Evolution of Pavement Design at ADOT

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2012 Arizona Pavements / Materials Conference

October 30-31, 2012

Arizona State University

A Little History

- 1960’s to Present

The 60’s

- AASHO Interim Guide for the Design of Rigid and Flexible Pavements - 1961
- Asphalt Institute Thickness Design (MS-1) – April1965
  - Traffic Analysis – 18 kip single axle loads
  - Mechanical Strength Tests – (CBR, R-Value, Plate Bearing Test)
  - Thickness Design Charts


Seventies
70s

The 70's

- 1972 AASHTO Interim Guide for Pavement Structures
- Deflection Based Designs for O/L's
- Pavement Management System
- Soil Stabilization
- Recycle projects
- Asphalt Rubber SAM's and SAMI's
- Heater Scarification

80s

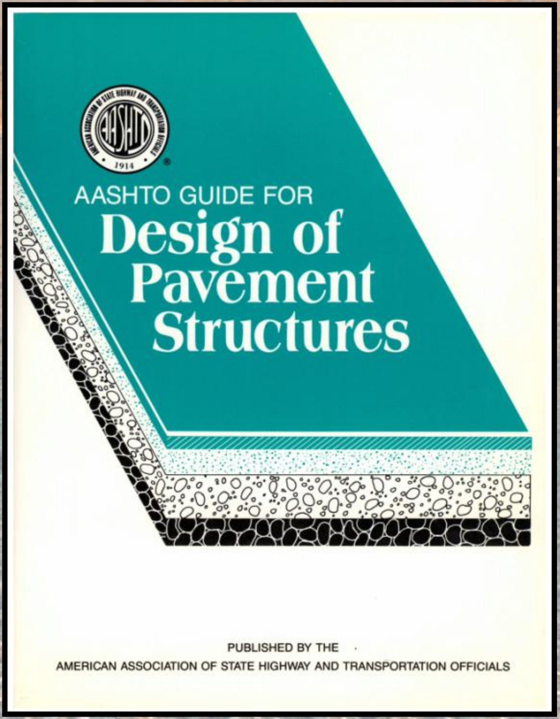
The 80’s

- AASHTO 1986
- Milling Machines
- Falling Weight Deflectometer (FWD)
- SODA
- Cold In-Place Recycling
- Asphalt Rubber

Where We Are:
ADOT Current Design Practices

- 1993 AASHTO Pavement Design Guide
  - Flexible Pavements
  - Rigid Pavements

- Materials
  - Superpave Mix Design
  - PG Binder Grading System
  - WMA
  - Back to RAP
  - CIR and HIR



ADOT

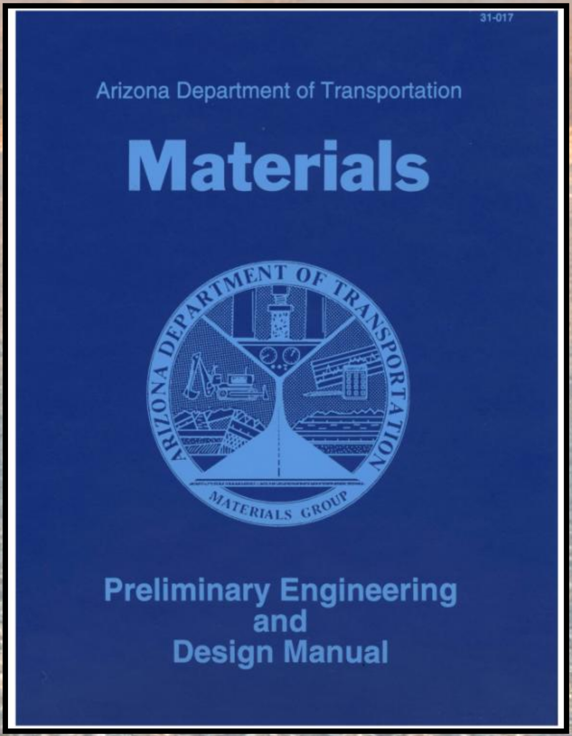
Designing New Pavements

$$\mathrm{Log}_{10}(W_{18}) = Z_R \times S_O + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

- 1993 AASHTO Pavement Design Guide
- Calculates Structural Number (SN)
- Traffic (cumulative 18 –Kip ESAL’s)
- Standard error for traffic and overall pavement performance prediction (S_0)
- Initial and Terminal design serviceability index (P_0 & P_t)
- Reliability (Z_R) – likelihood of pavement failure within design period. Typically 90% – 99% used.
- Resilient Modulus (M_R)
- Seasonal Variation Factor (SVF)

ADOT Current Design Practices

- Structural Overlay Design for Arizona (SODA)
  - Rehabilitation of existing flexible pavements



Pavement Rehabilitation

- Structural Overlay Design for Arizona (SODA)
- Traffic (18-Kip ESAL's)
- Deflection Data (FWD)
- Spreadability Index
- Seasonal Variation Factor (SVF)
- Road Roughness (IRI)

A Vision for the Future – SPR-402

"Development of Performance Related Specifications for Asphalt Pavements in the State of Arizona"

Arizona State University

Plan and Committee

- Five year research effort
- 3 phases
- 14 individual projects
- $1.5 million effort
- Began in 1999

