The National Academies of
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TRANSPORTATION RESEARCH BOARD

Developing Pavement Performance Models

Wednesday, October 11, 2017
2:30-4:00 PM ET

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

Purpose

Provide guidance to state and municipal roadway authorities on how they may improve the prediction capabilities of their pavement management systems by incorporating recent advances in performance prediction models.

Learning Objectives

At the end of this webinar, you will be able to:

- List the available statistical and numerical tools for processing data
- Understand how to select the appropriate computational or statistical technique for developing performance prediction models
- Describe the methods used to evaluate and improve the prediction capability of performance models
- Describe best practices for implementation of new performance modeling techniques

Developing Pavement Performance Models: Overview of Methods

Nima Kargah-Ostadi, PhD, PE, PMP

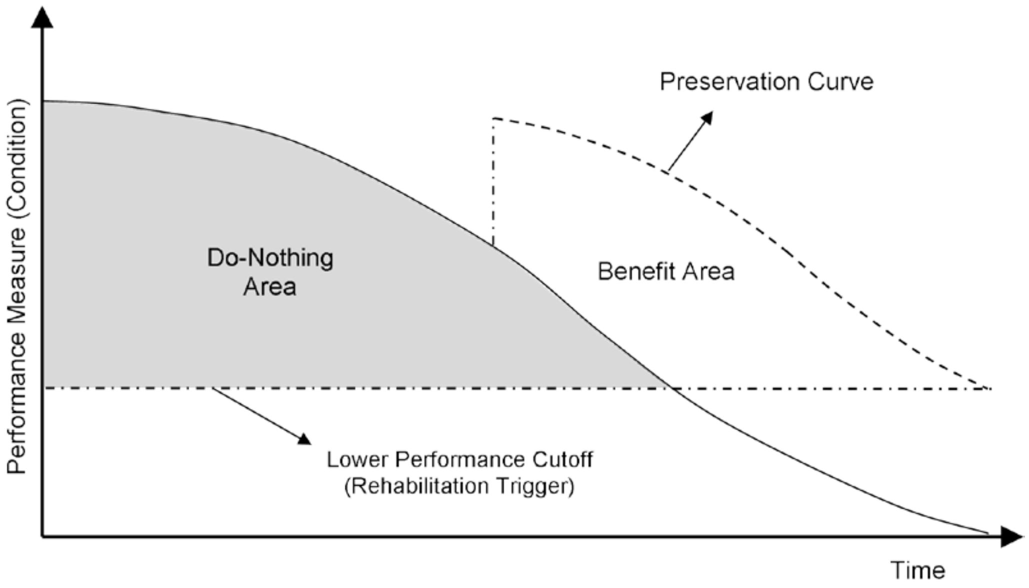
AFD10 Committee Communications Coordinator

Transportation Infrastructure Specialist, Fugro Roadware

Uses of Performance Models

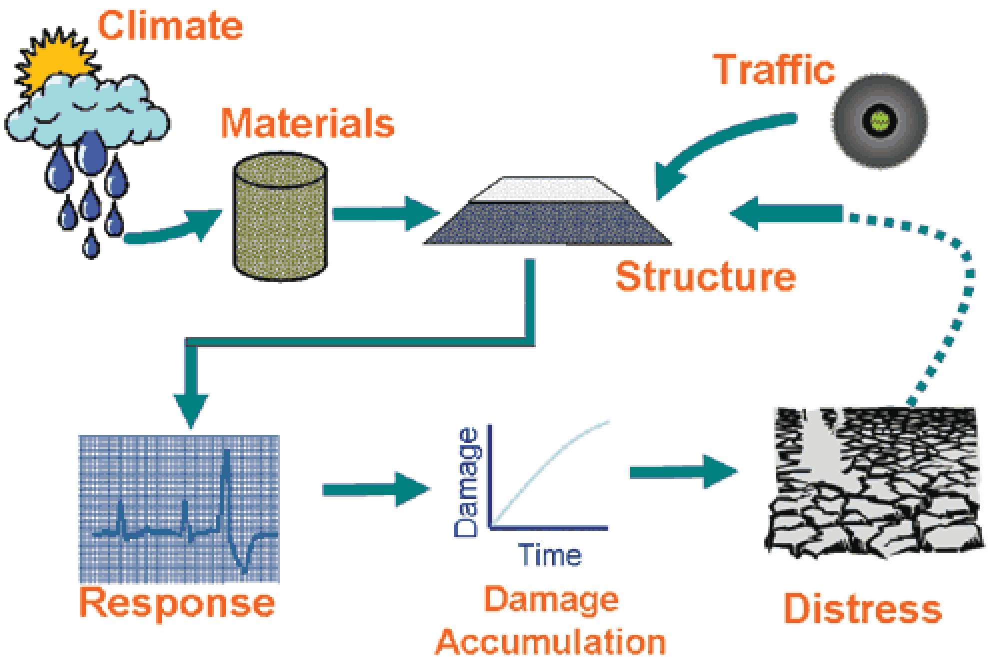
Used in Pavement Management Systems for (Haas et al. 1994):

- Future condition
- Type and time of treatments
- Treatment effectiveness
- Optimize or prioritize treatment actions for multiple years
- life-cycle cost analysis (LCCA) of alternative treatment scenarios
- Provide feedback to the pavement design process

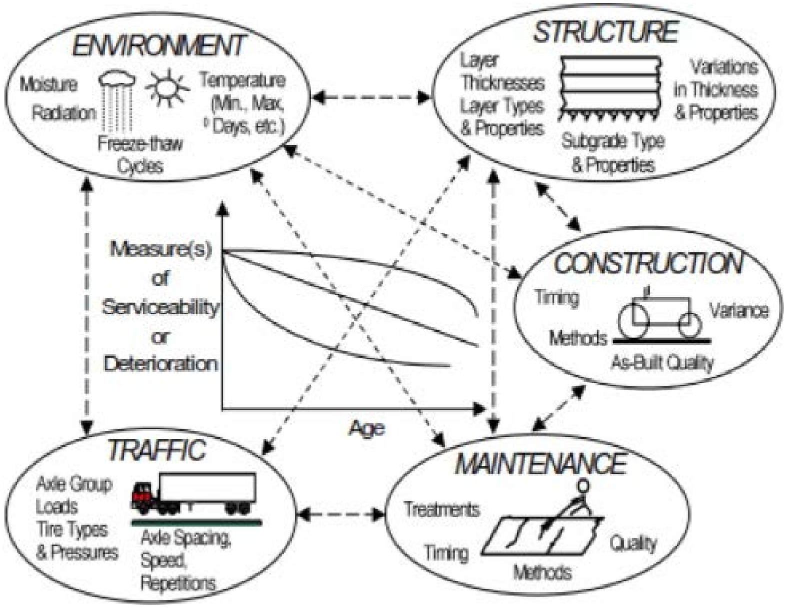


Model Development Approach

- Empirical
  - Materials-Traffic-Climate → Empirical Performance
- Mechanistic-Empirical
  - Materials-Traffic-Climate → Mechanistic Responses → Empirical Performance



Data for Performance Models



Source: Haas et al. 1994

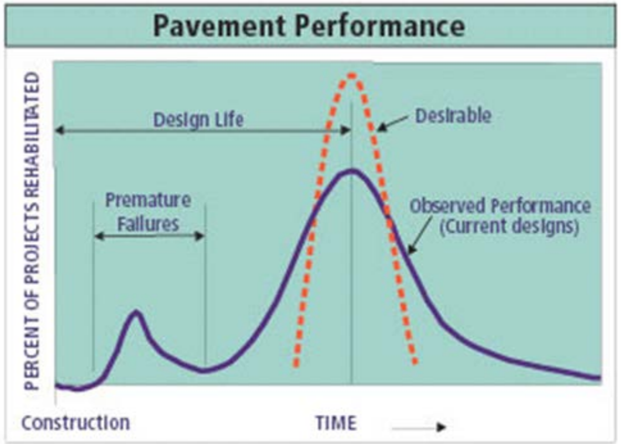
Performance measurements and factors affecting performance

- Inherent spatial variability
- Intercorrelation of inputs
- Missing data
- Measurement errors
- Measurement subjectivity
- Outliers
- Seasonal or daily changes
- Noise

38 best tools for data visualization

Data Preprocessing

- Outliers → Detect and Remove
- Missing Data → Averaging, Bootstrapping and Imputation, etc.
- Spatial Variability → Dynamic Segmentation
- Seasonal Variation or Noise → Smoothing (denoising)
- Different Variable Scales → Normalization
  - Mean Removal or Standardization
  - Min-Max Normalization
- Correlated Inputs →Decorrelation
  - Principal component analysis

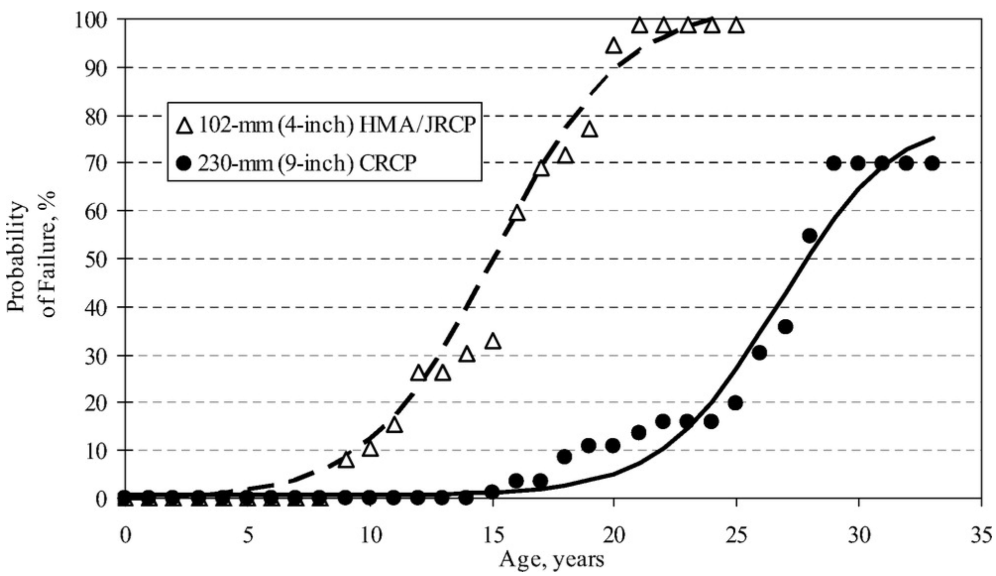


Source: National Cooperative Highway Research Program

Data Preprocessing for Supervised Learning

Statistical Methodology

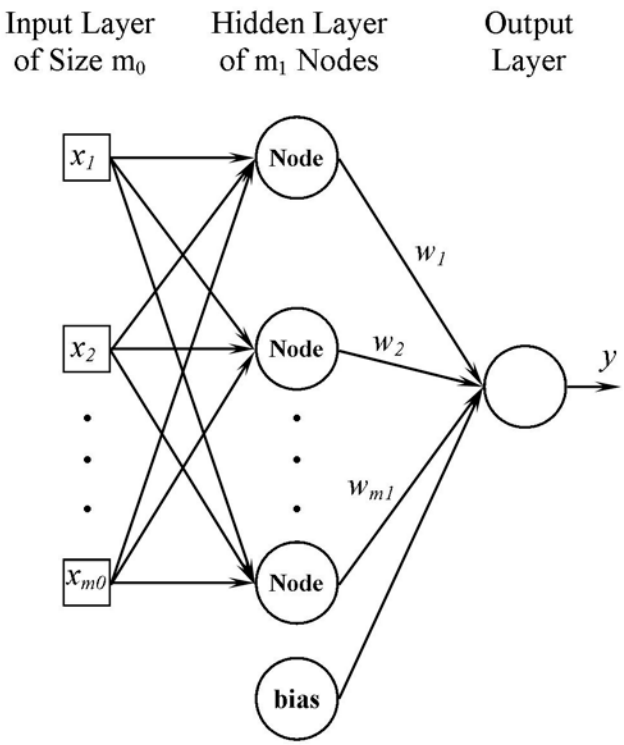
- Deterministic
  - Regression (linear, sigmoidal, polynomial, etc.)
  - Machine Learning
- Probabilistic
  - Markov Probability Matrices
  - Survivor Curves
  - Bayesian Techniques
  - Machine Learning



Source: Gharaibeh and Darter 2003

Machine Learning

- NOT a black box, but matching an existing pattern (statistical learning)
- As good as the provided training data
- A variety of available techniques:
  - Artificial Neural Networks
  - Support Vector Machines
  - Radial Basis Function Networks
  - etc.

