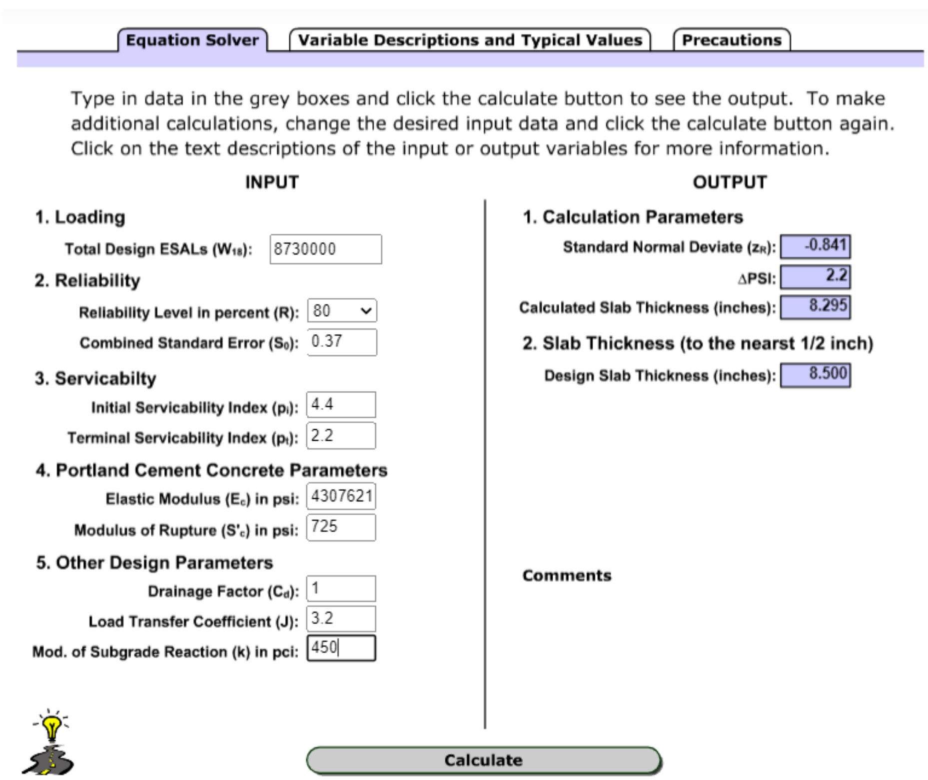

Figure 2.2: PCC design (Pavement Tools Consortium, 2024)

General parameters such as reliability, serviceability, etc. were chosen as typical values for a collector road. The AASHTO 93 design method results in a slab thickness of 210 mm (8.54 inches), and 200 mm of Granular A. The authors acknowledge that the concrete design using AASHTO 93 may be considered conservative.

A design check was performed through the AASHTOWareME software by inputting the PCC design and comparing with performance results from the AC structure (130 mm of AC, 150 mm of Granular A, 400 mm Granular B). The results showed that a doweled PCC structure consisting of 200 mm of concrete (10 mm less than the AASHTO 93 design) and 200 mm of Granular A would have similar performance. This confirms that AASHTO93 can lead to conservative PCC design. However, to provide a consistent methodology across the different pavement types, only AASHTO 93 results were used in the LCCA. The design parameters used to design the AC and PCC pavement structures equivalent to the ICP project are presented in Table 2.3. The initial design life for all pavement types evaluated is 25 years.

Table 2.3: Design Parameters

Category	Parameter	Value
General Design Parameters	Initial Serviceability	4.4
	Terminal Serviceability	2.2
	Reliability (%)	80
Subgrade Strength	Subgrade resilient modulus (Mr)	40
	California Bearing Ratio (CBR)	5
	Modulus of subgrade reaction with granular layer of 200 mm (MPa/m)	122
Traffic	Equivalent Single Axle Load (ESALs)	8,730,000
Portland Cement Concrete (PCC) specific design parameters	Standard deviation	0.37
	Concrete flexural strength (MPa)	5
	Concrete elastic modulus (MPa)	29,700
	Load transfer coefficient	3.2

2.1 Comparable Pavement Designs

The designs of comparable structures are presented in Table 2.4.

