Life Cycle Cost Analysis of Engineered Pavements

Understanding The True Costs And Savings With Modified Binders

AMAP Annual Meeting, Feb 2, 2005

Mark Buncher, Ph.D., P.E.

Director of Field Engineering, Asphalt Institute

E-Motion -- August 12, 2004 - Message (HTML)

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From: E-motion [e-motion@triad-inc.com]
Sent: Thu 8/12/2004 10:41 AM
To: e-motion@triad-inc.com
Cc:
Subject: E-Motion -- August 12, 2004

E-motion

Addressing Pennsylvania's Mobility Needs

phia
PENNSYLVANIA HIGHWAY INFORMATION ASSOCIATION

August 12, 2004 Volume , Issue 52

Transportation Needs Exceed Revenue

Pennsylvania's current spending on transportation infrastructure is not sufficient, and the funding gap is so wide that the Commonwealth is already billions behind in preserving and expanding the state's highways and bridges. These new findings have come out in a report released by the Keystone State Transportation Funding Coalition, a broad-based group made up of leaders from several industries.

The 2004 "Pennsylvania's Transportation Infrastructure Funding Needs" study found that the state is currently spending $5.2 billion each year on its transportation infrastructure. However, an *additional $1.6 billion* more is needed to adequately preserve current infrastructure and *another $4.7 billion* is required annually to expand the system.

In total, the state has $17.5 billion in unfunded transportation needs. Yet, PENNDOT announced in March that it is trimming billions from the 12-Year Transportation Program.

"The lack of adequate investment in our transportation

The use of Polymer Modified Asphalt (PMA) to lower overall pavement cost is best illustrated using life cycle cost.

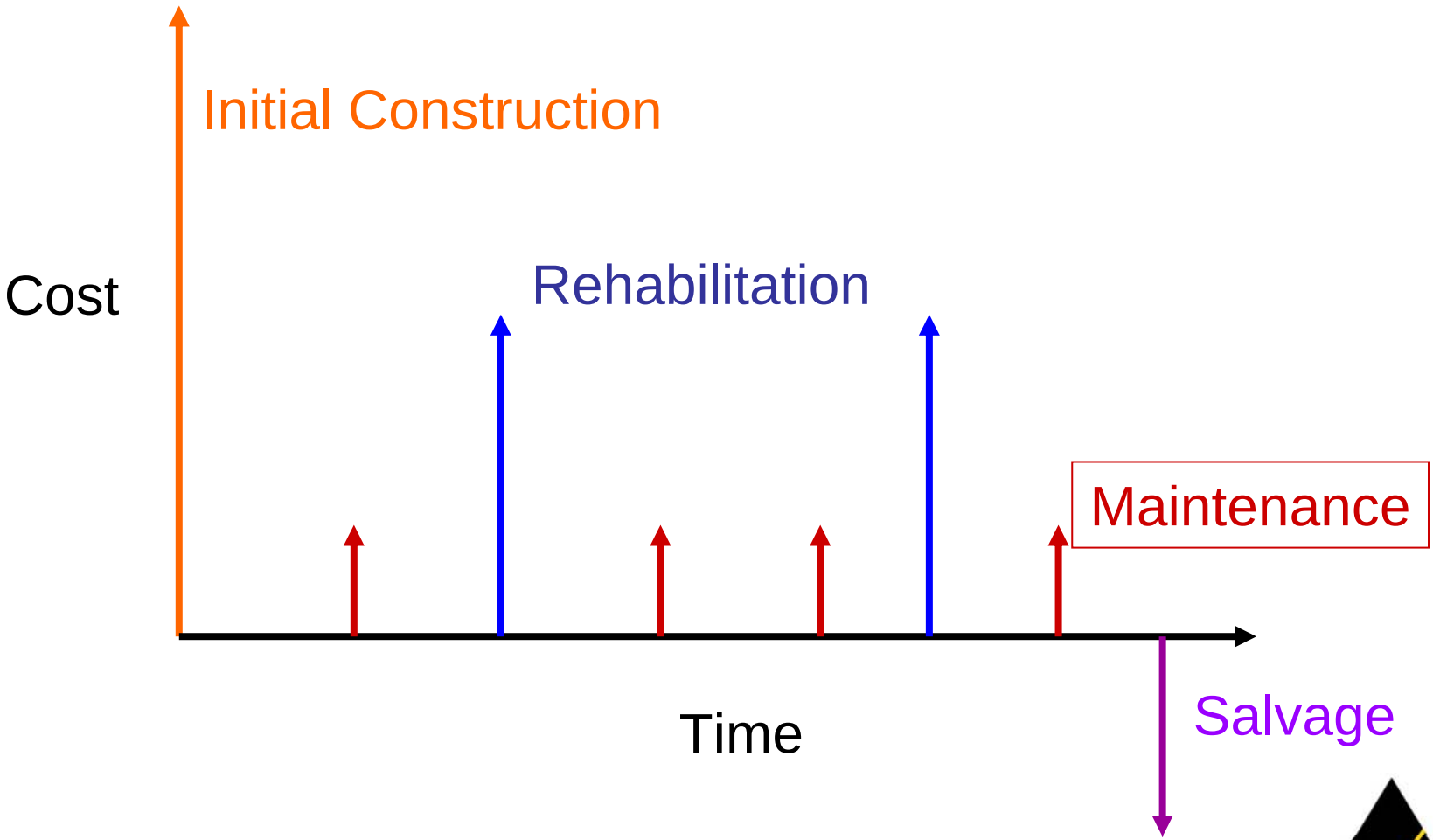
Today's Overview

- **LCCA**
  - **101 - Basic Concepts**
  - **401 - Advanced Concepts**
    - Per FHWA Guidance
- **Performance Study of PMA**
  - ***Quantifying the Effects of PMA for Reducing Pavement Distress***
    - Harold L. Von Quintus, P.E.
    - AI's ER 215 and IS 215
- **PMA Impact to LCC**
  - **Example Scenarios Illustrating Concepts**

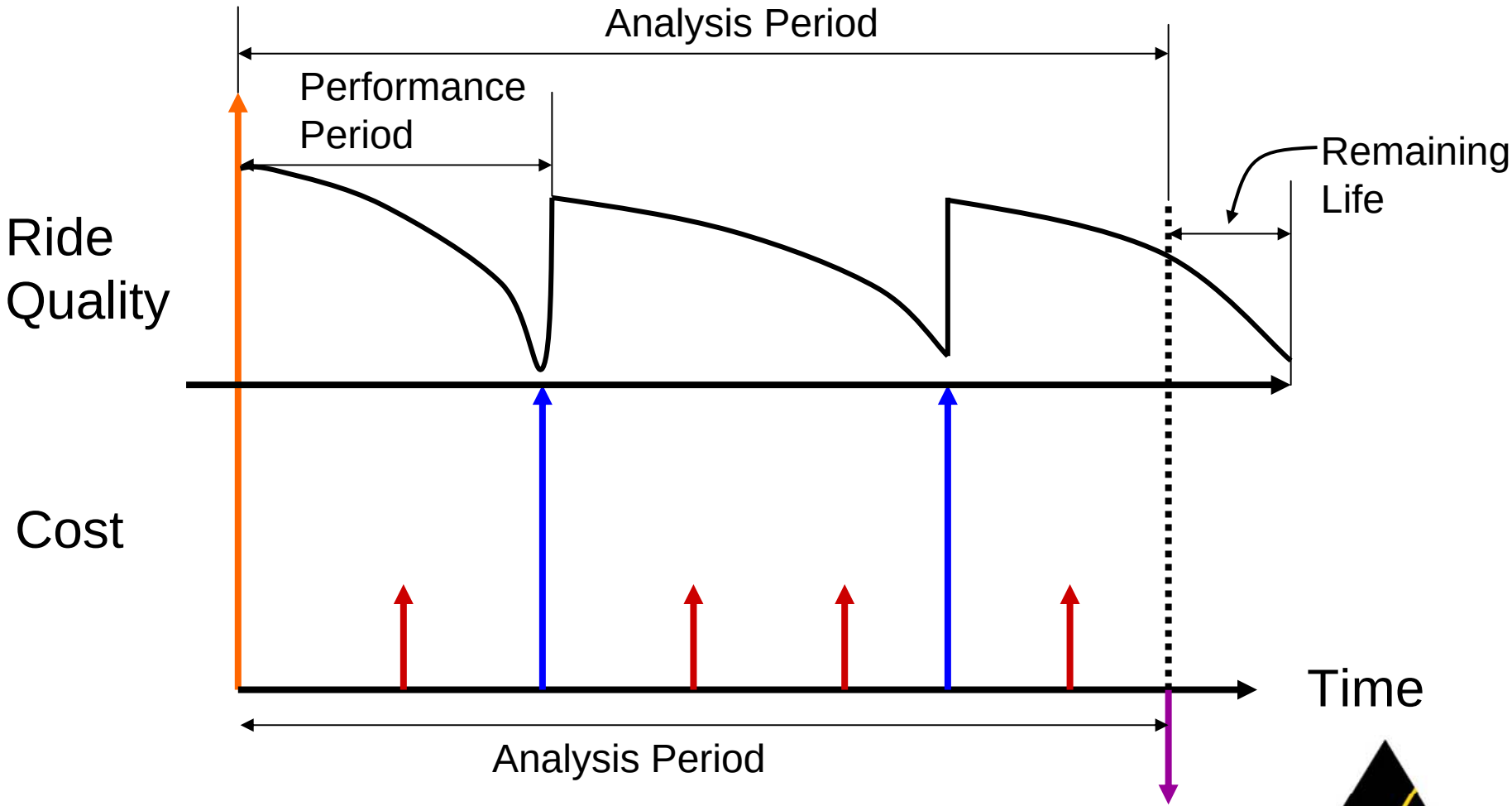
LCCA Objective

- **Evaluate the overall long-term economic efficiency between competing alternative investment options.**