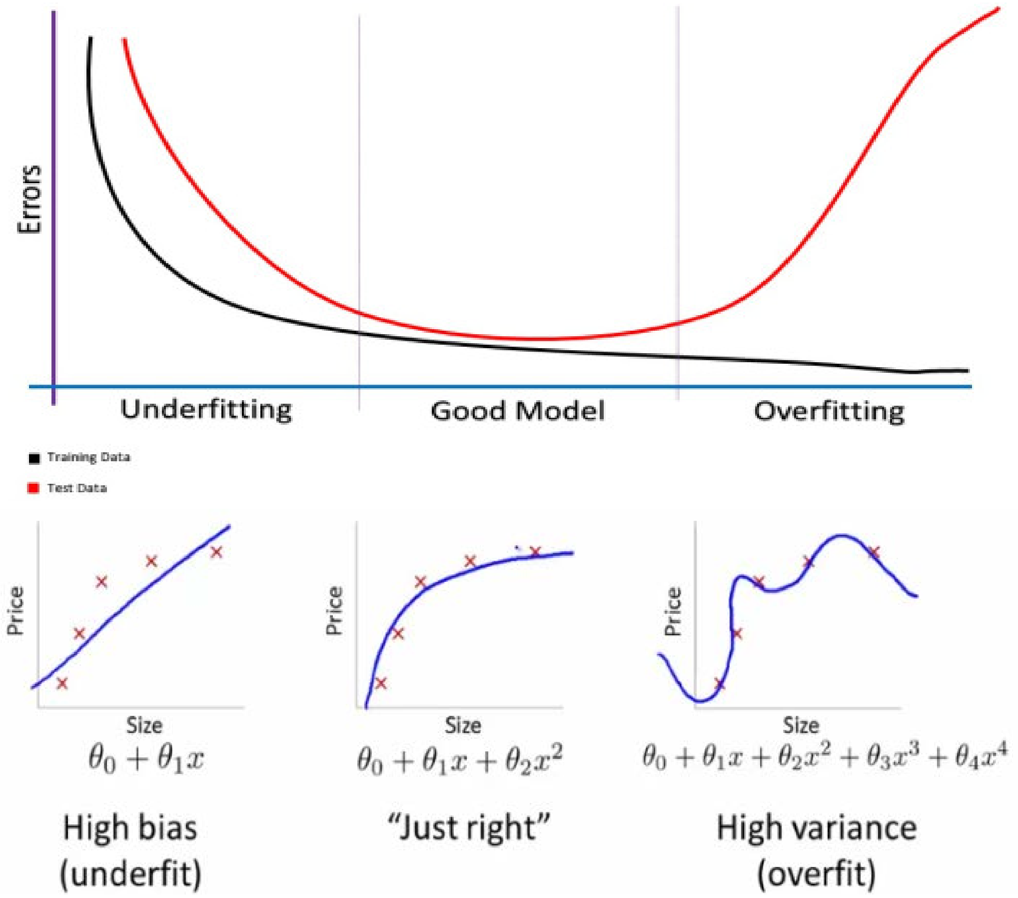


$$F(x) = \varphi_l\left(\sum_{k=1}^{p} w_{lk}\varphi_k\left(\sum_{i=1}^{m} w_{ki}\varphi_i\left(\sum_{j=1}^{n} w_{ij}x_j + b_i\right) + b_k\right) + b_l\right)$$

A Visual Introduction to Machine Learning

Principles of Model Development

- Maximum Likelihood
  - Accuracy → bias
  - Precision → variance
- Consistency: Generalization
  - Training vs test dataset
  - Bias-Variance Balance
- Parsimony: Simplicity
- Engineering Credibility
  - Evaluation of form
  - Sensitivity analysis



[A Diagnostic Approach to Model Evaluation]

Further Reading

- [Pavement Performance Modeling: State of the Art]
- [Framework for Development and Comprehensive Comparison of Empirical Pavement Performance Models]
- [Example Regression Performance Model Development]
- [Example Machine Learning Performance Model Development]
- [Example Mechanistic-Empirical Model Development]
- [Example Development of Survivor Curves]
- [Relationship between Deterministic and Probabilistic Models]
- [Review of PMS Performance Modeling Efforts for 6 State DOTs]

Pavement Management Quarterly Webinars

FHWA in collaboration with TRB AFD10 presents:

Primary focus: AASHTO Pavement Management Guide

- Chapter 4 - Data Consistency Issues & Developing Pavement Condition Indices 10/19/2017
- Chapter 4 - Pavement Management Data Quality 07/20/2017
- Chapter 4 - Pavement Condition Assessment 04/20/2017
- Chapter 3 - Inventory Data Collection and Data Integration Issues 01/19/2017
- Kickoff 10/20/2016

Pavement Performance Models - Opportunities with 3D Pavement Data

Presented by

Yichang (James) Tsai, Ph.D., P.E., Professor
Georgia Institute of Technology

October 11, 2017

Outline

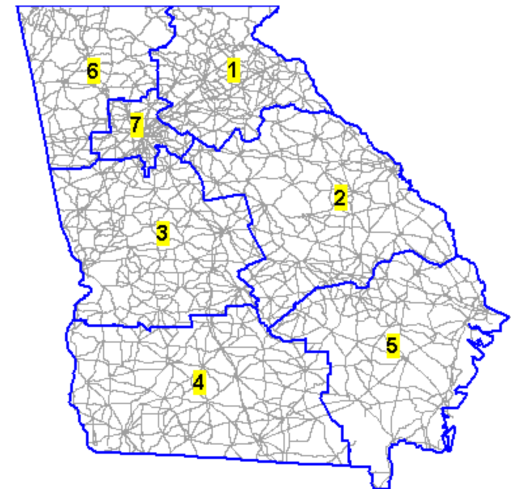
- GDOT pavement management practices

- A systematic method to quantify the quality and reliability of pavement life/performance

- GDOT **pavement performance models**
  - Project level: **Empirical models** are used to determine the timing of maintenance and rehabilitation method, like resurfacing
  - Network level: **Markov chain models** are used to forecast long-term MR&R need analysis and pavement condition

- **High resolution 3D pavement data - opportunities** for advancing the development of accurate pavement performance models with existing and new pavement performance indicators having high level of granularity.

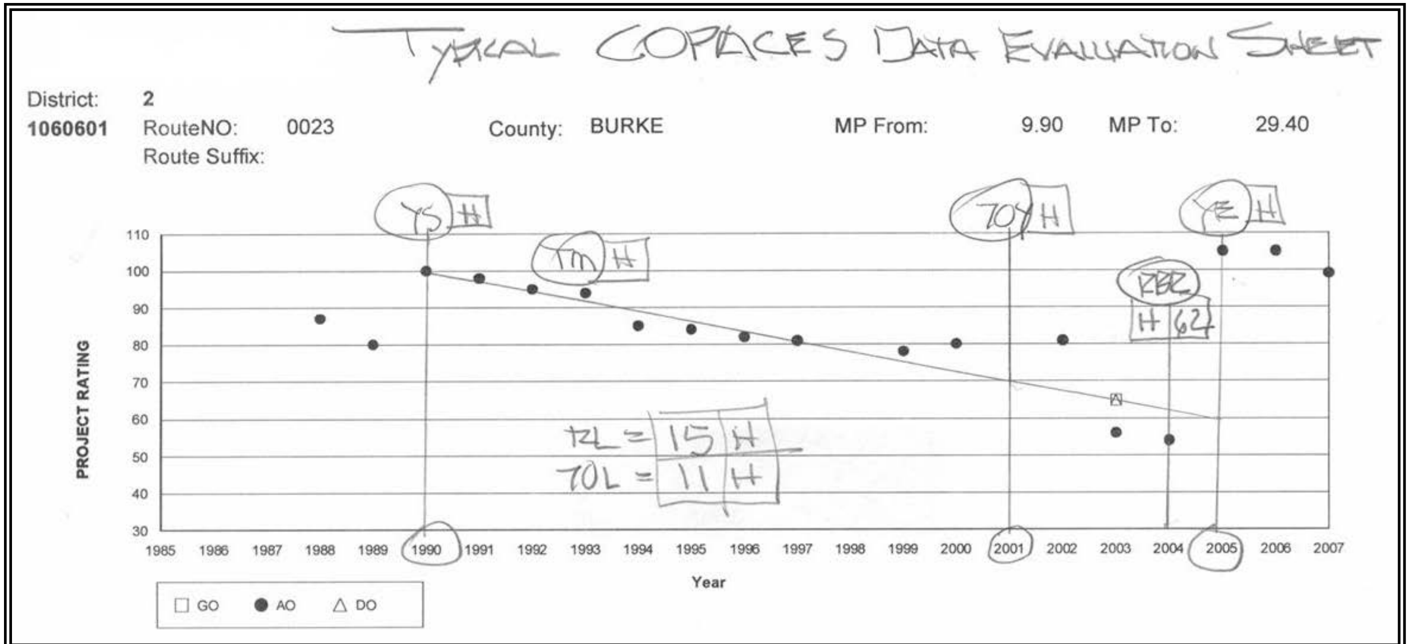
GDOT Pavement Management Practices



- 18, 000 mile centerline highway.
- 7 working districts.
- Pavement surveyed annually with about 60 engineers.
- 10 different types of distresses surveyed (i.e. load cracking, block cracking, etc.)
- Project rating is between 0 and 100. It is also used to determine different treatment timing.
- More than 30 years of survey data (1986 – 2017)
- Survey data used to determine suitable treatments based on GDOT's treatment decision tree
- Total miles of projects treated are subject to budget availability.

GDOT is one of the leading state DOTs having active pavement preservation and management program to cost effectively sustain its pavement system.

Quantify the quality and reliability of pavement life/performance



Variables Shown:

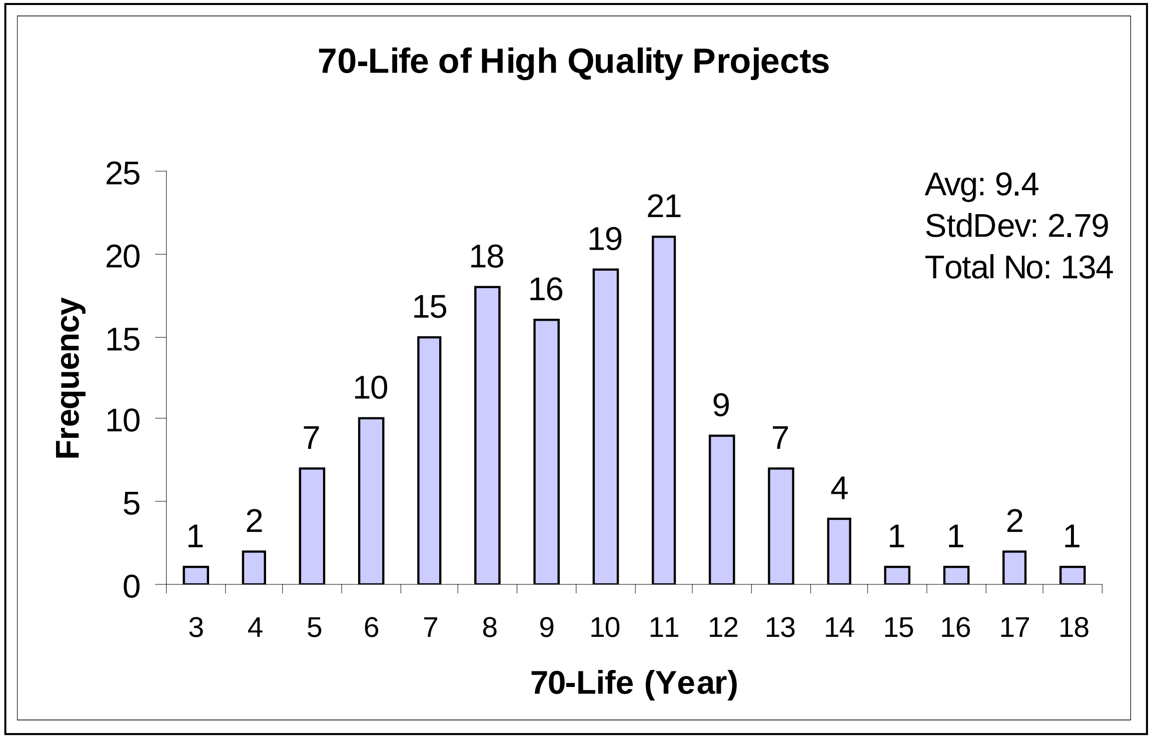
YS – Year Start
TM – Trend in the Middle
YE – Year End
70Y - 70 Year
RBR – Rating before Resurfacing
RL – Resurfacing Life
70L – 70 Life

Confidence Levels:
H – High
M – Medium
L - Low

Overall project confidence = minimum confidence of (YS, TM and YE). Note, for the project shown above the 70Y (70 year) occurs in 2001 and the RBR (Rating before Resurfacing = 62) in Year 2004.

Tsai, Y., Feng, L., Purcell, R., and Rabun J. (2012) “A Reliable Statewide Pavement Performance Study Using a Confidence Evaluation System”, ASCE Journal of Transportation Engineering, Vol. 138(3), pp. 339-347.

