



Pavement Condition Index (PCI): There's More *(and Less)* to the Score

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CCPIC Mission and Vision

- **Mission**
 - CCPIC works with local governments to increase pavement technical capability through timely, relevant, and practical support, training, outreach and research
- **Vision**
 - Making local government-managed pavement last longer, cost less, and be more sustainable



City and County Pavement Improvement Center



CAL POLY

- Sponsored by the League of California Cities, County Engineers Association of California, and the California State Association of Counties
- Chartered September 28, 2018



City and County Pavement Improvement Center



CAL POLY

- **University of California Partners**
 - University of California Pavement Research Center (lead)
 - UC Berkeley ITS Tech Transfer
- **California State University Partners**
 - CSU-Chico, CSU-Long Beach, Cal Poly San Luis Obispo

CCPIC Organization

- **Governance**
 - Governance Board consisting of 6 city and 6 county transportation professionals
- **Current Funding**
 - Seed funding from SB1 through:
 - Institute of Transportation Studies at UC Davis, UC Berkeley, UC Los Angeles, UC Irvine
 - Mineta Transportation Institute at San Jose State University

CCPIC Scope

- **Technology Transfer:**
 - Training courses
 - Pavement engineering and management certificate program for working professionals through UC Berkeley ITS Tech Transfer
 - Outreach
- **Technical Resources:**
 - Technical briefs, guidance, sample specifications, tools, and other resources
- **Resource Center:**
 - Outreach, questions, pilot study documentation, and forensic investigations
- **Research and Development:**
 - For local government needs that are not covered by State and Federal efforts
 - Adapting work done for state government

Pavement Engineering & Management (PEM) Certificate Program

- **PEM Certificate Program Overview**
 - For engineers, asset managers, upper-level managers, technicians and construction inspectors
 - 88.5 hours of training
 - 56.5 hours in core classes, 32 hours in electives
 - Majority of classes to be offered online
 - In four categories:
 - Fundamentals
 - Management
 - Materials and Construction
 - Design

Pavement Engineering & Management Certificate: Curriculum

	Fundamentals	Hrs	Management	Hrs	Materials and Construction	Hrs	Design	Hrs
CORE 56.5 required	CCA-01 Introduction to Pavement Engineering and Management	10	CCB-01 Life Cycle Cost Analysis	4	CCC-01 Asphalt Concrete Materials and Mix Design	8		
	CCA-02 Pavement Sustainability	4	CCB-02 Pavement Management Systems and Preservation Strategies	10	CCC-02 Pavement Preservation Treatments, Materials, Construction, Quality Assurance	8		
					CCC-03 Pavement Construction Specifications and Quality Assurance	12.5		
56.5	Fundamentals, CORE	14	Management, CORE	14	Materials and Construction, CORE	28.5	Design, CORE	0
ELECTIVE 32 required 84 offered			CCB-21 Financing and Cash Flow for Pavement Networks	4	CCC-21 Concrete Materials & Mix Design	8	CCD-21 Asphalt Pavement Structural Section Design	8
			CCB-22 Integrated Asset Management for Multi-Functional Pavements	8	CCC-22 In-Place Recycling	8	CCD-22 Design, Construction, and Maintenance of Interlocking Concrete Pavers	6
					CCC-23 Gravel Roads Engineering, Construction, and Management	8	CCD-23 Concrete Pavement Design	8
					CCC-24 Roadway Construction Phasing, Scheduling, and Traffic Control	4		
					MISC Classes from Pavement Construction Inspection Certificate curriculum			
					CCC-26 Pavement Construction Management	8		
					CCC-27 Asphalt Pavement Maintenance Construction	6		
					TS-10 Work Zone Safety	8		
84	Fundamentals, ELECTIVE	0	Management, ELECTIVE	12	Materials and Construction, ELECTIVE	50	Design, ELECTIVE	22
Total for Certificate 88.5 hours	Fundamentals	14	Management	26	Materials and Construction	78.5	Design	22

Pavement Construction Inspection (PCI) Certificate Program

- **PCI Certificate Program Overview**
 - For engineers, material testing technicians and construction inspectors
 - 80.5 hours of training
 - 68.5 hours in core classes, 12 hours in electives
 - Majority of classes to be offered online

Pavement Construction Inspection Certificate: Curriculum

Core		Hrs	
CORE 68.5 required	PD-01	Construction Inspection	16
	CCI-01	Asphalt Pavement Construction Inspection	4
	CCI-02	Concrete Pavement Construction Inspection	4
	CCI-03	Concrete Street Improvements Construction Inspection	4
	CCI-04	Pavement Preservation Construction Inspection	4
	CCC-02	Pavement Preservation Treatments, Materials, Construction, Quality Assurance	8
	CCC-03	Pavement Construction Specifications and Quality Assurance	12.5
	CCC-26	Pavement Construction Management	8
	TS-10	Work Zone Safety	8
68.5	Core	68.5	
Electives (choose 12 hours from list below)		Hrs	
ELECTIVE 12 required 26 offered	CCC-22	In-Place Recycling	8
	CCC-24	Roadway Construction Phasing, Scheduling, and Traffic Control	4
	CCI-06	Construction Inspection of Asphalt-Rubber Pavement Materials	2
	PD-02	Construction Inspection of Traffic Signals	8
	TS-18	Excavation and Trenching Safety	4
12	Electives	26	
80.5	Total required for certificate		

CCPIC Classes Currently Open for Enrollment and Planned Through June 2024

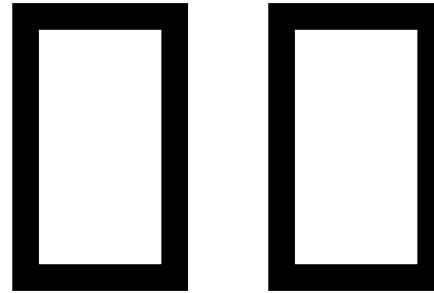
Code	Title	Date	Location
CCC-02	Asphalt Pavement Preservation Treatments, Materials, Construction and Quality Assurance (50 people registered)	November 27-30, 2023	Online
PD-01	Fundamentals of Inspection Practice	December 6-7, 2023	Rancho Cucamonga
CCA-02	Pavement Sustainability	February 13-15, 2024	Online
CCB-02	Pavement Management Systems and Preservation Strategies	March 4-8, 2024	Online
CCC-03	Pavement Construction Specifications and Quality Assurance	March 12-20, 2024	Online
CCC-01	Asphalt Concrete Materials & Mix Design	April 22-25, 2024	Online
CCA-01	Introduction to Pavement Engineering and Management	TBD	Online
CCC-02	Asphalt Pavement Preservation Treatments, Materials, Construction and Quality Assurance	TBD	Online
CCI-04	Pavement Preservation Construction Inspection	TBD	Online (Self-Paced)
CCI-06	Construction Inspection of Asphalt-Rubber Pavement Materials	TBD	Online (Self-Paced)