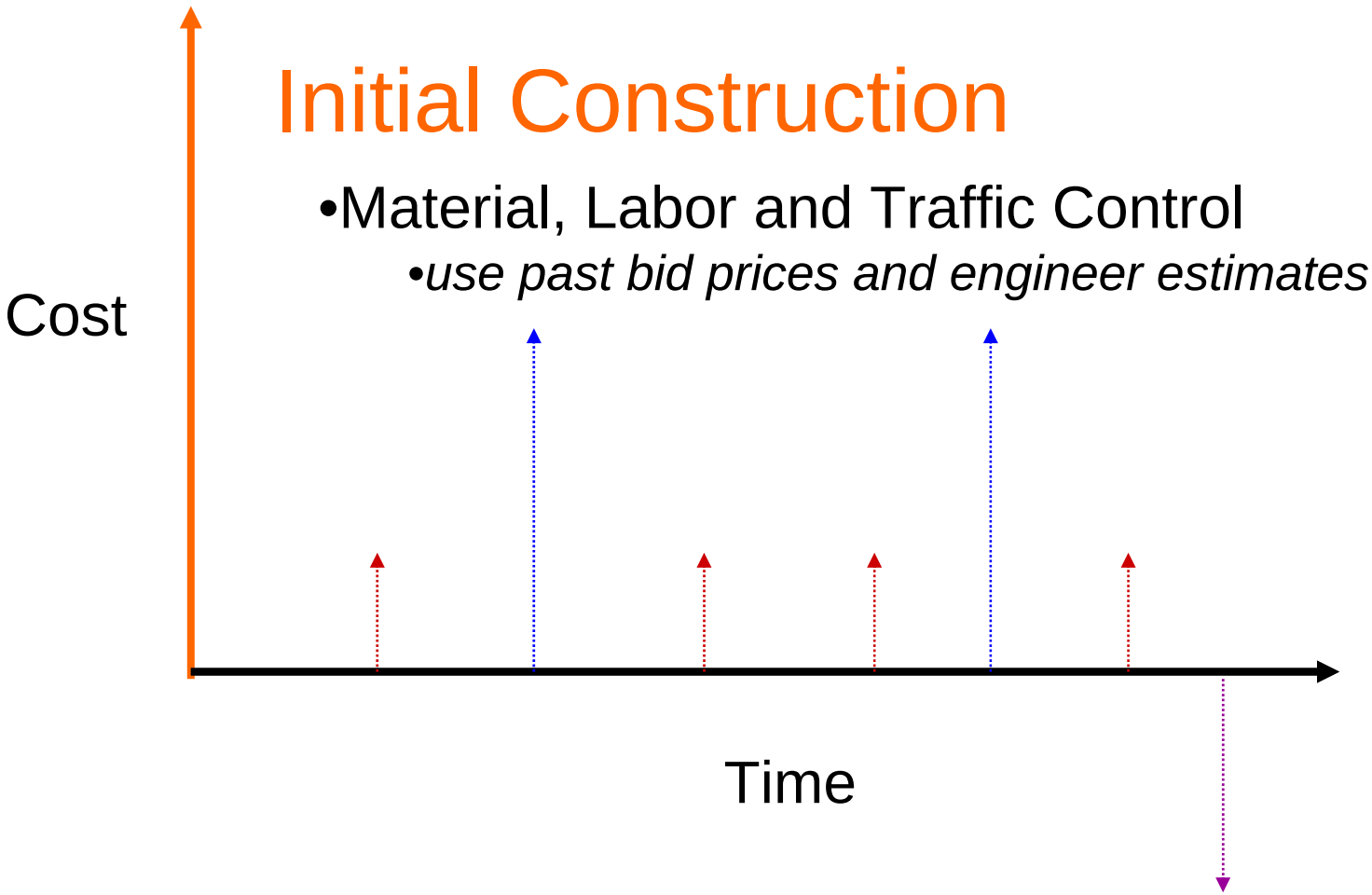
The Life Cycle



Performance



Agency Costs



Agency Costs

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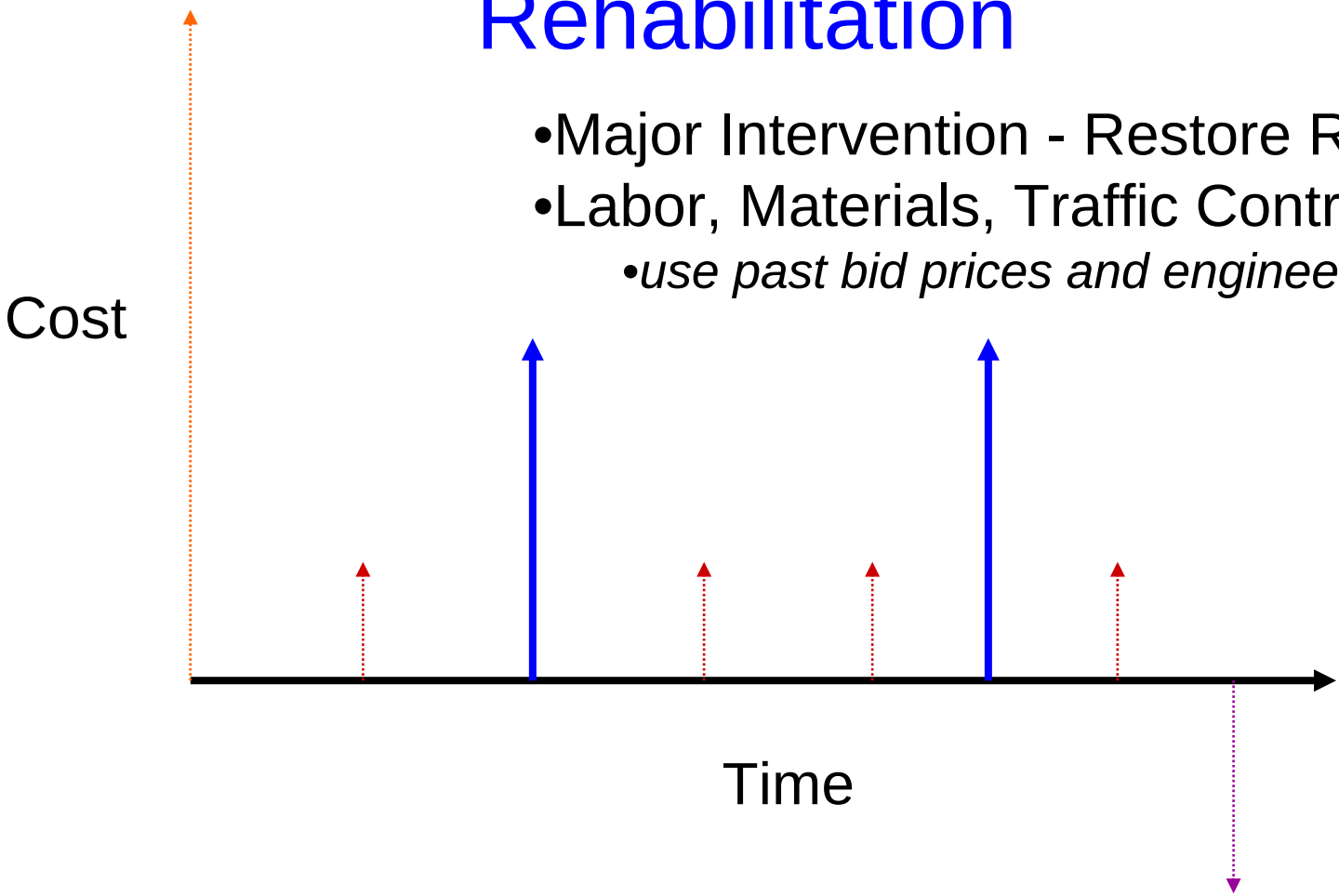
Rehabilitation

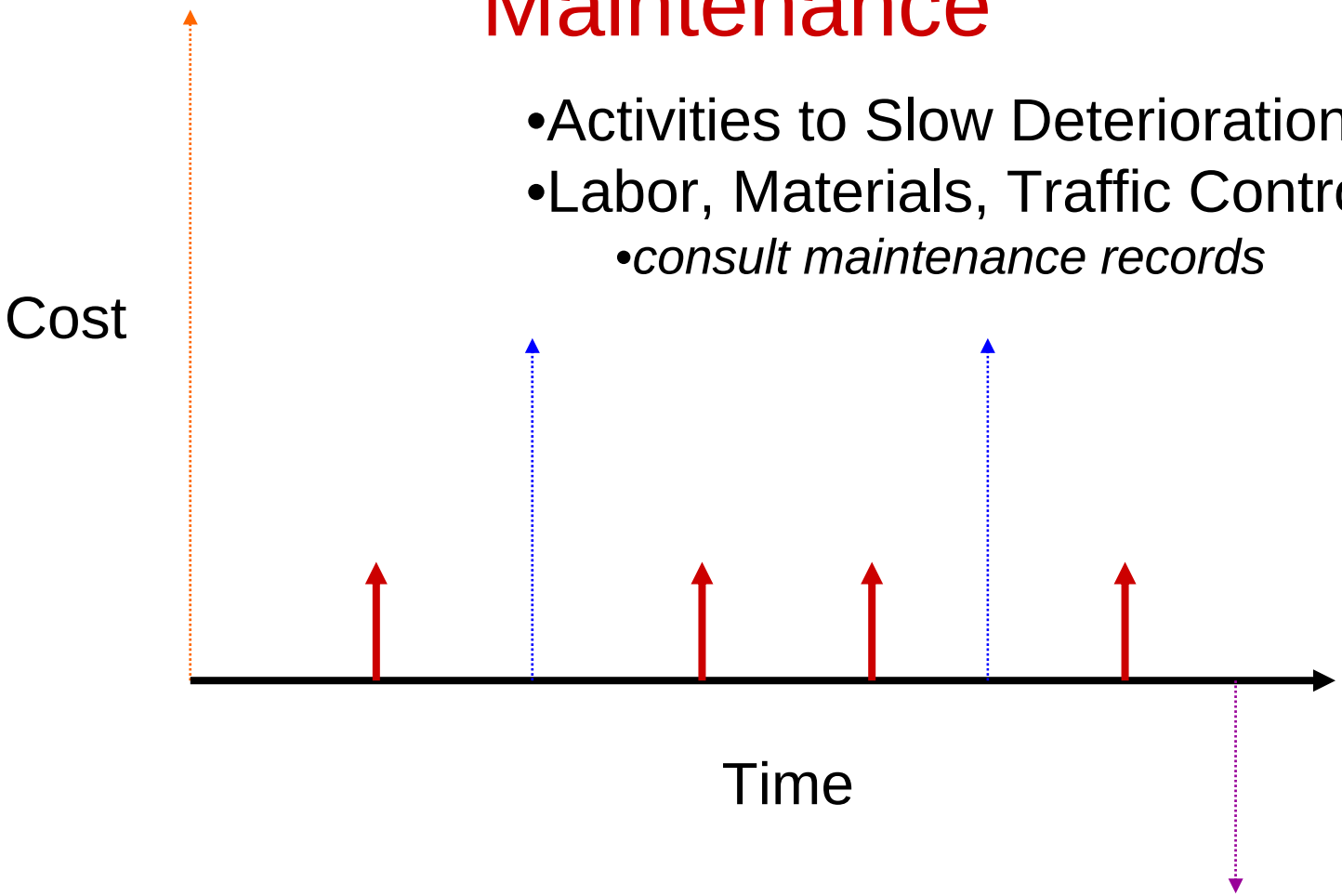
- Major Intervention - Restore Ride
- Labor, Materials, Traffic Control
  - *use past bid prices and engineer estimates*



Agency Costs

Maintenance

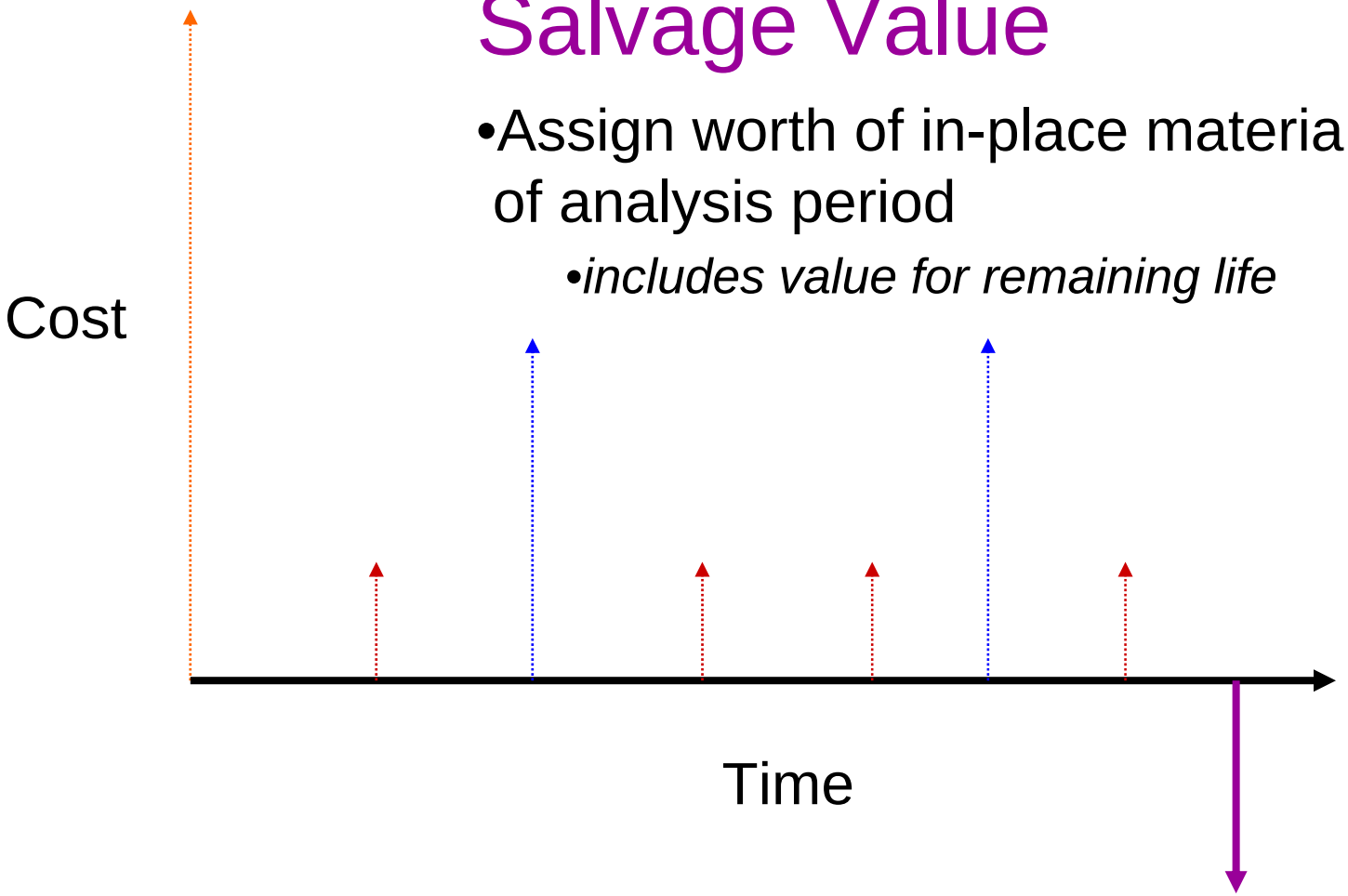
- Activities to Slow Deterioration
- Labor, Materials, Traffic Control
  - *consult maintenance records*



