COLORADO
Department of Transportation

M-E Pavement Design Manual

2021 Addendum

SUMMARY OF MANUAL REVISIONS FROM 2021

SECTION	MAJOR REVISIONS
Introduction, Acronyms and Definitions	
Chapter 1	
Chapter 2	▪ Section 2.7 Recommended Initial IRI Values updated with 5-year running averages.
Chapter 3	
Chapter 4	
Chapter 5	
Chapter 6	▪ Section 6.4 Recommended Initial IRI Values updated with 5-year running averages.
Chapter 7	▪ Section 7.4 Recommended Initial IRI Values updated with 5-year running averages.
Chapter 8	
Chapter 9	
Chapter 10	
Chapter 11	
Chapter 12	
Chapter 13	▪ Section 13.2.3 Years to First Rehabilitation: Explanation and examples for both HMA and PCCP added. ▪ Section 13.4 Discount Rate: Updated to 1.12% with a standard deviation of 0.54%. ▪ Table 13.3 Present Worth Factors for Discount Rates updated. ▪ Section 13.5.2 AC Cost Adjustment update; includes process for calculating. ▪ Section 13.5.3 Maintenance Cost: data collection timeframe updated. ▪ Table 13.5 Annual Maintenance Costs: Thickness added and Average Annual Cost per Lane Mile values updated.
Chapter 14	
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Supplement	

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CHAPTER 2
PAVEMENT DESIGN INFORMATION

2.7 Design Performance Criteria and Reliability (Risk)

Performance verification is the basis of the acceptance or rejection of a trial design evaluated using the M-E Design software. A successful design is one where all selected performance threshold limits are satisfied at their chosen levels of reliability at the end of the design life.

M-E Design requires the designer to specify the critical levels or threshold values of pavement distresses and smoothness to judge the adequacy of a design. The type of distresses used in performance verification is specific to the pavement type (flexible or rigid) and design (rehabilitation or new design). Additionally, design reliability levels are required to account for the uncertainty and variability expected to exist in pavement design and construction and the application of traffic loads and climatic factors over the design life. The threshold and reliability levels for distresses and smoothness significantly impact construction costs and performance. The designer must set realistic numerical limits or threshold values for each performance criterion and reasonable reliability levels for a given design life.

Limits on the various performance criteria should be considered along with design reliability and design period. Both performance criteria and reliability factors are determined based on the roadway's functional classification and whether it is in an urban or a rural location. Once selected, the limits should be used consistently throughout the pavement type selection and design calculations. **Consultation of the mix design(s) with the RME shall occur**.

Recommended Range for Reliability

The reliability is a factor of safety to account for the inherent variations in construction, materials, traffic, climate, and other design inputs. **Table 2.3 Reliability (Risk)** provides the pavement structure's recommended values to survive the design period traffic. Reliability values recommended for use in previous editions of the AASHTO Design Guide should not be used with M-E Design. Reliability is not dependent on either type of pavement or type of project.

Table 2.1 Reliability (Risk)

Functional Classification	Value for Reliability
Interstate	80-95
Principal Arterials (freeways and expressways)	75-95
Principal Arterials (other)	75-95
Minor Arterial	70-95
Major Collectors	70-90
Minor Collectors	50-90
Local	50-80

Table 2.4 Recommended Threshold Values of Performance Criteria for New Construction or Reconstruction of Flexible Pavement Projects, Table 2.5 Recommended Threshold Values of Performance Criteria for New Construction or Reconstruction Projects of Rigid Pavement, Table 2.6 Recommended Threshold Values of Performance Criteria for Rehabilitation Projects of Flexible Pavements and **Table 2.7 Recommended Threshold Values of Performance Criteria for Rehabilitation Projects of Rigid Pavements** provide the threshold values recommended in M-E Design for pavements. M-E Design also requires the designer to enter the expected initial smoothness (IRI) at the time of construction. **It is recommended to use an initial IRI value of 60.1 inches/mile for all HMA projects and 72 inches/mile for all PCC projects** as they reflect targets that are documented using smoothness data from flexible and rigid pavements constructed between 2014 and 2020. **The same reliability value is recommended for all distresses; any changes should have Region Materials and Staff Materials approval.**

Figure 2.1 Performance Criteria and Reliability in the M-E Design Software for a Sample Flexible Pavement Design presents the M-E Design software screenshot showing performance criteria and the corresponding design reliability values selected for the design/analysis of a sample flexible pavement design.