Three Phases

- Phase I, (project 1) - work plan for long range pavement research program
- Phase II, (project 2 – 11) - materials characterization
- Phase III, (project 12 – 14) - calibration /validation, performance related specifications

SPR-402 – Phase II

- Materials Characterization
- Subgrade materials
- Base materials
- Binders
- Mixes
- Acquired Testing Equipment
- 2006 – ran out of $

Three Phases

- ✓ Phase I, (project 1) - work plan for long range pavement research program
- ✓ Phase II, (project 2 – 11) - materials characterization
- ● Phase III, (project 12 – 14) - calibration /validation, performance related specifications

Traffic Inputs – SPR 672

- Development of a Traffic Data Input System in AZ for the MEPDG
  - Research completed by ARA
    - Default Statewide level 2/3 traffic inputs
      - Vehicle class distribution
      - Monthly adjustment factors
      - Hourly distribution
      - Axle load distribution factors
      - Number of axles per truck
      - Lateral wander
      - Truck wheel base

Calibration & Validation – SPR-606

"Calibration and Implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide in Arizona"

Applied Research Associates

ARA

Why Local Calibration?

- To ensure that all design inputs are proper and that they are tailored to Arizona conditions and resources.
- To ensure that the distress and IRI prediction models are unbiased (e.g., do not consistently over or under predict).
- To reduce the error of prediction of the distress and IRI models (used in design reliability).
- To provide a user's guide and training for ADOT designers.

Calibration Steps

- Verification
  - Verification involved testing the model predictions using global coefficients but using only AZ performance data. If the model showed bias (over or under prediction overall) it was identified for re-calibration.

Calibration Steps

- Re-Calibration
  - Re-Calibration involved deriving new local coefficients for each model using the AZ performance data to remove the bias and reduce the prediction error. (90% of calibration database used).

Calibration Steps

- Validation
  - Validation involved a further independent check of the models using the 10 percent of the calibration database withheld from the calibration effort.

  This process was done to check that the MEPDG "local Arizona" models work as intended

Why Calibrate?

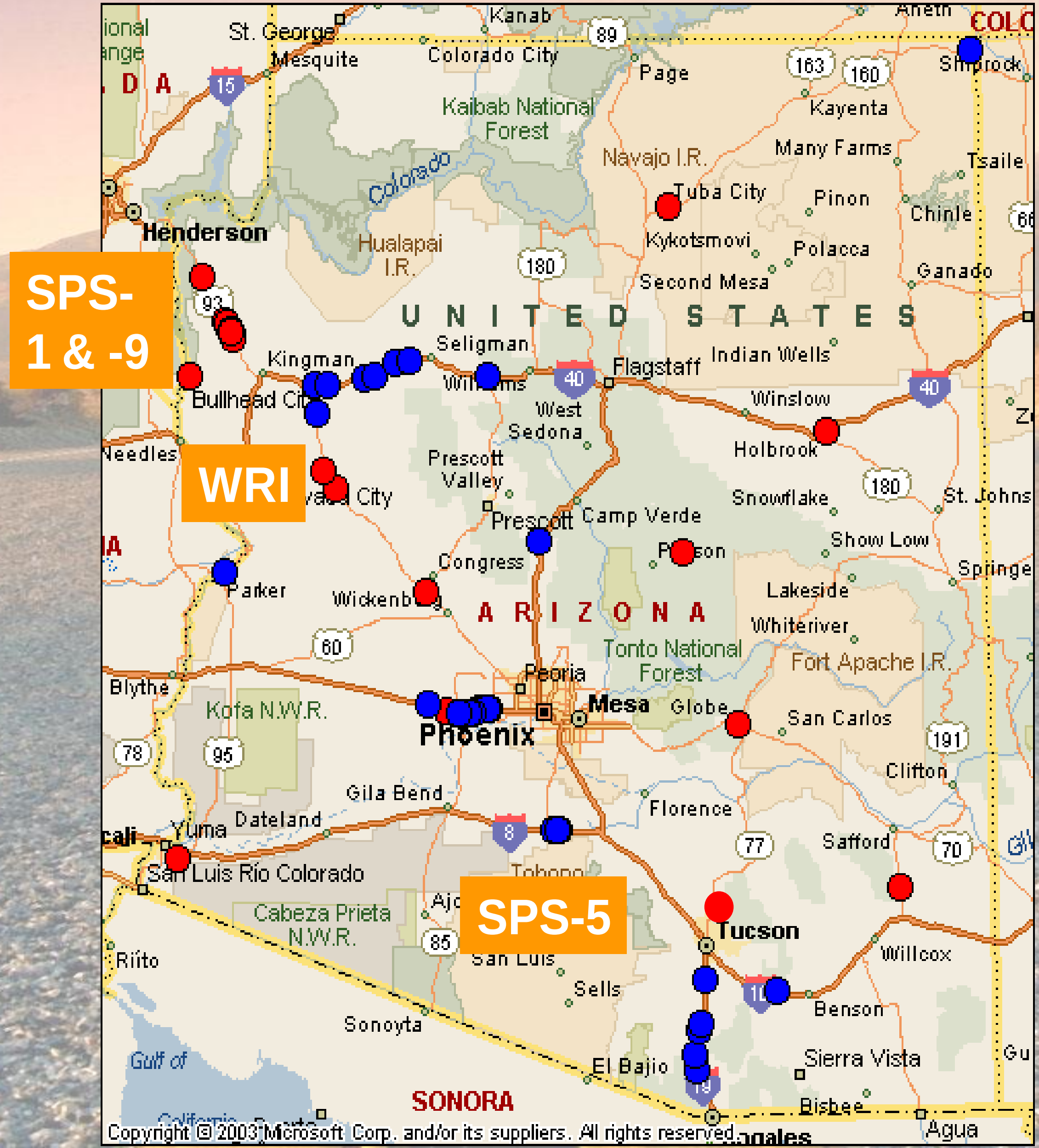
- The goodness of fit for the HMA IRI model improved from R^2 = 30% with global coefficients to 80% with Arizona specific coefficients. The standard error of IRI was reduced from 19 to 8 in/mile.