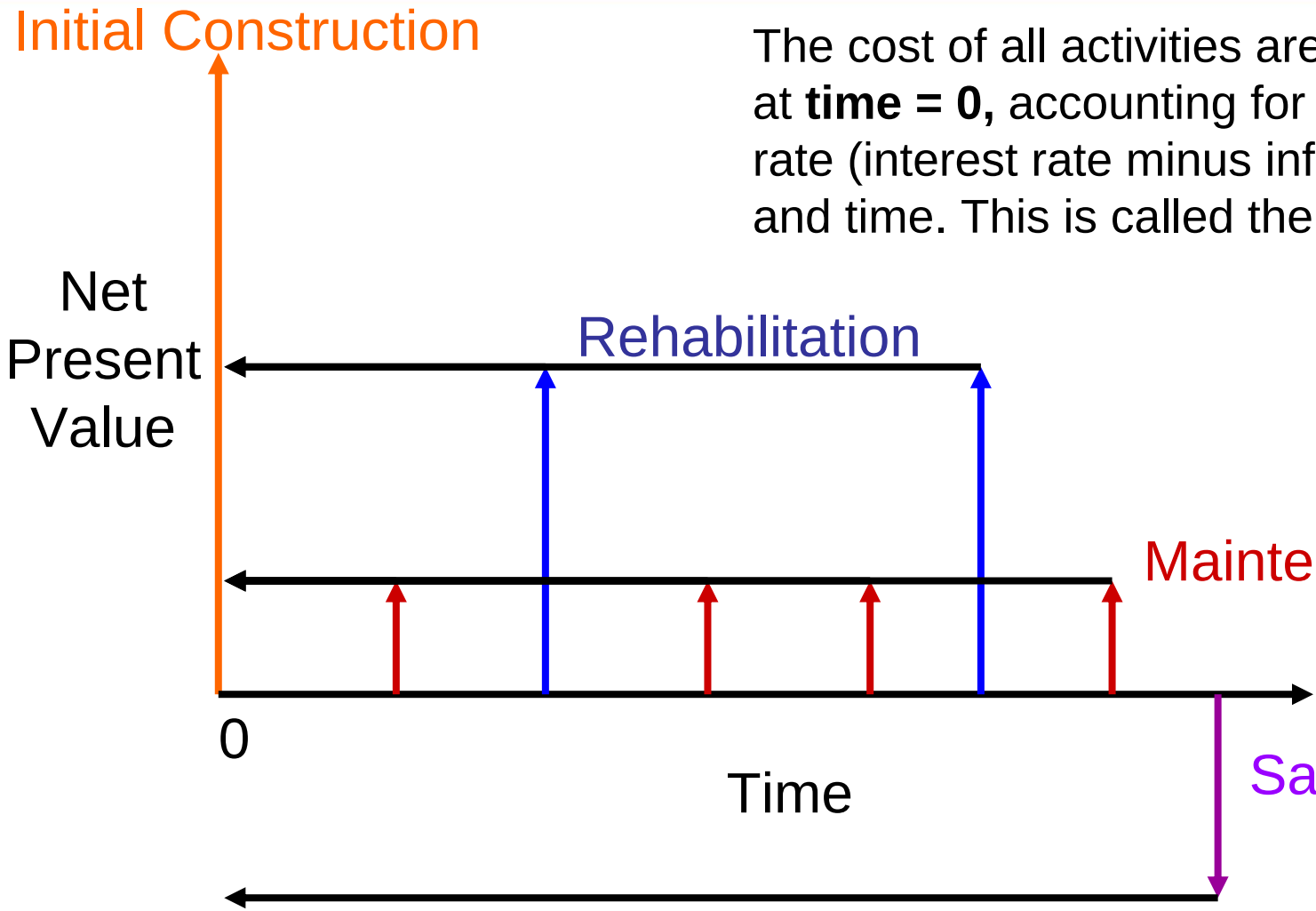
Agency Costs

Salvage Value

- Assign worth of in-place materials at end of analysis period
  - *includes value for remaining life*

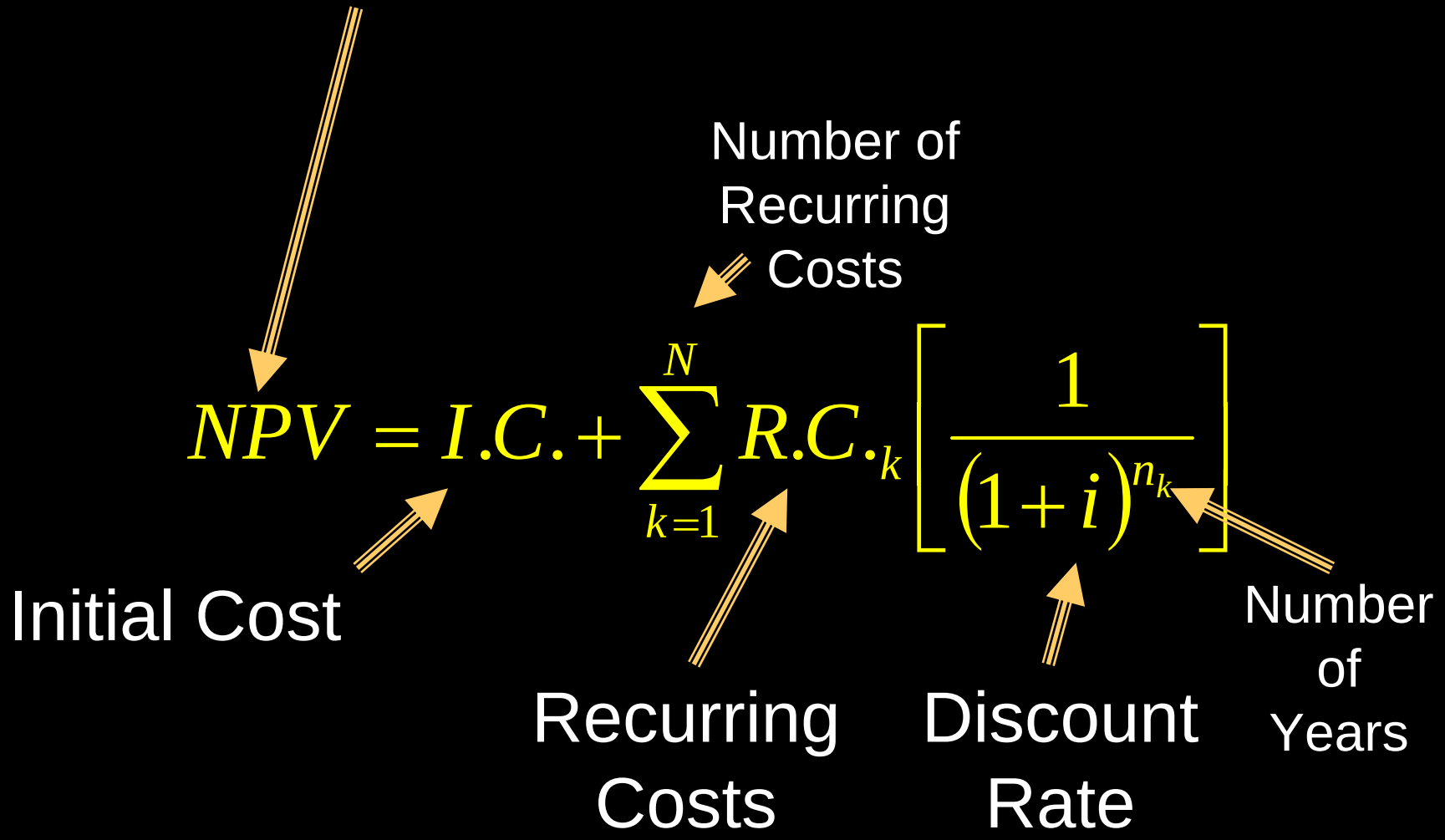


Net Present Value

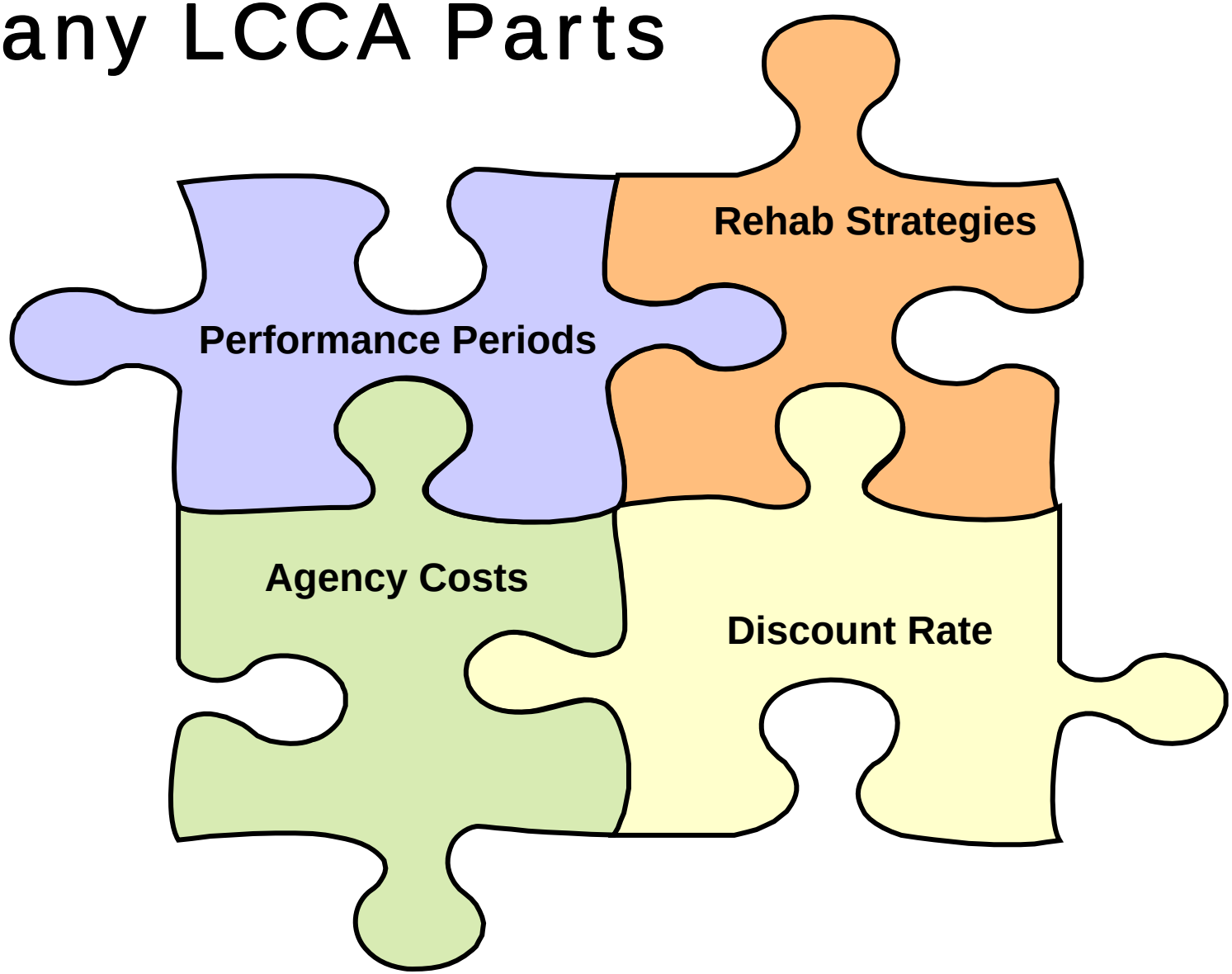


The cost of all activities are computed at **time = 0,** accounting for discount rate (interest rate minus inflation rate) and time. This is called the **NPV.**

Net Present Value



Many LCCA Parts



Most Critical: initial cost and initial performance period

Typical Breakdown of NPV

40 yr. economic analysis, HMA Pavement

- **Initial Construction**
  - **65 to 85%**
- **Rehabilitations**
  - **10 to 30%**
- **Maintenance**
  - **3 to 5%**
- **Salvage Value**
  - **1 to 2%**

Typical Pa DOT LCCA for Hwy.