Pavement Distresses

Identifying Types to Better Manage Asphalt
Pavement

Bottom Up Fatigue Cracking

At *moderate* temperatures, tensile strains under loading



Asphalt

Concrete

Base

Sub-Base

Subgrade

← Tensile Strain ϵ_t →



Load-Related: Bottom-Up Fatigue Cracking

- **Interaction** of asphalt concrete layer, support of underlying structure, materials selection, construction compaction
- **Traffic loading:**
 - Only the truck loads count, cars are too light
 - Slower speeds = longer durations = bigger strains
- **Environment:**
 - Temperature
 - Water sensitivity
 - Aging



Initial Wheel Path Cracking

- May be transverse or Longitudinal
- Distress descriptions can be seen in the ***FHWA Distress Identification Manual***



Cracks Connect: Alligator Cracking

- Distress descriptions can be seen in the ***FHWA Distress Identification Manual***



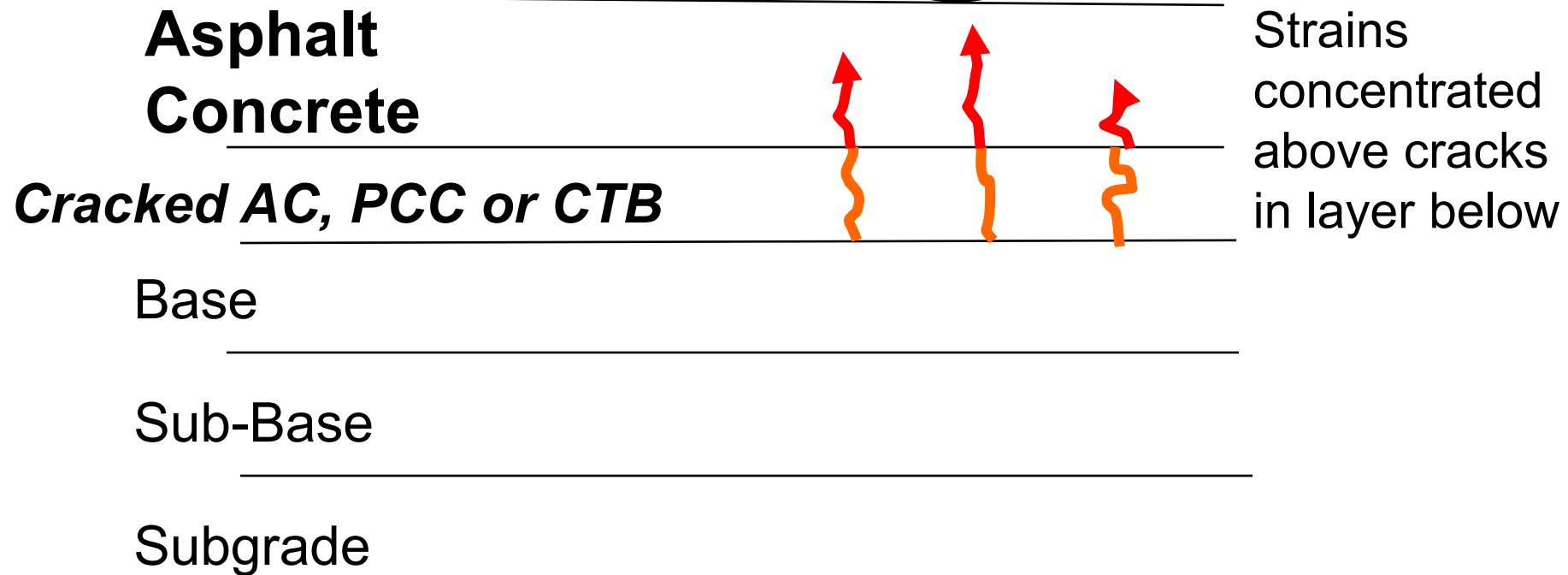
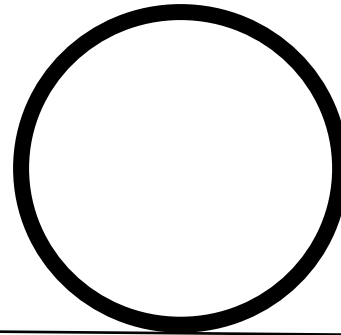
Fatigue Cracking in Wheel Paths

- Distress descriptions can be seen in the ***FHWA Distress Identification Manual***



Reflective Fatigue Cracking

- Shear and tensile strains from loads passing over, tensile strains from thermal contraction
- Crack pattern resembles pattern before overlay



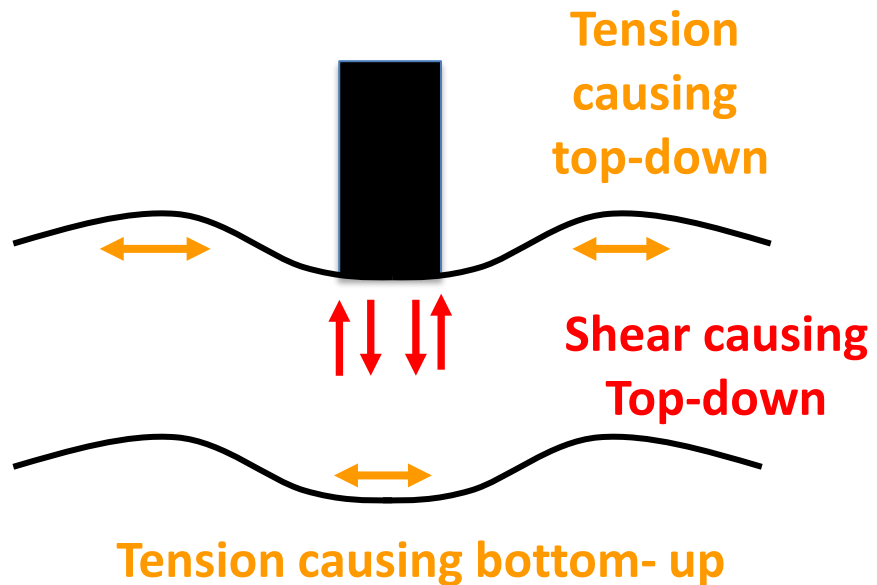
Reflective Cracking of Underlying Block Cracking and Longitudinal Joint, 7 Years Old



