Tennessee Department of Transportation
Aeronautics Division
Life-Cycle Cost Analysis Framework

FINAL REPORT

PREPARED FOR:
Tennessee Department of Transportation
Aeronautics Division
7335 Centennial Boulevard
Nashville, Tennessee 37209
615-741-3208
www.tn.gov/tdot/aeronautics

PREPARED BY:
Applied Pavement Technology, Inc.
115 West Main Street, Suite 400
Urbana, IL 61801
217-398-3977
www.appliedpavement.com

November 2022

applied pavement
TECHNOLOGY

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Project Overview

The Tennessee Department of Transportation Aeronautics Division (Aeronautics) is interested in developing an analytical framework that can be used by Aeronautics and its consultants to complete a reasonable life-cycle cost analysis (LCCA) of airport pavement reconstruction alternatives. LCCA can be a valuable tool for comparing alternatives of varying costs and service lives. The use of a LCCA methodology by those who perform pavement designs has several benefits, including encouraging the development of alternate design options, introducing a consistent and repeatable analysis process into what has been more ad hoc, and helping to shift the focus in project selection away from alternatives with the lowest initial costs and toward those which have the lowest costs over the life of the pavement.

In this project Applied Pavement Technology, Inc. (APTech) worked with Aeronautics to develop a LCCA framework to compare feasible reconstruction alternatives to assist with evaluating cost-effective options. The development of the LCCA framework considered the guidelines provided in the Airfield Asphalt Pavement Technology Program's *Life Cycle Cost Analysis for Airport Pavements* study (AAPTP Project 06-06, 2011), as well as FAA guidance in Advisory Circular 150/5320-6G, *Airport Pavement Design and Evaluation*.

Life-Cycle Cost Analysis Framework

For the LCCA framework, the following aspects were developed:

- Analysis method
- Design alternatives
- Initial costs
- Analysis period
- Discount rate
- Salvage value
- Maintenance and rehabilitation activities

Each of these are discussed below.

Present Worth Analysis Method

In accordance with FAA design guidance, the Present Worth (PW) economic analysis method will be used for the LCCA to evaluate pavement rehabilitation and reconstruction alternatives. The variables in a PW analysis include initial cost, maintenance and rehabilitation costs, discount rate, salvage value, and analysis period. The basic equation for determining PW is shown below:

$$PW = C + \sum_{i=1}^{m} M_i \left(\frac{1}{1+r}\right)^{n_i} - S\left(\frac{1}{1+r}\right)^{z}$$

Where:

PW = Present Worth
C = Present cost of initial design or rehabilitation activity
m = Number of maintenance or rehabilitation activities

M_i = Cost of the i[th] maintenance or rehabilitation alternative in terms of present costs
r = Discount rate
n_i = Number of years from the present to the i[th] maintenance or rehabilitation activity
S = Salvage value at the end of the analysis period
z = Length of analysis period in years.

Design Alternatives

Typical design alternatives considered in the LCCA include the following:

- Asphalt reconstruction
- Concrete reconstruction

There are design options within each of these, such as the use of full-depth reclamation (FDR) as part of asphalt reconstruction, re-utilizing base/subbase layers or asphalt layers for concrete reconstruction, unbonded concrete overlays, and so on. These will be accounted for in developing the initial costs for the project, with future repairs being identified for the surface type.

Conventional milling and overlay with asphalt is not currently compared with reconstruction alternatives. The initial cost of an asphalt overlay is significantly lower than reconstruction and would nearly always be selected on an initial cost basis. There are factors beyond cost that need to be considered to determine whether a pavement is a candidate for milling and asphalt overlay or requires reconstruction.

Bonded thin concrete overlays (or ultra-thin-whitetopping [UTW]) have been constructed at some general aviation airports (see Innovative Pavement Research Foundation [IPRF] report IPRF-01-G-002-3, *Innovative Rehabilitation of Pavement for Light Load Aircraft*), but there is limited experience with these in TN or sufficient experience elsewhere that could be used to model these in the LCCA tool.

Initial Costs

The LCCA is intended to compare structurally similar pavement alternatives. It is not intended to provide a complete Engineer's Opinion of Cost, as there are ancillary costs and maintenance implications, such as lighting, signage, drainage, and so on, that are not typically captured in the pavement alternative LCCA. Whether or not to include shoulder pavement in the LCCA is a project-specific consideration, especially if the shoulder design will be different depending on the alternatives being considered. Costs developed for the LCCA are strictly for comparison of the pavement alternatives and should not be used as the final cost estimate. Costs for consideration based on FAA pay items are included in the Excel file provided for the LCCA framework. Many of the unit costs are available from the previously conducted Pavement Management Program (PMP) unit cost study. However, these should always be reviewed before carrying out a LCCA so that applicable recent costs are used. Unit costs for pay items that were not determined as part of the TDOT Aeronautics statewide PMP study will need to be obtained from Aeronautics.

Each pavement alternative should also incorporate mobilization and engineering/administration costs (or supplemental costs). Ten percent of the construction costs is currently incorporated for each in the tool. These costs may also vary depending on repair and reconstruction activity.

User costs (or indirect costs) can be difficult to determine for airside projects. Each airport is unique, and the following elements are complicated to calculate and also unique: how aircraft traffic operates around the airfield to estimate delays or possible weight restrictions, revenue reductions to airport operators, such as fuel sales, and possible loss of daily airport revenues (passenger or freight fees, although unlikely at most general aviation airports). Due to the complexity of estimating and analyzing user costs, they are not recommended for inclusion in this LCCA framework but should be considered in final alternative selection.

Analysis Period

While the FAA's structural design period for pavements is currently 20 years, this design period should not be confused with the LCCA analysis period. The LCCA analysis period is a common period of time over which all of the costs associated with different alternatives are analyzed. The analysis period should be long enough so that total cost differences between alternatives are considered. At a minimum, the analysis period should be long enough to include the initial construction cost of the reconstruction and at least one subsequent rehabilitation action for each alternative.

The AAPTP report identified the following inputs for expected pavement lives based on industry input (AAPTP 2011):

- Concrete Expected Life = 40 years.
- Asphalt Expected Life = 30 years, with mill and overlay at 15 years.

For either concrete or asphalt, a 20-year LCCA analysis period is too short based on expected pavement life spans. The AAPTP project's survey found that fewer than half of the respondents used a 20-year analysis period. The analysis period for LCCA must be sufficiently long such that each alternative includes at least one future major rehabilitation event.

For this project, APTech assessed the data collected during our work on the PMP and other resources. Under that project APTech developed performance prediction models based on collected pavement condition index (PCI) distress data. Those models are summarized in table 1 for the various pavement types (or families). Figure 1 summarizes the average PCI performance results for the developed prediction models. Asphalt pavements appear to reach a PCI of 40 (selecting a PCI of 40 to indicate failure or the need for reconstruction) in approximately 42 years, and concrete pavements reach a PCI of 40 in approximately 73 years. Both time periods are much longer than reported by industry, as noted in the AAPTP study. A basic comparison of the asphalt PMP model and assumed AAPTP model is shown in figure 2, which highlights the difference in timeframes for rehabilitation and reconstruction.

Table 1. Summary of state-wide PCI prediction models.

Pavement Family	Performance Model	Established Critical PCI	Years to Critical PCI
AAC Aprons & Helipads; East Region	100-2.6282x+0.0845x2-0.0012x3	60.0	35.1
AAC Aprons & Helipads; Middle Region	100-2.9529x+0.1138x2-0.0019x3	60.0	31.9
AAC Aprons & Helipads; West Region	100-1.3032x	60.0	30.7
AC Aprons & Helipads; East Region	100-0.5577x-0.0309x2	60.0	28.1
AC Aprons & Helipads; Middle Region	100-2.2672x+0.0726x2-0.002x3	60.0	23.9
AC Aprons & Helipads; West Region	100-1.2226x	60.0	32.7
PCC Aprons & Helipads; East Region	100-0.8977x	60.0	44.6
PCC Aprons & Helipads; Middle Region	100-0.9884x	60.0	40.5
PCC Aprons & Helipads; West Region	100-0.3737x-0.0056x2	60.0	57.5
APC, All Pavement Use, All Regions	100-1.8918x	60.0	21.1
AAC Runways; Middle Region	100-3.398x+0.1757x2-0.0039x3	65.0	24.4
AC & AAC Runways; East Region	100-1.0222x	65.0	34.2
AC & AAC Runways; West Region	100-1.6692x	65.0	21.0
AC Runways; Middle Region	100-1.8735x+0.0853x2-0.0025x3	65.0	26.0
PCC Runways; All Regions	100-0.4146x+0.0068x2-0.0002x3	65.0	54.7
AAC Taxiways; East Region	100-2.3281x+0.0987x2-0.0017x3	60.0	38.3
AAC Taxiways; Middle Region	100-1.055x	60.0	37.9
AAC Taxiways; West Region	100-1.2117x	60.0	33.0
AC Taxiways; East Region	100-1.9784x+0.0711x2-0.0015x3	60.0	32.2
AC Taxiways; Middle Region	100-2.2033x+0.094x2-0.0022x3	60.0	29.6
AC Taxiways; West Region	100-1.2104x	60.0	33.0
PCC Taxiways; All Regions	100-0.2919x-0.0039x2	60.0	70.5