Table 2.4: Comparable Pavement Designs

Pavement Type	Material	Thickness (mm)
ICP	Pavers (80 mm) and Bedding Sand (25 mm)	105
	CTB	150
	Granular A	300
AC	AC	130
	Granular A	150
	Granular B	400
PCC	PCC	210
	Granular B	200

3 Maintenance and Rehabilitation (M&R) Plans

The maintenance and rehabilitation (M&R) plan defined for the AC and PCC pavements follow the strategies proposed by Holt, et. Al. (2011). M&R strategies for the ICP follow a study conducted by Applied Research & Associates (ARA) in 2020.

3.1 ICP

The life cycle maintenance activities for the ICP were obtained from a study conducted by ARA in 2020. It consists of replacing cracked, worn and rutted pavers (ARA, 2020). The maintenance activities proposed in the ARA study were developed for an ICP structure with a granular base layer. The incidence of rutting would likely be lower in an ICP with a CTB base layer than what is presented in Table 3.1.

Table 3.1: ICP Preservation Plan (ARA, 2020)

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

3.2 AC Pavements

For AC pavements the most common M&R procedures are spot repairs, mill and overlay of part or total AC layer. The recommended M&R plan is outlined in Table 3.2.

Table 3.2: AC Preservation Plan (Holt, Sullivan, & Hein, 2011)

Expected Year	Activity Description	Quantity (per 1 km of road)
10	Rout and Seal Cracks	250 m
10	Spot repairs, mill, and patch (40mm)	2%
15	Spot repairs, mill, and patch (40mm)	10%
20	Mill 40mm existing asphalt	100%
20	Resurface with surface course asphalt	100%
25	Rout and Seal Cracks	500 m
30	Spot repairs, mill, and patch (40mm)	5%
35	Mill 40mm existing asphalt	100%
35	Full depth asphalt base repair (300 mm)	10%
35	Resurface with surface course asphalt	100%
40	Rout and Seal Cracks	500 m
43	Spot repairs, mill, and patch (40mm)	5%
48	Mill 90mm existing asphalt	100%
48	Resurface with binder course asphalt (50mm)	100%
48	Resurface with surface course asphalt (40mm)	100%

3.3 PCC Pavements

Deterioration of PCC pavements are typically slower than AC pavements resulting in a less extensive maintenance schedule to maintain acceptable levels of service. For the PCC pavements, the most common activities are joint resealing, partial depth repairs, and slab replacements with full depth repairs. The recommended M&R plan for PCC pavements is outlined in Table 3.3.

Table 3.3: PCC Pavement Preservation Plan (Holt, Sullivan, & Hein, 2011)

Expected Year	Activity Description	Quantity (per 1 km 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%

4 Unit Costs

4.1 ICP

The unit costs related to ICP bedding sand and paver installation, as well as maintenance and rehabilitation costs, were obtained through a survey in 2021/2022. A total of eight (8) Ontario municipalities responded to the survey, however, only half of the participants were able to provide costs. Other construction costs (i.e., granular A, granular B and earth excavation) were obtained through the Ministry of Transportation Ontario (MTO) Highway Costing (HiCo) System reported in 2021-2022 and filtered for small scale projects (up to 6km). The unit costs average, minimum, maximum and standard deviation (SD) for ICP pavements are presented in Table 4.1.