Calibration Sites

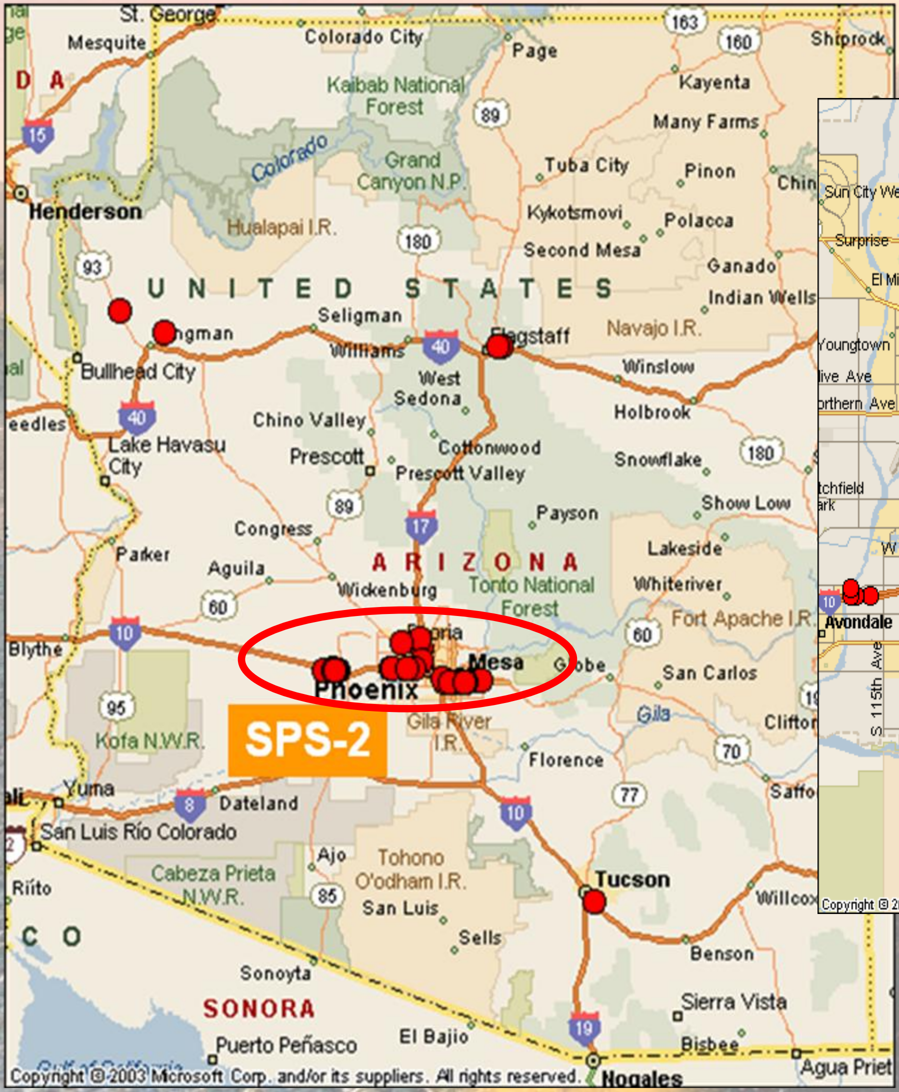
- Total of 180 sections
  - 120 LTPP
  - 36 ADOT Pavement Management Sections
  - 20 ADOT SPR 264 sections (concrete pavements)
  - 4 ADOT WRI sections