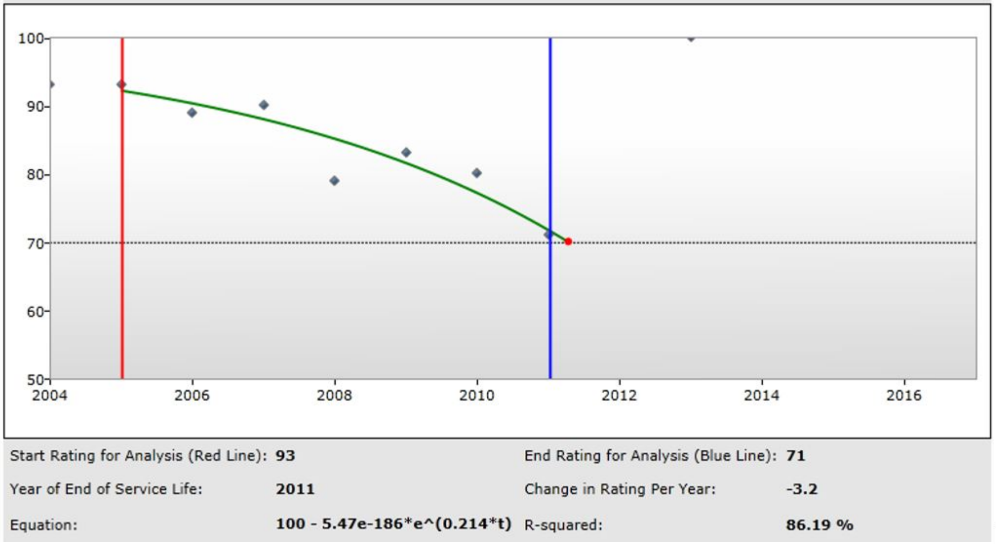
70-Life of total & high quality projects



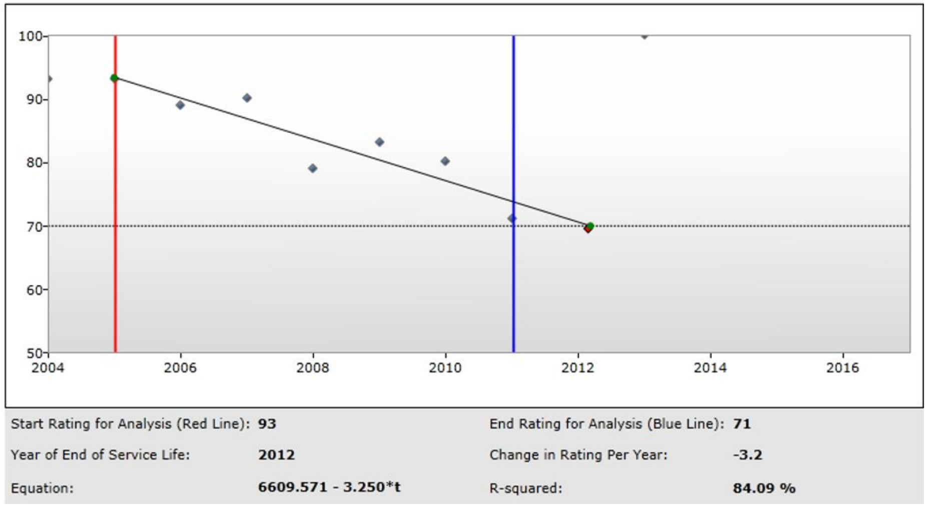
Tsai, Y., Wang, Z., and Purcell, R., "Improving GDOT's Highway Pavement Preservation", Final Report, Georgia Department of Transportation, 2009

The average 70-Life is **9.4 (11.4)** years in the High Quality and Total project groups, respectively. Therefore, 70-Life is much shorter than Resurfacing Life, which means that on average it takes around **2 years** for pavement to be treated after its rating has dropped to 70.

Determine pavement resurfacing timing based on project level pavement performance



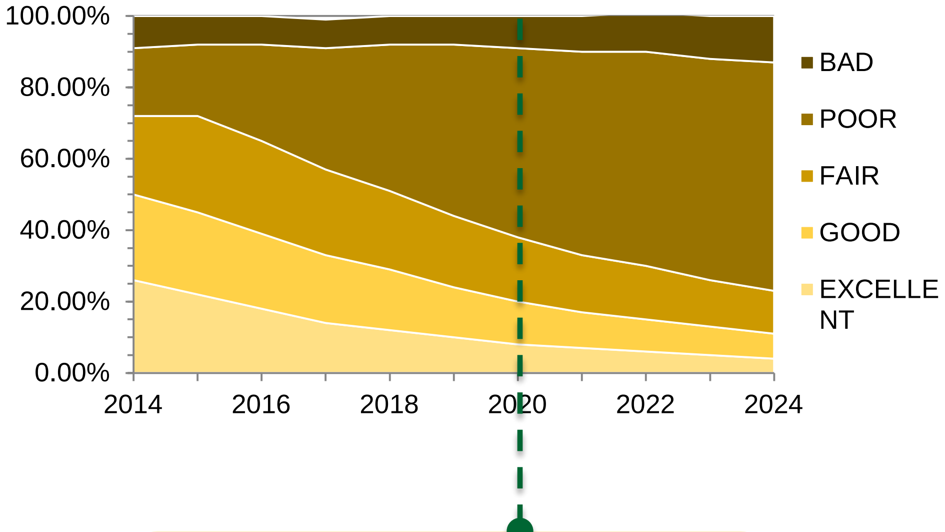
Empirical model is used to determine the timing of maintenance and rehabilitation method, like **resurfacing**, at project level (e.g. **a rating of 70**)



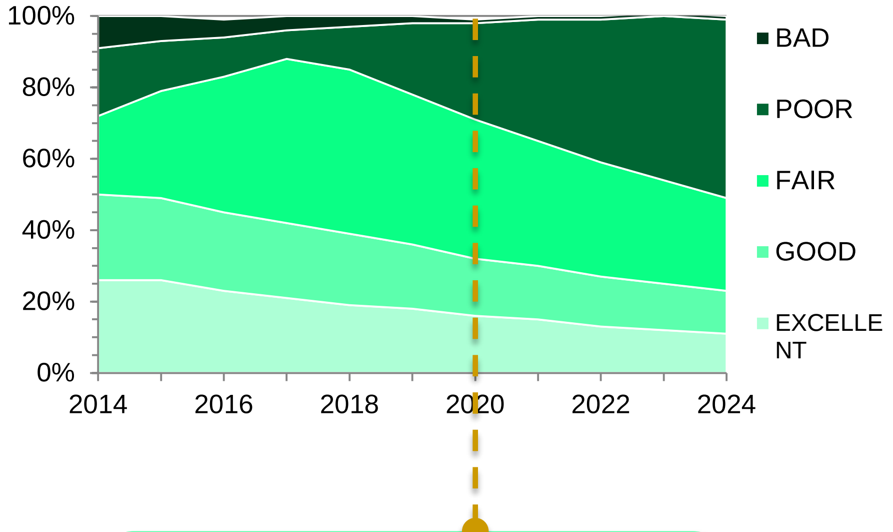
Wang, Z. and Tsai, Y., “Enhancement of GDOT’s Pavement Rehabilitation and Design Processes by Integrating New and Existing Data Sources and Developing Data Analysis and Reporting Procedures,” Final Report, Georgia Department of Transportation, 2014.

Network level long-term MR&R need analysis and pavement condition forecasting using Markov Chain

Yearly Condition Distribution:
$100M Budget



Yearly Condition Distribution:
$300M Budget



In 2020,
62% rated poor or below.
38% rated fair or better.

In 2020,
29% rated poor or below.
71% rated fair or better.

(from Meg Pirkle, GDOT Chief Engineer's presentation)

Discretization of Markov transition probability matrix

- Random series $\{S_t\}$– the whole pavement network
  - Time – 1 year cycle
  - Condition States

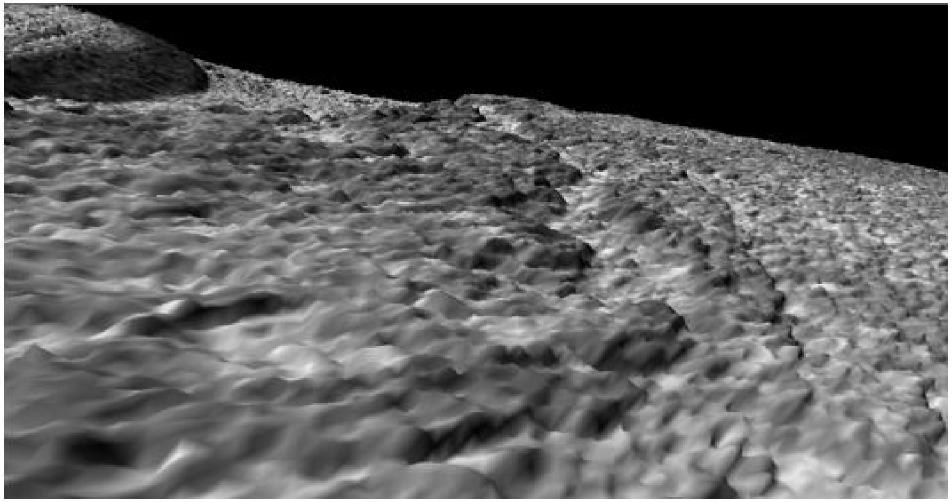
State	Minimum Rating	Maximum Rating
Excellent	91	100
Good	81	90
Fair	71	80
Poor	55	70
Bad	0	54

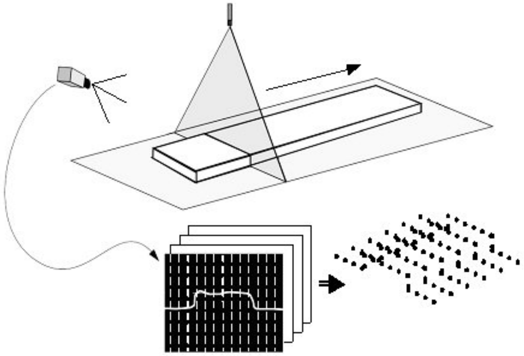
- Family – 7 districts and functional class (interstate and non-interstate), total 14 families
  - GDOT is now categorizing pavements into four categories: critical, high, medium, and low

Tsai, Y., Wang, Z., and Purcell, R., "Improving GDOT's Highway Pavement Preservation", Final Report, Georgia Department of Transportation, 2009

High-resolution 3D pavement data - **opportunities and challenges** for new performance indicators and accurate pavement performance models to revolutionize pavement management

High-resolution 3D continuous transverse profiles



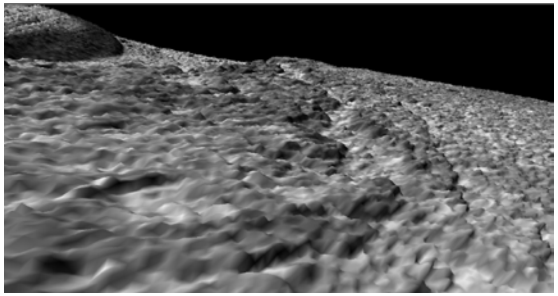


(Laurent, et. al., 2008)

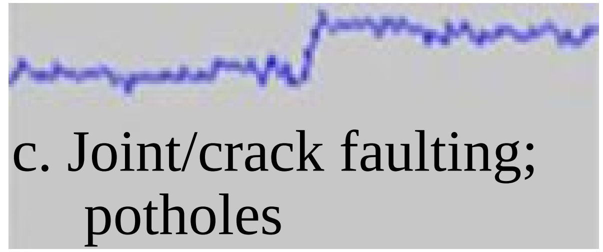
- Resolution
  - Driving direction: 1 – 5 mm
  - Transverse direction: 1 mm
  - Elevation: 0.5 mm
  - Data points collected per second and width covered
    - 2 (lasers) * 2048 (points/profile/laser) * 5600 HZ = 22,937,600 points/second

Pooled Fund Study on TPF-5(299) ***Improving the Quality of Pavement Surface Distress and Transverse Profile Data Collection and Analysis***.

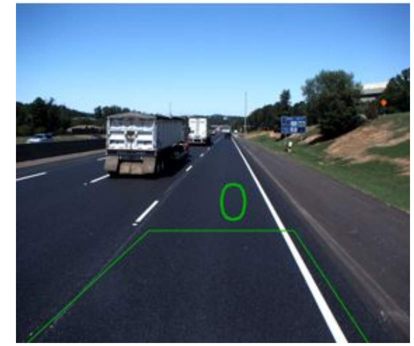
3D pavement data and its applications



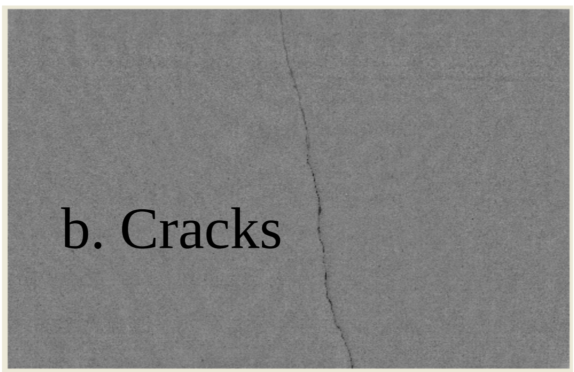
a. Texture (IRI; MPD; RVD)



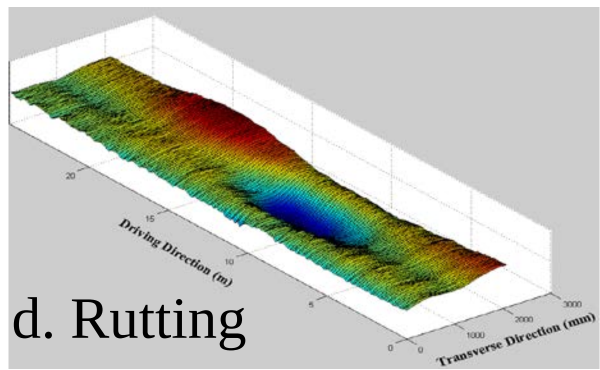
c. Joint/crack faulting; potholes



e. Raveling



b. Cracks



d. Rutting

1.Tsai, Y., Li*****, F. (2012) "Detecting Asphalt Pavement Cracks under Different Lighting and Low Intensity Contrast Conditions Using Emerging 3D Laser Technology", ASCE Journal of Transportation Engineering, 138(5), 649–656