Figure 2.2 Performance Criteria and Reliability in the M-E Design Software for a Sample JCPC Design presents the M-E Design software screenshot showing performance criteria and the corresponding design reliability values selected for the design/analysis of a sample rigid pavement design.

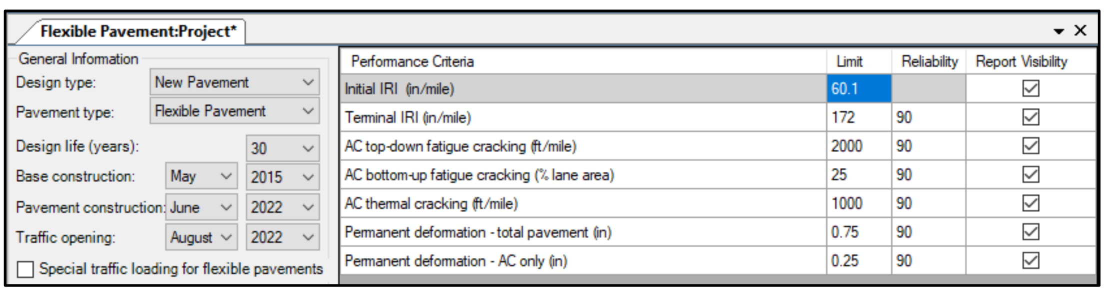

Figure 2.1 Performance Criteria and Reliability in the M-E Design Software for a Sample Flexible Pavement Design

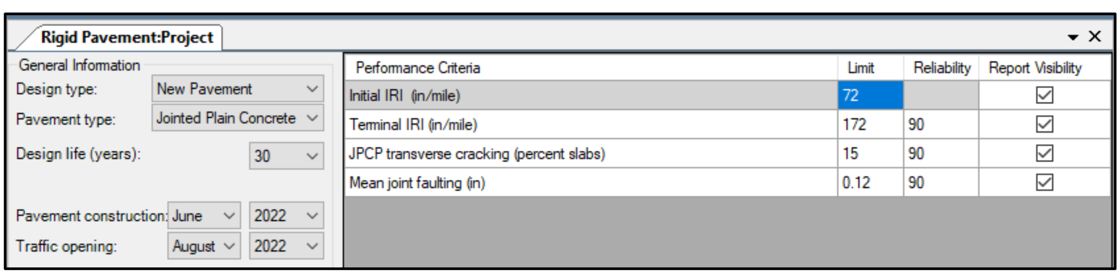

Figure 2.2 Performance Criteria and Reliability in the M-E Design Software for a Sample JPCP Design

Table 2.2 Recommended Threshold Values of Performance Criteria for New Construction of Flexible Pavement