- **Avoid putting longitudinal joints in the wheel paths!**

Load-Related: Top-Down Fatigue Cracking

- Identified in the 1990s
- Cracking due to high tensile and shear stresses at the HMA surface near edges of truck tires



Top-Down Fatigue Cracking

- Thin HMA ($< 4''$): Fatigue cracking generally starts at the bottom
- Thick HMA ($\geq 4''$): Fatigue cracking generally starts at the top
Note, thickness of AC in photo on the previous slide is 20''
- Traffic loading: High truck tire pressures

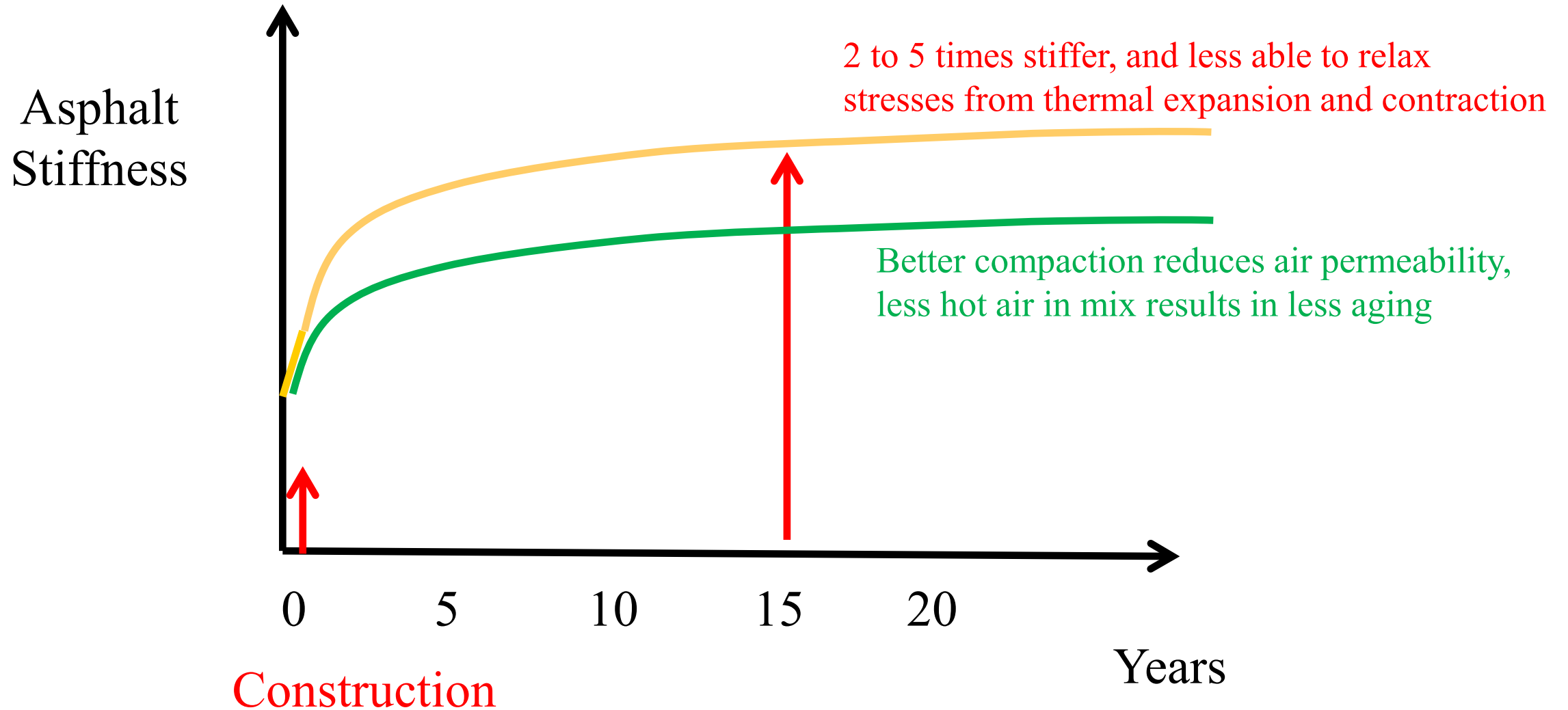
Load-Related Fatigue Cracking: Strategies

- Fatigue cracking becomes alligator cracking, and eventually forms potholes
- Surface treatments will slow a little, but mostly helps with block cracking, not fatigue
- Will need to do periodic mill and fill with digouts of localized deep cracking
- Mill and fill may not be cost-effective once alligator cracking is extensive
 - Consider partial-depth (cold in-place recycling) or full-depth reclamation (FDR) depending on crack and rutting depth
- Do not let wheel path cracking become extensive or must reconstruct



Aging

Amount of aging depends on asphalt chemistry, construction compaction, modifiers



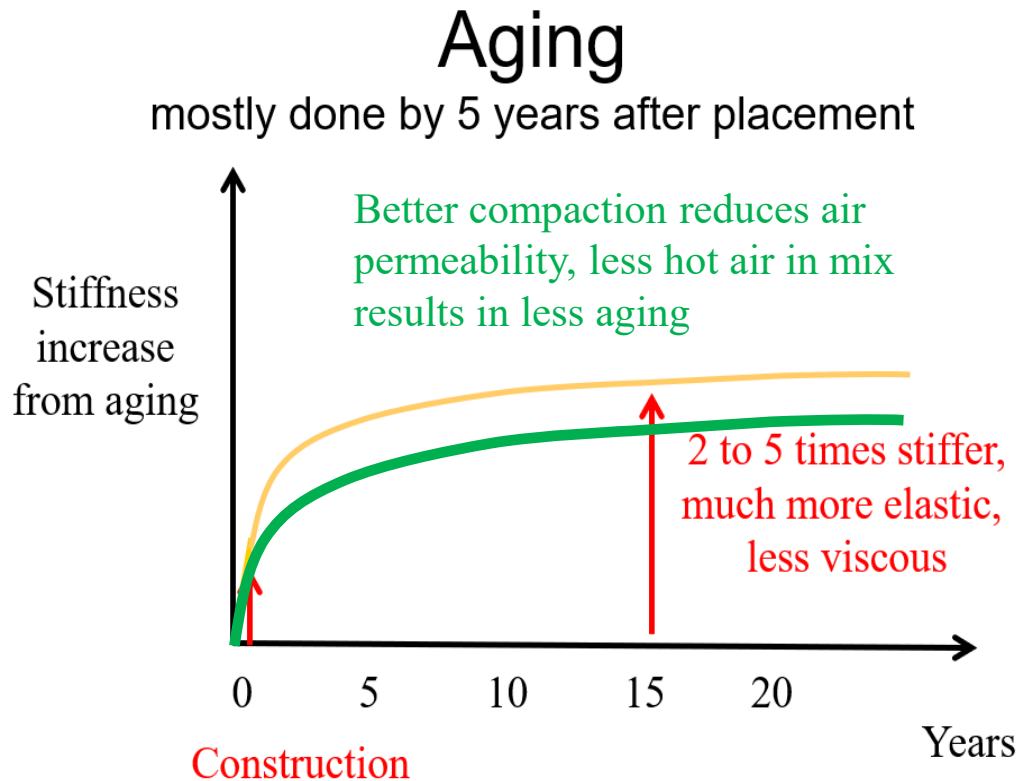
Aging of the Asphalt Binder and its Effects