Table 4.1: ICP Unit Costs

Activity Type	Activity	Unit Cost						Unit
		Weighted Average	Average	Min	Max	SD	Sample Size	
Initial Construction	Bedding Sand and Paver Installation[1]	-	$216	$110	$325	-	4	m^2
	Cement Treated Base[2]	-	$63	-	-	-	1	t
	Granular B, Type II[3]	$35	$40	$20	$89	$15	32	t
	Earth Excavation and Grading[3]	$36	$45	$16	$194	$35	59	m^3
Maintenance and Rehabilitation	Replace Cracked Pavers[1]	-	$105	$30	$161	-	4	m^2
	Replace Worn/Rutted Pavers(wheelpath) [1]	-	$187	$160	$215	-	4	m^2

[1]Costs based on 2021/2022 survey.
[2]Cost based on Alberta Unit Price Averages Report. Limited data (one project) available.
[3]Costs based on the MTO Highway Costing (HiCo) System.

The 2021-2022 survey obtained unit cost information in the format of ranges. For example, two Ontario municipalities reported that the unit cost of bedding sand and paver installation for vehicular applications ranged from $110 to $215 per m^2, while the other two reported prices ranging from $215 to $325. The calculation of a weighted average and standard deviation does not apply in such cases.

4.2 AC Pavements

Most unit costs considered in the AC pavement analysis were obtained through the MTO Highway Costing (HiCo) System reported in 2021-2022. The HiCo System contains small- and large-scale projects, for all regions in Ontario (i.e., central, eastern, northeast, northwest, and southwest).

ICPs are usually used in small-scale projects, which often have a higher unit cost when compared to large-scale projects. Since ICPs are more commonly used in smaller scale projects, it is reasonable to compare the LCCs of all pavements with unit costs corresponding to similar scale projects. An example of the influence of project road length in the unit cost of Superpave 19.0 is presented in Figure 4.1.

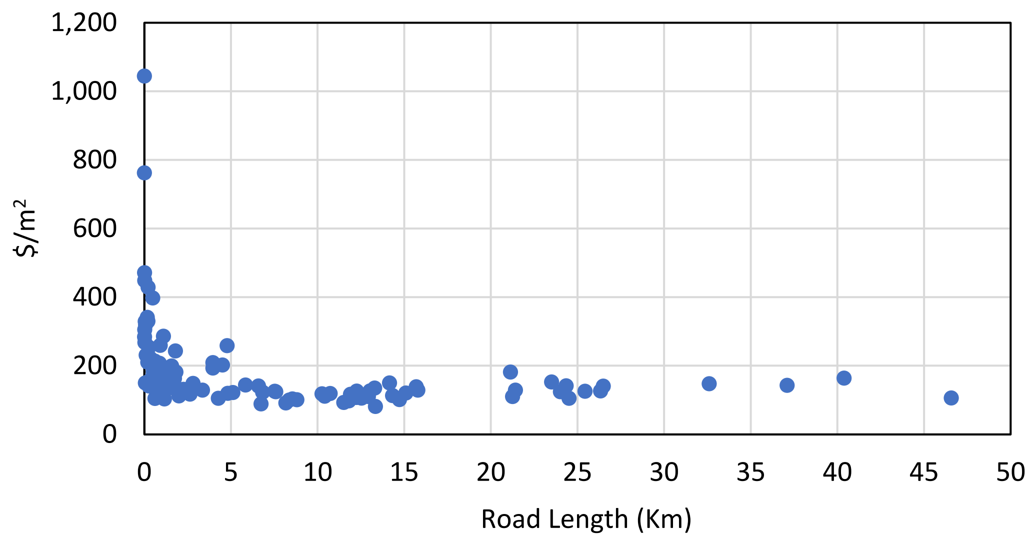

Figure 4.1: 2021-2022 Superpave 19.0 costs. Source: MTO Highway Costing (HiCo) System

Superpave 19.0 cost can be considerably higher in projects of road length below 6 km. The unit costs considered in the analysis of small-scale AC pavements (up to 6 km) are presented in Table 4.2. Unit costs from HiCO include the 2021-2022 costs, averaged for all regions. The authors acknowledge that the case study is less than 6 km and that costs for smaller projects (< 1 km) vary significantly.