Flexible Pavement		
Performance Criteria	**Maximum Value at End of the Design Life**	**Determines the Years to First Rehabilitation (Minimum Age Shall be 14 Years)**
Terminal IRI (inches per mile)		Interstate – 160 Principal Arterial – 200 Minor Arterial – 200 Major Collector – 200 Minor Collector – 200* Local Roadway – 200*
AC Top-Down Fatigue Cracking (feet per mile)		Interstate – 2,000 Principal Arterial – 2,500 Minor Arterial – 3,000 Major Collector – 3,000 Minor Collector – 3,000* Local Roadway – 3,000*
AC Bottom-Up Fatigue Cracking (percent lane area)	Interstate – 10 Principal Arterial – 25 Minor Arterial – 25 Major Collector – 25 Minor Collector – 25* Local Roadway – 25*	
AC Thermal Cracking (feet per mile)	Interstate – 1,500 Principal Arterial – 1,500 Minor Arterial – 1,500 Major Collector – 1,500 Minor Collector – 1,500* Local Roadway – 1,500*	
Permanent Deformation (total inches)		Interstate – 0.55 Principal Arterial – 0.65 Minor Arterial – 0.80 Major Collector – 0.80 Minor Collector – 0.80* Local Roadway – 080*
Permanent Deformation AC Only (inches)		Interstate – 0.40 Principal Arterial – 0.50 Minor Arterial – 0.65 Major Collector – 0.65 Minor Collector – 0.65* Local Roadway – 0.65*
Additional Thresholds for Chemically Stabilized Layer		
Fatigue Fracture (percent lane area) (For semi-rigid base layer)		Interstate – 10 Principal Arterial – 25 Minor Arterial – 25 Major Collector – 25 Minor Collector – 25* Local Roadway – 25*
AC Total Fatigue Cracking Bottom Up + Reflective (percent lane area) (For semi-rigid base layer)		Interstate – 10 Principal Arterial – 25 Minor Arterial – 25 Major Collector – 25 Minor Collector – 25* Local Roadway – 25*
AC Total Transverse Cracking Thermal + Reflective (feet per mile) (For semi-rigid base layer)		Interstate – 1,500 Principal Arterial – 1,500 Minor Arterial – 1,500 Major Collector – 1,500 Minor Collector –1,500* Local Roadway – 1,500*
Note: * M-E Design has not been calibrated for minor collectors or local roadways. Exceptions to the threshold values may be approved by the RME.		

Table 2.3 Recommended Threshold Values of Performance Criteria for Rehabilitation of Flexible Pavement Projects

<table>
<tr><th colspan="3">Flexible Pavement</th></tr>
<tr><th>Performance Criteria</th><th colspan="2">Maximum Value at End of the Design Life
(Minimum Age Shall Be 10 Years)</th></tr>
<tr><td>Terminal IRI
(inches per mile)</td><td colspan="2">Interstate – 160
Principal Arterial – 200
Minor Arterial – 200
Major Collector – 200
Minor Collector – 200*
Local Roadway – 200*</td></tr>
<tr><td>AC Top-Down
Fatigue Cracking
(feet per mile)</td><td colspan="2">Interstate – 2,000
Principal Arterial – 2,500
Minor Arterial – 3,000
Major Collector – 3,000
Minor Collector – 3,000*
Local Roadway – 3,000*</td></tr>
<tr><td>AC Bottom-Up
Fatigue Cracking
(percent lane area)</td><td colspan="2">Interstate – 10
Principal Arterial – 25
Minor Arterial – 25
Major Collector – 25
Minor Collector – 25*
Local Roadway – 25*</td></tr>
<tr><td>AC Thermal Cracking
(feet per mile)</td><td colspan="2">Interstate – 1,500
Principal Arterial – 1,500
Minor Arterial – 1,500
Major Collector – 1,500
Minor Collector – 1,500*
Local Roadway – 1,500*</td></tr>
<tr><td>Permanent Deformation
(total inches)</td><td colspan="2">Interstate – 0.55
Principal Arterial – 0.65
Minor Arterial – 0.80
Major Collector – 0.80
Minor Collector – 0.80*
Local Roadway – 0.80*</td></tr>
<tr><td>Permanent Deformation
AC Only
(inches)</td><td colspan="2">Interstate – 0.40
Principal Arterial – 0.50
Minor Arterial – 0.65
Major Collector – 0.65
Minor Collector – 0.65*
Local Roadway – 0.65*</td></tr>
<tr><td>AC Total Fatigue Cracking
Bottom-Up + Reflective
(percent lane area)</td><td>Interstate – 20
Principal Arterial – 35
Minor Arterial – 35
Major Collector – 35
Minor Collector – 35*
Local Roadway – 35*</td><td>Use 50% Reliability</td></tr>
<tr><td>AC Total Transverse Cracking
Thermal + Reflective
(feet per mile)</td><td colspan="2">Interstate – 2,500
Principal Arterial – 2,500
Minor Arterial – 2,500
Major Collector – 2,500
Minor Collector – 2,500*
Local Roadway – 2,500*</td></tr>
<tr><th colspan="3">Additional Thresholds for Chemically Stabilized Layer</th></tr>
<tr><td>Fatigue Fracture
(percent lane area)