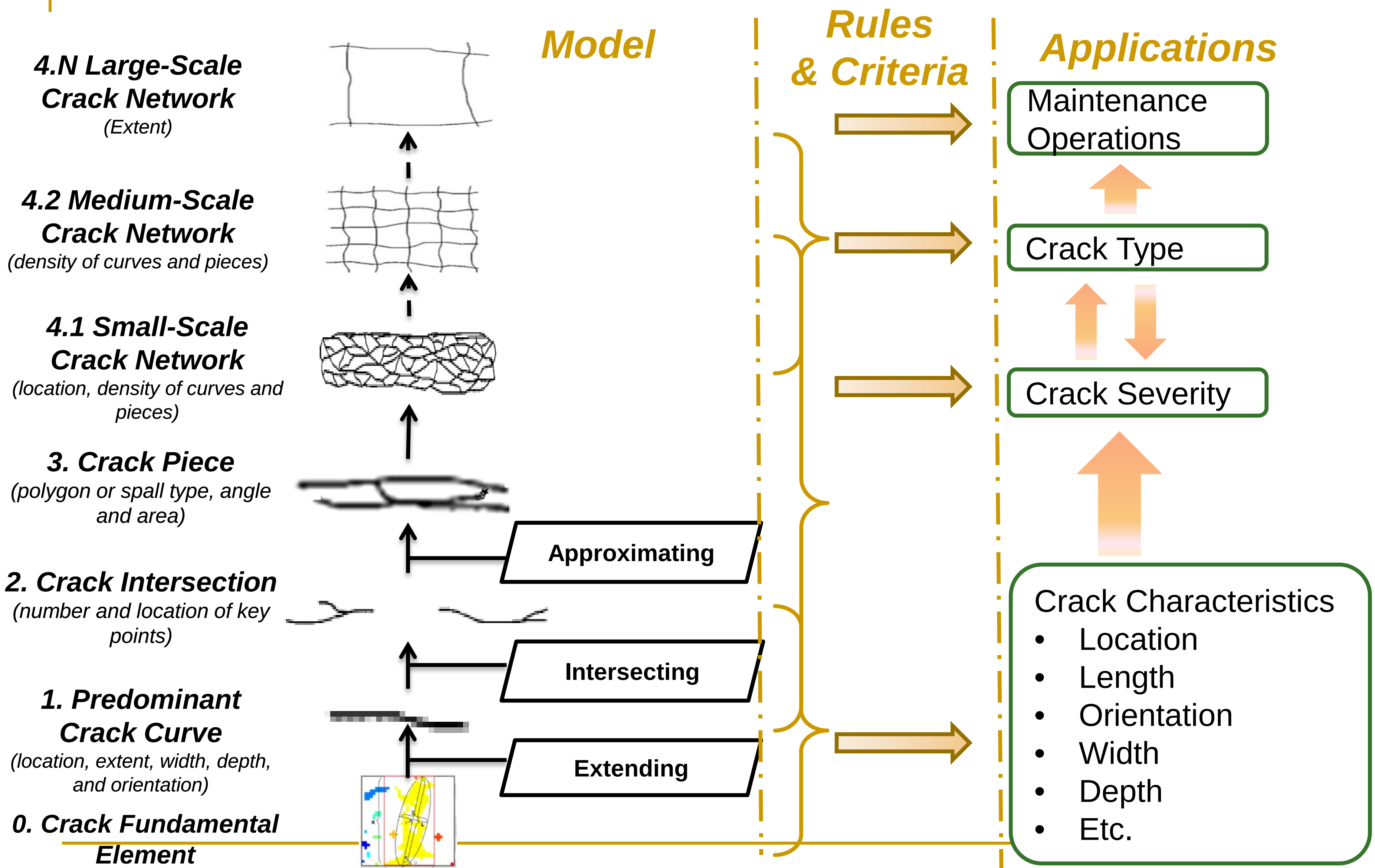
2. Tsai, Y., Wu, Y., Lai, J., Geary, G. (2012) Characterizing Micro-milled Pavement Textures Using RVD for Super-thin Resurfacing on I-95 Using A Road Profiler, Journal of The Transportation Research Record, No.2306, pp.144-150.

3. Tsai, Y., Wu, Y., Ai, C., Pitts, E. (2012) "Feasibility Study of Measuring Concrete Joint Faulting Using 3D Continuous Pavement Profile Data," ASCE Journal of Transportation Engineering,138(11),1291-1296.

4. Tsai, Y., Li, F., Wu, Y. (2013) "Rutting Condition Assessment Using Emerging 3D Line-Laser Imaging and GPS/GIS Technologies", the International Conference on Road and **Airfield Pavement Technology, Taipei, Taiwan, July 14, 2013.**

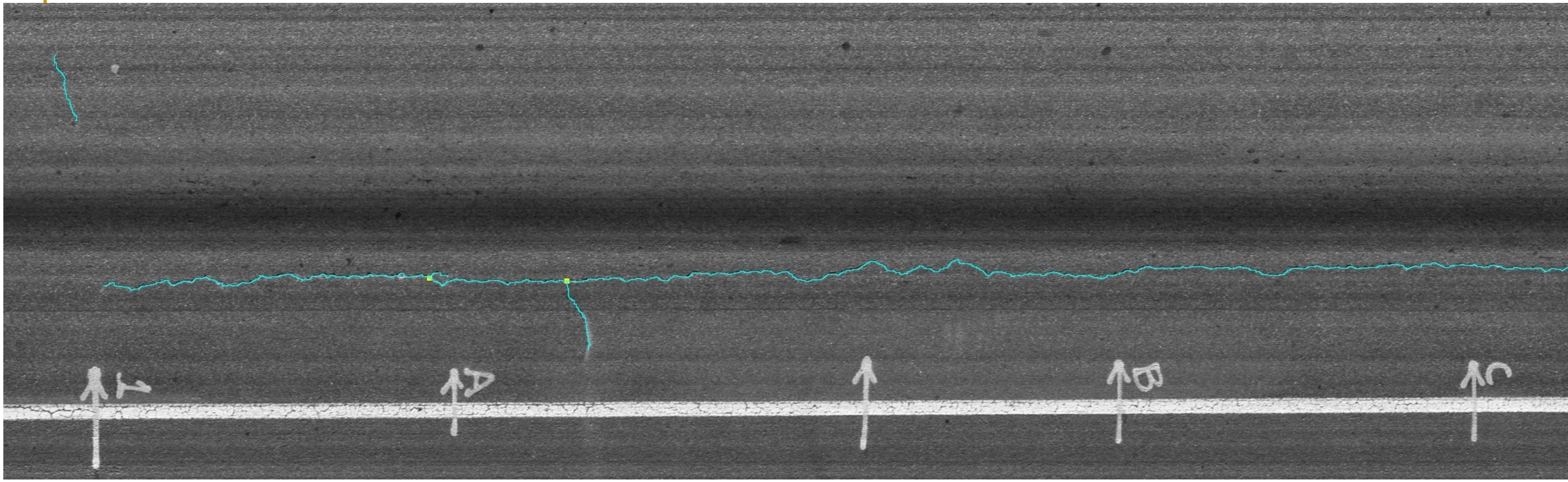
5. Tsai, Y. and Wang Z. (2015) "Development of an **Asphalt Pavement Raveling Detection Algorithm** Using Emerging 3D Laser Technology and Macrotexture Analysis", NCHRP IDEA-163 Final Report

Multi-scale crack fundamental element model

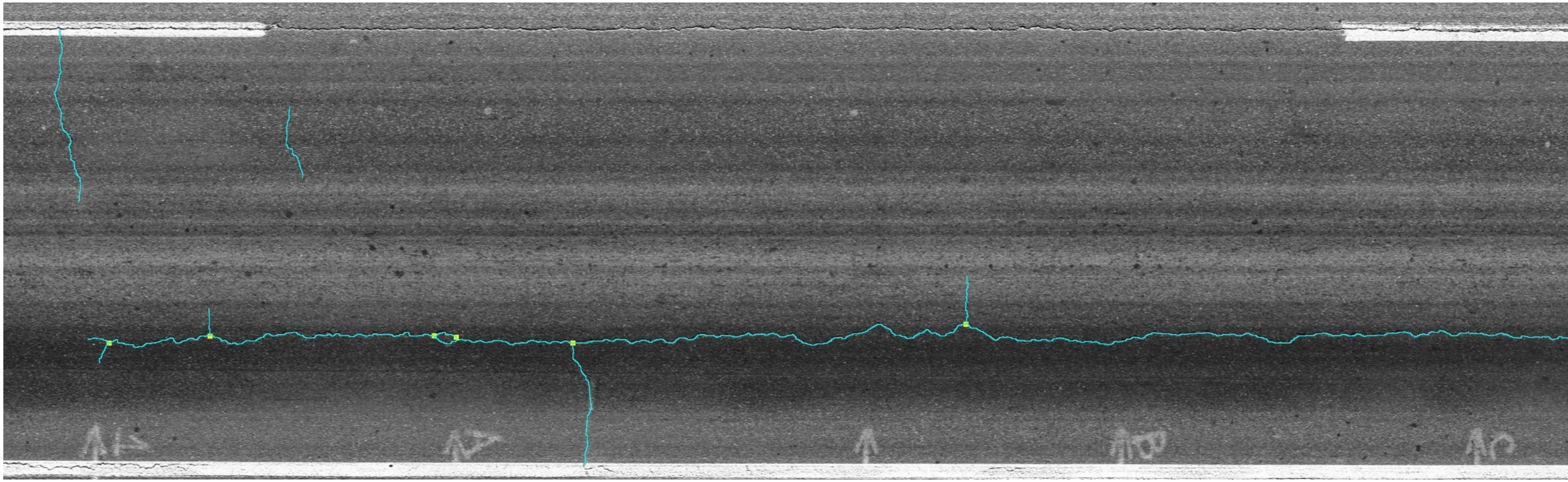


Tsai, Y., Jiang, C., Huang, Y. (2014) "A Multi-scale Crack Fundamental Element Model for Real World Pavement Crack Classification", ASCE Journal of Computing in Civil Engineering.