Table 4.2: AC Pavements Unit Costs

Activity Type	Activity	Unit Cost						Unit
		Weighted Average	Average	Min	Max	SD	Sample Size	
Initial Construction	Superpave 12.5	$164	$241	$104	$361	$81	12	t
	Superpave 19.0	$195	$236	$119	$397	$72	21	t
	Granular A	$37	$59	$23	$268	$42	39	t
	Granular B, Type II	$35	$40	$20	$89	$15	32	t
	Earth Excavation and Grading	$36	$45	$16	$194	$35	59	m^3
	Tack Coat	$3	$4	$1	$12	$3	46	m^2
Maintenance and Rehabilitation	Rout and seal asphalt[1]	$60	$143	$41	$229	$77	3	m
	Mill 40mm existing asphalt[2]	$6	-	-	-	-	-	m^2
	Mill 90mm existing asphalt	$9	$16	$4	$183	$25	74	m^2
	Spot repairs, mill and patch[3]	$63	-	-	-	-	-	m^2
	Full depth asphalt base repair (300mm)	$24	$24	-	-	-	1	m^2
	Resurface with surface course asphalt (Superpave 12.5 – 40 mm Lift Thickness)	34	$52	$17	$130	$29	19	m^2
	Resurface with binder course asphalt (Superpave 19.0 – 50 mm Lift Thickness)	$20	$30	$16	$54	$13	9	m^2

[1]The cost of rout and seal asphalt is high based on smaller quantities. If crack sealing is included as part of a crack sealing program, the costs would be lower.

[2]The average costs for milling 40 mm of existing asphalt filtered for small scale projects were inconsistent. For this reason, the weighted average presented in this table represents the complete sample percent difference of milling 90 mm vs. 40 mm.

[3]Obtained through the sum of the following services costs: Mill 90mm existing asphalt, resurface with surface course asphalt (Superpave 12.5 - 40 mm Lift Thickness) and resurface with binder course asphalt (Superpave 19.0 - 50 mm Lift Thickness).

4.3 PCC Pavements

The initial construction costs for the PCC pavements were based on experience from recent small-scale projects. The M&R costs were obtained from small scale projects (up to 6 km) reported in the MTO HiCo system in 2021-2022 and averaged for all regions. The unit costs for the construction of doweled PCC pavements, including soil excavation and 150 mm of granular sub-base, are presented in Table 4.3.

Table 4.3: PCC Pavements Unit Costs

Activity Type	Activity	Unit Cost						Unit
		Weighted Average	Average	Min	Max	SD	Sample Size	
Initial Construction[1]	210 mm PCC	$222	-	-	-	-	-	m^2
Maintenance and Rehabilitation	Reseal Concrete Joints	$17	$17	$16	$17	<$1	2	m
	Partial depth PCC repair[2]	$420	-	-	-	-	-	m^2
	Full depth PCC repair	$525	$520	$486	$559	$30	3	m^2

[1]Price estimated based on HiCO costs and other published material available at the time.

[2]Estimated as 30% less costly than the Full depth PCC repair.

5 Life Cycle Costs (LCC)

Most LCCA use the concept of the present worth (PW), which is the sum of all costs associated with a certain design, discounted to today's dollars. The PW is sensitive to the discount rate, length of analysis period, service life, cost factors, and salvage value. According to the MERO-018 document, Guidelines for the Use of Life Cycle Cost Analysis on MTO freeway Projects, the PW can be calculated as follows (Lane & Kazmierowski, 2005):

$$PW = C * \left(\frac{1}{1 + Dis}\right)^n$$

Where,

- PW = present worth cost, $
- C = Future cost in present-day terms, $
- Dis = Discount rate, decimal
- n = Time until cost C is incurred, years

The total PW cost for each pavement alternative evaluated should be determined as the sum of the construction cost, M&R activities, and the salvage value. The most cost-effective alternative should be the one with the lowest PW cost.