(For semi-rigid base layer)</td><td colspan="2">Interstate – 20
Principal Arterial – 35
Minor Arterial – 35
Major Collector – 35
Minor Collector – 35*
Local Roadway – 35*</td></tr>
<tr><td colspan="3">Note: * M-E Design has not been calibrated for minor collectors or local roadways. Exceptions to the threshold values may be approved by the RME.</td></tr>
</table>

Table 2.4 Recommended Threshold Values of Performance Criteria for New Construction of Rigid Pavement

Rigid Pavement (JPCP)		
Performance Criteria	**Maximum Value at End of the Design Life**	**Determines the Year to First Rehabilitation (Minimum Age Shall Be 27 Years)**
Terminal IRI (inches per mile)		Interstate – 160 Principal Arterial – 200 Minor Arterial – 200 Major Collector – 200 Minor Collector – 200* Local Roadway – 200*
Transverse Slab Cracking (percent)		Interstate – 7.0 Principal Arterial – 7.0 Minor Arterial – 7.0 Major Collector – 7.0 Minor Collector – 7.0* Local Roadway – 7.0*
Mean Joint Faulting (inches)	Interstate – 0.12 Principal Arterial – 0.14 Minor Arterial – 0.20 Major Collector – 0.20 Minor Collector – 0.20* Local Roadway – 0.20*	
Note: * M-E Design has not been calibrated for minor collectors or local roadways. Exceptions to the threshold values may be approved by the RME.		

Table 2.5 Recommended Threshold Values of Performance Criteria for Rehabilitation of Rigid Pavement Projects

Rigid Pavement (JPCP)	
Performance Criteria	**Maximum Value at End of the Design Life (Minimum Age Shall Be 20 Years)**
Terminal IRI (inches per mile)	Interstate – 160 Principal Arterial – 200 Minor Arterial – 200 Major Collector – 200 Minor Collector – 200* Local Roadway – 200*
Transverse Slab Cracking (percent)	Interstate – 7.0 Principal Arterial – 7.0 Minor Arterial – 7.0 Major Collector – 7.0 Minor Collector – 7.0* Local Roadway – 7.0*
Mean Joint Faulting (inches)	Interstate – 0.12 Principal Arterial – 0.14 Minor Arterial – 0.20 Major Collector – 0.20 Minor Collector – 0.20* Local Roadway – 0.20*
Note: * M-E Design has not been calibrated for minor collectors or local roadways. Exceptions to the threshold values may be approved by the RME.	

CHAPTER 6
PRINCIPLES OF DESIGN FOR FLEXIBLE PAVEMENT

6.4 Select the Appropriate Performance Indicator Criteria for the Project

Table 2.4 Recommended Threshold Values of Performance Criteria for New Construction or Reconstruction Projects presents recommended performance criteria for flexible pavement design. The designer should enter the appropriate performance criteria based on functional class. An appropriate initial smoothness (IRI) is also required. **For new flexible pavements, the recommended initial IRI is 60.1 inches/mile**.

CHAPTER 7
PRINCIPLES OF DESIGN FOR RIGID PAVEMENT

7.4 Select the Appropriate Performance Indicator Criteria for the Project

Table 2.4 Recommended Threshold Values of Performance Criteria for New Construction or Reconstruction Projects presents recommended performance criteria for rigid pavement design. The designer should enter the appropriate performance criteria based on functional class. An appropriate initial smoothness (IRI) is also required. **For new rigid pavements, the recommended initial IRI is 72 inches/mile**. This recommendation is for regular paving projects and projects with incentive-based smoothness acceptance; the designer may modify this value as needed.