- **Aging:**

- Caused by oxidation and volatilization
- Faster if high permeability and Temperature (curve)
- Permeability greatly reduced with better HMA/AC compaction (curve)

- **Effects:**

- Stiffening of the mix over time
- Won't relax stresses from thermal contraction as well



Age-Related: Block Cracking

- Typically caused by long-term aging of HMA/AC and daily temperature cycling (expansion/contraction)
- May also be reflection cracking from shrinkage cracks in cement treated base or underlying HMA/AC
- Poor HMA/AC compaction allows air to enter and age the asphalt faster



**Good compaction limits entry of air
and slows oxidation**

Block Cracking

- Block cracking is top-down
- Distress descriptions can be seen in the ***FHWA Distress Identification Manual***



Age-Related Cracking: Strategies

- Keep the surface protected from aging
- Can potentially use perpetual fog seals, or slurry seal or micro surfacings
 - Slurry seal typically not applied to RHMA/ARHM
- What frequency?
 - After aging has progressed
 - About 7 to 12 years
 - Before cracking starts
 - Do not let cracking get extensive
 - Doing more frequently is not cost-effective



Moisture Damage

- Moisture damage is assessed by taking both dry and wet cores and measuring the in-situ pavement permeability.
- The extent of moisture damage evaluated for each core.



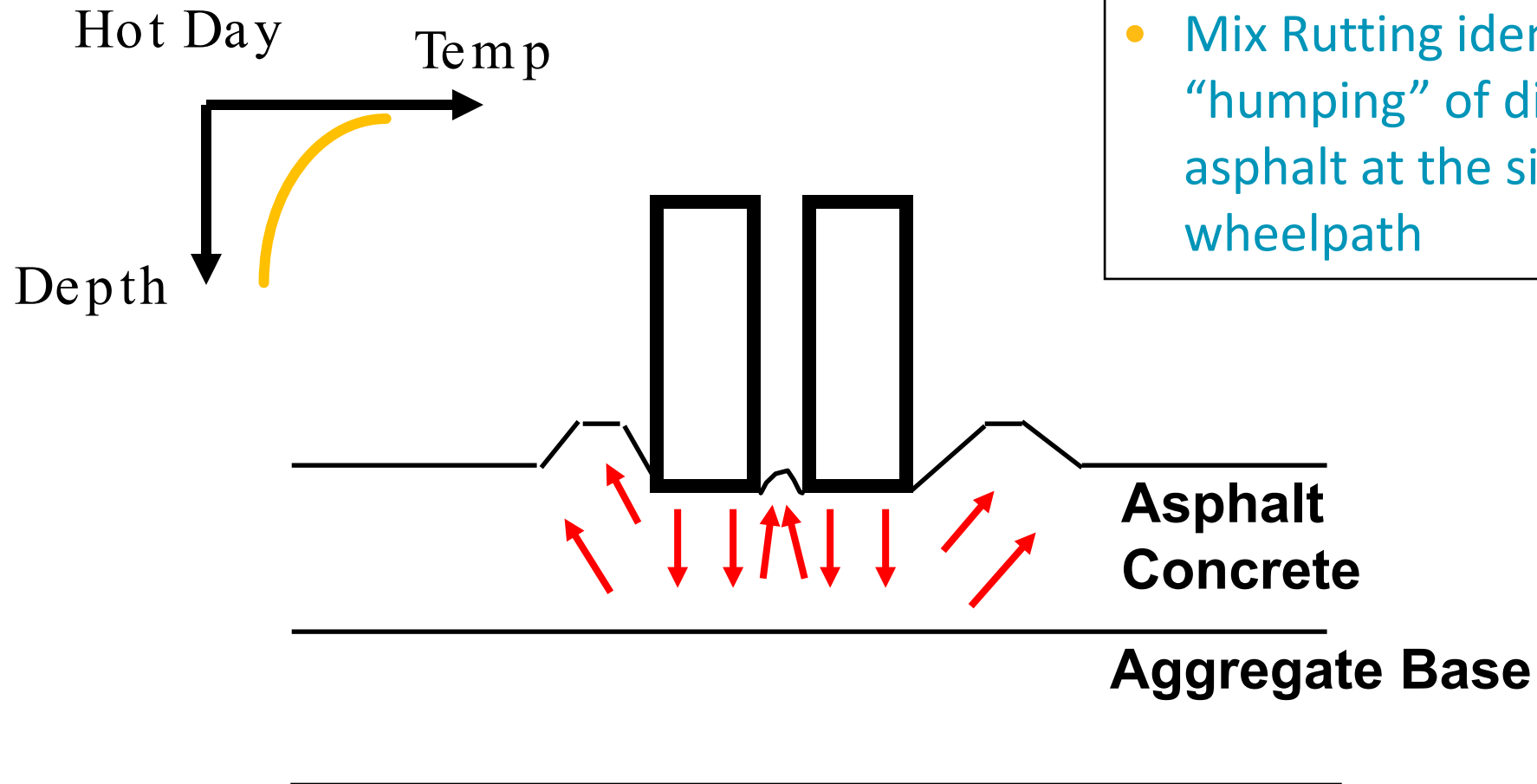
Moisture Damage



- Layer 1 AV=13%
- Layer 2 AV=6.3%
- Water entered 1, trapped between layers

AC/HMA Mix Rutting

- High shear stresses at edges of tires
- Asphalt softer under slow moving traffic
- Mix Rutting identified by “humping” of displaced asphalt at the sides of wheelpath