Present Worth Analysis (ln/mi) for - LCCPub408yr10/10.xls
14.5-inch section

Interest
6

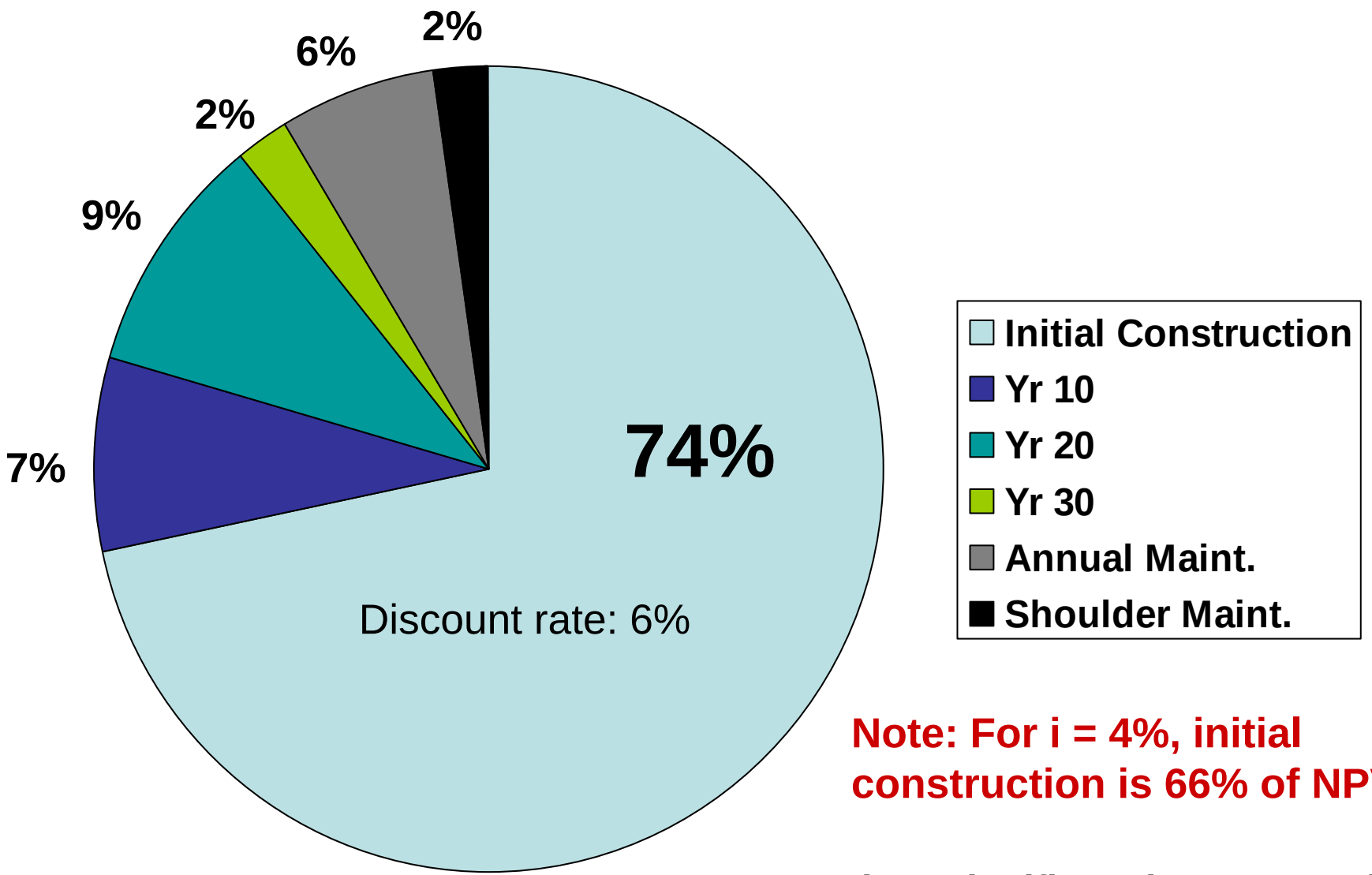
Year	Construction Item and/or Material	Quantit	Unit	Cost/Unit	Current Price	PW
0	10" HMA Base (3 - 10 EAL)	7040	sy	$ 15.95	$112,288	$112,288
0	2.5" HMA Binder (3 - 10 EAL)	7040	sy	$ 5.00	$35,200	$35,200
0	2" HMA Wearing (3 - 10 EAL)	7040	sy	$ 4.00	$28,160	$28,160
0	10" HMA Base (0.3 - 3 EAL)	4106	sy	$ 15.95	$65,491	$65,491
0	2.5" HMA Binder (0.3 - 3 EAL)	4106	sy	$ 5.00	$20,530	$20,530
0	2" HMA Wearing (0.3 - 3 EAL)	4106	sy	$ 4.00	$16,424	$16,424
0	Maint. & Protection of Traffic @2.3%	1	ls	$6,396	$6,396	$6,396
0	Mobilization @5.5%	1	ls	$15,295	$15,295	$15,295
5	Seal Coat Shoulders	4106	sy	$ 0.85	$3,490	$2,608
10	Deep Patch 2% (mainline)	141	sy	$ 81.00	$11,421	$6,377
10	Mill 2" (mainline)	7040	sy	$ 0.80	$5,632	$3,145
10	2" hma overlay (mainline)	7040	sy	$ 4.00	$28,160	$15,724
10	Seal Coat Shoulders	4106	sy	$ 0.85	$3,490	$1,949
10	Maint. & Protection of Traffic @2.3%	1	ls	$ 1,120.17	$1,120	$625
10	Mobilization @5.5%	1	ls	$ 2,678.67	$2,679	$1,496
15	Seal Coat Shoulders	4106	sy	$ 0.85	$3,490	$1,456
20	Deep Patch 2% (mainline)	141	sy	$ 81.00	$11,421	$3,561
20	#60 scratch course	211	ton	$ 34.00	$7,174	$2,237
20	2.5" hma overlay (binder)	7040	sy	$ 5.00	$35,200	$10,976
20	1.5" hma overlay (wearing)	7040	sy	$ 3.00	$21,120	$6,585
20	#60 scratch course	125	ton	$ 34.00	$4,250	$1,325
20	2.5" hma overlay (binder)	4106	sy	$ 5.00	$20,530	$6,401
20	1.5" hma overlay (wearing)	4106	sy	$ 3.00	$12,318	$3,841
20	Maint. & Protection of Traffic @2.3%	1	ls	$2,576	$2,576	$803
20	Mobilization @5.5%	1	ls	$6,161	$6,161	$1,921
					$0	$0
25	Seal Coat Shoulders	4106	sy	$1	$3,490	$813
					$0	$0
30	Same Scenario as Year 10	1	ls	$52,502	$52,502	$9,141
					$0	$0
35	Seal Coat Shoulders	4106	sy	$ 0.85	$3,490	$454
					$0	$0
20	Total Annual Maintenance ($1825/yr)	40	yr	$ 1,825.00	$73,000	$22,762
					$0	$0
					$0	$0
					$0	$0
					$0	$0
				Total	Present Worth	$403,986

Yr.	Activity
0	14.5” HMA
10	2” mill and fill 2% patching
20	4” struct. overlay 2% patching
30	Same as yr.10
Every 5th	seal shoulders
Annual	maintenance

Analysis Period = 40 yrs.

What's Significant

Typical Pa DOT LCCA for Hwy.



Note: For i = 4%, initial construction is 66% of NPV

To make a significant impact, need to extend the initial performance period.

Advanced LCCA Concepts

User Delay Costs

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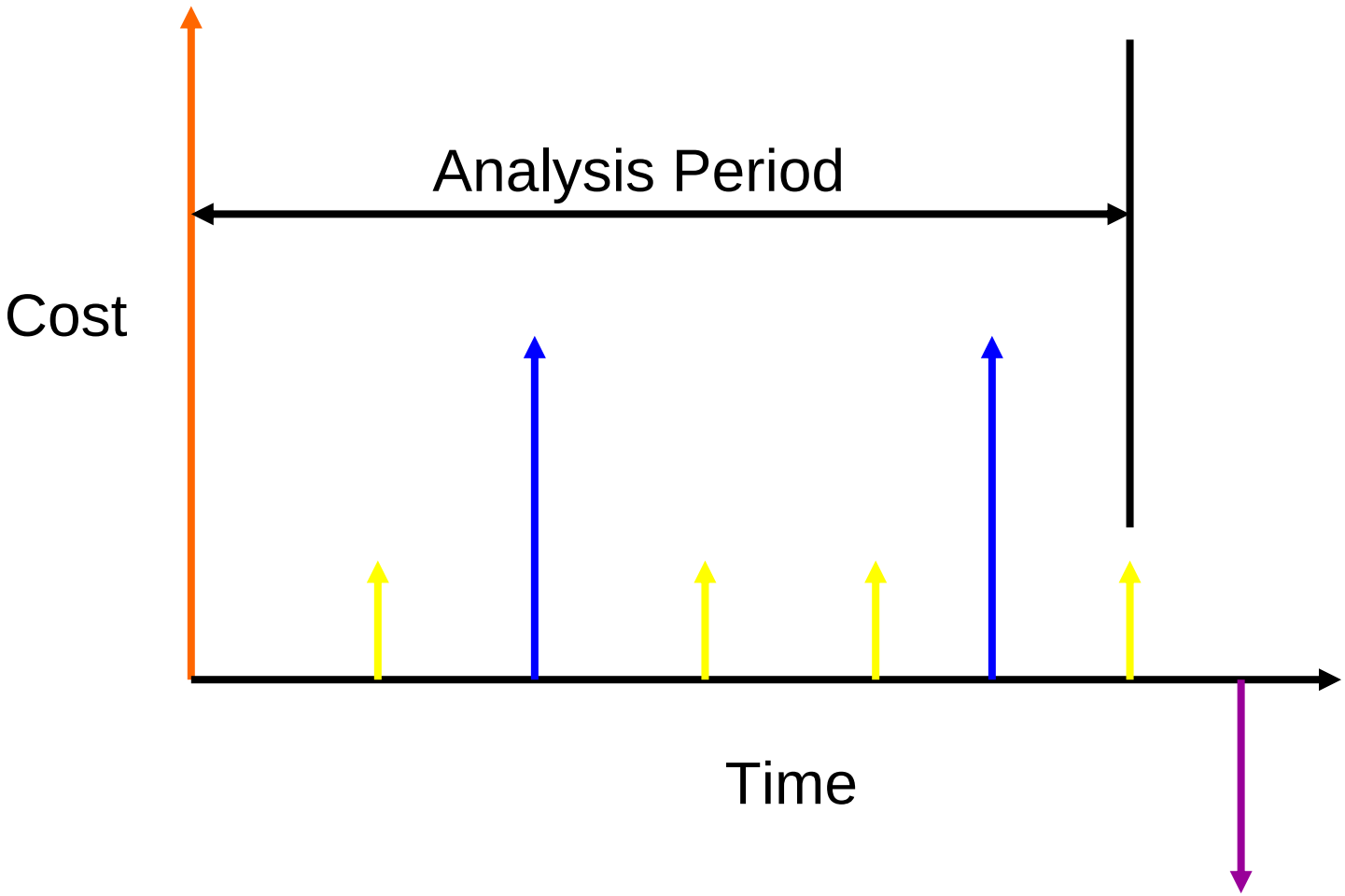
Costs incurred by users of a highway due to construction, rehabilitation and maintenance activities.

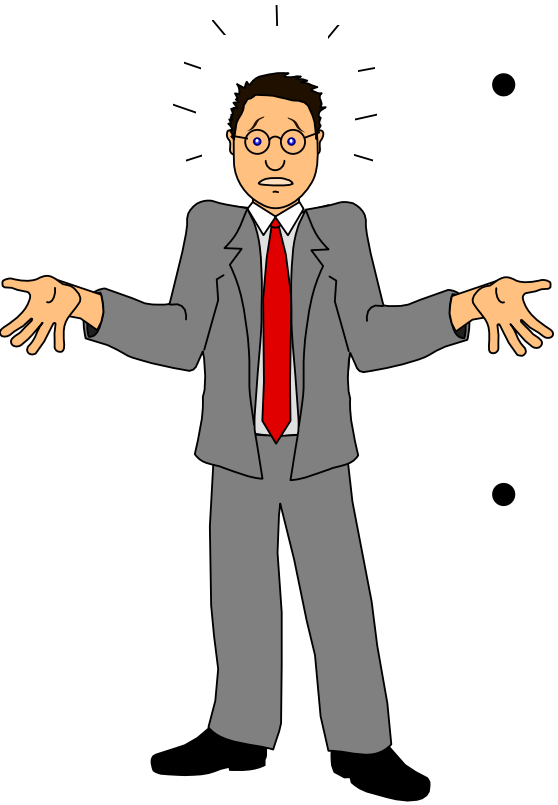
User Delay Costs



User Cost Components

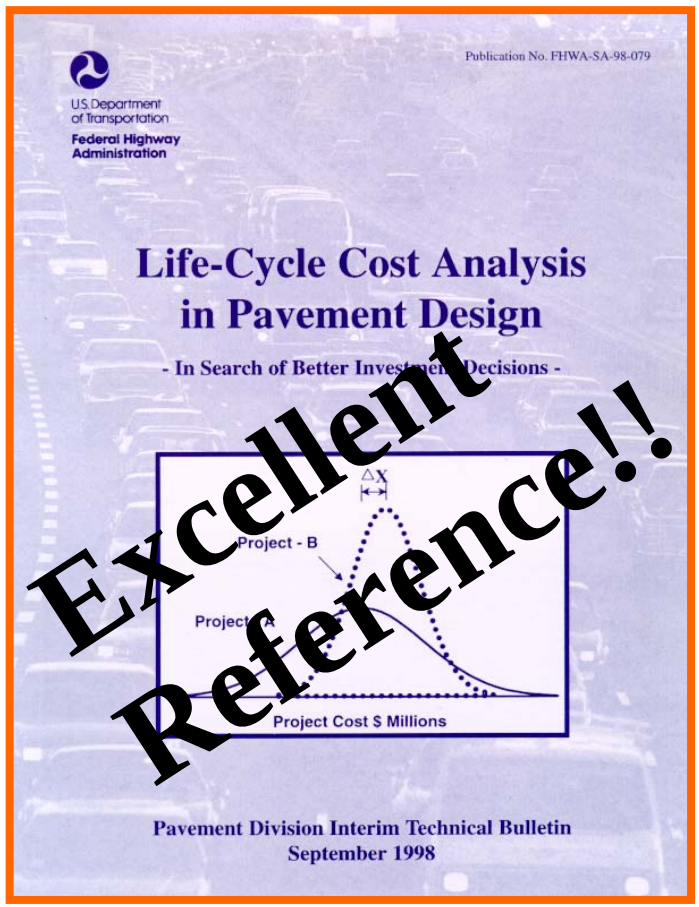
- **Vehicle Operating**
  - stopping, idling, starting
  - based on normal roadway speed and vehicle type
    - could be $1000 / 1000 trucks @70 mph
- **Delay**
  - FHWA Guidelines:
    - $11.58 / hour for passenger vehicle
    - $18.54 / hour for single unit truck
    - $22.31 / hour for combination truck
- **Others Difficult to Model**
  - Crash
  - Self Rerouting