CHAPTER 13
PAVEMENT TYPE SELECTION AND LIFE CYCLE COST ANALYSIS

13.2 Implementation of an LCCA

13.2.3 Years to First Rehabilitation

The M-E Design program is designed for a variety of uses, one of which is determining the projected life of a pavement structure which may be used to determine when the pavement will be rehabilitated. The following order of precedence is recommended for selecting the first year to rehabilitation to be used in the LCCA

The designer should use the life of the pavement determined by M-E Design in accordance to the terminal threshold requirements (refer to **Section 2.7 Design Performance Criteria and Reliability (Risk)**). In order to get a triangular distribution one should re-run the design using ±3% of the designed reliability to determine the pavement life. No other variables or input values shall be changed. **Pavement management data may be included in the Years to First Rehabilitation analysis.**

> **Example:** An interstate project has a 20-year design with various terminal thresholds reaching either 14 or 20 years per requirements in this manual. The design was originally run with a reliability of 95 percent, results indicate the triggering distress is AC Bottom-Up Cracking as shown in **Figure 13.2 AC Bottom-Up Cracking at 95 Percent** Reliability. The design is re-run at a reliability of 92 percent; no other variables or input values are changed. The resulting graph is shown in **Figure 13.3 AC Bottom-Up Cracking at 92 Percent Reliability**; the line crosses the terminal threshold of 10 at year 22. The design is re-run a second time, this time at a reliability of 98 percent; as before no other variables or input values are changed. The resulting graph is shown in **Figure 13.4 AC Bottom-Up Cracking at 98 Percent Reliability**; the line crosses the terminal threshold of 10 at year 13. Therefore, the minimum value is 13 years and the maximum value is 22 years.