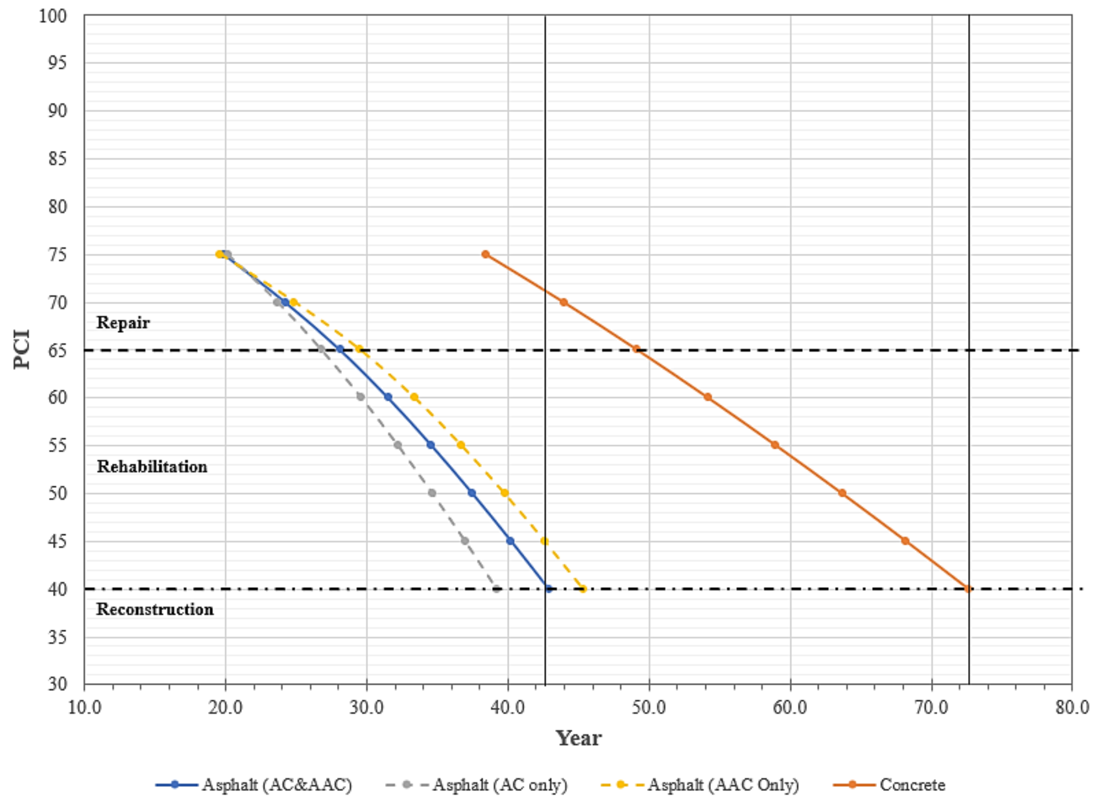

Figure 1. Summary of asphalt and concrete PCI models.

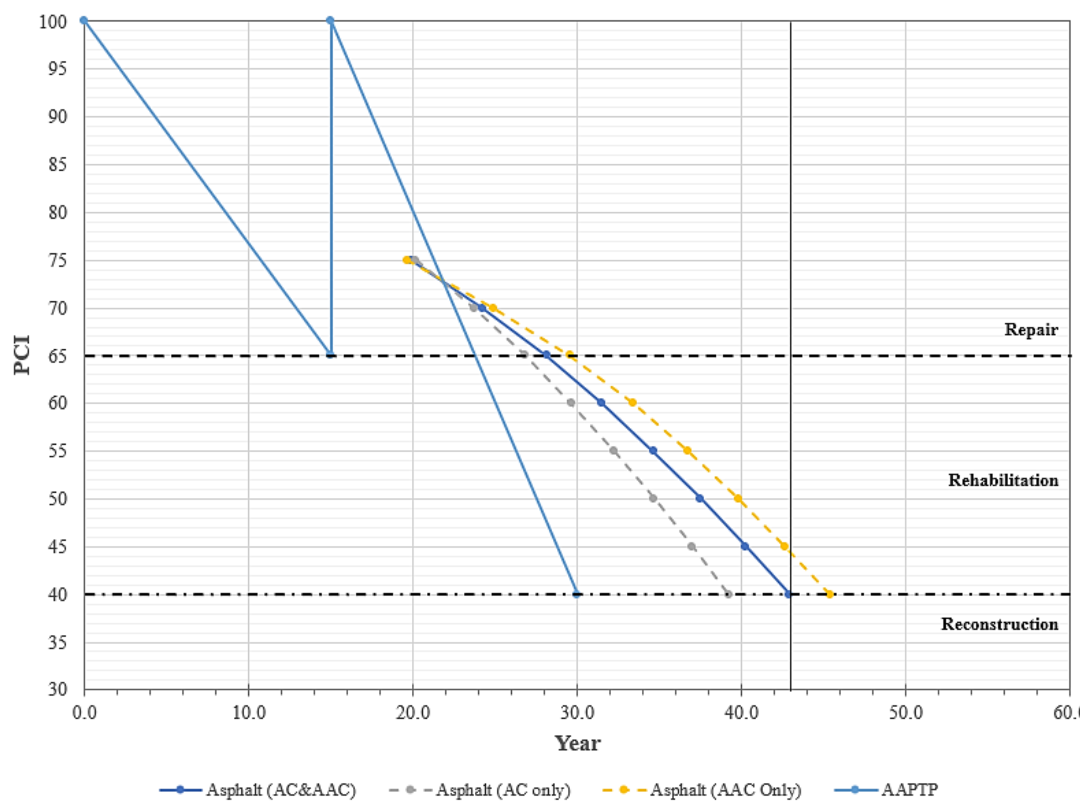

Figure 2. Comparison of asphalt performance models.

APTech also looked at the available construction history data for the asphalt overlay over asphalt (AAC) pavement sections for the timing of overlays (see table 2). As seen in the PMP performance models, the age of pavements when overlaid is greater than 15 years, with an average age for the first overlay being 28 years and the second overlay being 24 years later. There are only 4 sections that have received a third overlay and those are on average 12 years after the second overlay.

Table 2. Summary of overlay construction history.

	Years Between Overlays			**Existing Surface Age, Years**
	1st OL	**2nd OL**	**3rd OL**	
Average	28.0	23.8	11.8	19.6
Std Dev	16.0	8.2	2.2	12.0
COV	0.57	0.34	0.19	0.61
No. of Sections	252	58	4	252
Min	2.0	4.0	10.0	2.0
Max	75.0	37.0	15.0	42.0
Median	23.0	25.0	11.0	18.0

Because these results appear atypical to what is suggested in the national study, an adjusted model is proposed for the LCCA. One approach is to use the ratio of the predicted time periods to those commonly assumed (e.g., 43/30 for adjusting the asphalt timeframe), which is illustrated in figure 3. This results in rehabilitation at approximately 20 and 27 years for asphalt and concrete, respectively, to reach a PCI of 40. Note that maintenance and repairs would still be required at intermediate years.

If a 30-year LCCA analysis period is used, the asphalt option will have no remaining life at the end of the analysis, but the concrete option would have 10 years of remaining life. If a 40-year analysis period is used, the concrete pavement has no remaining life at the end of the analysis, but the asphalt pavement will need reconstruction at 30 years and will have life remaining at 40 years. An analysis period of 30 years is proposed since it is comparatively simpler to develop required cost and salvage inputs.

It is assumed for the LCCA analysis that an asphalt pavement can be milled and overlaid once before requiring reconstruction, as suggested in the AAPTP study, although there are pavements in Tennessee that have been overlaid two or even three times. The AAPTP study also contains an example cost stream (discussed later) that suggests two overlays (or rehabilitation events) occur to achieve an asphalt 30-year performance. Based on TN performance data, it is assumed one overlay will be required to reach 30 years.