Analysis Alternatives



- **Deterministic**
  - **Choose most economical option based on mean values**
- **Probabilistic**
  - **Examine distributions of cost and select most economical option at some level of probability**
  - **Typical inputs: average and standard deviation**

FHWA's Latest Guidance on LCCA



"Demo Project 115"

- **State of the Art Procedures Incorporating:**
  - work zone user delay costs
  - probabilistic approach
- **Very Complex**
- **Software Assists With Actual Implementation by Agencies**
  - FHWA version
  - APA version

APA's LCCA Software

- **Follows FHWA Guidelines**
- **Up to Four Alternatives**
- **Considers Agency and User Costs**
  - **Optimizes Work Zone Timing to Save $$$**
- **Built-in Default Costs**
- **Deterministic or Probabilistic**
- **Self-Contained Windows Program**
- **Comprehensive Help File**
- **Graphical Output**
- **Free at www.asphaltalliance.com**

Performance of PMA

IS-215 Quantifying the Effects of PMA for Reducing Pavement Distress

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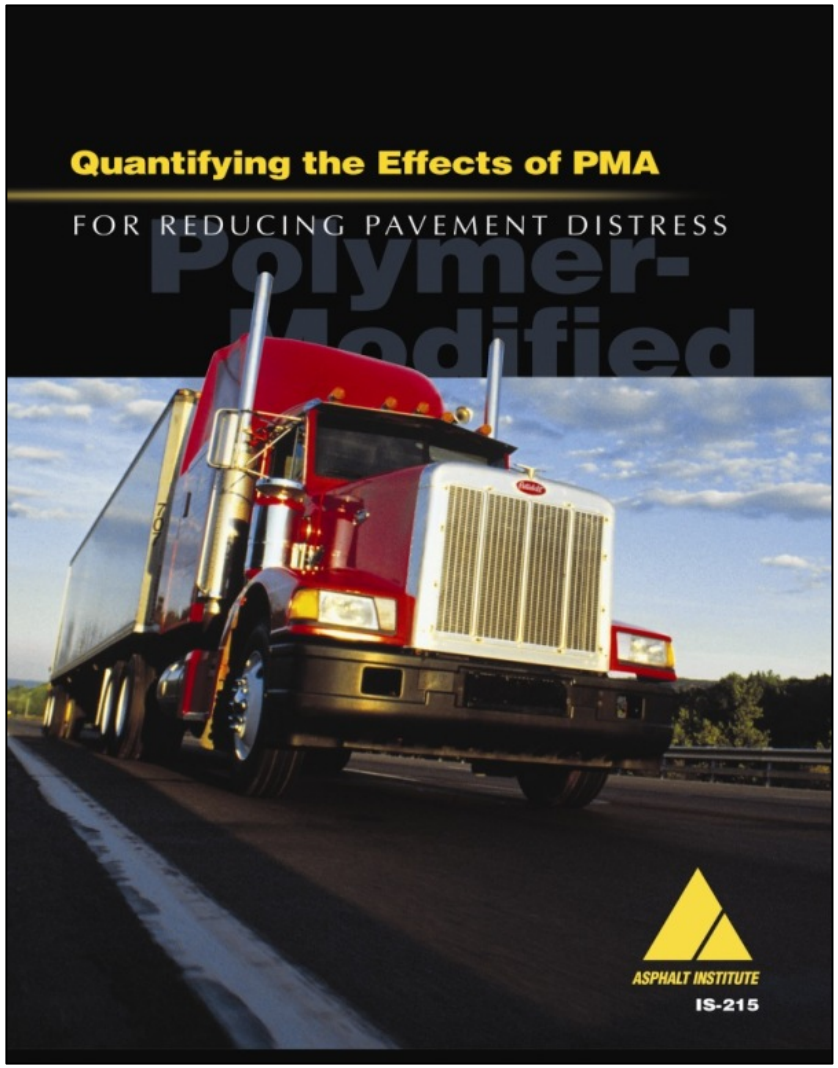

This revealing new study defines the advantages of polymer-modified asphalt (PMA) over conventional hot mix asphalt (HMA) when used in a variety of climates and traffic volumes within North America.

$30.00

ER-215 Engineer's Report: Quantification of the Effects of Polymer-Modified Asphalt for Reducing Pavement Distress

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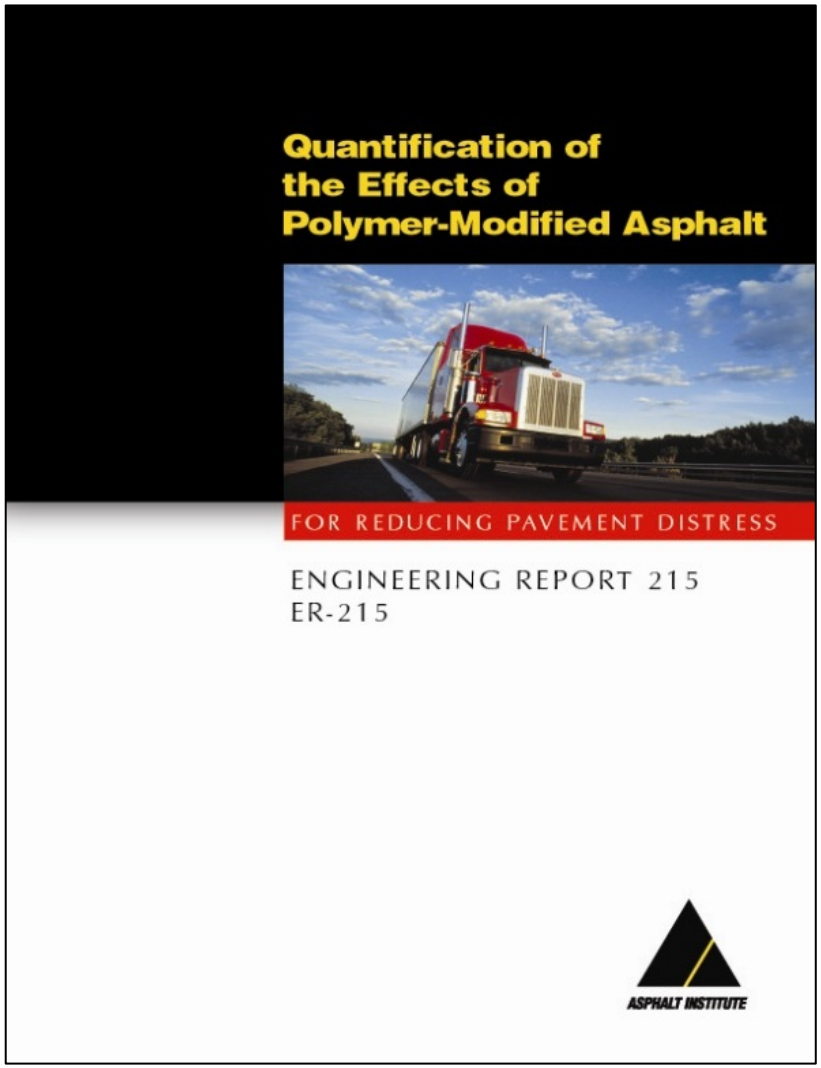

A detailed, in-depth version of the IS-215, the Engineer's Report includes all related data and findings of the study.

A CD accompanies the report with five appendices, tables, and other pertinent material. Includes a free copy of the related IS-215.

$40.00

Study Sponsors

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Industry Associations

- The Asphalt Institute
- The Association of Modified Asphalt Producers

Federal Highway Administration

Corporate Sponsors

- Arr-Maz Products
- ATOFINA Petrochemicals, Inc.
- Dexco Polymers LP
- Dynasol LLC
- KRATON Polymers
- Polimeri Europas Americas
- Ultrapave

Study Team

Project Team

ARA

- Harold L. Von Quintus, P.E.
- Jagannath Mallela
- Jane Jiang

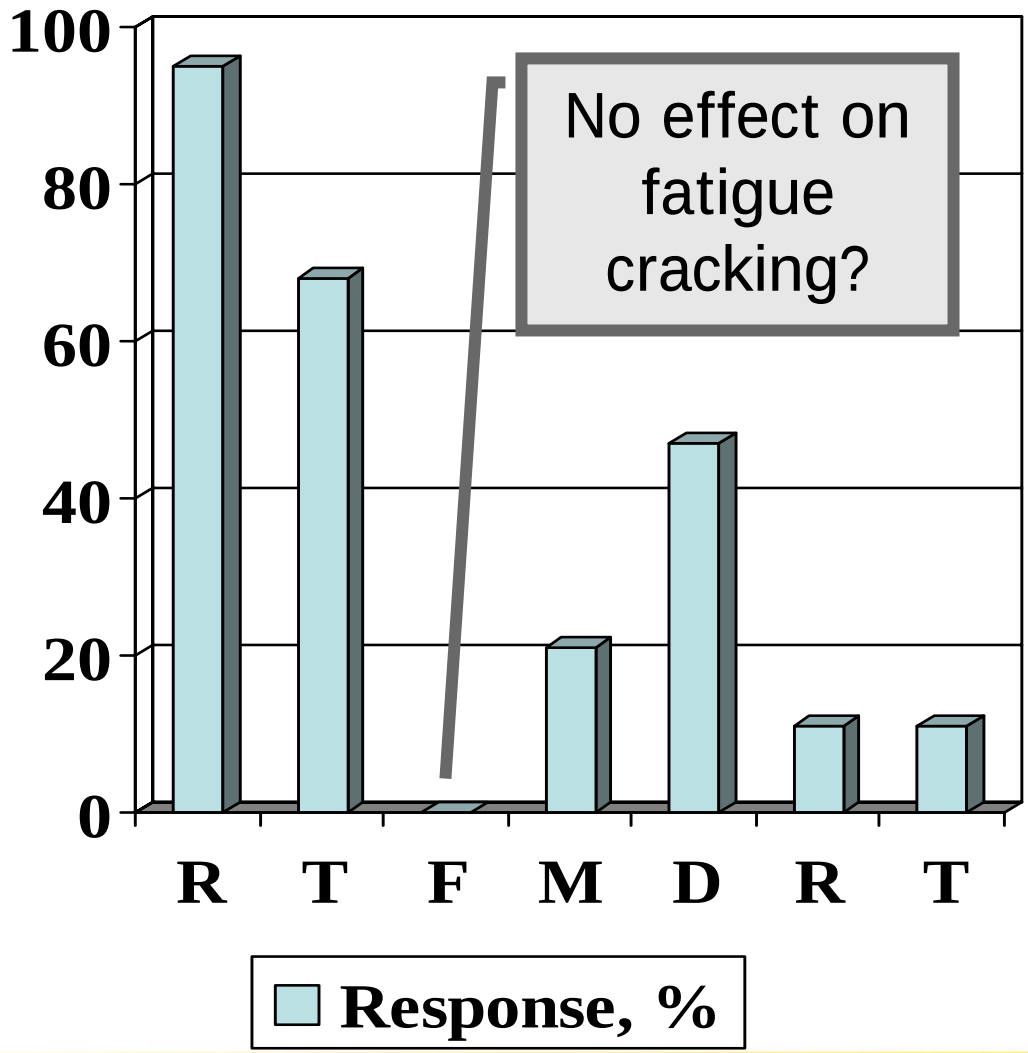
Project Monitors

- Mark Buncher
- Tim Glanzman

Study Objectives

1. Quantify the effect of using PMA as compared to conventional-unmodified HMA mixtures.
2. Identify conditions that maximize effect of PMA to increase HMA pavement & overlay life.

Agency Survey: Reasons for Using PMA?



R = Rutting

T = Thermal Cracking

F = Fatigue Cracking

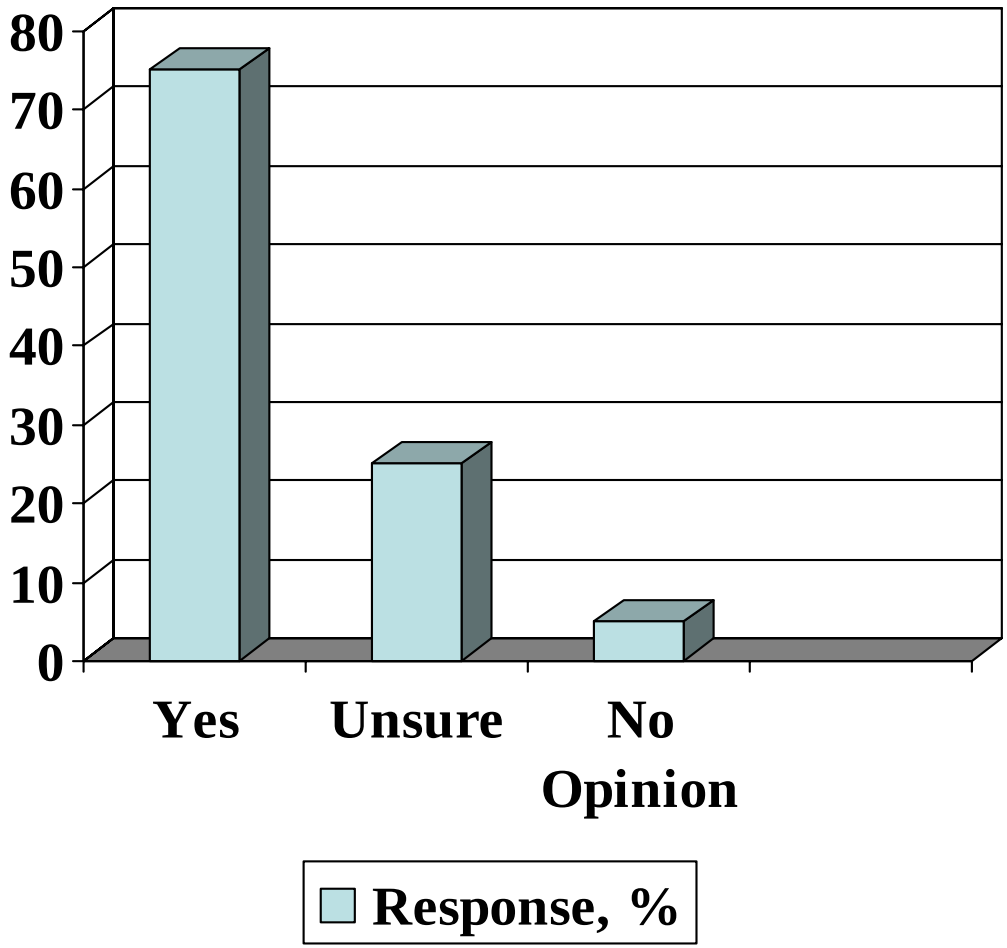
M = Moisture Damage or Stripping

D = Durability

R = Raveling

T = Tenderness

Is There a Benefit Using PMA?