5.1 Analysis Period

The LCCA considered a 50-year analysis period.

5.2 Discount Rate

Future costs were discounted to adjust for inflation and interest rates. The discount rate used to adjust the future costs is typically set at an agency level. The discount rate reduces the impact of future costs, especially after long time periods. Low discount rates tend to favor alternatives that combine large initial capital investments with low maintenance costs, while high discount rates favor the inverse. An initial analysis was performed with a discount rate of 4%, and a sensitivity analysis was performed later, varying the discount rates from 1 to 7%.

5.3 Salvage Value

The salvage value represents how much the pavement is worth at the end of the 50-year LCC analysis period. It is determined by dividing the remaining life of the last rehabilitation treatment, by the expected life of that treatment, multiplied by the cost of the last rehabilitation. The calculation follows the formula below (Lane & Kazmierowski, 2005):

$$SV = \frac{L_{rem}}{L_{exp}} * C_{pvt}$$

In which,

- SV = Salvage Value, $
- L_{rem} = Remaining life of last rehabilitation treatment, years
- L_{exp} = Expected life of last rehabilitation treatment, years
- C_{pvt} = Cost of final rehabilitation treatment, $

The salvage value is then converted to PW.

6 LCC Results

The LCCA consists of comparing the total cost to construct and maintain each design option. To that end, each cost is converted to the PW, and the total LCC is calculated as:

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

When following this procedure, the LCCA will result in economically comparable values.

6.1 Initial Costs

The results of the initial cost alternatives for the three pavement types are presented in Figure 6.1.

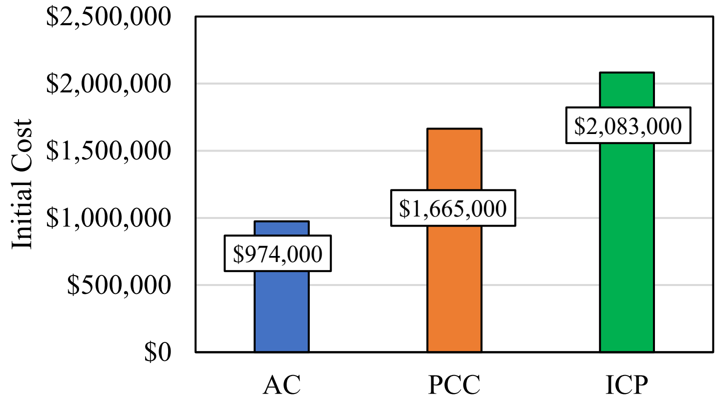

Figure 6.1: Initial Construction Cost

The initial construction costs for AC and PCC pavements are less than the ICP alternative. The initial AC construction costs are 53% lower than the ICP costs. The initial PCC construction costs are 20% lower than the ICP costs.

6.2 M&R Costs

The results of the PW M&R cost alternatives for the three pavement types are presented in Figure 6.2.

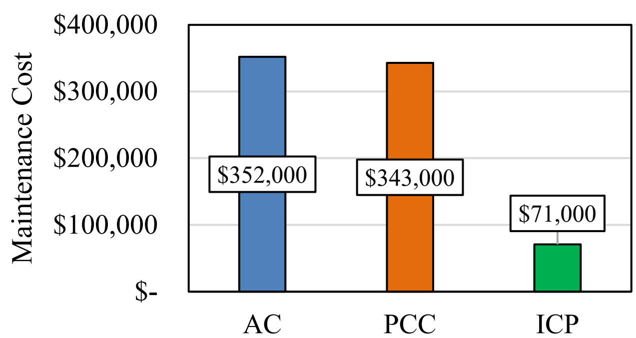

Figure 6.2: Maintenance and Rehabilitation Costs

The M&R PW costs for ICP pavements are much lower than AC and PCC pavements. AC is 396% higher, and PCC is 383% higher than ICP.