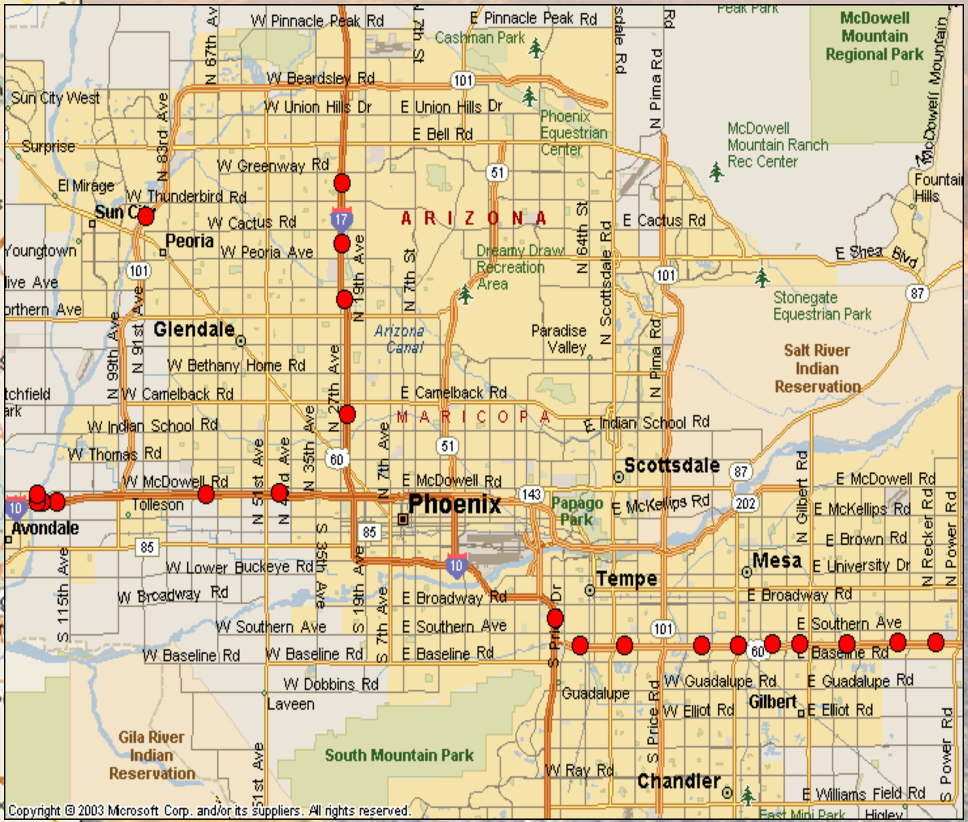
All sites had detailed design, construction, materials testing and distress survey data.

New HMA & HMA/HMA Pavements



New JPCP and CRCP





Composite (HMA overlaid JPCP and CRCP) Pavement

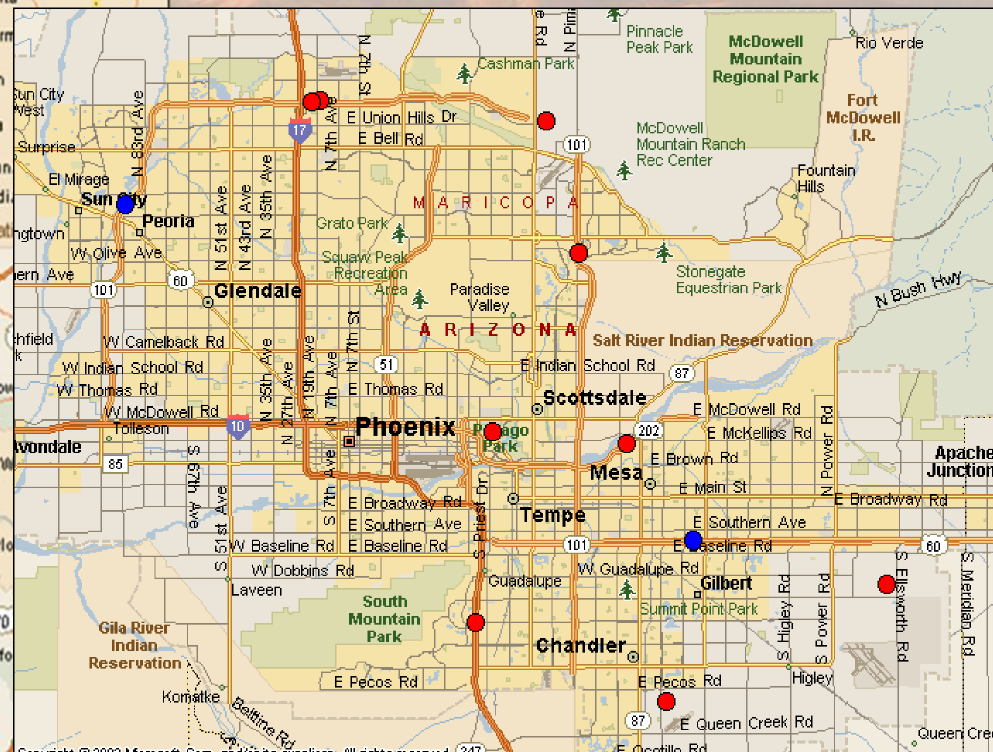


Table 59. DARWin-ME local calibration coefficients for new HMA and HMA overlaid HMA pavement.