AC/HMA Mix Rutting

- **Poor compaction makes rutting happen faster**
- **Much more shearing**
- **Some due to more compaction from traffic**
 - But only in wheel paths
 - Doesn't help with aging and block cracking



Other Distresses: Delamination/Debonding

- Lack of bonding reduces overlay fatigue life by about 50%, even if no shoving
- Due to insufficient tack coat application
- Surface must be dry, clean, free of dust and residual millings
- Place between lifts, even if underlying lift is still hot
- Specify by residual amount
- Track-resistant materials available
- Spray pavers available



Delamination/Debonding: Tack Coat Application

- Proper tack coat application results in the pavement layers acting as a composite section
- Analogous to glue used in structural laminated beam
- Uniform application over the pavement surface, not streaked
- Ensure spray bar is pressurized and discharge cones overlap at least twice
- Encourage proper application by making a **separate Bid Item**.



Pavement Condition Index (PCI)

The “More” and the “Less”

Choosing Cost-Effective Strategies: Use of PMS Data and LCCA

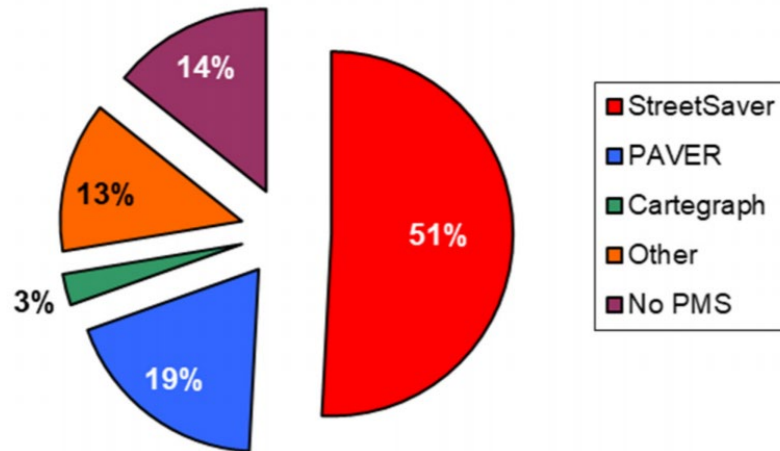


Figure B.4 PMS Software Used by Cities And Counties

- Understanding the performance of your pavements is key to good pavement management and life cycle cost analysis (LCCA).
- ***Pavement condition*** is typically calculated and described in terms of pavement condition index (PCI).
- Agencies need to take one step back behind PCI to better understand ***pavement performance*** in order to better understand PMS data and make better strategy decisions.

Pavement Condition Index (PCI)

- **Definition/Standard:**

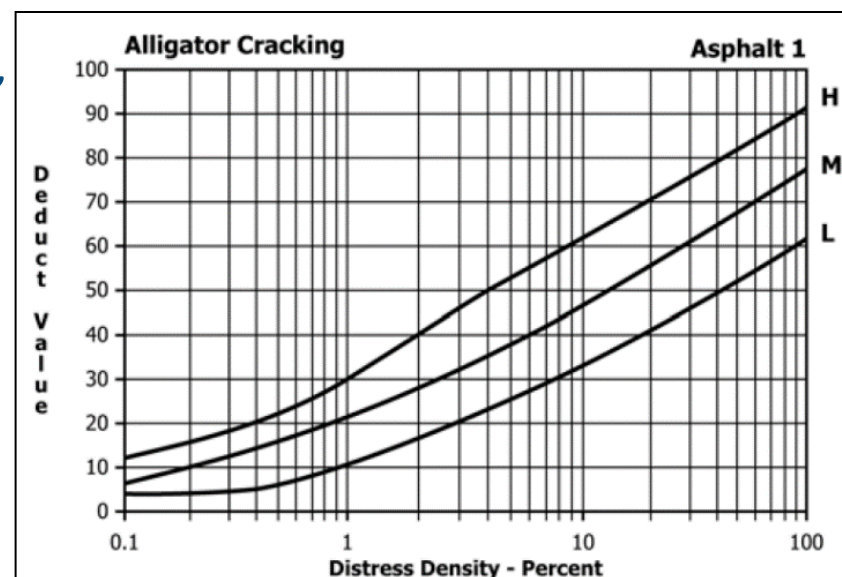
- *“A numerical rating resulting from a pavement condition survey that represents the severity of surface distresses.” FHWA, Practical Guide for Quality Management of Pavement Condition Data Collection, page 87*
- *ASTM D6433, “Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys”*



Pavement Condition Index (PCI)

- **Calculation:**

- *“An equation converts the severity and extent of each distress into a so-called “deduct value”; different deduct equations are used for the different distress types.*
- *All the deduct values obtained across all the distress types are then added up and subtracted from 100.*
- *The result is a PCI on a scale of 0 to 100.”*



Variables in the PCI

- **Fatigue cracking and potholes caused by heavy loads:**
 - Alligator cracking
 - Potholes
- **Cracking caused by aging:**
 - Block cracking
 - Joint reflections
 - Longitudinal and transverse cracking

- **Other distresses:**
 - Low ride quality
 - Bleeding
 - Bumps and sags
 - Corrugations
 - Depressions
 - Edge cracking
 - Lane/shoulder drop-off
 - Patching and utility cut patching
 - Polished aggregate
 - Rutting
 - Shoving
 - Slippage cracking
 - Swelling
 - Weathering and raveling

Pavement Condition Index (PCI)

- **Problems and Limitations:**
 - *“... it has **limitations as an engineering tool** for local governments making pavement management decisions.”*
 - *“Specifically, when a **PCI** is developed from condition survey data, **a lot of important engineering information is lost**, particularly data regarding cracking.”*
 - *“A major deficiency in **PCI** is that roadway segments **can have the same or similar PCI [a tie score]** but **very different types of distress**.”*

Same or Similar PCI:

Different Distresses = Different Strategies

CASE 1: TRAFFIC LOADING RELATED, PCI = 34

DISTRESS	SEVERITY	QUANTITY	DV
Alligator Cracks	High	1x6	18
Alligator Cracks	Medium	1x4 1x5 1x7	17
Potholes	Medium	3	48
Potholes	Low	3	30
Rutting	Low	2x5 2x8	10