Detailed crack propagation : US 80/S.R. 26 in Savannah, Georgia



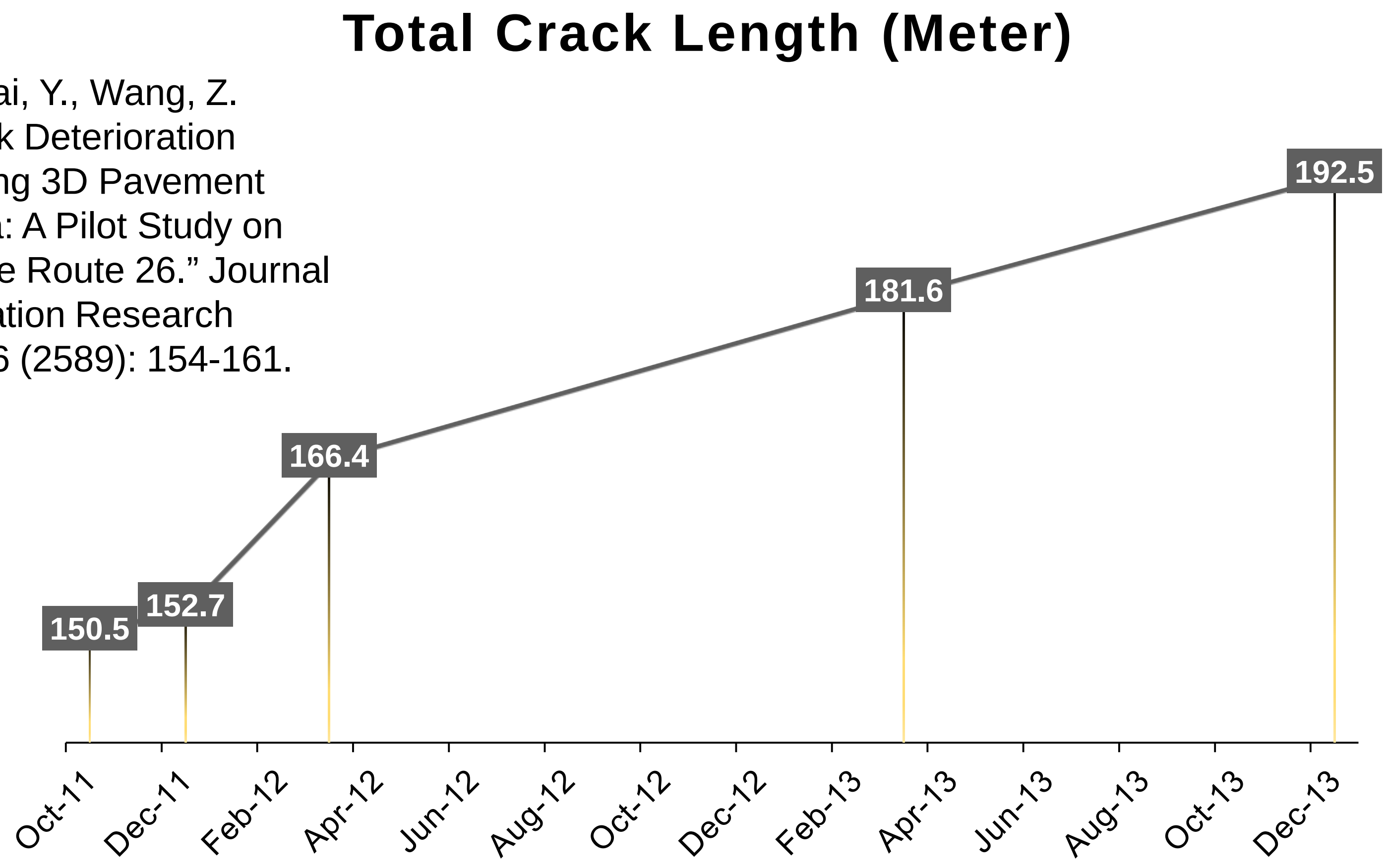
Oct. 15, 2011



Dec. 07, 2013

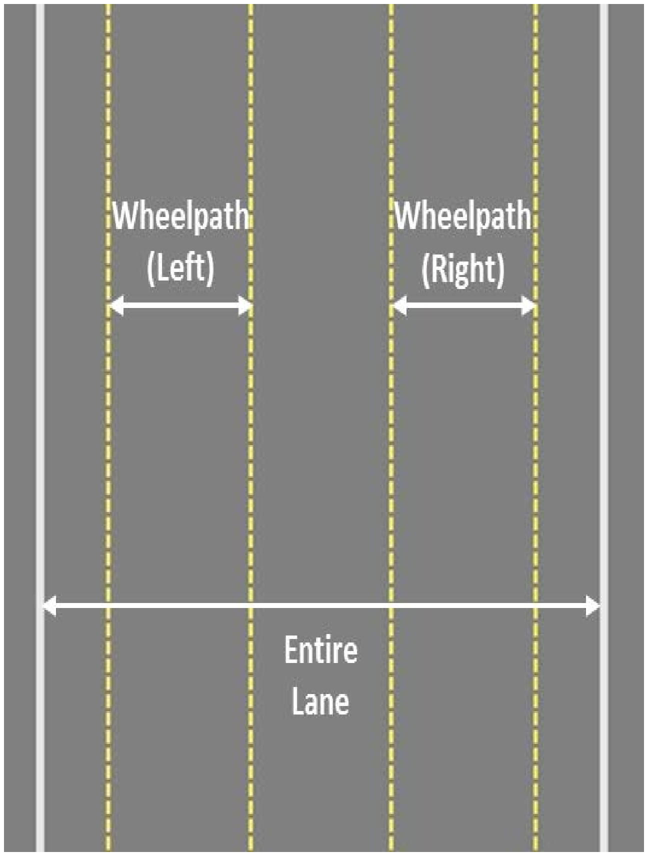
Property: crack length

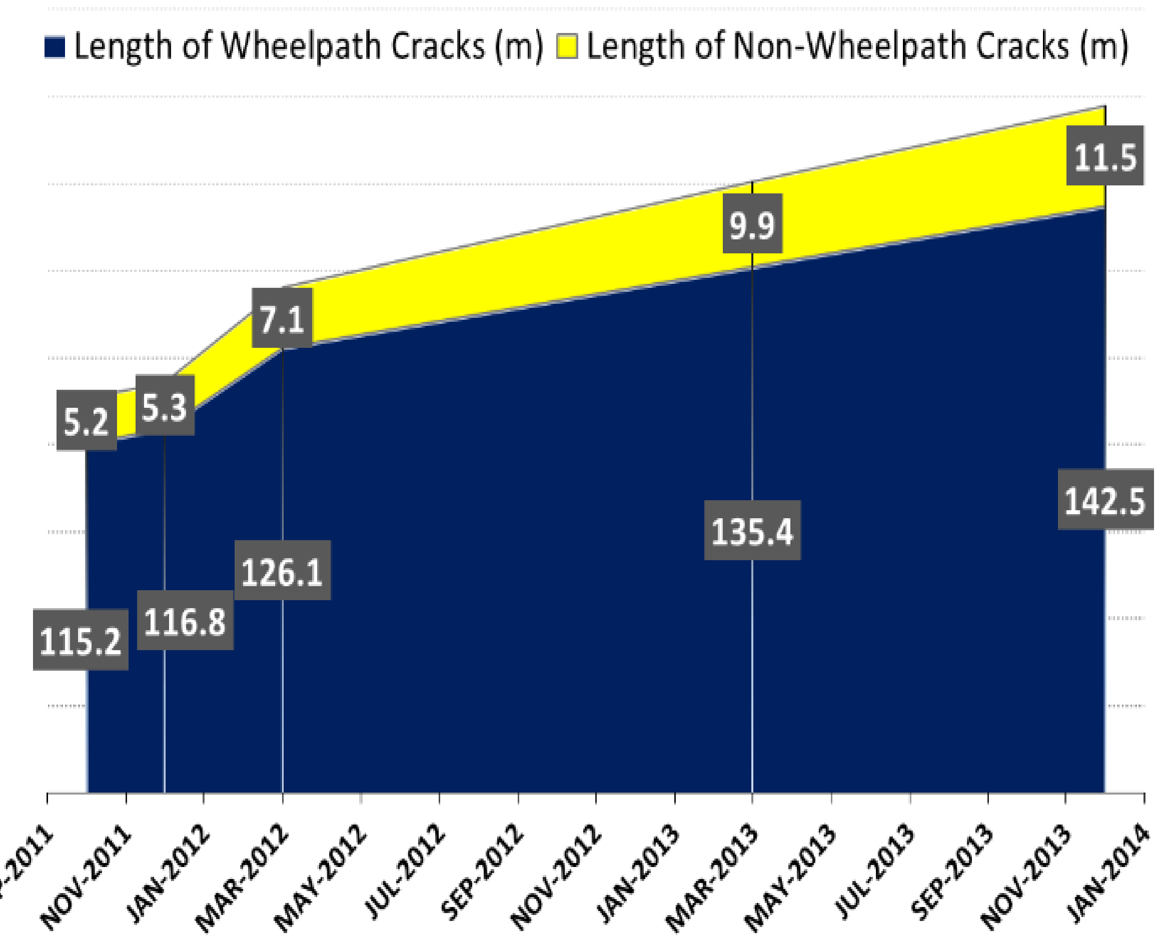
Jiang, C., Tsai, Y., Wang, Z. (2016) “Crack Deterioration Analysis Using 3D Pavement Surface Data: A Pilot Study on Georgia State Route 26.” Journal of Transportation Research Record, 2016 (2589): 154-161.



The following slides will show that the propagation on transverse direction is more significant than on longitudinal direction.

Comparison between crack propagation inside and outside the wheelpaths

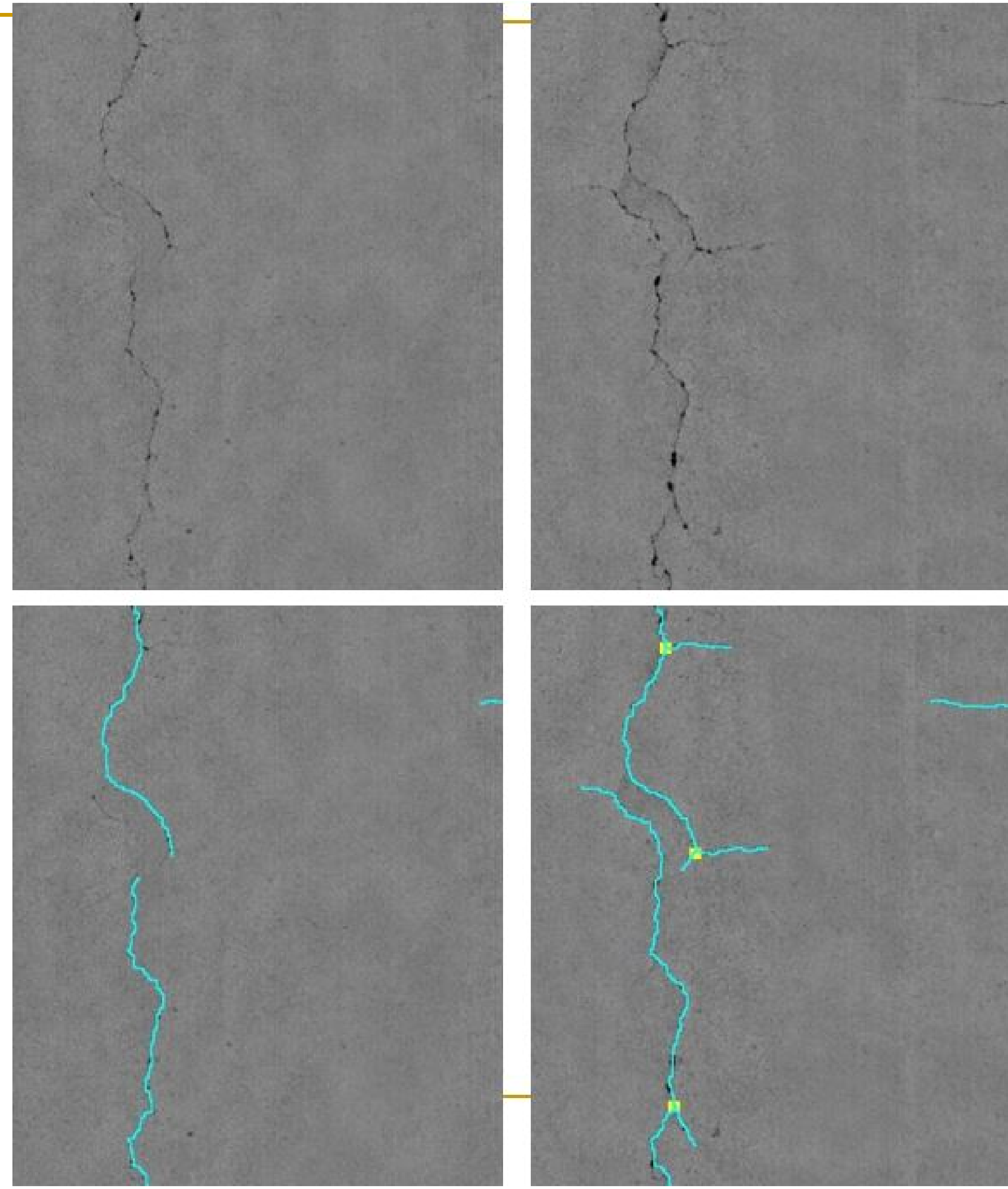




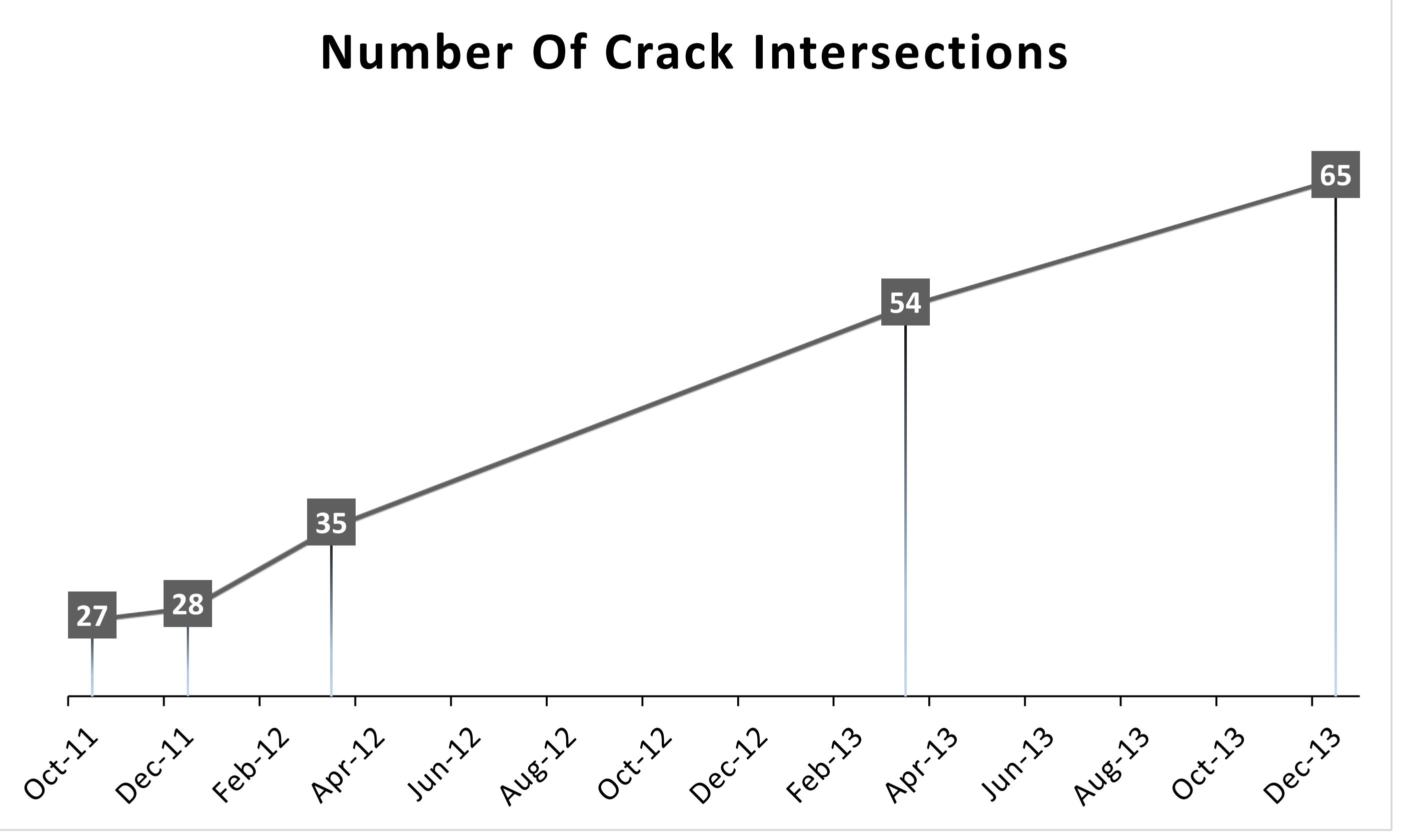
The following slides will show that the crack propagation on the wheelpath is more significant than on the ones on the non-wheelpath.