Model or Submodel Type	Model Coefficients	ADOT Local Calibration	Change from "Global" Models
Fatigue Damage Model (AC Fatigue)	K1	0.007566	No
	K2	3.9492	No
	K3	1.281	No
	BF1	249.0087232	Yes
	BF2	1	No
	BF3	1.233411397	Yes
Alligator Cracking Model (AC Cracking Bottom)	C1	1	No
	C2	4.5	Yes
	C4	6000	No
	AC Cracking Bottom Standard deviation	1.1+22.9/(1+exp(-0.1214-2.0565*LOG10(BOTTOM+0.0001)))	Yes
Reflection Cracking Model	a	3.5+0.75heff	No
	b	$-0.688584-3.37302*heff^{-0.915469}$	No
	c	2.55	Yes
	d	1.23	Yes
AC Rutting	K1	-3.35412	No
	K2	1.5606	No
	K3	0.4791	No
	BR1	0.69	Yes
	BR2	1	No
	BR3	1	No
	AC Rutting Standard Deviation	0.0999*Pow(RUT,0.174)+0.001	Yes
Base Rutting (Granular Subgrade Rutting)	K1 (Base)	2.03	No
	BS1 (Base)	0.14	Yes
	Base Rutting Standard Deviation	0.05*Pow(BASERUT,0.115)+0.001	Yes
Subgrade Rutting (Fine Subgrade Rutting)	K1 (subgrade)	1.35	No
	BS1 (Subgrade)	0.37	Yes
	Subgrade Rutting Standard Deviation	0.05*Pow(SUBRUT,0.085)+0.001	Yes
HMA Transverse Cracking Model (Thermal Fracture)	Thermal Fracture Level 1K	1.5	No
	Thermal Fracture Level 1Standard Deviation	0.1468 * THERMAL + 65.027	No
	Thermal Fracture Level 2K	0.5	No
	Thermal Fracture Level 2Standard Deviation	0.2841 *THERMAL + 55.462	No
	Thermal Fracture Level 3K	1.5	No
	Thermal Fracture Level 3Standard Deviation	0.3972 * THERMAL + 20.422	No
HMA IRI Model	C1 (for Rutting)	1.2281	Yes
	C2 (for Fatigue)	0.1175	Yes
	C3 (for Transverse)	0.008	No
	C4 (for Site Factor)	0.0280	Yes

Table 60. DARWin-ME local calibration coefficients for new JPCP.

Model or Submodel Type	Model Coefficients	ADOT Local Calibration	Change from NCHRP 1-40D "Global" Models
PCC Fatigue Model	C1	2	No
	C2	1.22	No
JPCP Transverse Cracking Model	C4	0.19	Yes
	C5	-2.067	Yes
	PCC Cracking Standard Deviation	Pow(9.87*CRACK,0.4012)+0.5	Yes
Faulting Model	C1	0.0355	Yes
	C2	0.1147	Yes
	C3	0.00436	Yes
	C4	1.1E-07	Yes
	C5	20000	Yes
	C6	2.0389	Yes
	C7	0.1890	Yes
	C8	400	No
	PCC Faulting Standard Deviation	Pow(0.037*FAULT,0.6532)+0.001	Yes
JPCP IRI Model	J1 (for Cracking)	0.60	Yes
	J2 (for Spalling)	3.48	Yes
	J3 (for Faulting)	1.22	Yes
	J4 (for Site Factor)	45.20	Yes
	PCC IRI JPCP Standard Deviation	5.4	No

Table 61. DARWin-ME local calibration coefficients for new CRCP.

Model or Submodel Type	Model Coefficients	ADOT Local Calibration	Change from NCHRP 1-40D "Global" Models
PCC Fatigue Model	C1	2	No
	C2	1.22	No
CRCP Punchout Model	C3	85	Yes
	C4	1.4149	Yes
	C5	-0.8061	Yes
	PCC Punchout Standard Deviation	1.5+2.9622*Pow(PO,0.4356)	Yes
CRCP IRI Model	C1	3.15	No
	C2	28.35	No
	PCC IRI CRCP Standard Deviation	5.4	No

Table 64. Comparison of MEPDG "global" and Arizona specific model goodness of fit statistics.

Pavement Type	Distress/IRI Models	Global Models		Arizona DOT Calibrated Models	
		Global R^2, percent*	Global Model Standard Error, SEE*	Arizona R^2, percent	Arizona Standard Error, SEE
New HMA & HMA Overlay	Alligator cracking	8	14 percent	58	13 percent
	Transverse "thermal" cracking	NA	NA	Not Calibrated	Not Calibrated
	Total rutting	5	0.31 in	21	0.12 in
	IRI	30	19 in/mile	80	8 in/mile
New JPCP	Transverse cracking	20	9 percent	78	6 percent
	Transverse joint faulting	45	0.03 in	52	0.03 in
	IRI	35	25 in/mile	81	10 in/mile
ARFC/JPCP	Transverse cracking	Same as JPCP	Same as JPCP	Same as JPCP	Same as JPCP
	Rutting	Same as HMA	Same as HMA	Same as AZ HMA	Same as AZ HMA
	IRI	Same as HMA	Same as HMA	Same as AZ HMA	Same as AZ HMA
New CRCP	Punchouts	68%	5 PO/mile	Same as Global	2 AZ CRCP matched global predictions
	Slab/Base Friction	Established Values	NA	Same as Global	NA

*Global calibration coefficients using the Arizona database.

Summary Of Changes To DARWin-ME For Arizona

DARWin-ME™

Mechanistic Empirical Pavement Design

ADOT

Summary Of AZ Calibration Changes

- **Distress & IRI prediction model coefficients were modified to provide improved prediction & design:**
  - HMA pavement
    - Total rutting
    - Fatigue cracking (bottom up)
    - IRI
    - Transverse cracking (could not be calibrated, will not predict cracking for warm climate locations)
  - JPCP & Composite
    - Transverse fatigue cracking
    - Joint faulting
    - IRI

Summary Of Other AZ Changes

- **Changes in various design input recommendations:**
  - Design reliability levels for AZ
  - Design standard deviation models all distresses for AZ
  - AZ recommended Level 2 and 3 inputs for all materials and design types
  - Recommended procedure for AC overlay design
  - Numerous other input recommendations tailored to AZ conditions (initial IRI, strength of PCC, traffic inputs, unbound base resilient modulus, other material defaults, etc.)