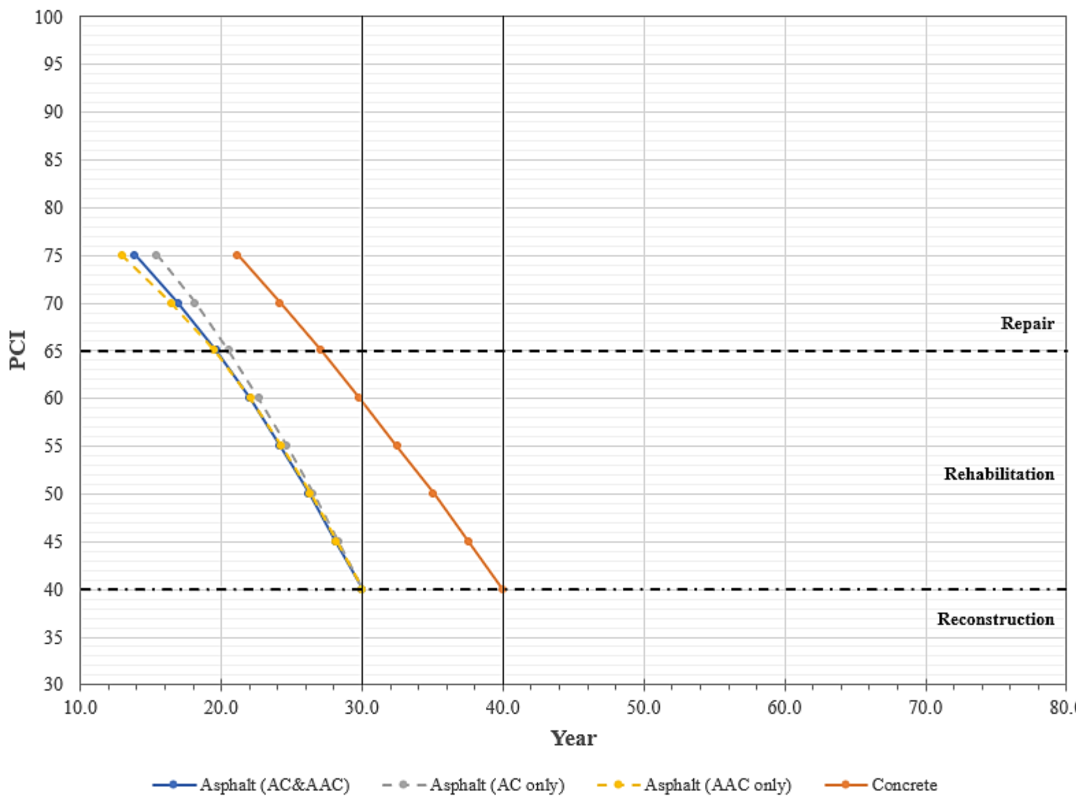

Figure 3. Adjusted asphalt and concrete performance models using ratio of predicted performance.

Discount Rate

Office of Management and Budget (OMB) Circular A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, identifies two discount rates, as follows (OMB 2020):

- A real discount rate that has been adjusted to eliminate the effect of expected inflation should be used to discount constant-dollar or real benefits and costs. A real discount rate can be approximated by subtracting expected inflation from a nominal interest rate.
- A nominal discount rate that reflects expected inflation should be used to discount nominal benefits and costs. Market interest rates are nominal interest rates in this sense.

AC 150/5320-6G, Section 1.6.3, indicates the real discount rate should be used for federal projects. Historical real treasury rates are summarized in figure 3. The current (2022) 30-year discount rate is 0.5 percent. The discount rate in 2021 was -0.3 percent. As seen in figure 4, although the overall trend in the real rate has steadily declined over the years, the overall trend does not enter a negative rate. Given current economic influences (especially the prolonged impact on the US economy from COVID-19), using very low rates may be partially short-sighted. Over the entire 44 years of data, the average real rate is 3.4 percent. The OMB began tracking 20-year (which corresponds to the FAA's structural design period) real rates only in 2004. The average 20- and 30-year real rates over the last 19 years are 1.7 and 1.8 percent, respectively. Based on available data, and the likelihood that negative rates will not continue, a real discount rate from 1 to 3 percent is a reasonable assumption. A real discount rate of 3 percent is set as the default value in the LCCA framework but can be adjusted by Aeronautics.

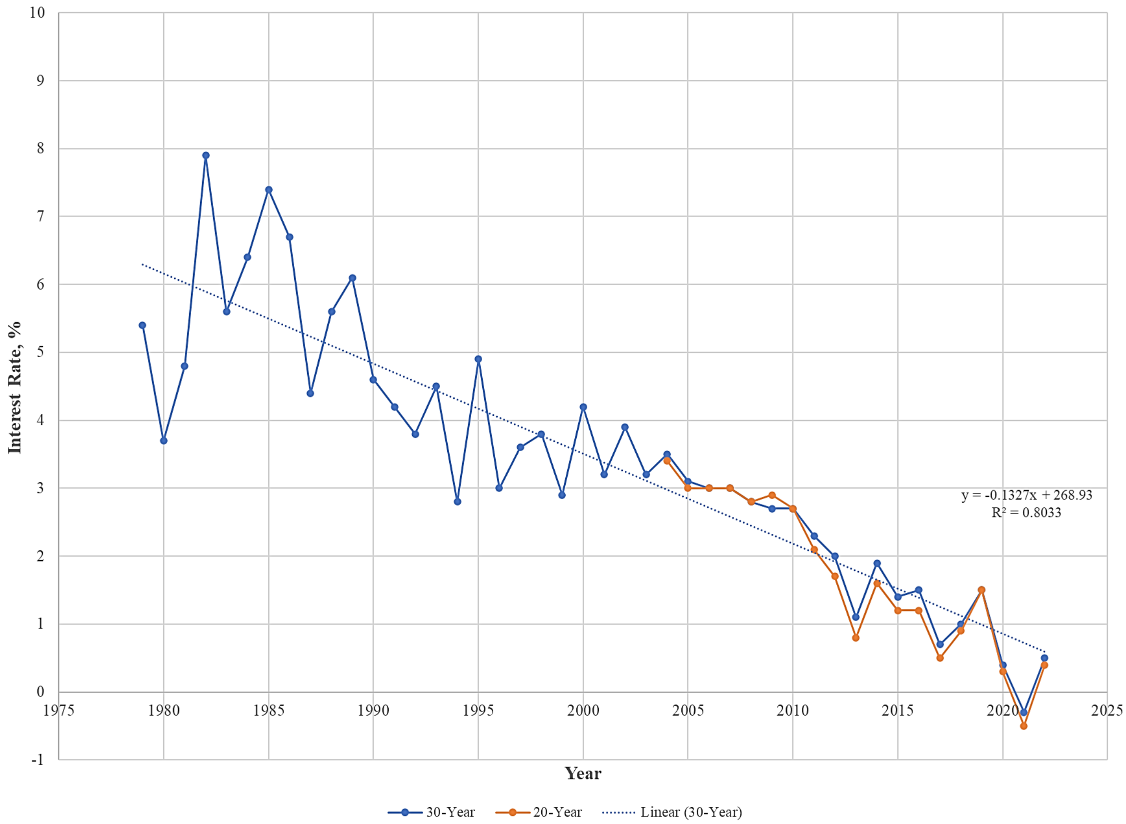

Figure 4. Historical real treasury discount rates.

Salvage Value

Salvage value is a variable that represents the remaining value of an alternative at the end of the analysis period. There are two accepted approaches to calculating salvage value: remaining service life and residual value. Remaining service life is the value of the pavement if it can continue to be used beyond the analysis period. Salvage value based on remaining service life is taken as the remaining life of the original pavement (or last rehabilitation) in years divided by the total expected life of the pavement (or last rehabilitation) times the cost of initial construction (or last rehabilitation). For example, if a 30-year analysis period is used, for a concrete pavement with a 40-year expected life, it has 10 years (or approximately 25 percent) of life remaining at the end. Therefore, its salvage value is assumed to be 25 percent of the initial construction cost. For the asphalt pavement, it is assumed the overlay placed at year 20 will provide 12 years of life. Therefore, there are two years of life remaining for the asphalt overlay or 12.5 percent of construction cost for a salvage value.

Residual value is a monetary calculation of the worth of the existing pavement at the end of the service life, such as potential revenue that may be obtained from recycling of the existing pavement. While there is certainly a value to recycling pavement materials at the end of their life, there are enough uncertainties associated with the suitability of the material for reuse, the future demand for the recycled material, and the costs associated with recycling the materials that residual value is not recommended for use in these calculations.

Maintenance and Rehabilitation Activities (Cost Streams)

Cost streams for subsequent maintenance and rehabilitation actions for asphalt and concrete pavement alternatives need to be developed as part of an LCCA (e.g., activity, timing, and cost, as shown in figures 5 and 6). The maintenance and rehabilitation activities, as well as the timing of these activities, are different for asphalt and concrete alternatives. Asphalt maintenance and rehabilitation is more frequent than concrete maintenance and rehabilitation, but repairs to concrete, when they occur, are typically more expensive.