Example of Branching Out (Crack Intersection Points)

Dec. 2011 Range Image	Dec. 2013 Range Image
Dec. 2011 Crack Map	Dec. 2013 Crack Map



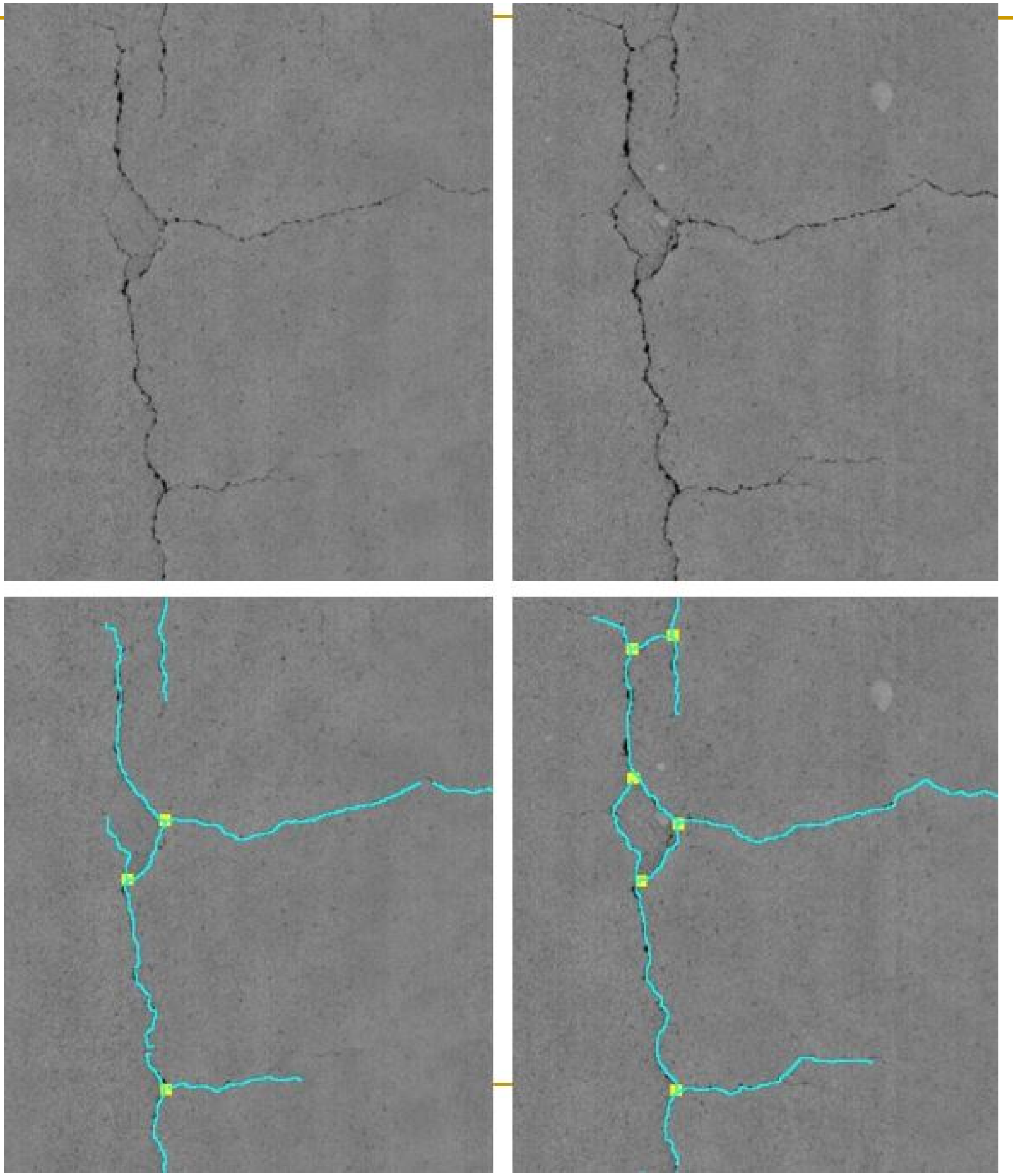
Property: crack intersection points



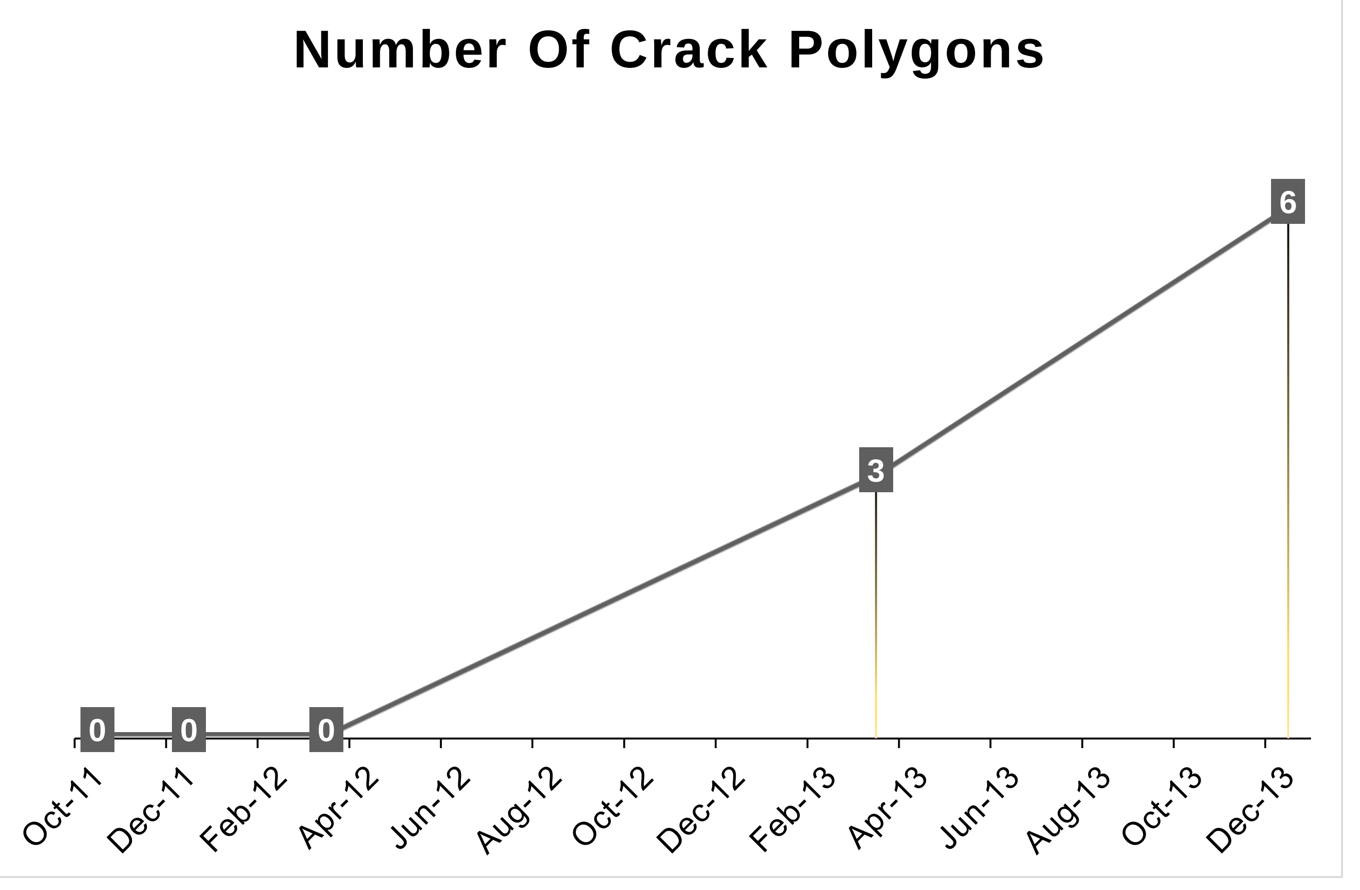
Jiang, C., Tsai, Y., Wang, Z. (2016) "Crack Deterioration Analysis Using 3D Pavement Surface Data: A Pilot Study on Georgia State Route 26." Journal of Transportation Research Record, 2016 (2589): 154-161.

Example of forming polygons (crack polygons)

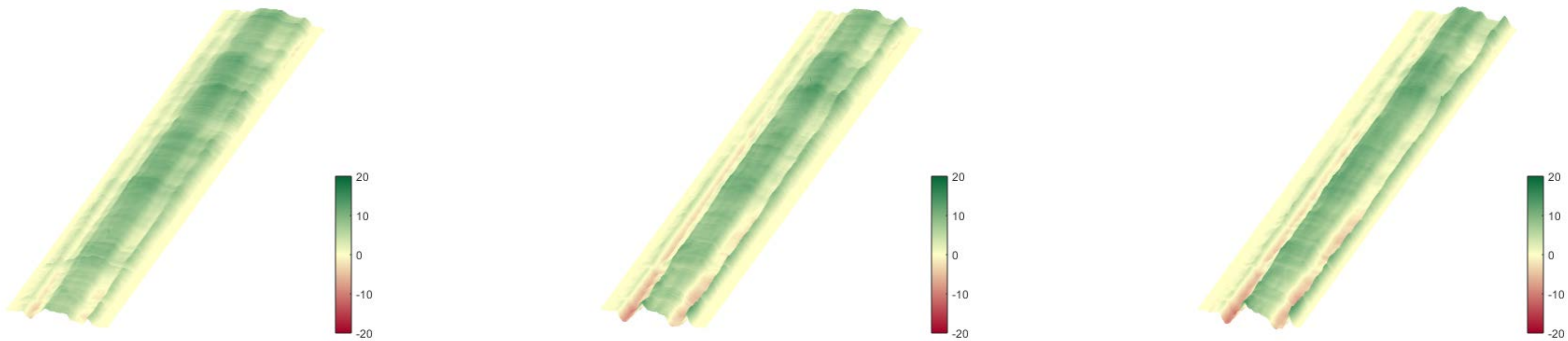
Dec. 2011 Range Image	Dec. 2013 Range Image
Dec. 2011 Crack Map	Dec. 2013 Crack Map



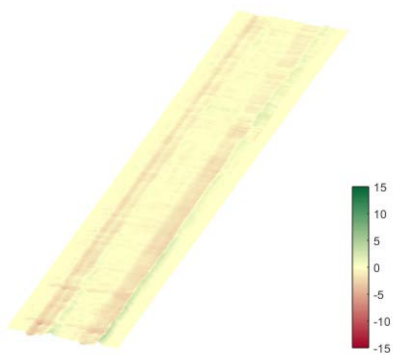
Property: crack polygons

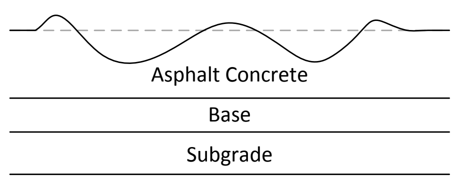


Individual rut-level deterioration

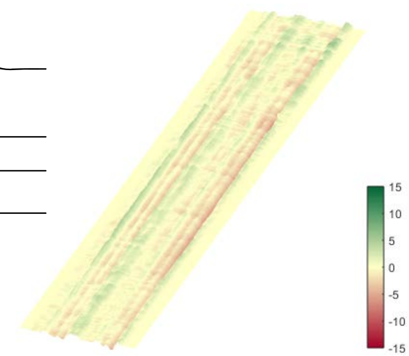


7/13/2012 7/18/2014 6/15/2015





Lateral Distortion



Rate of Change between 7/13/2012 and 7/18/2014 **Rate of Change between 7/18/2014 and 6/15/2015**

Wang, C. (2016) A spatiotemporal methodology for pavement rutting characterization and prediction using 3D data, Ph.D. Thesis, Georgia Institute of Technology

Summary

- Pavement life/performance is critical for pavement management decision and it is important to **quantify their quality and reliability for different applications**.

- GDOT uses **empirical models at project level** to determine the timing of maintenance and rehabilitation method and use **Markov models at network level** to simulate and predict long-term pavement performance and M&R need. ***Markov transition probability matrix*** needs to be constantly updated to reflect actual pavement deterioration behavior.

Summary (cont'd)

- **High-resolution 3D pavement data** provides great opportunities to advance the development of pavement performance models:
  - **New, valuable performance indicators,** like crack intersections and polygons, etc., defined in the crack fundamental element (CFE) need to be devised to characterize the detailed pavement distresses.
  - Linkage needs to be established between **new indicators** and the commonly used composite rating, as well as the **optimal treatment method and timing**.
  - **Small-scale, localized treatments (homogeneous pavement condition sections)** can be identified and planned cost effectively using the detailed pavement distress data and the corresponding pavement performance and deterioration models
  - Need for developing the **accurate pavement performance and forecasting models using existing and new indicators**.
  - Need for developing **a new method** to quantify raveling (rather than current qualitative H, M, L severity levels) for supporting the forecasting of optimal timing for fog seal treatment.