6.3 LCC Costs

The PW LCC comparison for the three pavement types is presented in Figure 6.3.

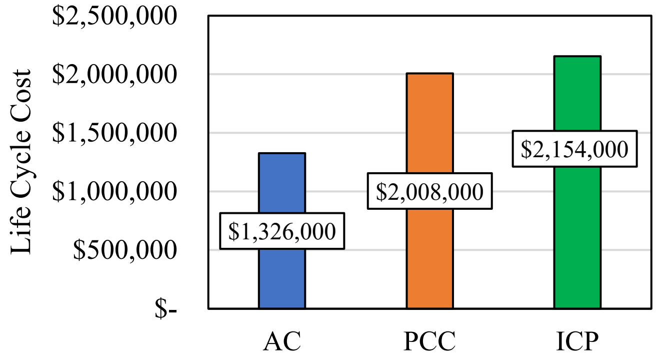

Figure 6.3: LCC

The PW LCC for AC pavements is 38% lower than the ICP alternative. The LCC for PCC pavement is 7% lower than ICP. Maintenance costs of the ICP are lower than that of AC and PCC pavements in all cases. The PW LCC of ICP is high due to the high construction costs.

7 Sensitivity Analysis

7.1 Discount Rate

Sensitivity analysis was performed to assess the effects of different discount rates in the LCCA. The higher the discount rate, the lower the LCC in all pavement types. However, the increase in discount rate has a smaller impact on the ICP LCC, due to its low M&R plan. Lower discount rates tend to benefit ICP in comparison to PCC, while higher discount rates tend to benefit AC and PCC LCC. The results of the LCC discount rate sensitivity analysis is presented in Table 7.1 for the three pavement types.

Table 7.1: Discount Rate Sensitivity Analysis Summary

Discount Rate	LCC ($ M)	Difference to ICP
AC		
1%	$1.8	-18%
2%	$1.6	-27%
3%	$1.4	-34%
4%	$1.3	-38%
5%	$1.2	-42%
6%	$1.2	-44%
7%	$1.1	-46%
ICP		
1%	$2.2	-
2%	$2.2	-
3%	$2.2	-
4%	$2.2	-
5%	$2.1	-
6%	$2.1	-
7%	$2.1	-
PCC		
1%	$2.5	10%
2%	$2.3	3%
3%	$2.1	-3%
4%	$2.0	-7%
5%	$1.9	-10%
6%	$1.9	-12%
7%	$1.8	-14%

With a discount rate of 1%, the AC pavement LCC is less expensive than ICP LCC, with the difference of 18%. With higher discount rates, the difference in AC LCC increases up to a maximum of 46% less expensive than ICP.

In the case of PCC, the LCC is 10% more expensive than ICP at a discount rate of 1%. At a discount rate of 2%, the LCC of PCC is 3% more expensive than ICP. For the discount rate of 3% to 7%, the LCC of PCC is less expensive than ICP, with differences ranging from 3% to 14%. The implementation of ICP becomes more attractive when the discount rates are less than 3%.

7.2 ICP Installation Cost

The survey costs for the bedding sand and paver installation were reported to vary from $110 to $325 per square metre (sq. m.). The variability in cost can be attributed to the location of the project, availability of materials and equipment in the region, or other specific project requirements. For this reason, a sensitivity analysis was performed to investigate the effects of different bedding sand and paver installation cost, varying from $110 to $325, in five (5) intervals of $43. Under this analysis, the discount rate was kept constant at 4%. ICP LCC becomes more competitive when the installation cost is lower. A summary of the paver installation cost sensitivity analysis is presented at Table 7.2.