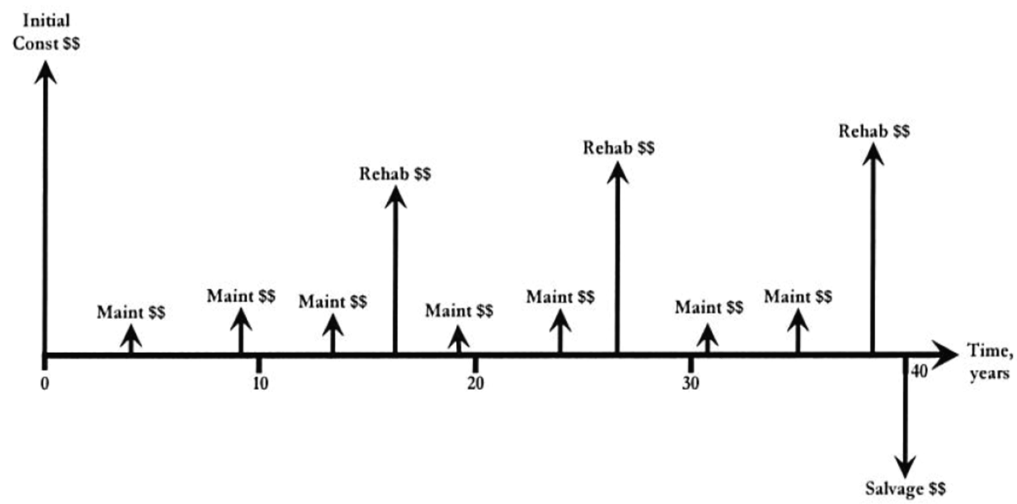

Figure 5. Example generic cost stream (FAA PaveAir).

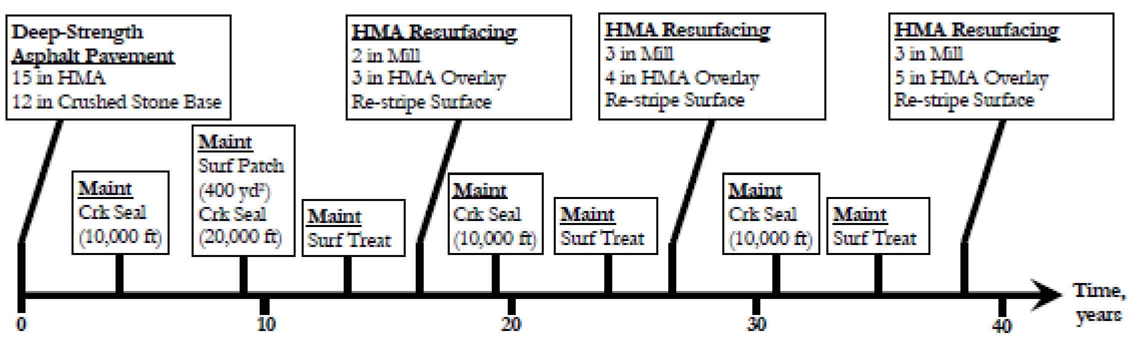

Figure 6. Example detailed cost stream (AAPTP 2011).

Based on the performance models developed with Tennessee data with adjusted performance period, information from the AAPTP study, and APTech's experience, the recommended cost streams for TDOT over a 30-year analysis period are summarized in table 3. The cost streams result in one rehabilitation effort for each pavement alternative, with maintenance identified in intermediate years.

Table 3. Maintenance and rehabilitation activities.

Alternative	Cost Item	Year
Asphalt	Initial Construction	0
	Maintenance – Surface treatment	4
	Maintenance – Surface treatment	8
	Maintenance – Patching, crack sealing, and surface treatment	12
	Maintenance – Patching, crack sealing, and surface treatment	16
	Rehabilitation – Mill and overlay	20
	Maintenance – Surface treatment	24
	Maintenance – Patching and crack sealing	28
	Salvage Value	30
Concrete	Initial Construction	0
	Maintenance – Joint resealing and partial-depth patching	19
	Rehabilitation – Slab replacements, patching, and sealing	27
	Salvage Value	30

For estimating future repair quantities as part of the cost streams, APTech analyzed the collected distress data and maintenance policies from the Tennessee statewide PMP with the objective of using data reflective of Tennessee experience. Numerous data points were available in the PMP for the typical repairs. Figure 7 illustrates all of the data available for asphalt crack sealing. This shows increasing variability in the quantities of crack sealing as the PCI decreases. However, the resulting models to estimate the repair quantities (polynomials are shown) have relatively poor fit. To develop a model for the LCCA framework, the average repair quantity per PCI point was considered, as illustrated in figure 8. Although based on averages, the model had less variability. To be slightly conservative, the data for the average plus one standard deviation for each PCI point was used to estimate repair quantities (as shown in figures 8 through 12). Slab replacements (figure 13) only had one data point for each PCI value, so those were used directly. Repair quantities were then selected based on PCIs of 75, 65, and 60. The resulting recommended repair quantities proposed for the LCCA are summarized in tables 4 and 5.

Each repair should also incorporate mobilization and engineering/administration costs, as discussed for initial construction. Ten percent of the construction costs is included in the LCCA framework for each but can be revised by Aeronautics, if required.

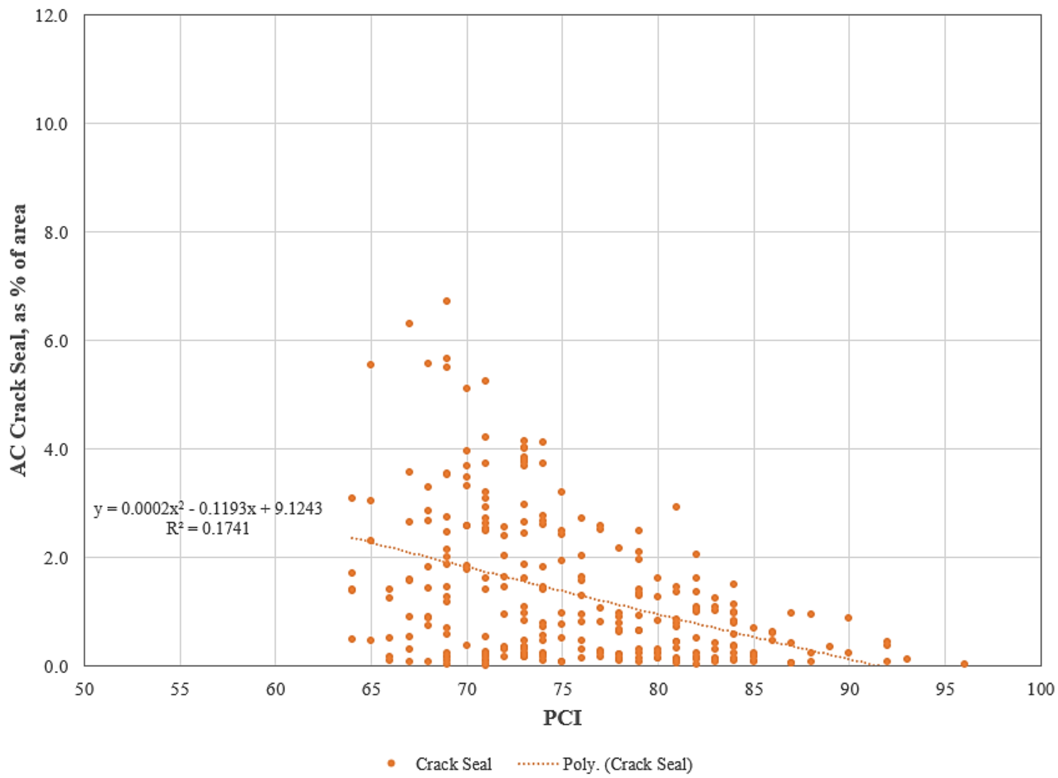

Figure 7. All PMP data for asphalt crack sealing.