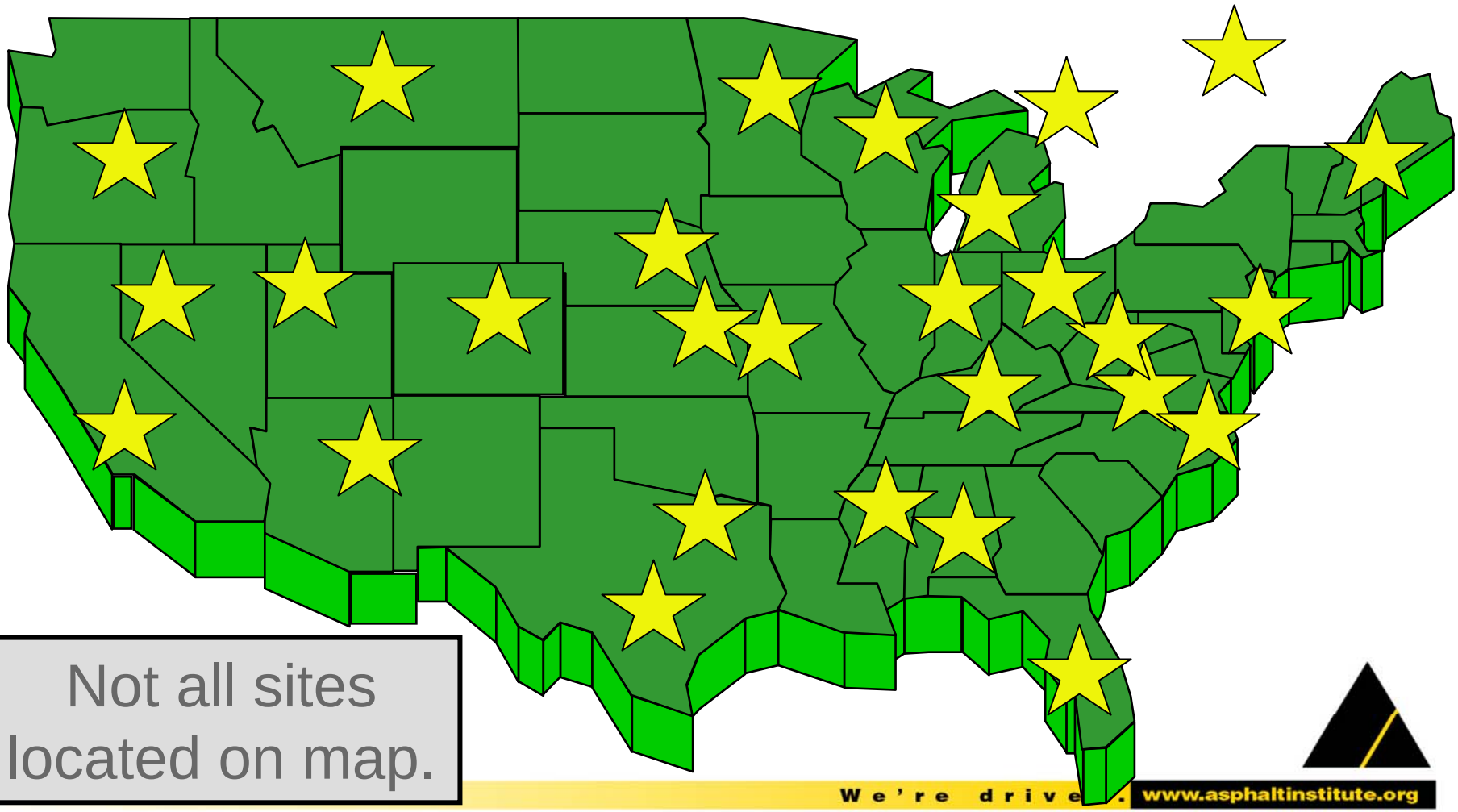


Yes, **BUT**: Insufficient data to quantify that benefit.

Test Sections - Experiments

- LTPP: Core & Supplemental Sections
  - **SPS-1; SPS-5; SPS-6; SPS-9**
  - **GPS-1; GPS-2; GPS-6; GPS-7**
- MTO Modifier Study
- Accelerated Pavement Tests
  - **FHWA ALF, Turner Fairbanks**
  - **NCAT Test Road**
  - **California HVS Studies**
  - **Ohio Test Road**
  - **Corp of Engineers**

Selected Locations for Comparison



Not all sites located on map.

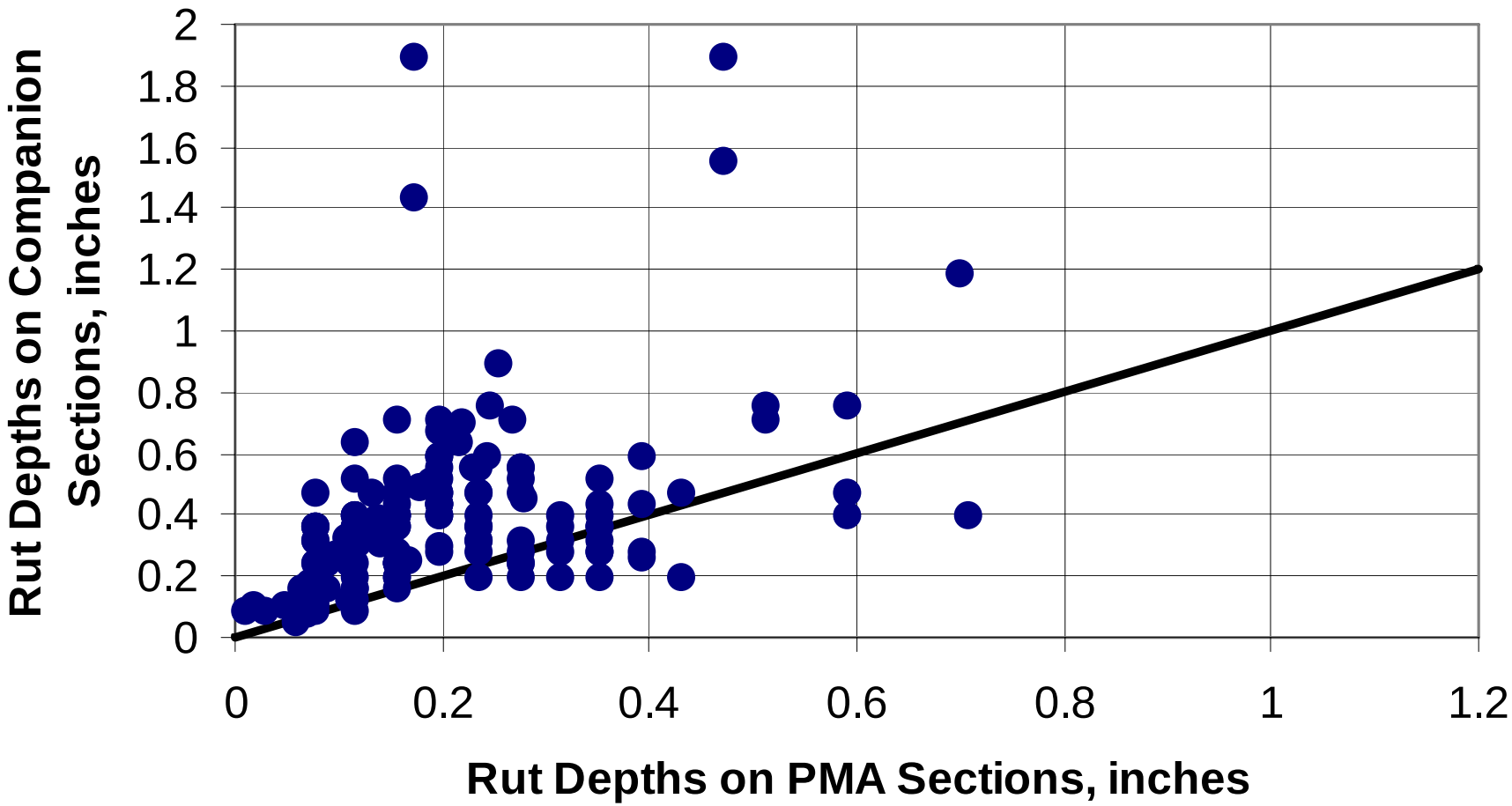
Comparison of Pavement Distress/Performance

- Fatigue Cracking
- Rutting
- Thermal Cracking

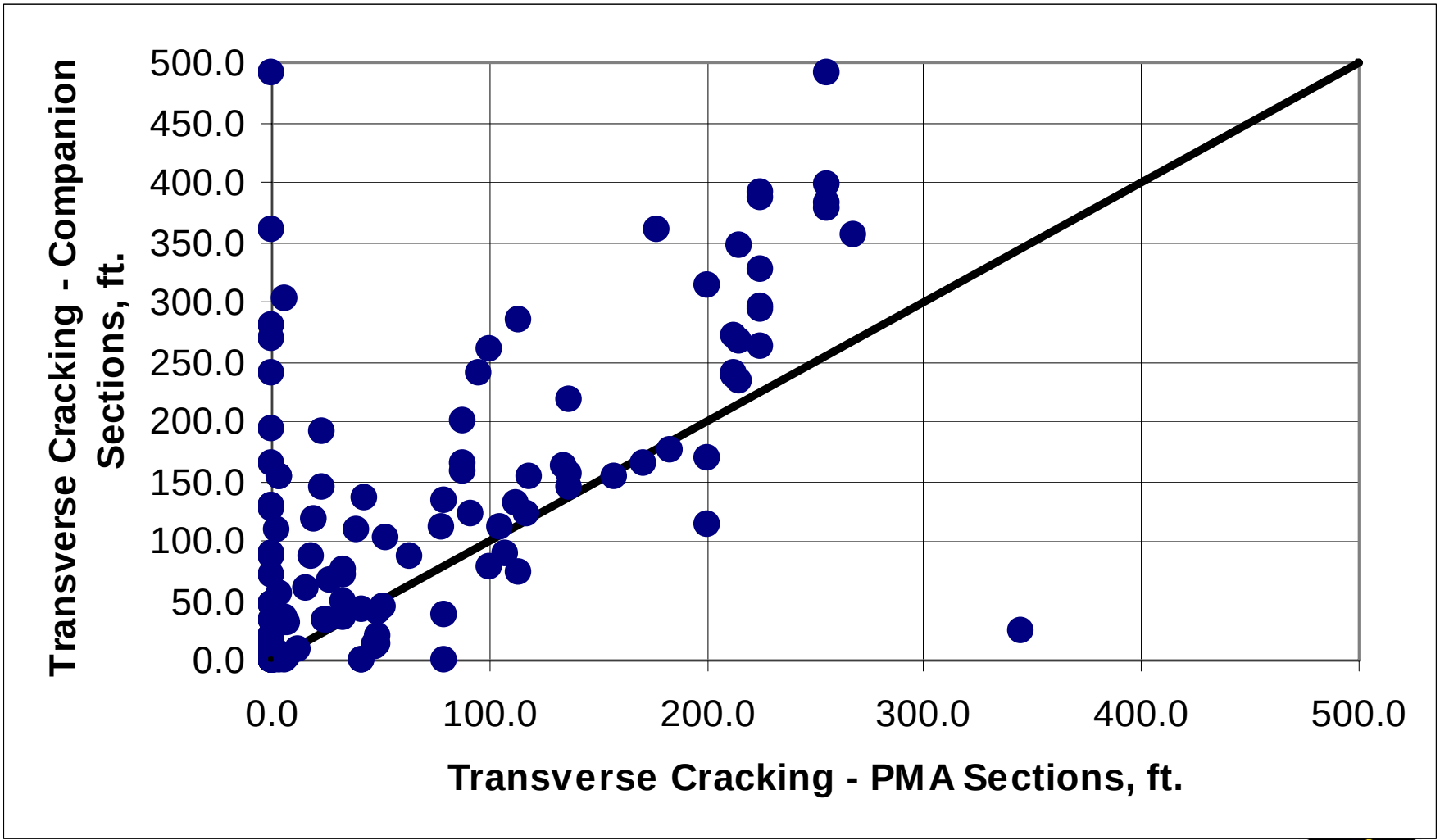
Experimental Factorial

Pavement Cross Section	Foundation	Climate			
		Freeze		Non-Freeze	
		Wet	Dry	Wet	Dry
Thin HMA	Fine-Grained	2	2	4	3
	Coarse-Grained	3	3	3	3
Thick HMA	Fine-Grained	2	2	2	3
	Coarse-Grained	2	2	3	2
Full-Depth	Fine-Grained	0	1	2	2
	Coarse-Grained	0	1	2	2
HMA Overlays	HMA	3	3	6	6
	PCC	4	3	4	4
Total No. PMA + Comp. Sections		16	17	26	25