Table 7.2: ICP Installation Cost Sensitivity Analysis Summary

ICP Unit Cost Range	ICP LCC ($ M)	Difference to AC	Difference to PCC
$110	$1.4	2%	-39%
$153	$1.7	24%	-18%
$196	$2.0	41%	0%
$216	$2.2	48%	7%
$239	$2.3	55%	15%
$282	$2.6	67%	28%
$325	$3.0	77%	39%
AC and PCC			
AC	$1.3	-	
PCC	$2.0	-	

When ICP installation cost is $110 per sq. m., ICP LCC is only 2% higher than AC. In the $153 to $325 price range, ICP LCC is 24% to 77% higher than AC. Comparing the ICP and PCC Pavements, for the cases where the paver installation cost was set at $110 and $153 per sq. m., the ICP LCC was lower than the PCC. At $196, ICP LCC was the same as PCC pavements. As the paver installation cost increases from $216 to $325 per sq. m., the LCC of ICP becomes 7% to 39% higher than the PCC pavement.

8 Other Considerations

When comparing alternative pavement designs there are many factors to consider beyond LCC. In a recent study of 17 municipalities across North America ICP was selected for the following benefits (Barbi, Ahmed, Whiteley-Lagace, Bowers, & Venema, 2023):

- Aesthetics (71%)
- Facilitates utility cuts (29%)
- Improve surface drainage (6%)
- Strong support (6%)
- Traffic calming/safety (6%)

From a road user cost perspective, Vehicle Operating Costs (VOCs) may be lower for ICP due to reduced frequency of maintenance, reduced project time (e.g., rehabilitation days, ability to open quickly to traffic), and smaller work zones.

From a sustainability perspective, pavers can be reused or recycled. Moreover, ICP installation emits neither fumes, nor carcinogenic gases or odours.

While pavers can be replaced, it often requires agencies to have a stockpile of pavers available for replacement. Agencies may weigh these and other factors as part of their project selection process.

9 Conclusions

The LCCs between three pavement types: ICP, AC and PCC, were compared for a 50-year analysis period. The case study evaluated a neighborhood connector road in Ontario. The initial analysis included a discount rate of 4%, with the unit costs of AC and PCC pavements corresponding to small scale projects. The results indicate that maintenance costs of ICP are approximately 80% lower than the maintenance costs of AC and PCC. The LCC of ICP is approximately 62% higher than AC pavement due to the ICP higher construction costs. The LCC of ICP is only 7% higher than PCC pavements.

Sensitivity analyses was used to assess the effects of different discount rates in the LCCA. It was observed that the higher the discount rate, the lower the LCC for all pavement types. However, an increase in the discount rate has a smaller impact in the ICP LCC. Lower discount rates tend to benefit systems with lower future costs like ICP in comparison to AC and PCC. Higher discount rates tend to benefit AC and PCC in comparison to ICP.

The LCC for the AC Pavement was the lowest of all pavements at all discount rates. At discount rates of 1% to 2%, the LCC of ICP is lower than the LCC of PCC pavements. At discount rates of 3% to 7%, the LCC of ICP ranges from 3% to 14% higher than PCC pavements.

Sensitivity analyses was used to assess the variation in ICP installation costs. The costs of ICP installation varied from $110 to $325 per sq. m. based on the Ontario survey data. The variability in cost was attributed to project location, availability of materials and equipment, selection of a standard or premium paver, or other specific project requirements. Using the lowest ICP installation cost of $110 per sq. m., the LCC of ICP is 2% lower than AC pavements, and 39% lower than PCC pavements. At an installation cost of $153 per sq. m., the LCC of ICP is 24% higher than AC and 18% lower than PCC pavements. As the paver installation cost increases, the LCC of ICP becomes higher than the alternative pavements, with differences up to 77%.

In design, LCC is a useful tool to help jurisdictions decide on a pavement type, however there are other factors to consider in the decision-making process. Factors may include, but are not limited to traffic, soils, material availability, construction, maintenance, aesthetics, environment, and user costs.

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