ADOT DARWin-ME Users Guide

Arizona DOT
USER GUIDE FOR
AASHTO DARWin-ME
Pavement Design Guide

Submitted to:

Arizona Department of Transportation
206 S. 17th Ave.
Phoenix, AZ 85007

Submitted by:

ARA
100 Trade Centre Dr., Suite 200
Champaign, IL 61820

July 19 2012

ADOT

ADOT DARWin-ME Users Guide

- Overview of Manual
- General Information
- Performance Criteria
- Reliability
- Traffic Inputs
- Climate
- Materials
- Sensitivity
- Concrete
- Rehabilitation
- AZ Calibration Factors
- Example Problems

Design Example – New HMA

US 93, MP 2.4 to MP 17.2

93' AASHTO DESIGN

- ESAL's – 16,200,000
- R-value – 46
- Mr – 26,000
- SVF – 1.2
- Reliability – 95%
- Std Dev – 0.35

- SN_{req} – 3.55
- SN_{des} – 3.60
- 5" AC over 10" AB

Same Project – DARWin-ME

Hoover Dam to MP 17_AC5.0

File Name: C:\Documents and Settings\b5395\Desktop\Hoover Dam to MP 17_AC5.0.dgpx

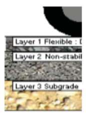
Design Inputs

Design Life: 20 years
Design Type: Flexible Pavement

Base construction: March, 2011
Pavement construction: April, 2011
Traffic opening: May, 2011

Climate Data Sources (Lat/Lon): 35.259, -113.937

Design Structure



Layer type	Material Type	Thickness (in.):
Flexible	Default asphalt concrete	5.0
NonStabilized	AB (Aggregate Base)	10.0
Subgrade	A-1-a	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.8
Air voids (%)	7.6

Traffic

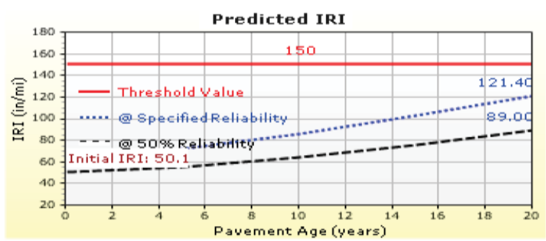
Age (year)	Heavy Trucks (cumulative)
2011 (initial)	801
2021 (10 years)	1,509,270
2031 (20 years)	3,537,600

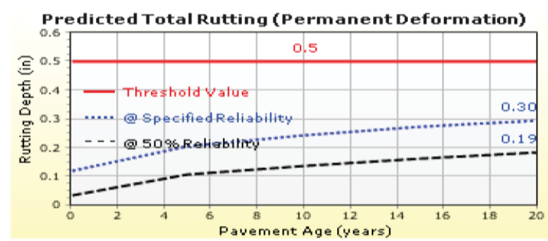
Design Outputs

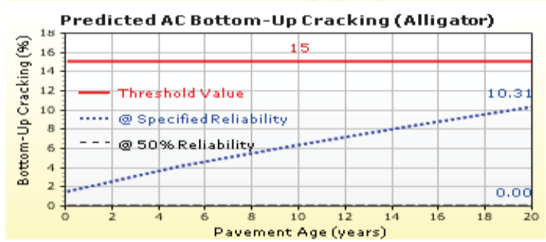
Distress Prediction Summary

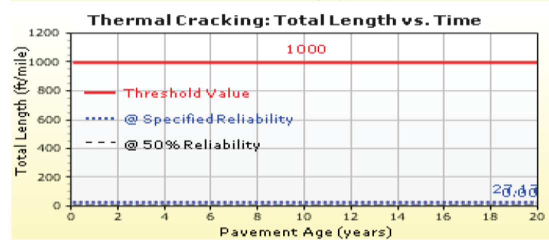
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	150.00	121.38	90.00	99.21	Pass
Permanent deformation - total pavement (in.)	0.50	0.30	90.00	99.99	Pass
AC bottom-up fatigue cracking (percent)	15.00	10.31	90.00	96.88	Pass
AC thermal fracture (ft/mile)	1000.00	27.17	90.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	2066.62	90.00	89.22	Fail
Permanent deformation - AC only (in.)	0.50	0.22	90.00	100.00	Pass

Distress Charts









Same Project – DARWin-ME at 4.5” AC

Hoover Dam to MP 17_AC4.5

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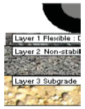
Design Inputs

Design Life: 20 years
Design Type: Flexible Pavement

Base construction: March, 2011
Pavement construction: April, 2011
Traffic opening: May, 2011

Climate Data Sources (Lat/Lon): 35.259, -113.937

Design Structure



Layer type	Material Type	Thickness (in.):
Flexible	Default asphalt concrete	4.5
NonStabilized	AB (Aggregate Base)	10.0
Subgrade	A-1-a	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.8
Air voids (%)	7.6