Acknowledgements

- Sponsors
  - The Office of the Assistant Secretary for Research and Technology (OST-R) , USDOT
  - NCHRP IDEA program
  - Georgia Department of Transportation

- Research team
  - Research engineers: Dr. Zhaohua Wang and Yiching Wu
  - Previous Ph.D. students: Dr. Feng Li, Dr. Chenglong Jiang, Dr. Chieh Wang, and Dr. Chengbo Ai, Dr. Roger Purcell
  - Current Ph.D. Students: Anirban Chatterjee, Georgene Geary
  - Current Students: Lauren Gardner and April Gadsby

Thanks
Questions

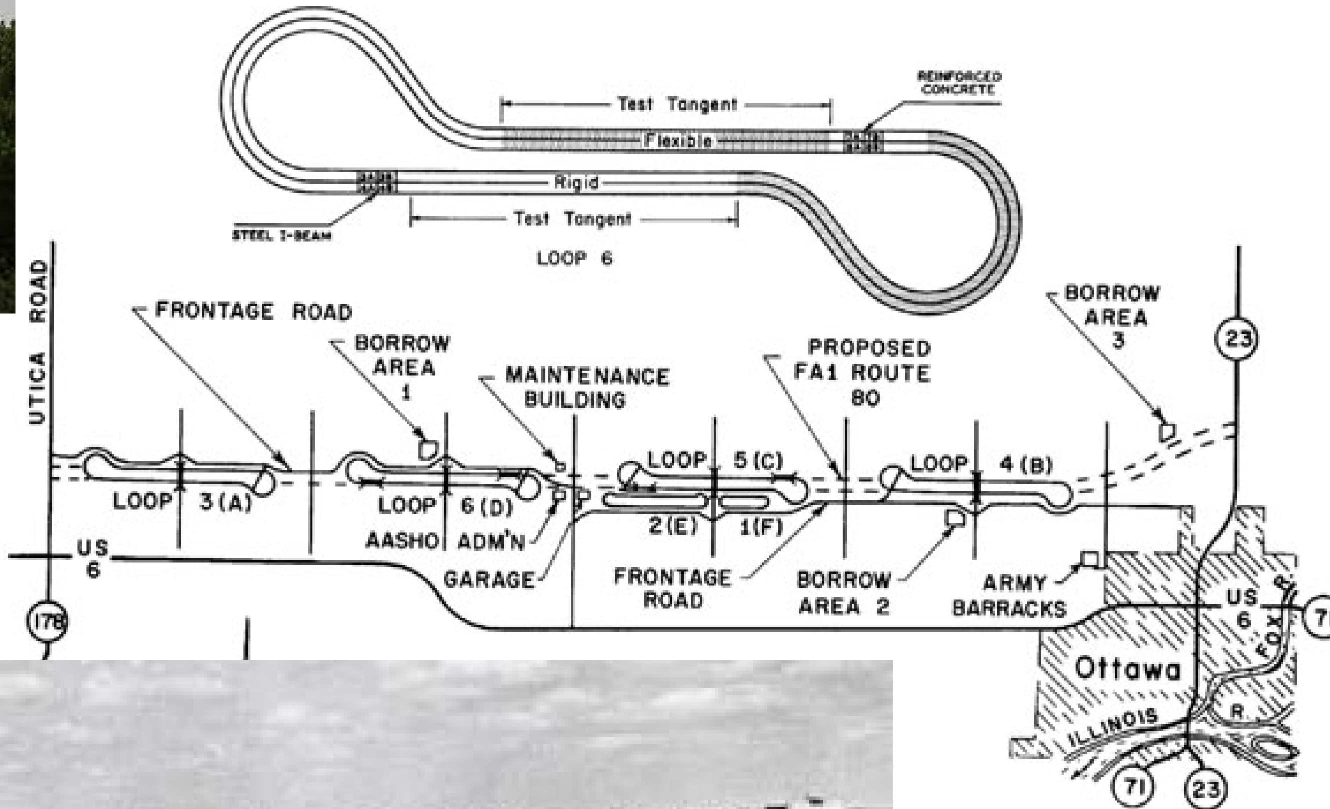
Pavement Performance Modeling at Washington State DOT

David Luhr
Pavement Management Engineer

Outline

- Historic Perspective
  - AASHO Road Test
  - Experimental Design
- Difficulties caused by Pavement Variability
- WSDOT Procedures
- Example of Simplified Factor Evaluation


AASHO
TEST ROAD SITE
1956-1962


REINFORCED CONCRETE
Test Tangent
Flexible
Rigid
Test Tangent
STEEL I-BEAM
LOOP 6
UTICA ROAD
FRONTAGE ROAD
BORROW AREA 1
MAINTENANCE BUILDING
PROPOSED FA1 ROUTE 80
BORROW AREA 3
23
LOOP 3 (A)
LOOP 6 (D)
LOOP 5 (C)
LOOP 4 (B)
2 (E)
1 (F)
AASHO ADM'N
GARAGE
FRONTAGE ROAD
BORROW AREA 2
ARMY BARRACKS
US 6
178
US 6
71
FOX R.
Ottawa
ILLINOIS
R.
71
23

Experimental Design

- Develops most robust pavement models
- Best way to examine effects of many variables
- Avoids problems with correlations among variables
- Use of "replicates" examines the repeatability of results

Loop 4

Axle Load: Lane 1 18,000-S; Lane 2 32,000-T

Main Factorial Design, Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No. Lane 1	Test Section No. Lane 2
3	0	4	1	633	634
		8	2	607	608
		12	3	571	572
			3	569	570
	3	4	2	599	600
		8	3	573	574
		12	1	617	618
	6	4	3	585	586
		8	1	623	624
		12	2	601	602
4	0	4	3	583	584
		8	1	619	620
		12	2	603	604
	3	4	1	627	628
		8	2	589	590
			2	597	598
		12	3	575	576
	6	4	2	595	596
		8	3	577	578
		12	1	625	626
5	0	4	2	605	606
		8	3	587	588
		12	1	621	622
	3	4	3	579	580
		8	1	631	632
		12	2	593	594
	6	4	1	629	630
			1	615	616
		8	2	591	592
		12	3	581	582

Loop 5

Axle Load: Lane 1 22,400-S; Lane 2 40,000-T

Main Factorial Design, Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No. Lane 1	Test Section No. Lane 2
3	3	4	1	485	486
		8	2	451	452
		12	3	415	416
			3	429	430
	6	4	2	449	450
		8	3	419	420
		12	1	487	488
	9	4	3	413	414
		8	1	471	472
		12	2	441	442
4	3	4	3	411	412
		8	1	481	482
		12	2	443	444
	6	4	1	473	474
		8	2	455	456
			2	453	454
		12	3	425	426
	9	4	2	437	438
		8	3	417	418
		12	1	477	478
5	3	4	2	439	440
		8	3	421	422
		12	1	479	480
	6	4	3	423	424
		8	1	469	470
		12	2	445	446
	9	4	1	475	476
			1	483	484
		8	2	447	448
		12	3	427	428

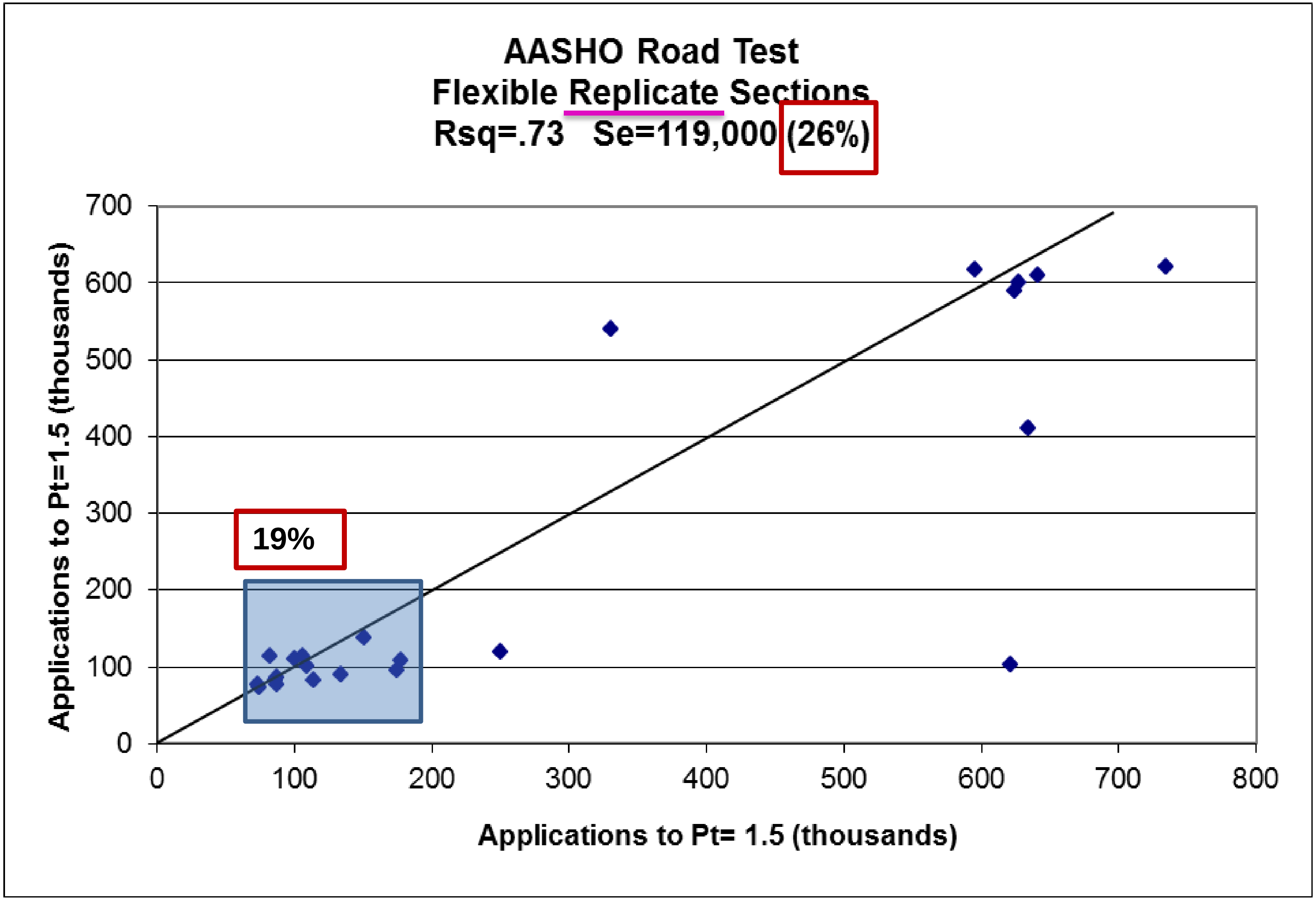
Loop 6

Axle Load: Lane 1 30,000-S; Lane 2 48,000-T

Main Factorial Design, Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No. Lane 1	Test Section No. Lane 2
4	3	8	3	269	270
		12	2	299	300
		16	1	317	318
			1	329	330
	6	8	2	303	304
		12	1	323	324
		16	3	253	254
	9	8	1	321	322
		12	3	267	268
		16	2	309	310
5	3	8	1	319	320
		12	3	261	262
		16	2	315	316
	6	8	3	259	260
		12	2	307	308
			2	305	306
		16	1	327	328
	9	8	2	313	314
		12	1	331	332
		16	3	265	266
6	3	8	2	297	298
		12	1	335	336
		16	3	255	256
	6	8	1	325	326
		12	3	257	258
		16	2	301	302
	9	8	3	263	264
			3	271	272
		12	2	311	312
		16	1	333	334