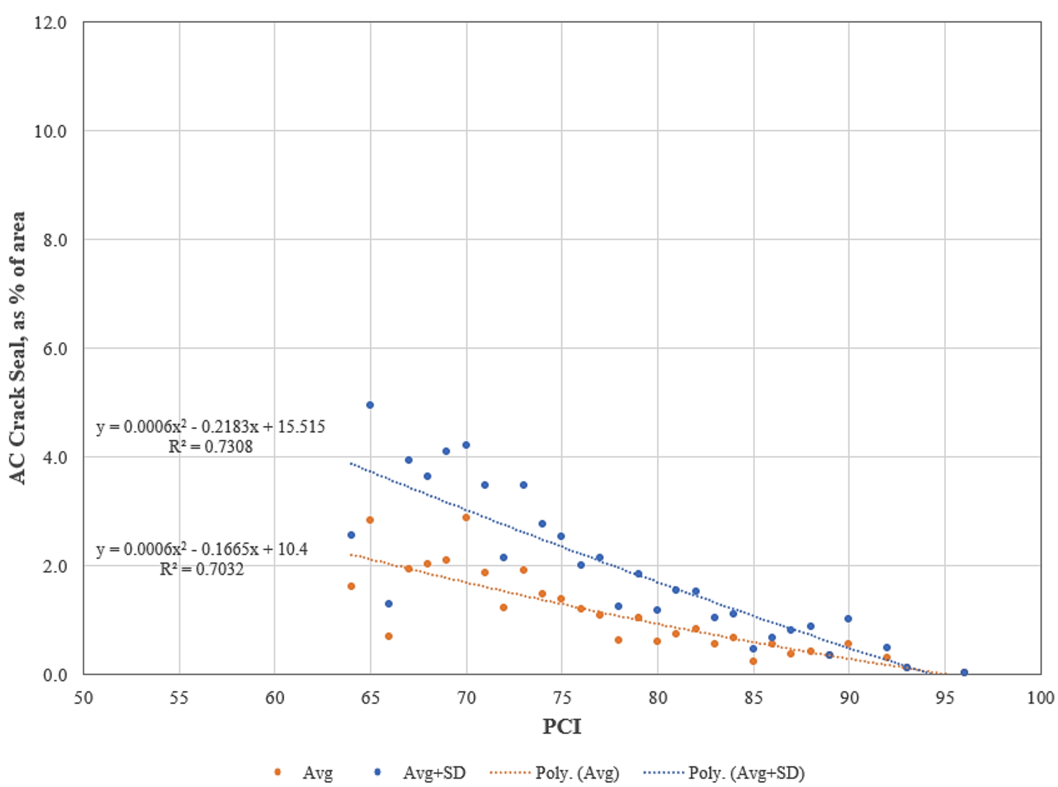

Figure 8. Average PMP data for asphalt crack sealing.

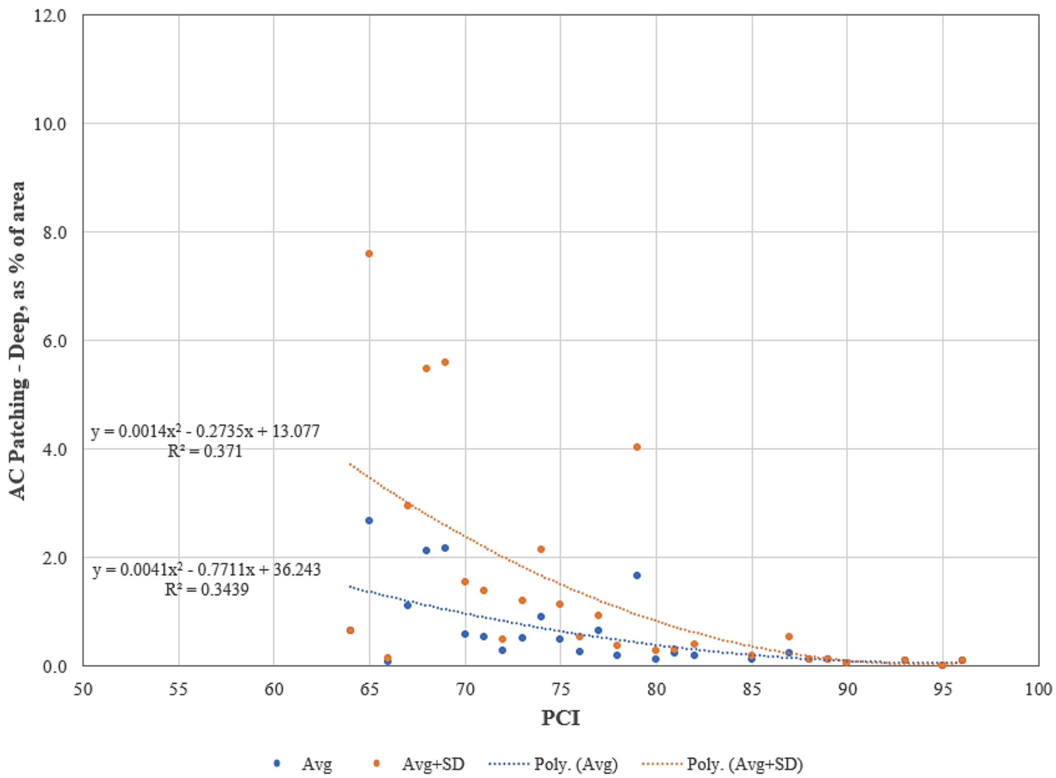

Figure 9. Average PMP data for asphalt patching.

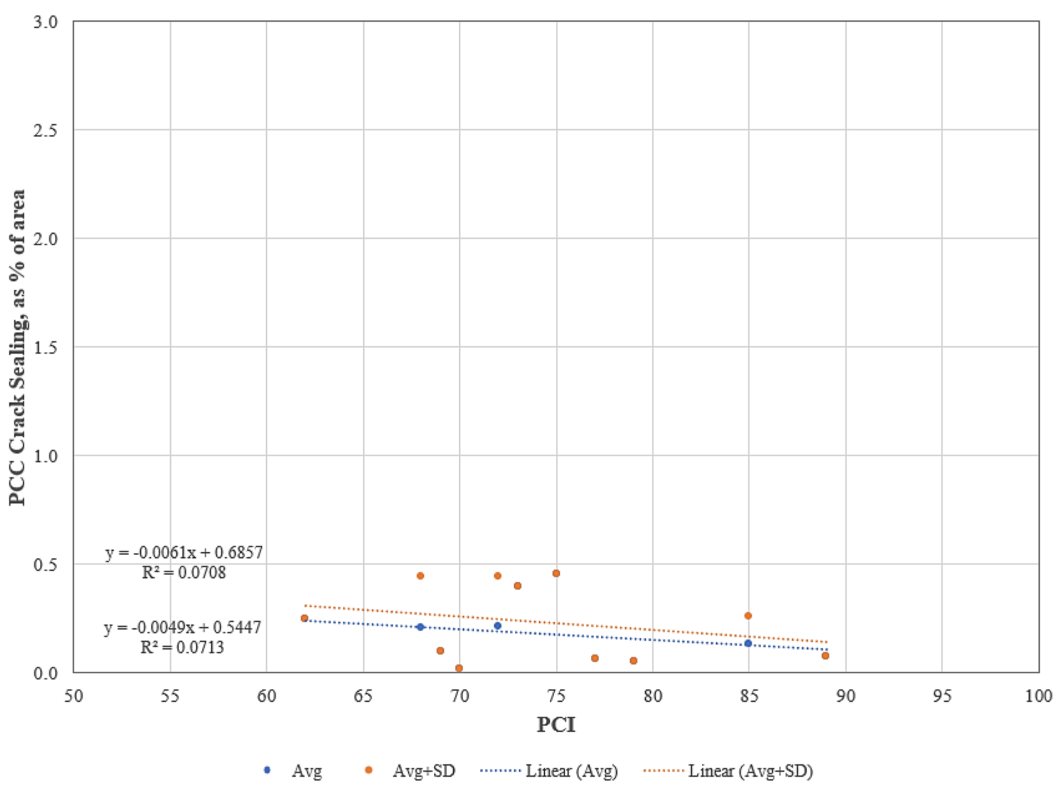

Figure 10. Average PMP data for concrete crack sealing.

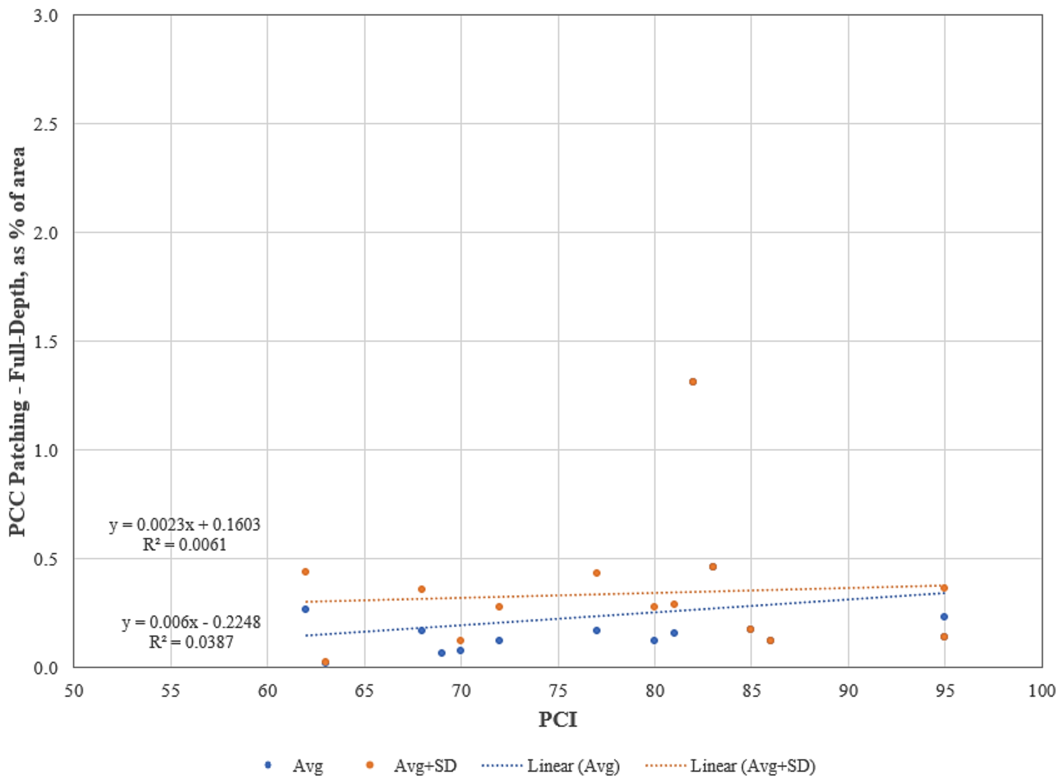

Figure 11. Average PMP data for concrete full-depth patching.