Traffic

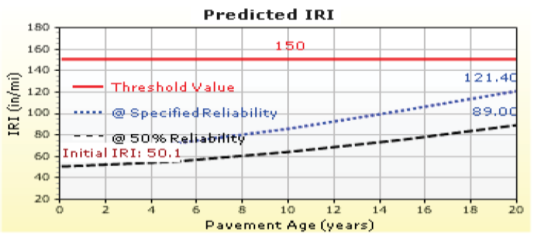
Age (year)	Heavy Trucks (cumulative)
2011 (initial)	801
2021 (10 years)	1,509,270
2031 (20 years)	3,537,600

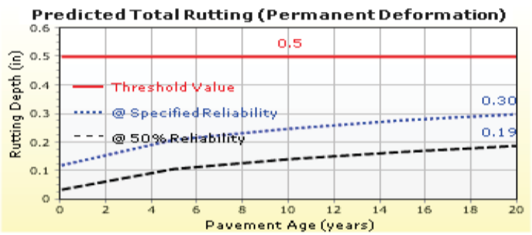
Design Outputs

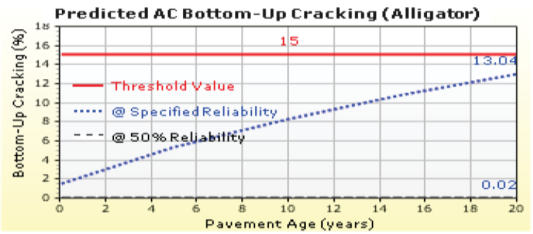
Distress Prediction Summary

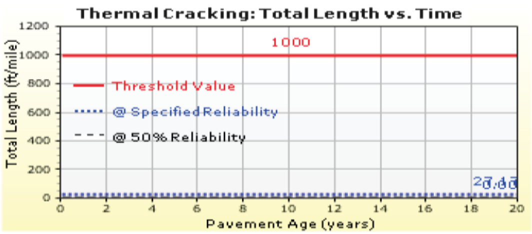
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	150.00	121.40	90.00	99.21	Pass
Permanent deformation - total pavement (in.)	0.50	0.30	90.00	99.98	Pass
AC bottom-up fatigue cracking (percent)	15.00	13.04	90.00	92.99	Pass
AC thermal fracture (ft/mile)	1000.00	27.17	90.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	2097.06	90.00	88.86	Fail
Permanent deformation - AC only (in.)	0.50	0.22	90.00	100.00	Pass

Distress Charts









Same Project – DARWin-ME at 4”

Hoover Dam to MP 17_AC4.0

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Design Inputs

Design Life: 20 years
Design Type: Flexible Pavement

Base construction: March, 2011
Pavement construction: April, 2011
Traffic opening: May, 2011

Climate Data Sources (Lat/Lon): 35.259, -113.937

Design Structure

Layer type	Material Type	Thickness (in.):
Flexible	Default asphalt concrete	4.0
NonStabilized	AB (Aggregate Base)	10.0
Subgrade	A-1-a	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.8
Air voids (%)	7.6

Traffic

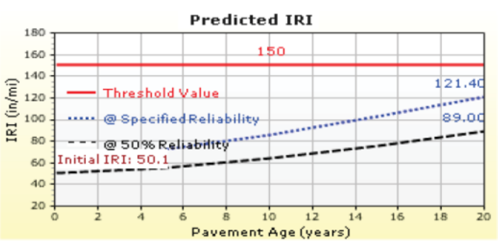
Age (year)	Heavy Trucks (cumulative)
2011 (initial)	801
2021 (10 years)	1,509,270
2031 (20 years)	3,537,600

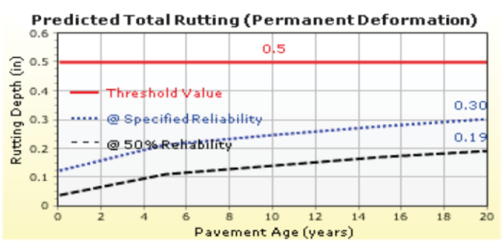
Design Outputs

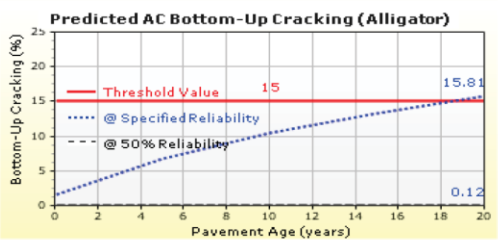
Distress Prediction Summary

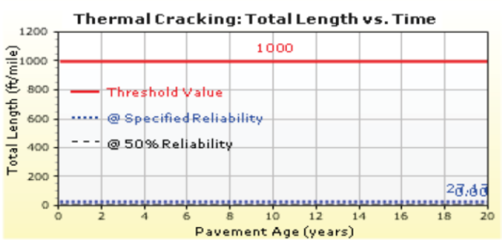
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	150.00	121.44	90.00	99.20	Pass
Permanent deformation - total pavement (in.)	0.50	0.30	90.00	99.98	Pass
AC bottom-up fatigue cracking (percent)	15.00	15.81	90.00	88.80	Fail
AC thermal fracture (ft/mile)	1000.00	27.17	90.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	2040.87	90.00	89.52	Fail
Permanent deformation - AC only (in.)	0.50	0.22	90.00	100.00	Pass