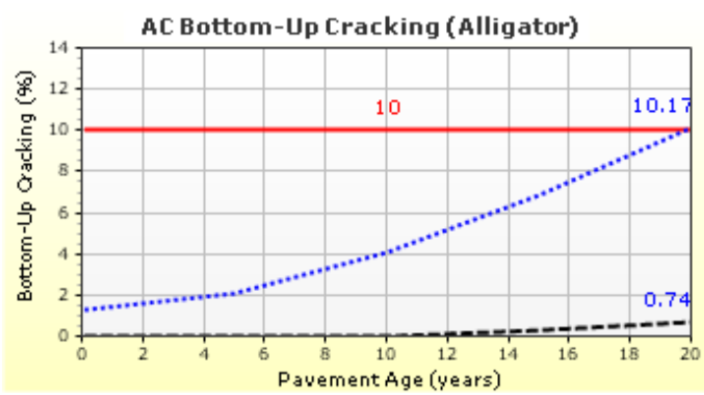

Figure 13.1 AC Bottom-Up Cracking at 95 Percent Reliability

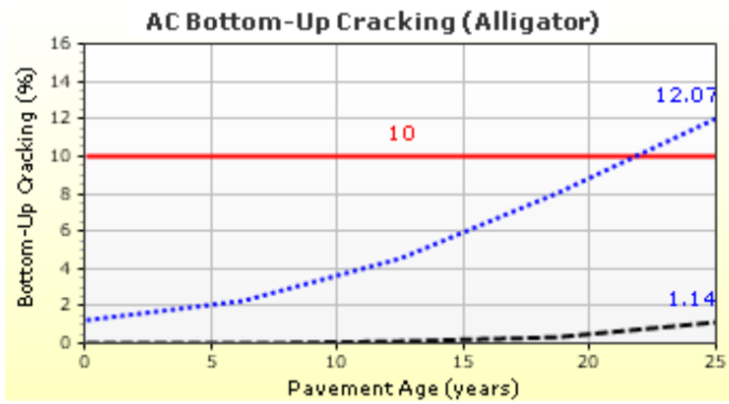

Figure 13.2 AC Bottom-Up Cracking at 92 Percent Reliability

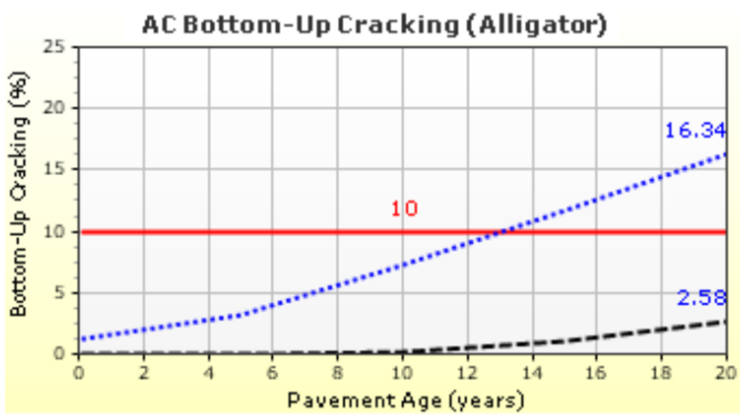

Figure 13.3 AC Bottom-Up Cracking at 98 Percent Reliability

The engineer will likely encounter situations where the minimum thickness passing design surpasses the required terminal thresholds. For example, a PCCP design at 9.5 inches is projected to last 26 years, one year short of the required 27 years. Increasing the design to 10 inches results in a projected life of 31 years. The +3% reliability used for the triangular distribution would result in 28, 31, 34 years as the minimum, most likely, and maximum respectfully.

The engineer has the option to create a design that exceeds the terminal threshold values shown on Figures 2.4 through 2.7. An extra thickness may be used to move one or more rehabilitations further out on the timeline. For example a HMA design is required to have a minimum 20 year life which will result in two 10 year rehabilitation cycles, however if one increases the thickness by 1.5 inches it may push the first year to rehabilitation to year 30 at which time only one 10 year rehabilitation cycle is required. The engineer needs to do a separate analysis using the original design versus the enhanced thickness design to verify the increased cost associated with the initial construction of the thicker design offsets the extra rehabilitation cycle(s) in the original design.

When performing the LCCA analysis, all subsequent rehabilitations start at year zero. The following examples show how to calculate when the rehabilitation cycles occur.

Example 1: An HMA design meets the 14 and 29 year terminal threshold criteria (see Figures 2.4 and 2.5) with a successful design passing at year 16. Each rehabilitation is designed to last 10 years. A 40 year LCCA would result in a rehabilitation at year 16, 26, and 36.

16 (initial) + 10 (rehab) + 10 (rehab) + 10 (rehab) = 46 years

Example 2: An PCCP design meets the 27 and 30 year terminal threshold criteria (see Figures 2.6 and 2.7) with a successful design passing at year 28. Each rehabilitation is designed to last 20 years. A 40 year LCCA would result in a rehabilitation at year 28.

28 (initial) + 20 (rehab) = 48 years

13.4 Discount Rate

All future costs are adjusted according to a discount rate prorated to a present worth. Costs incurred at any time into the future can be combined with initial construction costs to give a total cost over the life cycle. See **Table 13.3 Present Worth Factors for Discount Rates** for a uniform series of deposits, S_n. **The current discount rate is 1.12 percent with a standard deviation 0.54 percent** (6).

The discount rate and standard deviation will be calculated annually. If the new 10-year average discount rate varies by more than two standard deviations from the original discount rate used at the time of the design, in this case 1.09 percent resulting in a discount rate range of 0.03 to 2.21 percent, a new LCCA should be performed. Thus, all projects that have been shelved prior to 2017 and/or not been awarded should rerun the analysis with the new discount rate. The designer is responsible for checking previous pavement designs to ensure an appropriate discount rate was used and the pavement choice is still valid.

The discounting factors are listed in **Table 13.4 Discount Factors for Discrete Compounding** in symbolic and formula form and a brief interpretation of the notation. Normally, it will not be necessary to calculate factors from these formulas. For intermediate values, computing the factors from the formulas may be necessary, or linear interpolation can be used as an approximation.