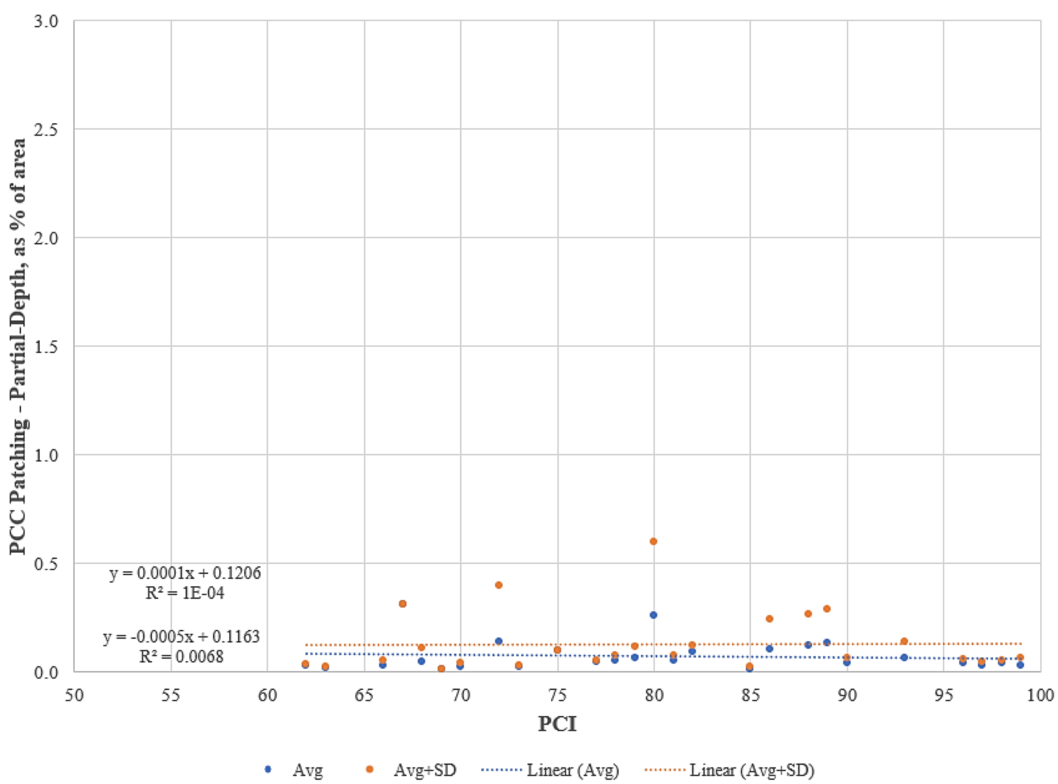

Figure 12. Average PMP data for concrete partial-depth patching.

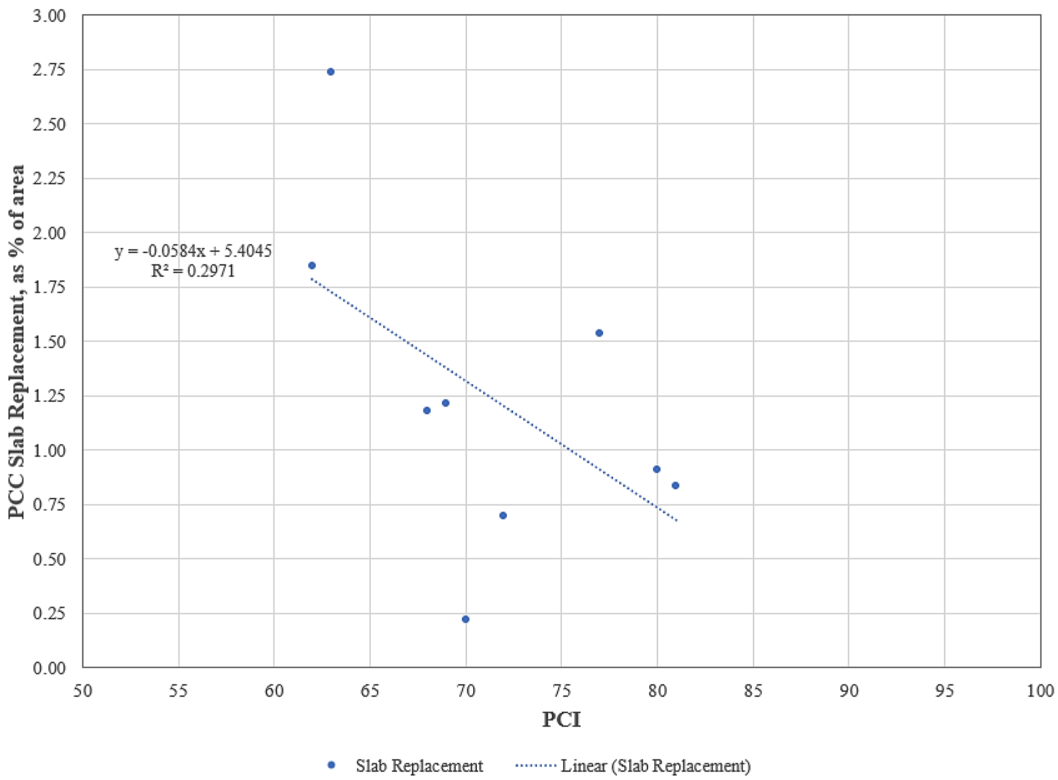

Figure 13. All PMP data for concrete slab replacement.

Table 4. Summary of asphalt future repair and rehabilitation activities.

Alternative	Cost Item	Year
Maintenance 1	Surface treatment: 100% of area Paint markings: 100% of markings	4
Maintenance 2	Surface treatment: 100% of area Paint markings: 100% of markings	8
Maintenance 3	Patching: 0.75% of area Crack sealing: 3.25% of area as linear feet Surface treatment: 100% of area Paint markings: 100% of markings	12
Maintenance 4	Patching: 1.00% of area Crack sealing: 3.50% of area as linear feet Surface treatment: 100% of area Paint markings: 100% of markings	16
Rehabilitation 1	Mill and overlay: 4-inch cold mill, tack coat, and asphalt overlay Pre-overlay crack repair: 1.5% of area as linear feet Pre-overlay patching: 0.5% of area Paint markings: 100% of markings	20
Maintenance 5	Surface treatment: 100% of area Paint markings: 100% of markings	24
Maintenance 6	Patching: 1.25% of area Crack sealing: 4.0% of area as linear feet Surface treatment: 100% of area Paint markings: 100% of markings	28
Salvage	Salvage value: 2 years (0.125) of mill and overlay	30

Table 5. Summary of concrete future repair and rehabilitation activities.

Alternative	Cost Item	Year
Maintenance 1	Joint resealing: 100% of joints Crack sealing: 0.25% of area as linear feet Partial-depth patching: 0.13% of area Full-depth patching: 0.30% of area	19
Rehabilitation 1	Slab replacements: 2% of area Full-depth patching: 0.30% of area Partial-depth patching: 0.13% of area Crack sealing: 0.30% of area as linear feet Joint sealing: 100% of joints	27
Salvage	Salvage value: 10 years (0.25) of initial construction	30

Summary of LCCA Parameters

Based on the information gathered and reviewed, the recommended LCCA parameters for the present worth analysis are summarized in table 6.

Table 6. Summary of recommended LCCA parameters.