CASE 2: AGE, CONSTRUCTION, UTILITIES, OTHER FACTORS, PCI = 32

Long/Trans Crack	High	15 20 8 6 12 18 6x7	43
Long/Trans Crack	Medium	25x2 18 13 9 10	20
Patching/Utility	High	25x4 25x2	40
Patching/Utility	Medium	12x6 4x7	20
Block Cracks	High	4x6 6x5	13

Pavement Condition Index (PCI)

- The “Tiebreaker:”
 - *“For these cases, **examining the distress types and extents of the distresses and their effect on the pavement structure, along with other available project-level data**, could serve as a tiebreaker to augment PCI making network-level and project scoping decisions.”*

Summary: The “More” and the “Less”

- **What’s “Less”?**
 - *“PCI is a simple, effective communication tool, but when used alone it is insufficient for choosing the right strategy at the right time to maximize the cost-effectiveness of pavement funding.”*
 - PCI is not a measure of structure.
 - PCI alone is less information than is needed to select the appropriate strategy based on pavement distress
- **What’s “More?”**
 - *“Managing pavement networks primarily based on identification of age- and load-related cracking will result in **more** informed and cost-effective treatment timing and selection.”*
 - More project-level analysis and information is needed in order to select the appropriate strategy.

Project-Level Analysis

An overview of common destructive and non-destructive testing

Destructive/Non-Destructive Testing

- **Destructive Testing:**
 - Cores
 - Borings
 - Material Testing
- **Non-Destructive Testing:**
 - Falling Weight Deflectometer (FWD)
 - Dynamic Cone Penetrometer (DCP)
 - Ground Penetrating Radar



Cores



- Notes (photos to the right):
 - Core was taken around the crack
 - Various layers include soil mix pavement (bottom)

Material Testing

- **Material Testing (Subgrade Soil Characterization):**
 - Atterberg Limits: CT 204/ASTM D4318/AASHTO T 90
 - Liquid Limit (LL)
 - Plastic Limit (PL)
 - Plasticity Index (PI)
 - Expansive Soils: $PI > 12$
 - Sieve Analysis: CT 202
- **Material Testing (Subgrade Strength):**
 - California R-Value
 - California Bearing Ratio

Falling Weight Deflectometer (FWD)

- California Test 356 (357 for M-E design)



Dynamic Cone Penetrometer (DCP)

- ASTM D6951
- Works well with core holes
- Limited to upper one meter of soil
- Approximate (empirical) relationships with CBR and R-Value
- Relates to elastic modulus



Ground Penetrating Radar (GPR)

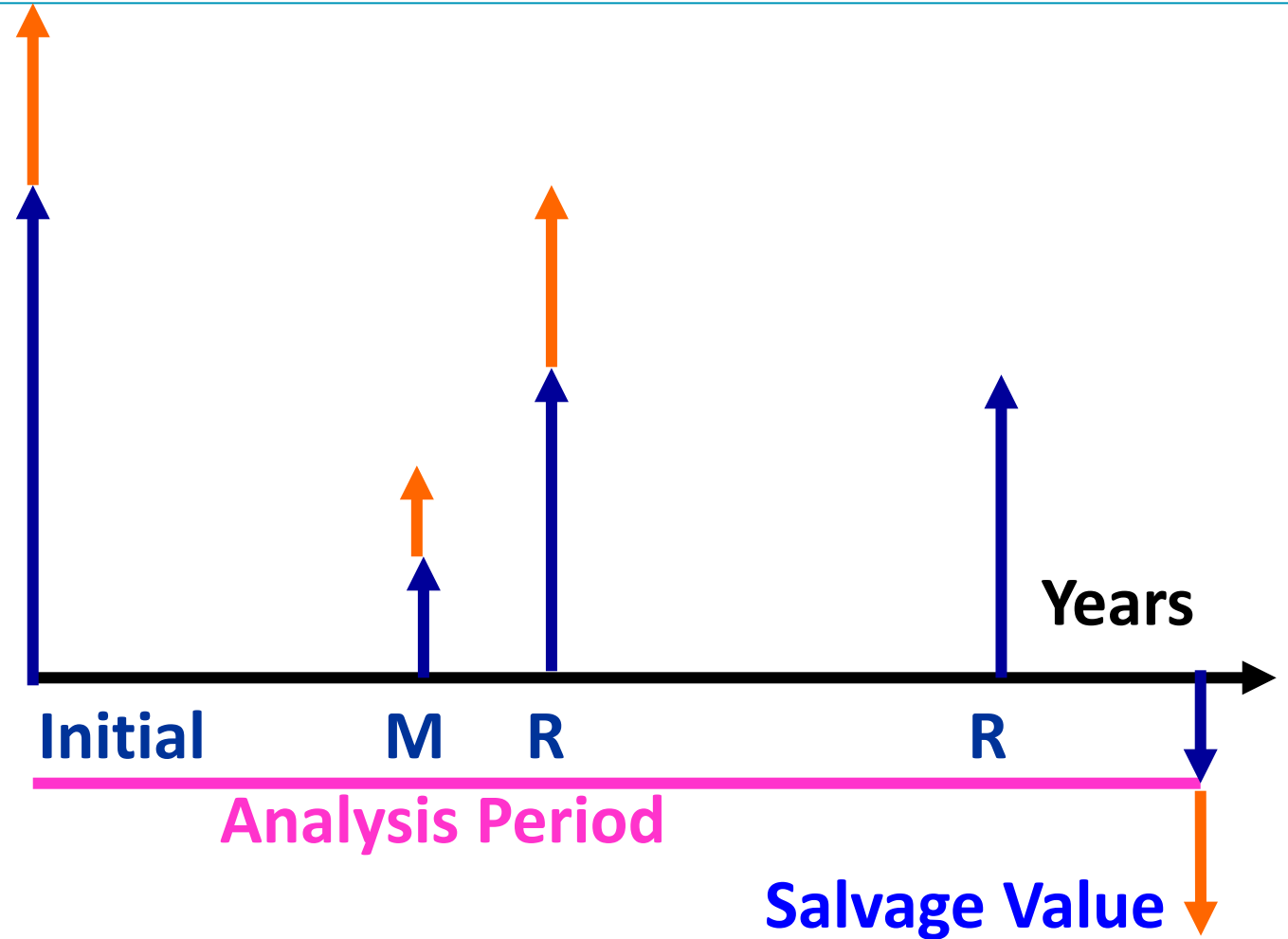
- Analogous to an X-Ray
- Provides continuous pavement thicknesses
- Compare to, and calibrate based on, cores
- Readily performed on a network or project level
- Incorporate data into pavement management system