The single payment present worth P = F(P/F, i $_{\%}$, *n*) notation is interpreted as, “Find P, given F, using an interest rate of i $_{\%}$ over n years”. Thus, an annuity is a series of equal payments, A, made over a period of time. In the case of an annuity that starts at the end of the first year and continues for *n* years, the purchase price, P, would be P = A × (P/A, i $_{\%}$, *n*). See **Table 13.3 Present Worth Factors for Discount Rates.**

Table 13.1 Present Worth Factors for Discount Rates

n (years)	Discount Rate	
	1.38%	
	PWF_n	S_n
5	0.9458	4.8363
6	0.9354	5.7717
7	0.9250	6.6966
8	0.9148	7.6114
9	0.9046	8.5160
10	0.8946	9.4106
11	0.8847	10.2953
12	0.8749	11.1702
13	0.8652	12.0354
14	0.8556	12.8910
15	0.8461	13.7372
16	0.8368	14.5739
17	0.8275	15.4015
18	0.8183	16.2198
19	0.093	17.0291
20	0.8003	17.8294
21	0.7914	18.6208
22	0.7827	19.4035
23	0.7740	20.1775
24	0.7654	20.9430
25	0.7570	21.6999
30	0.7160	25.3608
35	0.6772	28.8234
40	0.6405	32.0984

Note: PWF_n = present worth factor
S_n = uniform series of deposits

Table 13.2 Discount Factors for Discrete Compounding

Factor Name	Converts	Symbol	Formula	Interpretation of Notation
Single Payment Present Worth	F to P (future single payment to present worth)	(P/F, i%, *n*)	$(1+i)^{-n}$	Find P, given F, using an interest rate of i% over *n* years
Uniform Series Present Worth	A to P (annual payment to present worth)	(P/A, i%, *n*)	$\frac{(1+i)^n-1}{i(1+i)^n}$	Find P, given A, using an interest rate of i% over *n* years
Note: P = the single payment present worth; F = future single payment; i % = the interest rate percent, and *n* = number of years.				

13.5 Life Cycle Cost Factors

13.5.2 Asphalt Cement Adjustment

Included in the unit cost of HMA should be an adjustment for the Force Account Item. This item revises the Contactor's bid price of HMA found in the Cost Data book based on the price of crude oil at the time of construction. The data varies from year to year, Region to Region, and by the various binders used by CDOT. In 2020 a new specification concerning the asphalt cement adjustment was implemented. The result of this new specification is an adjustment of $0. Since this is the first year of implementation a triangular distribution cannot be calculated. Subsequent years will result in a triangular distribution using a 10 year weighted average.

The processes used to calculate the asphalt cement adjustment consists of collecting yearly unit cost modification data for each year starting January 1 and ending December 31. The data is sorted and vetted by removing any emergency repair work and anomalous data. Anomalous data consists of an invoice which is missing either tonnage or cost modification (force account) information. Once the data is vetted the total cost modification of projects accepting the new specification is divided by the total tonnage resulting in the average price per ton cost modification paid out for that year. The minimum value will be selected from the year which had the least amount of unit cost modification. Similarly, the maximum value is selected from the year which had the most amount of unit cost modification. The most likely value is the 10 year weighted average in which the total unit cost modification is divided by the total tons.

13.5.3 Maintenance Cost

The designer should exercise good judgment in the application of maintenance costs. Inappropriate selection can adversely influence the selection of alternatives to be constructed. Maintenance costs should be based on the best available information. The CDOT Maintenance Management System compiled data on state highway maintenance costs. The annual maintenance cost per lane mile is shown in **Table 13.5 Annual Maintenance Costs**. The HMA data was collected from January 1, 2000 to December 31, 2014 and normalized to 2021 dollars. The PCCP data was collected from, January 1 to December 31, 2020 and normalized to 2021 dollars. If actual cost cannot be provided, use the following default values:

Table 13.3 Annual Maintenance Costs

Type of Pavement	Thickness	Average Annual Cost per Lane Mile
HMA	All	$1,123
PCCP	≤ 7 inches	$843
	> 7 inches	$629