	Value
Analysis Period	30 years
Discount Rate	3 percent
Initial Cost	Construction (FAA pay items) and supplemental costs (mobilization, engineering, and so on)
Maintenance and Rehabilitation	See Tables 4 and 5
Salvage Value	Remaining service life at end of analysis period

Case Studies

Two case studies were performed utilizing the LCCA framework to compare results with previous projects. LCCAs previously developed for projects at Jamestown Municipal Airport (Jamestown) and Savannah-Hardin County Airport (Savannah) were provided to APTech and the results are compared to the proposed model framework. In this report, references to “framework” or “model framework” are to the values and analytical approach incorporated in the Excel LCCA framework tool while references to “project” are to the actual LCCA reports completed by other consultants.

Initial Costs

A comparison of initial costs for Jamestown and Savannah are provided in tables 7 through 10. Note that only items related to paving have been included for comparison. The initial quantities for the Jamestown project were not clear from available documentation. The overall project area in the documentation is 42,550 syd. However, the paving area for the concrete alternative is 40,295 syd. The pavement removal quantity (or pavement removal, cold milling, and full-depth reclamation quantities) also does not match the overall project area. It is assumed other areas, such as overruns or shoulders, are included but not reconstructed. For a more consistent comparison in the proposed framework, initial construction quantities were recalculated based on the concrete pavement area. The Savannah analysis is based on 60,600 syd.

There are several differences in initial cost pay items that are included, as seen in the tables. For example, Jamestown includes joint sealing and steel reinforcement. In our experience, these are incidental to the cost of the concrete paving. Paint markings are also addressed quite differently in all three analyses. This project and LCCA framework are being done to help create more uniformity in these types of analyses.

Overall, for Jamestown, the concrete alternatives are within 1 percent (the LCCA framework being slightly less) and the asphalt alternatives are 17 percent different. The LCCA framework is approximately 13 percent greater for the Savannah concrete alternative and 8 percent less for the asphalt alternative.

Table 7. Jamestown concrete alternative initial construction cost items.

Item No.	Item Description	Project				Model Framework			
P-101-5.1	Pavement Removal (Asphalt, 5" Typ.)	SY	6,075	$4.20	$25,515	SY	40,925	$4.20	$171,885
P-101-5.8	Crack Filler/Sand, for Cracks 1 Inch and Wider	LF	20,000	$1.35	$27,000	-[1]	-	-	-
P-152-4.1	Unclassified Excavation	CY	40,000	$6.65	$266,000	CY	6,820	$20.00	$136,400
P-209-5.1	Crushed Aggregate Base Course (6"Depth)	SY	13,050	$10.95	$142,898	CY	6,820	$65.00	$443,300
P-501-8.1	Concrete Pavement, 5" Min. Thickness	SY	40,925	$79.40	$3,249,445	SY	40,925	$79.00	$3,233,075
P-602-5.1	Emulsified Asphalt Prime Coat	GAL	3,925	$7.90	$31,008	-[1]	-	-	-
P-605-5.1	Joint Sealing Filler	LF	99,000	$2.10	$207,900	-[2]	-	-	-
P-610-6.2	Steel Reinforcement	SY	1,000	$2.85	$2,850	-[2]	-	-	-
P-620-5.1	Markings (Permanent, White, Reflectorized)	SF	19,585	$1.00	$19,585	-[3]	-	-	-
P-620-5.2	Markings (Permanent, Yellow, Reflectorized)	SF	1,915	$1.00	$1,915	-[3]	-	-	-
P-620-5.3	Markings (Black, Non-Reflectorized)	SF	7,425	$0.65	$4,826	-[3]	-	-	-
P-620-5.4	Reflective Media, Type I Beads	LB	1,310	$1.25	$1,638	-[3]	-	-	-
P-620-5.1	Markings (prep, markings, reflective media)	-	-	-	-	SF	28,925	$0.67	$19,283
Subtotal									
	Mobilization				$190,000				$383,206
	Maintenance of Traffic				$83,000				-[1]
Total					$4,253,579				$4,215,264

Notes:
1. Pay item not included.
2. Item considered incidental to primary pay item.
3. Included in combined pay item.

Table 8. Jamestown asphalt alternative initial construction cost items.

Item No.	Item Description	Project				Model Framework			
P-101-5.1	Pavement Removal (Asphalt, 5" Typ.)	SY	5,450	$4.15	$22,618	S.Y.	40,925	$5.00	$204,625
P-101-5.6	Cold Milling, 2" Thickness	SY	400	$11.30	$4,520	-[1]	-	-	-
P-152-4.1	Unclassified Excavation	CY	40,000	$6.65	$266,000	-[1]	-	-	-
P-207-5.1	In-Place Full Depth Recycled (FDR) Asphalt Aggregate Base Course (16 Inch)	SY	30,150	$7.65	$230,648	S.Y.	40,925	$15.70	$642,523
P-207-5.2	Cement	TON	1,245	$195.00	$242,775	-[2]	-	-	-
P-209-5.1	Crushed Aggregate Base Course (6" Depth)	SY	12,400	$10.50	$130,200	C.Y.	6,820	$65.00	$443,300
P-401-8.1	Asphalt Surface Course, 2 - 2" Lifts (4" Total Min. Compacted Thickness)	TON	9,800	$154.00	$1,509,200	TON	9,820	$130.00	$1,276,600
P-602-5.1	Emulsified Asphalt Prime Coat	GAL	3,700	$7.90	$29,230	-[1]	-	-	-
P-603-5.1	Emulsified Asphalt Tack Coat	GAL	2,050	$4.70	$9,635	GAL	2,700	$4.50	$12,150
P-609-5.1	Double Bituminous Surface Treatment (DBST)	SY	30,135	$6.30	$189,851	-[1]	-	-	-
P-620-5.1	Markings (Permanent, White, Reflectorized)	SF	19,585	$1.00	$19,585	-[3]	-	-	-
P-620-5.2	Markings (Permanent, Yellow, Reflectorized)	SF	1,915	$1.00	$1,915	-[3]	-	-	-
P-620-5.3	Markings (Black, Non-Reflectorized)	SF	7,425	$0.65	$4,826	-[3]	-	-	-
P-620-5.4	Reflective Media, Type I Beads	LB	1,310	$1.25	$1,638	-[3]	-	-	-
P-620-5.1	Markings (prep, markings, reflective media)	-	-	-	-	SF	28,925	$0.67	$19,283
Subtotal					$2,662,639				$2,393,856
	Mobilization				$440,000				$239,386
	Maintenance of Traffic				$83,000				-[1]
Total					$3,185,639				$2,633,241

Notes:
1. Pay item not included.
2. Item considered incidental to primary pay item.
3. Included in combined pay item.

Table 9. Savannah concrete alternative initial construction cost items.

Item No.	Item Description	Project				Model Framework			
2	Demolition/Removal of Existing Runway Pavement	LS	1	$475,000.00	$475,000	SY	68,600	$4.20	$288,120
4	P-155 Lime-Treated Subgrade	SY	68,600	$10.00	$686,000	SY	68,600	$10.00	$686,000
5	P-154 Subbase Course (4" thick)	TON	15,500	$46.00	$713,000	CY	11,500	$55.00	$632,500
6	P-501 - Portland Cement Concrete (8-1/2" thick)	CY	16,200	$300.00	$4,860,000	SY	68,600	$85.00	$5,831,000
11	Markings (prep, markings, reflective media)	LS	1	$125,000.00	$125,000	SF	95,000	$0.67	$63,333
Subtotal					$6,859,000				$7,212,833
	Mobilization				$150,000				$721,283
Total					$7,009,000				$7,934,117

Table 10. Savannah asphalt alternative initial construction cost items.

Item No.	Item Description	Project				Model Framework			
2	Demolition/Removal of Existing Runway Pavement	LS	1	$475,000.00	$475,000	SY	68,600	$4.20	$288,120
4	P-155 Lime-Treated Subgrade	SY	68,600	$10.00	$686,000	SY	68,600	$10.00	$686,000
5	P-154 Subbase Course (9-1/2" thick)	TON	36,800	$45.00	$1,656,000	CY	27,300	$55.00	$1,501,500
6	P-209 Crushed Aggregate Base (8" Thick)	TON	31,000	$50.00	$1,550,000	CY	23,000	$65.00	$1,495,000
7	P-603 Bituminous Tack Coat	TON	100	$1,200.00	$120,000	GAL	4,800	$4.50	$21,600
8	P-401 (3/4" Max Aggregate) Plant Mix Bituminous	TON	7,800	$120.00	$936,000	TON	7,800	$120.00	$936,000
9	P-401 (1/2" Max Aggregate) Plant Mix Bituminous	TON	7,400	$130.00	$962,000	TON	7,400	$130.00	$962,000
10	P-631 Refined Coal Tar Emulsion	GAL	27,500	$5.00	$137,500	-[1]	-	-	-
15	Markings (prep, markings, reflective media)	LS	1	$100,000.00	$100,000	SF	95,000	$0.67	$63,333
Subtotal					$6,622,500				$5,665,433
	Mobilization				$150,000				$566,543
Total					$6,772,500				$6,231,977

Notes:
1. Pay item not included.