Life Cycle Cost Analysis

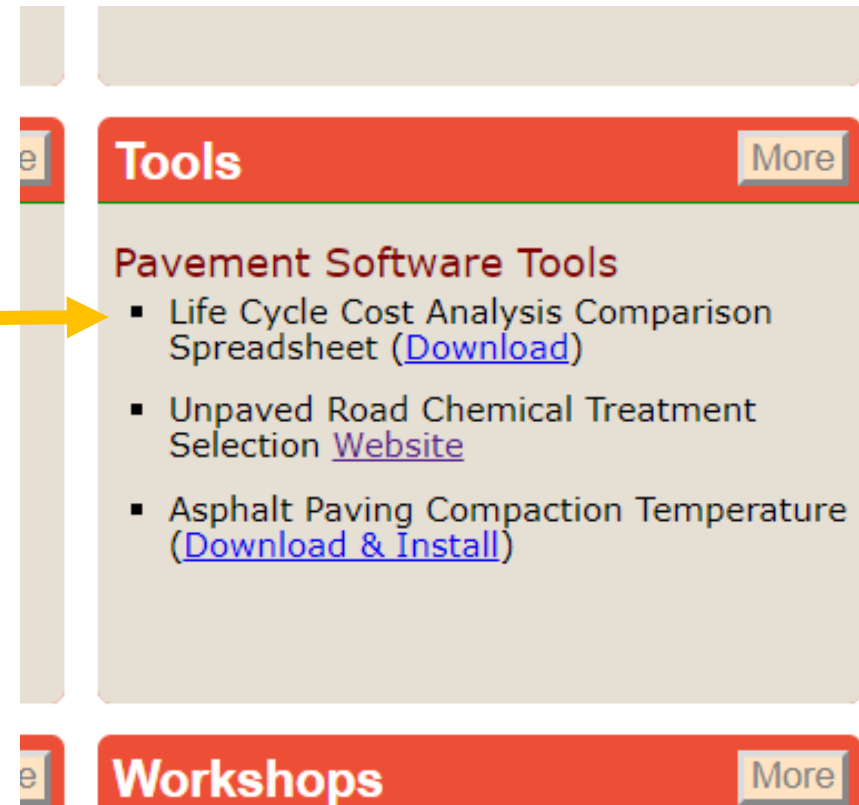
Life Cycle Cost Analysis (LCCA)

- Net Present Value = the total of costs over the analysis period, including discount rate.
- Equivalent Uniform Annual Cost = spread NPV over time, with discount.
- \$ (Agency Costs)
- \$ (User Costs)



CCPIC LCCA Excel Tool

- Excel tool to calculate Net Present Value, Salvage Value and Equivalent Uniform Annual Cost
- Can compare 3 scenarios side by side
- Can choose and edit the list and sequence of treatments



The screenshot shows a website navigation menu with two main sections: 'Tools' and 'Workshops'. The 'Tools' section is highlighted in red and contains a sub-section titled 'Pavement Software Tools'. Under this sub-section, there are three items listed with bullet points:

- Life Cycle Cost Analysis Comparison Spreadsheet ([Download](#))
- Unpaved Road Chemical Treatment Selection [Website](#)
- Asphalt Paving Compaction Temperature ([Download & Install](#))

The 'Workshops' section is also highlighted in red and has a 'More' button next to it. A yellow arrow points from the first bullet point in the text box on the left to the 'Tools' section header.

LCCA: Effect of Asphalt Compaction

- Use a quantitative (*not method*) specification to measure compaction.
- Reference a standard specification or write the spec in terms of *in-place bulk density* and *theoretical maximum density* (TMD), and not *laboratory theoretical maximum density* (LTMD)
- Use cores or nuclear gauges correlated for the specific mix/project as the basis for determining the in-place density on at least a daily basis
- Apply, **and enforce**, payment reductions if the compaction doesn't meet your specifications.
- Caltrans Standard Specifications specify TMD
- A future change to the Greenbook, Change No. 301SM, will specify TMD.

General rule: 1% increase in constructed air-voids = 10% reduction in fatigue life



LCCA: Effect of Asphalt Compaction

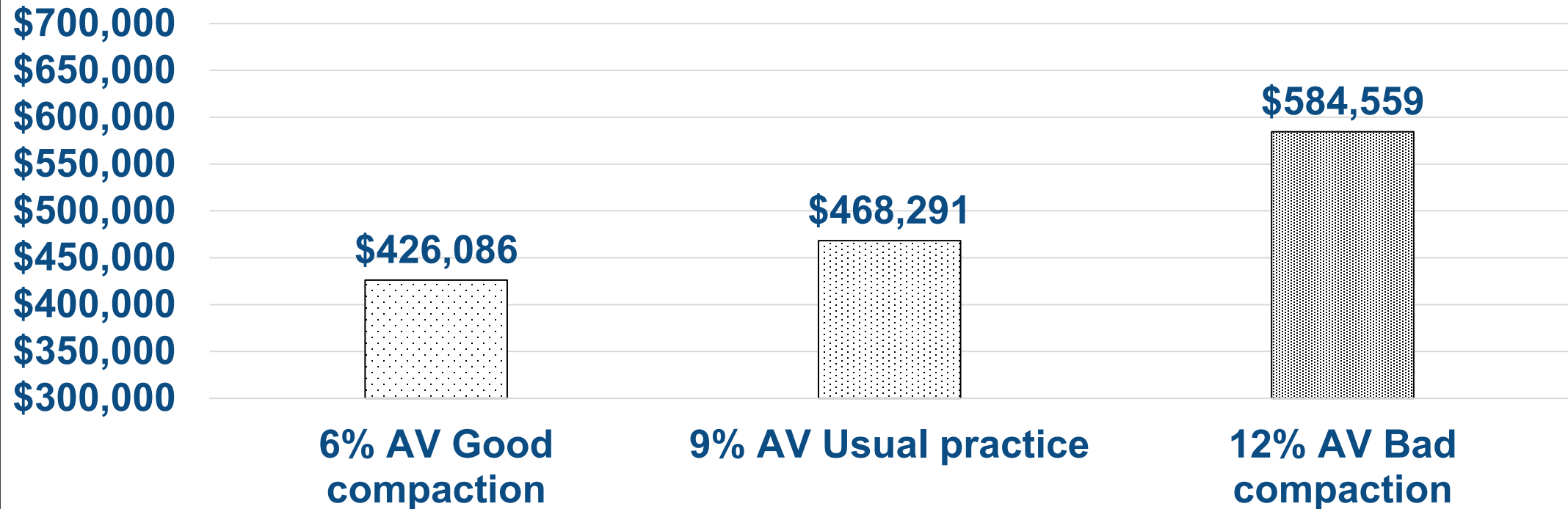
- Won't this increase the bid cost for my asphalt?
- Isn't the cost of managing this specification high?
- Won't coring damage my new pavement?
- What can I do to help my contractors meet and exceed the specification and further increase the life of my overlays?