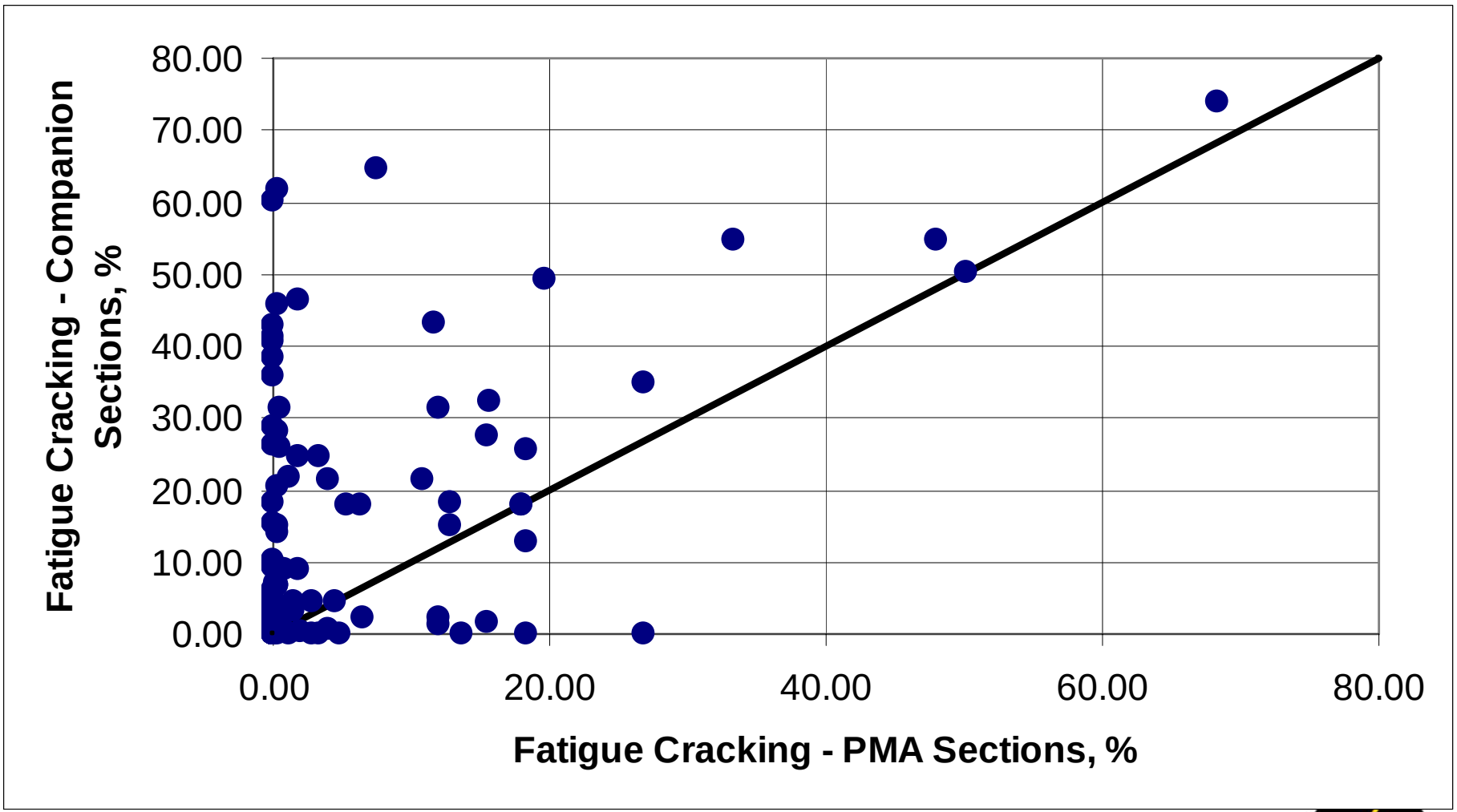
Distress Comparisons - Rutting



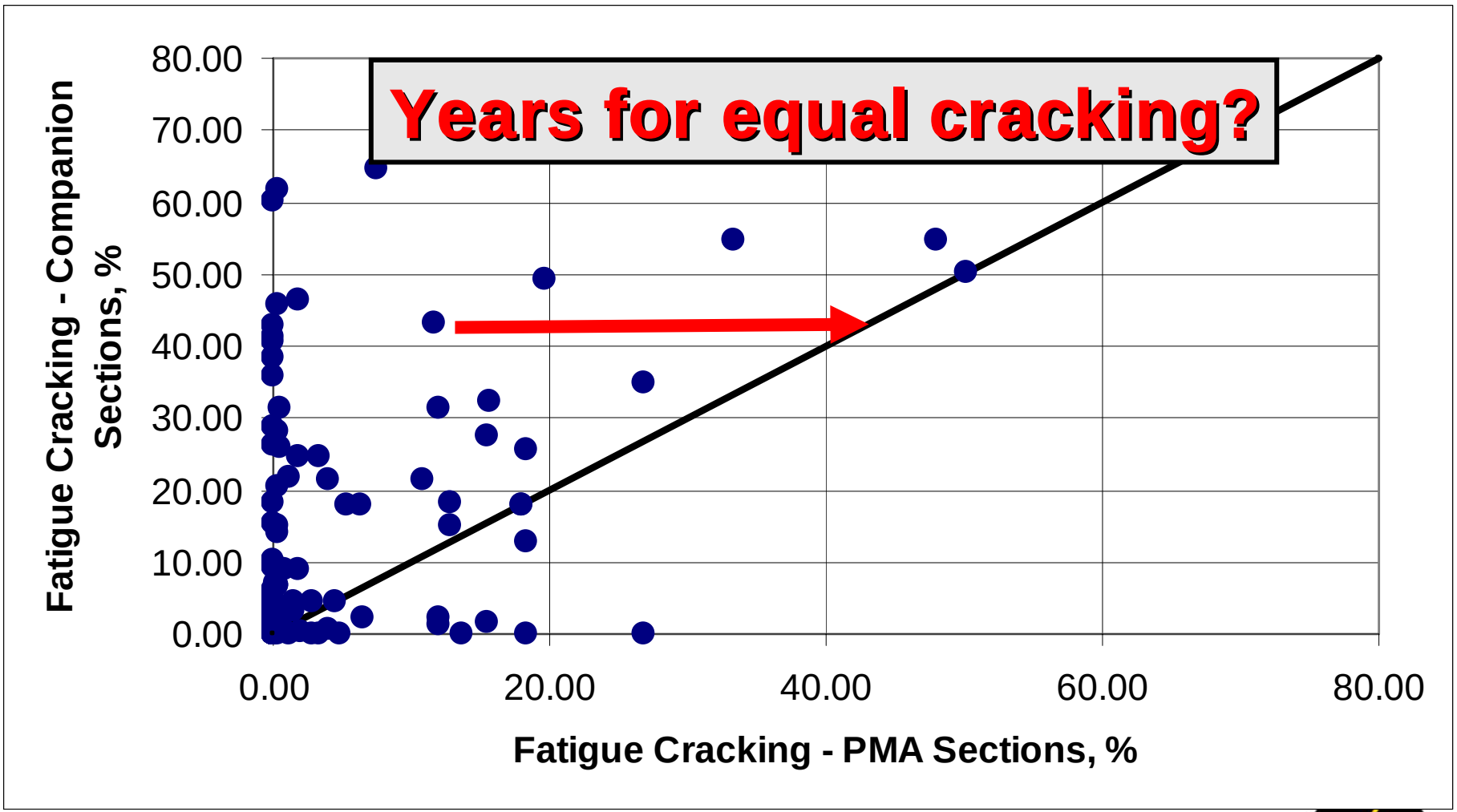
Distress Comparisons – Transverse Cracking



Distress Comparisons – Fatigue Cracking



Distress Comparisons – Fatigue Cracking



M-E damage based analysis completed for load-related distresses comparing damage indices w/ actual distress observations.

- ☑ Fatigue Cracking
- ☑ Rutting
- Thermal Cracking

Damage indices computed for both rutting and fatigue using local, cell specific calibration.

Pavement Cross Section	Foundation	Climate			
		Freeze		Non-Freeze	
		Wet	Dry	Wet	Dry
Thin HMA	Fine-Grained	2	2	4	3
	[illegible]	3	3	3	3
Thick HMA	[illegible]	2	2	2	3
	[illegible]	2	2	3	2
Full-Depth	Fine-Grained	0	1	2	2
	Coarse-Grained	0	1	2	2
HMA Overlays	HMA	3	3	6	6
	PCC	4	3	4	4
Total No. PMA Sections		16	17	26	25

Unmodified Sect. used for Calibration

Summary of Expected Increase in Service Life, Years, Based on M-E Damage Based Analysis

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Site Factor	Condition Description		Added Life
Foundation	Non-Expansive		5-10
	Expansive		2-5
	Frost Susceptible – Cold Climate		2-5
Water Table & Drainage	Deep		5-10
	Shallow; Adequate		5-8
	Shallow; Inadequate		0-2
Existing Pavement Condition	HMA	Good	5-10
		Poor-Extensive Cracking	1-3
	PCC	Good	3-6
		Poor-Faulting & Cracking	0-2

Summary of Expected Increase in Service Life, years

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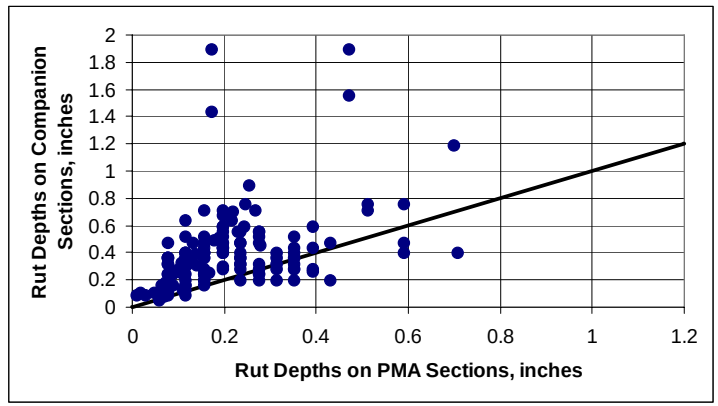
Site Factor	Condition Description		Added Life
Climate; Temp. Fluctuations	Hot	Hot Extremes	5-10
	Mild		2-5
	Cold	Cold Extremes	3-6
Traffic, Truck Volumes	Low	Intersections	5-10
		Thoroughfares	3-6
		Heavy Loads	5-10
	Moderate		5-10
	High		5-10

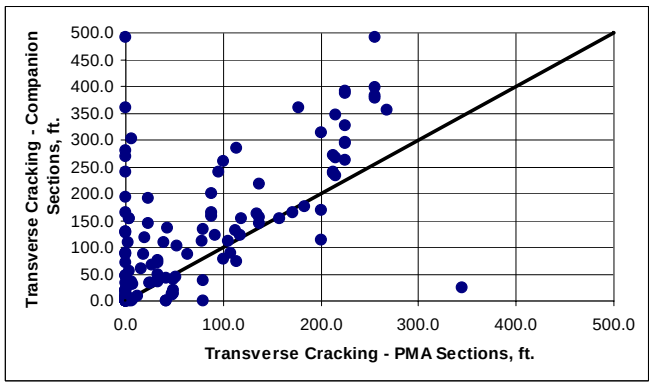
Generic LCCA Strategy/ Timeline and Revised PMA Timelines Based on Results

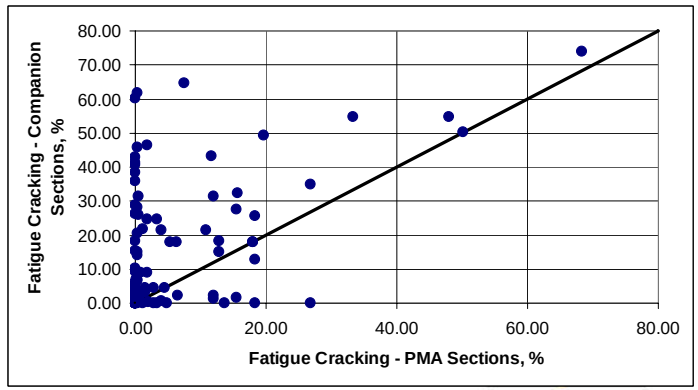
Years	5	10	15	20	25	30	35	40
Conv. Struct.	R. Maint.		R. Maint.		R. Maint.		R. Maint.	
		Mill-Fill		HMA Over.		Mill-Fill	HMA Over	
PMA Surface 2-4 in.		R. Maint.				RM		RM
				HMA Over.			HMA Over.	
PMA Full Depth			RM			RM		RM
				Mill-Fill			Mill-Fill	