Distress Charts









Design Example – Rehabilitation

I-40, MP 239.95 to MP 250.25

Constructed 2009

SODA Design

- AADT - 16,500 (2007); 47% Trucks; AADTT - 7,755;
- ESAL's – 18,800,000 (10 years)
- Existing 11" AC; 4" BB; 2" AB, 6" SM
- SODA: @4" mill – No Overlay needed; 2005 FWD
- Design: 5" mill, 4.5" replace and ½" AR-ACFC

Same Project – DARWin-ME (As – Built)

DARWin ME Mechanistic Empirical Pavement Design

Dennison to County Line_Constructed

File Name: C:\Documents and Settings\b5395\Desktop\Dennison to County Line_Constructed.dgpx

AASHTOWare

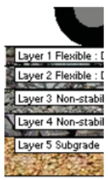
Design Inputs

Design Life: 10 years
Design Type: AC over AC

Existing construction: May, 1991
Pavement construction: August, 2009
Traffic opening: September, 2009

Climate Data Sources (Lat/Lon): 35.022, -110.722

Design Structure



Layer type	Material Type	Thickness (in.):
Flexible	Default asphalt concrete	5.0
Flexible	Default asphalt concrete	6.0
NonStabilized	AB (Aggregate Base)	6.0
NonStabilized	AS (Aggregate Subbase)	6.0
Subgrade	A-2-7	Semi-infinite

Volumetric at Construction:

Effective binder content (%)	10.8
Air voids (%)	7.6

Traffic

Age (year)	Heavy Trucks (cumulative)
2009 (initial)	7,755
2014 (5 years)	6,767,190
2019 (10 years)	14,612,200

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	150.00	107.49	97.00	100.00	Pass
Permanent deformation - total pavement (in.)	0.50	0.43	97.00	99.66	Pass
Total Cracking (Reflective + Alligator) (percent)	100.00	100.00	-	-	-
AC thermal fracture (ft/mile)	1000.00	39.41	97.00	100.00	Pass
AC bottom-up fatigue cracking (percent)	10.00	2.88	97.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	480.75	97.00	100.00	Pass
Permanent deformation - AC only (in.)	0.50	0.43	97.00	99.66	Pass

Same Project – Optimized

Dennison to County Line_2.5_Fair_1

File Name: C:\Documents and Settings\b5395\Desktop\Dennison to County Line_2.5_Fair_1.dgpx

Design Inputs

Design Life:	10 years	Existing construction:	May, 1991	Climate Data Sources (Lat/Lon)	35.022, -110.722
Design Type:	AC over AC	Pavement construction:	August, 2009		
		Traffic opening:	September, 2009		

Design Structure

Layer type	Material Type	Thickness (in.):
Flexible	Default asphalt concrete	2.5
Flexible	Default asphalt concrete	8.5
NonStabilized	AB (Aggregate Base)	6.0
NonStabilized	AS (Aggregate Subbase)	6.0
Subgrade	A-2-7	Semi-infinite

Volumetric at Construction:

Effective binder content (%)	10.8
Air voids (%)	7.6

Traffic

Age (year)	Heavy Trucks (cumulative)
2009 (initial)	7,755
2014 (5 years)	6,767,190
2019 (10 years)	14,612,200

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	150.00	107.52	97.00	100.00	Pass
Permanent deformation - total pavement (in.)	0.50	0.45	97.00	99.41	Pass
Total Cracking (Reflective + Alligator) (percent)	100.00	100.00	-	-	-
AC thermal fracture (ft/mile)	1000.00	39.41	97.00	100.00	Pass
AC bottom-up fatigue cracking (percent)	10.00	2.24	97.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	483.10	97.00	100.00	Pass
Permanent deformation - AC only (in.)	0.50	0.45	97.00	99.42	Pass

Existing Composite Pavement Comparison At Calibration Site

I-10, MP 60 – MP 70

- Constructed 1994, outer lane
- 0.5-in ARFC
- 14-in JPCP, 1.5-dowels, widened slab
- 13, 15, 17-ft perpendicular joint spacing
- 6-in Aggregate base
- HMA shoulders

Example AZ Composite Design:

DARWin–ME Design (Calibration Site)

- Project on I-10, MP 60
- 20 year design trucks = 42 million
- Climate: Desert
- Soil: A-2-4, Mr = 28,000 psi (back-calculated & adjusted)
- DARWin-ME design results (99% R)
  - 1-in ARFC
  - 11-in JPCP, 15-ft joint space, 1.5-in dowels
  - 6-in Aggregate base
  - HMA shoulder

Existing Composite ARFC/JPCP (Calibration Site)

After 17 years

IRI = 54 in/mi

Negligible rutting,

trans. jt. refl. cracks

no JPCP fatigue cracks

Implementation of DARWin-ME

- ADOT currently running DARWin-ME designs on all projects
- Training continuing with ARA (AASHTO Service Units)
- Plan to begin phasing in DARWin-ME designs on a case by case basis
- Consultant community

Future Improvements

- Evaluation of ASU Lab Testing
- Evaluation of Low Temperature Cracking Model
- Research into cause of transverse cracking of HMA in desert warm non-freezing areas
- WIM data collection (SPR – 672 Recommendations)
- Asphalt Rubber Mixes


Thank You