- Yes, but not significantly. The additional expense will be recovered by the lower life cycle cost.
- No.
- Cores are only needed from the test strip to correlate the nuclear gauge. If the compaction meets specifications, no further coring will be necessary.
- Require QC testing. Discuss at a pre-paving meeting.



LCCA: Effect of Asphalt Compaction

Compaction effect, continuous rehab strategy
(1 lane mile)



Strategy Selection

Considerations for Future Projects

Questions to Ask

- Are the cracks due to fatigue in the wheel paths (traffic), or aging of entire surface (environment), or both?
- Is the network-level strategy in the PMS appropriate for the types of cracking?
- Did the last project on the same route perform as expected? If not:
 - What's changed?
 - Is the structural section adequate?
 - Was a thorough project-level investigation, associated testing, and calculations performed?
 - Was the appropriate strategy selected?
 - What binder was used? Should a modified binder (polymer, asphalt-rubber) be used in the next project (particularly useful if inlay/overlying cracking)?

Pavement “MRI”: Before Strategy Selection

- **M = Materials:**
 - What is the structural section composed of?
 - Subgrade, base material type and thickness, HMA/AC (gradation, binder type, thickness).
- **R = Review:**
 - Completed projects at 3, 5, and 10-year milestones.
 - As-built plans,
 - Material testing records,
 - Traffic counts/traffic index calculations/projections,
 - Resident Engineer/Inspector records,
 - Change Orders.

Pavement “MRI”: Before Strategy Selection

- **I = Investigation:**

- Was a project-level site investigation performed?
- Borings
- Cores
- Dynamic Cone Penetrometer (DCP)
- Falling Weight Deflectometer (FWD)
- Subgrade Soil Classification Testing (SE, R-Value/CBR, PI)

Summary

Takeaways for thought and application

Takeaways

- The ability to make good engineering decisions regarding the timing and type of strategy based only on PCI is limited; analyze the cracking.
- Life cycle cost analysis (LCCA) is a practical tool to determine the most cost-effective strategies:
 - Needs good performance estimates, agencies can use their own information
 - Focus on cracking, separated by:
 - Streets with heavy trucks/buses, wheel path fatigue cracking and age related cracking: will need rehabilitation eventually
 - Streets with no heavy vehicles, age related cracking only: can use only preservation treatments if timely

Resources

References and Links

References/Links

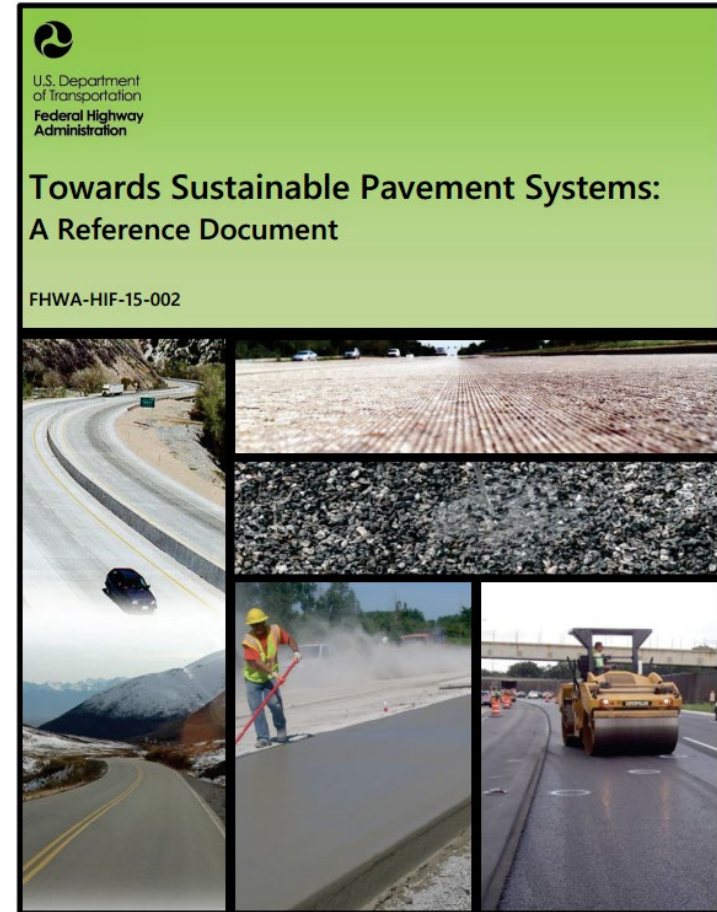
- **City and County Pavement Improvement Center (CCPIC):**
www.ucprc.ucdavis.edu/ccpic
- ***“Pavement Condition Index (PCI): There’s More (and Less) to the Score”***
[www.ucprc.ucdavis.edu/ccpic/pdf/PCI 4-Page final v2.pdf](http://www.ucprc.ucdavis.edu/ccpic/pdf/PCI%204-Page%20final%20v2.pdf)
- **University of California Pavement Research Center (UCPRC):**
www.ucprc.ucdavis.edu
- **Maintenance Technical Advisory Guides (MTAG):**
<https://www.csuchico.edu/cp2c/library/caltrans-documents.shtml>

References/Links

- **FHWA “*Distress Identification Manual:*”**
<https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/13092/13092.pdf>
- **Caltrans “*Tack Coat Guidelines:*”**
www.ucprc.ucdavis.edu/ccpic/pdf/Caltrans%20Tack%20Coat%20Guidelines.PDF

Sustainable Pavements

- FHWA Sustainable Pavements Task Group
 - Sustainable pavement reference document (2015)
 - Covers everything about pavement and sustainability
 - Cost
 - Environment
 - (they usually go together)
 - Tech briefs and webinars



- http://www.fhwa.dot.gov/pavement/sustainability/ref_doc.cfm

Questions?

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- **Erik Updyke:** eupdyke@ucdavis.edu