Findings

- Use of PMA reduces distress in pavements & overlays
  - Less Fatigue Cracking
  - Fewer Transverse Cracks
  - Smaller Ruts







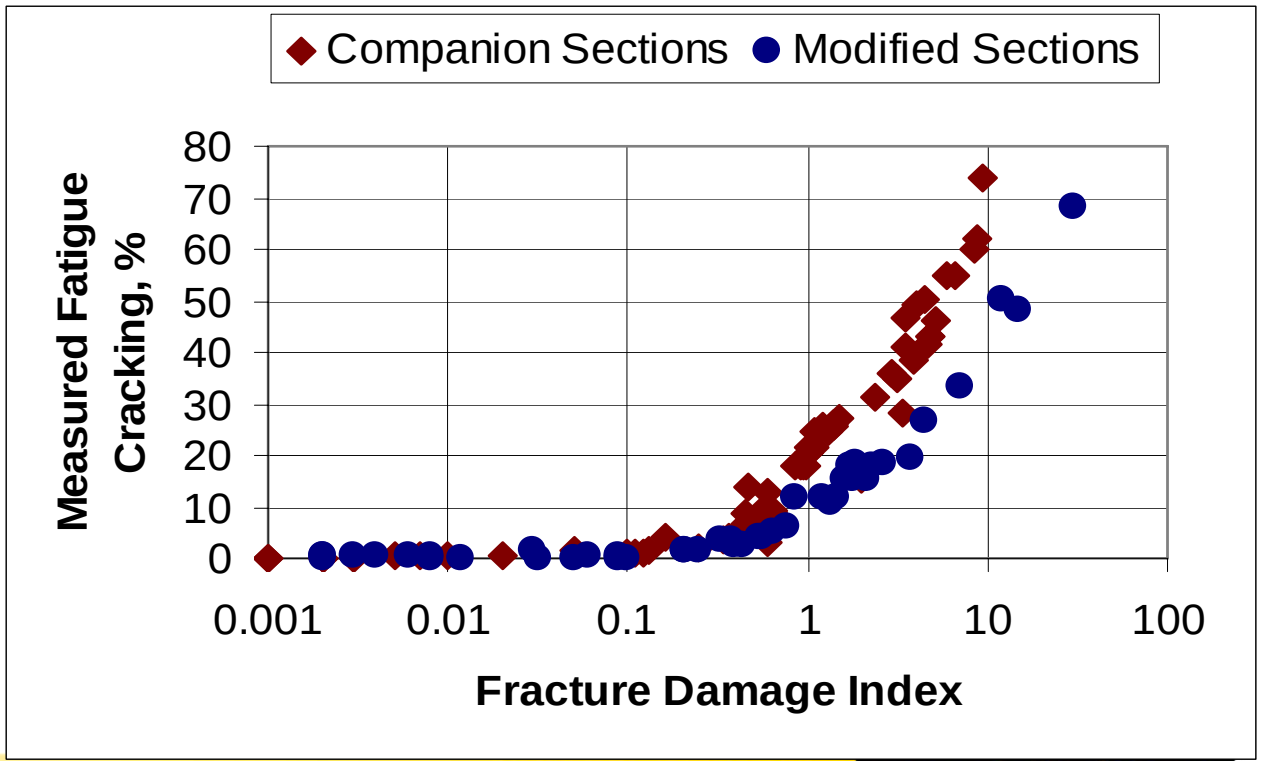
Findings

Field & laboratory investigations of PMA mixes suggest:

- Enhanced Performance
  - 25 to 100 % increase in service life
  - 3 to 10 years increase in service life
- Reduced Maintenance Activities
  - Crew Safety
  - Traffic Delay

Findings & Conclusions

- Mechanistic-empirical analysis confirms need for **different calibration factors** for predicting performance of PMA mixtures.



Economic Impact of PMA

- Use LCCA to Evaluate Actual Cost/Savings with Enhanced Performance from PMA
  - Examples, But…
- Each Agency Must Evaluate Using Their Unique Inputs:
  - Prices, Performance Periods, Designs, Strategies, Discount Rates, User Costs, Etc

Assumptions for Examples

14.5" HMA Pavement	**Interest Rate: 4%**		**No User Costs Considered**	
	Analysis Period = 40 yrs.			
Prices				
Wearing (PG 64-22)	**$36/ton**	**$1.97/sy-in**		
Wearing (PG 76-22)	**$41/ton**	**$2.24/sy-in**		
Binder (PG 64-22)	**$35/ton**	**$1.91/sy-in**		
Binder (PG 76-22)	**$40/ton**	**$2.19/sy-in**		
Base (PG 64-22)	**$35/ton**	**$1.91/sy-in**		
Base (PG 76-22)	**$40/ton**	**$2.19/sy-in**		
Milling		**$1.40/sy**		
HMA Patching		**$36/sy**		
Quantities (per mile)				
Mainline: 2-lanes @ 12 ft ea.		**14,080sy**		
Shoulders: 1 @ 10 ft and 1 @ 4 ft		**8,212sy**		
References				
Prices from Maryland's "Pavement Selection Process"				
Maintenance from "Pa DOT Pub. 242, Pavement Policy Manual"				
Performance Scenarios are Examples from "Quantifying Effects of PMA ..."				

EXAMPLE 1, Unmodified All Layers

Year	Construction Item and/or Material	Quantity	Unit	Cost/Unit
0	10" HMA Base (3 - 10 EAL)	14080	sy	$ 19.10
0	2.5" HMA Binder (3 - 10 EAL)	14080	sy	$ 4.78
0	2" HMA Wearing (3 - 10 EAL)	14080	sy	$ 3.94
0	10" HMA Base (0.3 - 3 EAL)	8212	sy	$ 19.10
0	2.5" HMA Binder (0.3 - 3 EAL)	8212	sy	$ 4.78
0	2" HMA Wearing (0.3 - 3 EAL)	8212	sy	$ 3.94
0	Maint. & Protection of Traffic @2.3%	1	ls	$14,264
0	Mobilization @5.5%	1	ls	$34,109
10	Deep Patch 1% (mainline)	141	sy	$ 36.00
10	Mill 2" (mainline)	14080	sy	$ 1.40
10	2" hma overlay (mainline)	14080	sy	$ 3.94
10	Maint. & Protection of Traffic @2.3%	1	ls	$ 1,846.05
10	Mobilization @5.5%	1	ls	$ 4,414.48
18	Mill 2"	22292	sy	$ 1.40
18	Deep Patch 3% (mainline)	422	sy	$ 36.00
18	#60 scratch course	422	ton	$ 36.00
18	2.5" hma overlay (binder)	14080	sy	$ 4.78
18	2" hma overlay (wearing)	14080	sy	$ 3.94
18	#60 scratch course	246	ton	$ 36.00
18	2.5" hma overlay (binder)	8212	sy	$ 4.78
18	2" hma overlay (wearing)	8212	sy	$ 3.94
18	Maint. & Protection of Traffic @2.3%	1	ls	$6,091
18	Mobilization @5.5%	1	ls	$14,566
28	Same Scenario as Year 10	1	ls	$86,524
34	SameScenario as Year 18	1	ls	$285,492
20	Total Annual Maintenance ($1825/yr)	40	yr	$ 1,825.00
				Total

Yr.	Activity	Cost,$	NPW,$
0	10” Base 2.5” Binder 2” Wearing	668K	668K
10	2” mill/fill 1% patching (not on shoulders)	87K	58K
18	2” mill 3% patching scratch 2.5” Binder 2” Wearing (incl. shoulders)	285K	141K
28	Same as yr.10	87K	29K
34	Same as yr.18	285K	75K
Annual	Maint ($1.8K/yr)	73K	33K
	Total NPW:		1,005K

EXAMPLE 2, Modified Wearing Course

(top 2”, including shoulders)

Year	Construction Item and/or Material	Quantity	Unit	Cost/Unit
0	10" HMA Base (3 - 10 EAL)	14080	sy	$ 19.10
0	2.5" HMA Binder (3 - 10 EAL)	14080	sy	$ 4.78
0	2" HMA Wearing (3 - 10 EAL)	14080	sy	$ 4.48
0	10" HMA Base (0.3 - 3 EAL)	8212	sy	$ 19.10
0	2.5" HMA Binder (0.3 - 3 EAL)	8212	sy	$ 4.78
0	2" HMA Wearing (0.3 - 3 EAL)	8212	sy	$ 4.48
0	Maint. & Protection of Traffic @2.3%	1	ls	$14,541
0	Mobilization @5.5%	1	ls	$34,771
18	Mill 2"	22292	sy	$ 1.40
18	Deep Patch 3% (mainline)	422	sy	$ 36.00
18	#60 scratch course	422	ton	$ 36.00
18	2.5" hma overlay (binder)	14080	sy	$ 4.78
18	2" hma overlay (wearing)	14080	sy	$ 4.48
18	#60 scratch course	246	ton	$ 36.00
18	2.5" hma overlay (binder)	8212	sy	$ 4.78
18	2" hma overlay (wearing)	8212	sy	$ 4.48
18	Maint. & Protection of Traffic @2.3%	1	ls	$6,368
18	Mobilization @5.5%	1	ls	$15,228
34	SameScenario as Year 18	1	ls	$298,469
20	Total Annual Maintenance ($1825/yr)	40	yr	$ 1,825.00
				Total

Yr.	Activity	Cost,$	NPW,$
0	10” Base 2.5” Binder 2” Wearing	682K	682K
18	2” mill 3% patching scratch 2.5” Binder 2” Wearing	298K	147K
34	Same as yr.18	298K	79K
Annual	Maint ($1.8K/yr)	73K	33K
	Total NPW:		941K

EXAMPLE 3, Perpetual Pavement: Modified Wearing Course (top 2”) and Bottom 4” of Base (incl. shoulders)

Interest
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Year	Construction Item and/or Material	Quantity	Unit	Cost/Unit
0	4" HMA Modified Base (3 - 10 EAL)	14080	sy	$ 8.76
0	6" HMA Base (3 - 10 EAL)	14080	sy	$ 11.46
0	2.5" HMA Binder (3 - 10 EAL)	14080	sy	$ 4.78
0	2" HMA Wearing (3 - 10 EAL)	14080	sy	$ 4.48
0	4" HMA Base (0.3 - 3 EAL)	8212	sy	$ 8.76
0	6" HMA Base (3 - 10 EAL)	8212	sy	$ 11.46
0	2.5" HMA Binder (0.3 - 3 EAL)	8212	sy	$ 4.78
0	2" HMA Wearing (0.3 - 3 EAL)	8212	sy	$ 4.48
0	Maint. & Protection of Traffic @2.3%	1	ls	$15,115
0	Mobilization @5.5%	1	ls	$36,144
18	Mill 2"	22292	sy	$ 1.40
18	2" hma overlay (wearing)	14080	sy	$ 4.48
18	2" hma overlay (wearing)	8212	sy	$ 4.48
18	Maint. & Protection of Traffic @2.3%	1	ls	$3,015
18	Mobilization @5.5%	1	ls	$7,209
34	SameScenario as Year 18	1	ls	$141,301
20	Total Annual Maintenance ($1825/yr)	40	yr	$ 1,825.00
				Total

Yr.	Activity	Cost,$	NPW,$
0	10” Base 2.5” Binder 2” Wearing	709K	709K
18	2” mill/fill	141K	70K
34	Same as yr.18	141K	37K
Annual	Maint ($1.8K/yr)	73K	33K
	Total NPW:		849K

PMA - Smart Economics

Pavement Type	Initial Cost	Change	NPV	Savings
1) Unmodified (resurface yr.10 and 28, structural overlay yr.18 and 34)	669K	-	1,005K	-
2) Modified Wearing (structural overlay yr.18 and 34)	682K	+ 2.0%	941K	6.5%
Extra) Modified Wearing and Binder (structural overlay yr.18 and 34)	698K	+ 4.5%	964K	4.5%
3) Modified Wearing & Base (Perpetual Pavement: resurface yr. 18 and 34)	709K	+ 6.0%	849K	15.5%
Extra) Modified Wearing, Binder & Base (Perpetual Pavement: resurface yr. 18 and 34)	725K	+ 8.5%	864K	14.0%

Note: Modified mainline and shoulders

West Virginia LCCA Example

- Changed Only Initial Performance from 10 to 15 yrs
  - Overlays at yr.15 (vs yr.10), yr.25 and yr.35
  - Result: 5% savings in NPV
- Last Example: Cost to Modify was Approx. 1% of Pavement Cost per Inch Modified
  - Based on PMA mix costing approx 14% more
  - Included modifying shoulders
- Ballpark Breakeven Rule of Thumb: Need approx. 10% Performance Increase per Inch Modified
  - Doesn't consider user delay costs which would mak PMA even more attractive


Polymer Modified Asphalt -
Smart Economics
Questions?