Analysis Period

A 30-year analysis period is used for the LCCA framework, as discussed previously, to include one major rehabilitation activity in each asphalt and concrete alternative. In the previously completed analyses by others, the Jamestown analysis used a 20-year period while the Savannah project did not indicate an analysis period.

Discount Rate

The developed LCCA framework uses a discount rate of 3 percent. The Jamestown LCCA (from 2020) used a discount rate of 7 percent. The Savannah project did not utilize a discount rate.

Salvage Value

Salvage value based on remaining service life is assumed for the LCCA framework (remaining service life is considered the value of the pavement if it can continue to be used beyond the analysis period). The Jamestown LCCA accounts for a salvage value based on remaining life. A performance life of 30 years is assumed for asphalt, but only 25 years is assumed for concrete. The Savannah project did not include salvage value.

Maintenance and Rehabilitation Activities (Cost Streams)

The cost streams previously summarized in tables 4 and 5 are used within the LCCA framework. Cost streams from the Jamestown and Savannah project LCCAs are summarized in tables 11 and 12, respectively. The Jamestown LCCA project utilized four maintenance activities and one rehabilitation. Savanah utilized one maintenance and rehabilitation activity for asphalt pavement and one maintenance activity for concrete pavement. While the Jamestown analysis included the timing for the activities, the Savannah LCCA project did not indicate anticipated timing of the maintenance and rehabilitation activities. In general, the maintenance and rehabilitation activities are very different between the projects and proposed framework.

Table 11. Maintenance and rehabilitation activities included in Jamestown project LCCA.

Alternative	Cost Item	Year
Asphalt	Initial Construction	0
	Maintenance 1 – Surface treatment	5
	Maintenance 2 – Patching, crack sealing, and surface treatment	8
	Maintenance 3 – Patching, crack sealing, and surface treatment	11
	Rehabilitation 1 – Patching, crack preparation, stress relief layer, and mill and overlay	15
	Maintenance 4 – Patching, crack sealing, and surface treatment	19
	Salvage Value	20
Concrete	Initial Construction	0
	Maintenance 1 – Joint resealing	10
	Maintenance 2 – Slab replacements, patching, and joint sealing	20
	Salvage Value	20

Table 12. Maintenance and rehabilitation activities included in Savannah project LCCA.

Alternative	Cost Item	Year
Asphalt	Initial Construction	0
	Maintenance 1 – Crack sealing, surface treatment, and markings	-
	Rehabilitation 1 – Mill and overlay, surface treatment, and markings	-
Concrete	Initial Construction	0
	Maintenance 1 – Markings	-

The following contingency costs are applied to all future maintenance and rehabilitation activities for Jamestown:

- Mobilization of 10.0 percent
- Safety and Maintenance of Traffic of 5.0 percent
- Engineering / Administrative of 15.0 percent

The costs associated with the maintenance and rehabilitation activities are summarized in tables 13 and 14. While some costs are similar, most vary widely. A direct comparison of these costs is difficult because the included activities and assumptions regarding quantities are quite different. Applying this LCCA framework will provide more consistent future comparisons for Aeronautics.

Table 13. Comparison of maintenance and rehabilitation costs for Jamestown model framework and project LCCA.

		Model Framework		Project	
Alternative	**Activity**	**Year**	**Cost**	**Year**	**Cost**
Asphalt	Maintenance 1	4	$236,303	5	$337,634
	Maintenance 2	8	$236,303	8	$387,338
	Maintenance 3	12	$318,370	11	$437,041
	Maintenance 4	16	$331,607		
	Rehabilitation 1	20	$1,049,930	15	$2,016,245
	Maintenance 5	24	$236,303	19	$387,338
	Maintenance 6	28	$349,079		
	Salvage Value	30	-$131,241	20	-$347,357
Concrete	Maintenance 1	19	$562,506	10	$229,123
	Rehabilitation 1	27	$658,328	20	$289,886
	Salvage Value	30	-$443,389	20	-$287,074

Table 14. Comparison of maintenance and rehabilitation costs for Savannah model framework and project LCCA.

Alternative	Activity	Model Framework		Project	
		Year	Cost	Year	Cost
Asphalt	Maintenance 1	4	$473,366	-	$408,750
	Maintenance 2	8	$473,366		
	Maintenance 3	12	$610,930		
	Maintenance 4	16	$633,118		
	Rehabilitation 1	20	$1,693,037	-	$1,693,000
	Maintenance 5	24	$473,366		
	Maintenance 6	28	$662,406		
	Salvage Value	30	-$211,630		
Concrete	Maintenance 1	19	$942,893	-	$250,500
	Rehabilitation 1	27	$1,103,513		
	Salvage Value	30	-$970,176		

Case Study Summary

The overall results of the LCCA comparison are summarized in table 15. For these cases, both the Jamestown and Savannah analyses indicated concrete had the lower NPW. For the Jamestown project, the adjusted analysis performed for this study indicates NPWs are within approximately 10 percent. The LCCA framework analysis for Savannah has the two NPWs within 10 percent of each other, but the project difference is approximately 22 percent.

Table 15. Comparison of LCCA results.

Alternative	Cost	Jamestown		Savannah	
		Framework	Project	Framework	Project
Concrete	Initial	$4,215,264	$4,253,579	$7,934,117	$7,009,000
	NPW	$4,669,489	$4,157,892	$8,606,070	$7,259,500
Asphalt	Initial	$2,633,241	$3,185,639	$6,231,977	$6,772,500
	NPW	$4,255,748	$4,349,962	$9,221,858	$8,874,250

Summary and Recommendations

APTech has worked with TDOT Aeronautics to develop an analytical framework that can be used by Aeronautics and its consultants to complete a reasonable LCCA of airport pavement reconstruction alternatives. LCCA can be a valuable tool for comparing alternatives of varying costs and service lives. The use of a LCCA methodology encourages the development of alternate design options and helps to shift the focus in project selection away from alternatives with the lowest initial costs and toward those which have the lowest costs over the life of the pavement. The adoption of this LCCA framework will provide more uniform analyses to assist Aeronautics with assessing pavement type selection.

As part of the development of an LCCA framework, the statewide PMP data was used to develop maintenance and repair timing and quantities. These policies are summarized in tables 4 and 5. As additional data is collected and analyzed, these policies should be revisited and adjustments made to repair timings and quantities. An analysis period of 30 years is recommended based on industry data as well as TN performance data. A longer analysis period (such as 40 years) could be considered, but a shorter one is not recommended. The discount rate in the LCCA framework is set to 3 percent. However, based on the volatility of discount rates, this should be reassessed annually at a minimum. It should also be adjusted if the FAA requests the analysis be based on the OMB real discount rate at the time of the analysis. Salvage value for the pavement alternatives is based on the assumed remaining life as a percentage of construction cost. Residual value, the monetary calculation of the worth of the existing pavement at the end of the service life, is not recommended for use in these calculations.

Based on collected data, development of the LCCA framework, and the case studies performed for this project, the following summary points are provided:

Initial Costs

- Pay item costs need to be verified prior to use for each project, particularly those pay items with costs impacted by thickness. The current table of unit costs is not yet developed to include a range of possible designs.
- Mobilization costs are assumed to include Maintenance of Traffic. Ten percent of the estimated construction cost is used for mobilization.
- An Emulsified Asphalt Surface Treatment is the default maintenance treatment for asphalt pavements. If an alternate treatment is planned, the LCCA framework will need to be revised.
- Incidental cost items (such as joint sealing or reinforcement for concrete pavements, cement for FDR, and so on) are considered to be included in the primary pay items. These can be separate pay items, if needed.

Maintenance and Rehabilitation Costs

- The LCCA framework is based on Aeronautics' planning for more frequent routine surface treatments for asphalt pavements, so maintenance activities have been timed more often than previous LCCA estimates.
- Maintenance policies based on APMS data are currently being used (automated) in the LCCA framework. As more data becomes available and models are re-assessed, maintenance policies should be updated.
- Maintenance items that may occur at the end of the analysis period (30 years) are not included for comparing the design alternatives.

The LCCA framework is provided in the accompanying Excel file.

References

Federal Aviation Administration (FAA). 2021. *Airport Pavement Design and Evaluation*. Advisory Circular 150/5320-6G. U.S. Department of Transportation, Federal Aviation Administration, Washington, DC.

Applied Pavement Technology, Inc. 2020. *2019-2020 Tennessee Statewide Airport Pavement Management Program Update*. Urbana, IL.

Applied Research Associates, Inc. 2011. *Life Cycle Cost Analysis for Airport Pavements*. Airfield Asphalt Pavement Technology Program (AAPTP) 06-06. Auburn, AL.

CHA Consulting, Inc. 2019. *Unit Cost Analysis*. Louisville, TN.