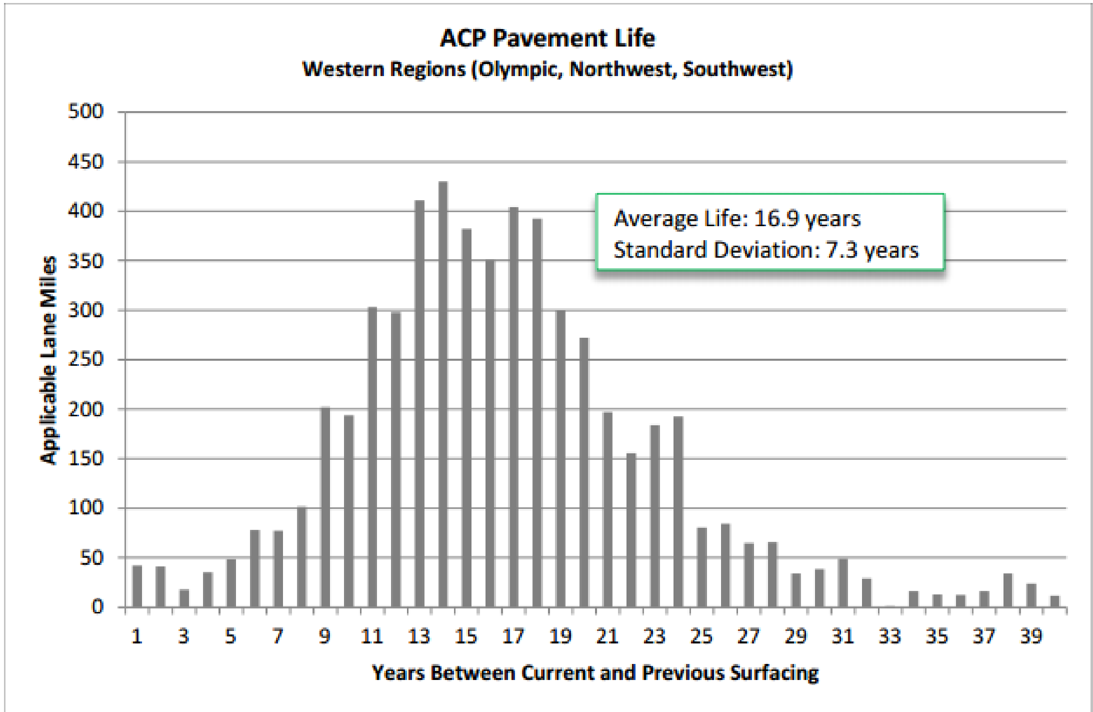
Pavement Variability

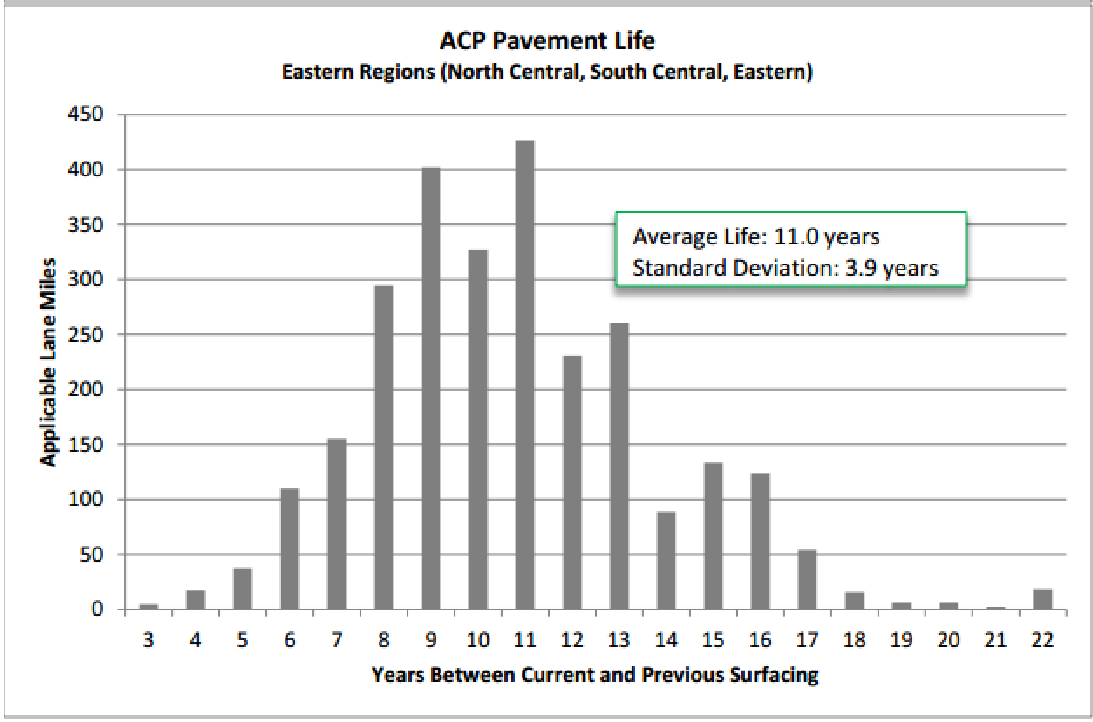


Pavement Variability (cont.)

Significant variability in pavement life due to variability in conditions. Because of this, the WSDOT does close monitoring on a site specific basis.

Modeling does not replace Monitoring!



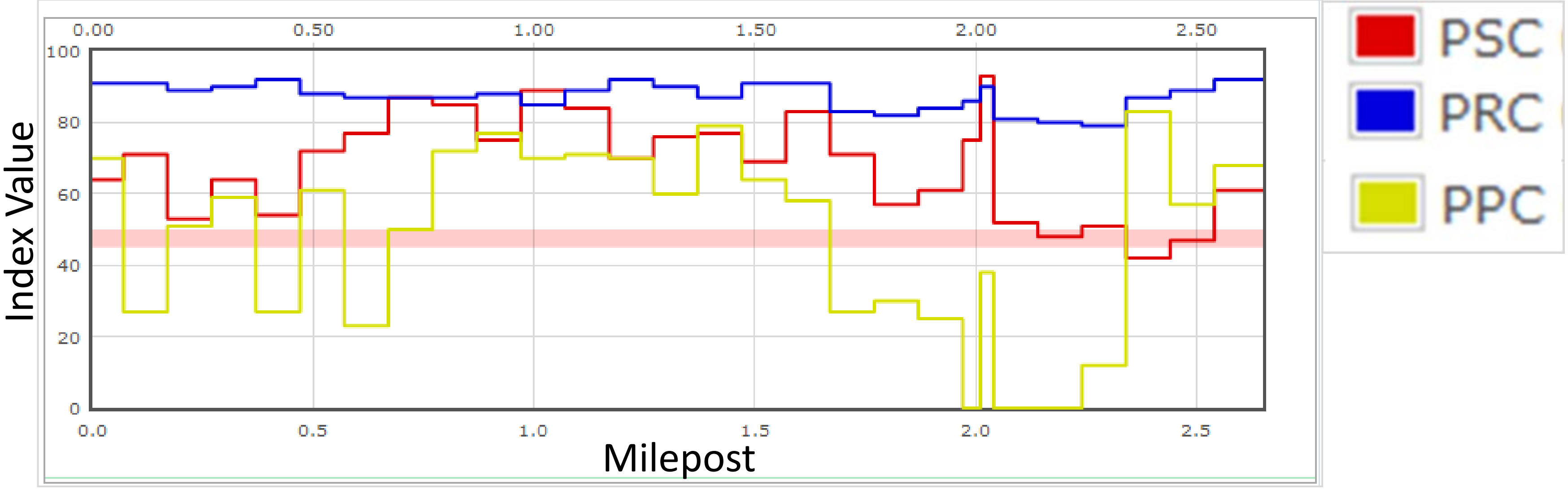


WSDOT Performance Modeling

- Primarily used to forecast time for rehabilitation ("Due Year")
- Network is broken up into 0.1 mile units
- Use Empirical Modeling of close pavement monitoring (annual condition survey)
- Aggregate 0.1 mile units into segments with similar Due Years

Pavement Indexes

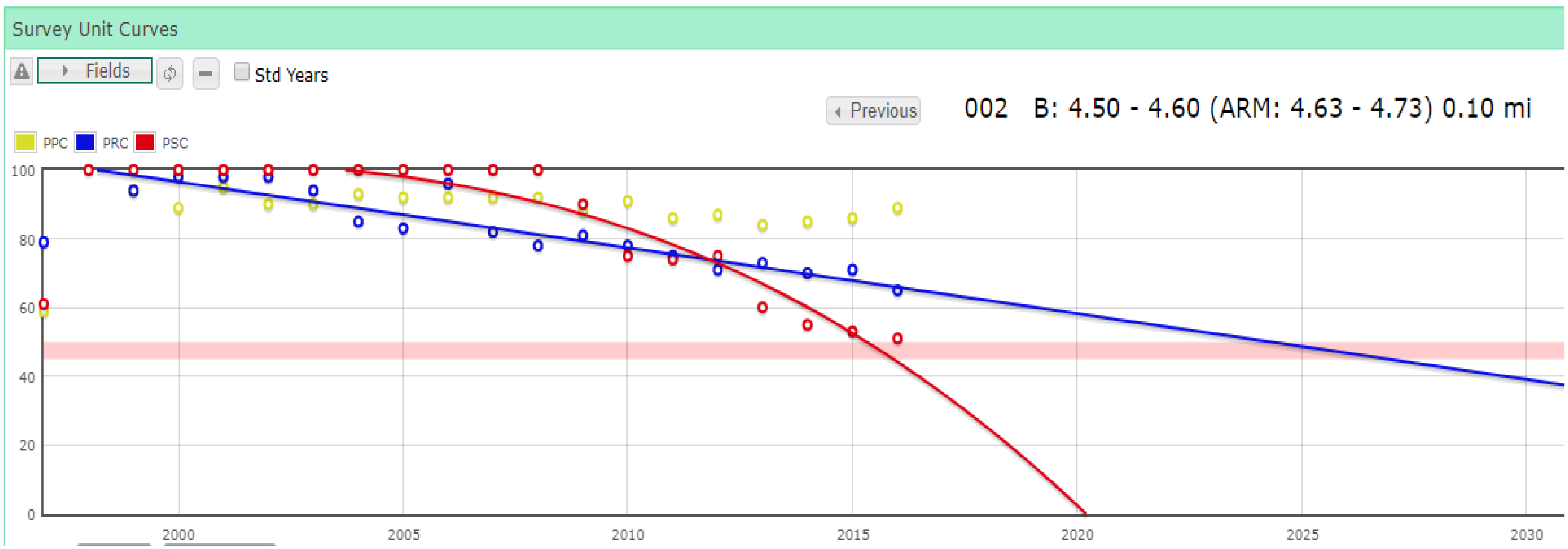
- Normalizes defects from 0 (very poor) to 100 (very good) scale
- Rehabilitation needed at 45-50
- PSC (Pavement Structural Condition)
  - Input: Cracking
- PRC (Pavement Rutting Condition)
  - Input: Rutting
- PPC (Pavement Profile Condition)
  - Input: IRI



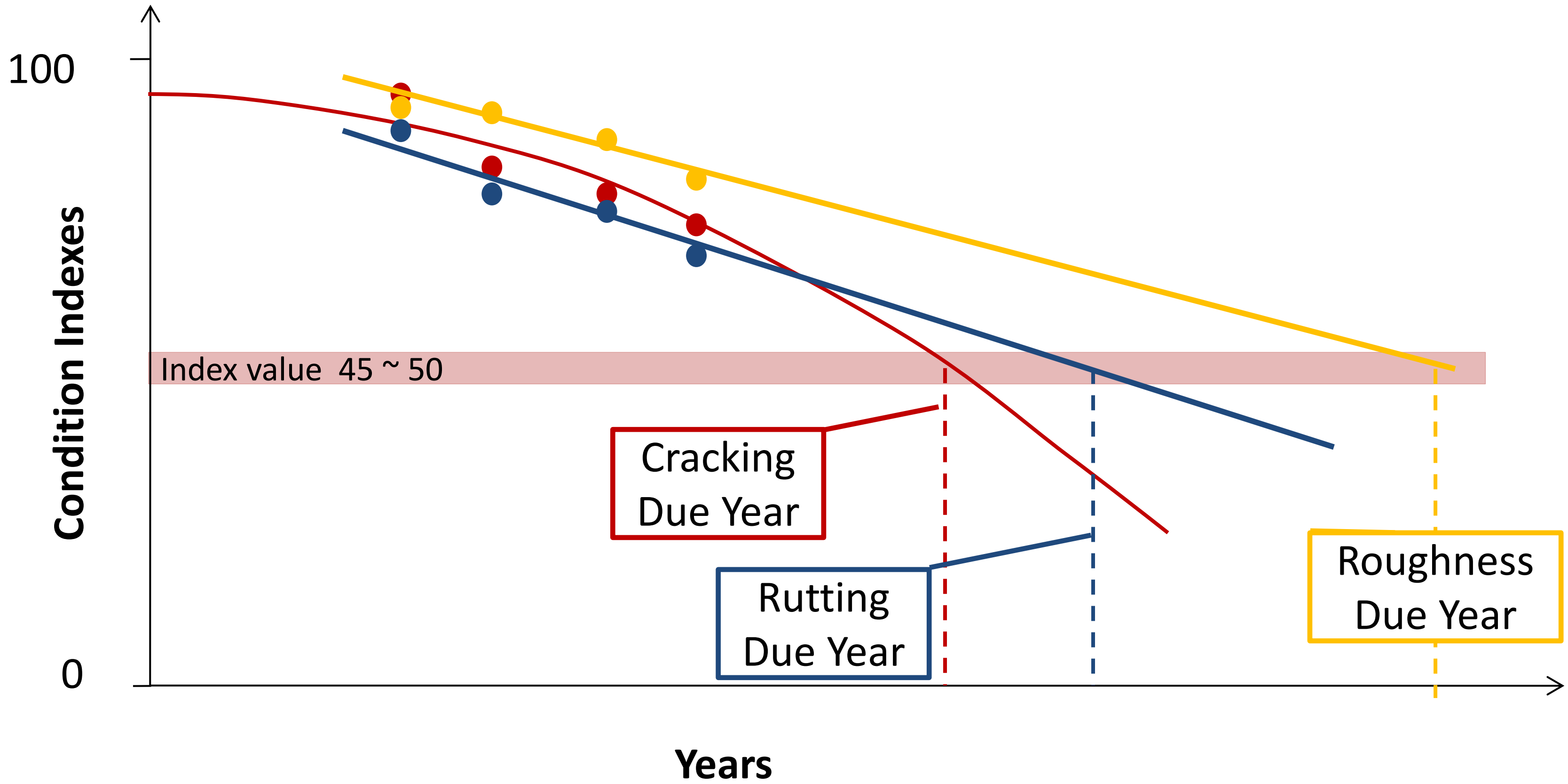
Empirical Modeling

Models based on form: Condition Index = $a - b(\text{age})^c$

where: a, b, c are coefficients fit to the data



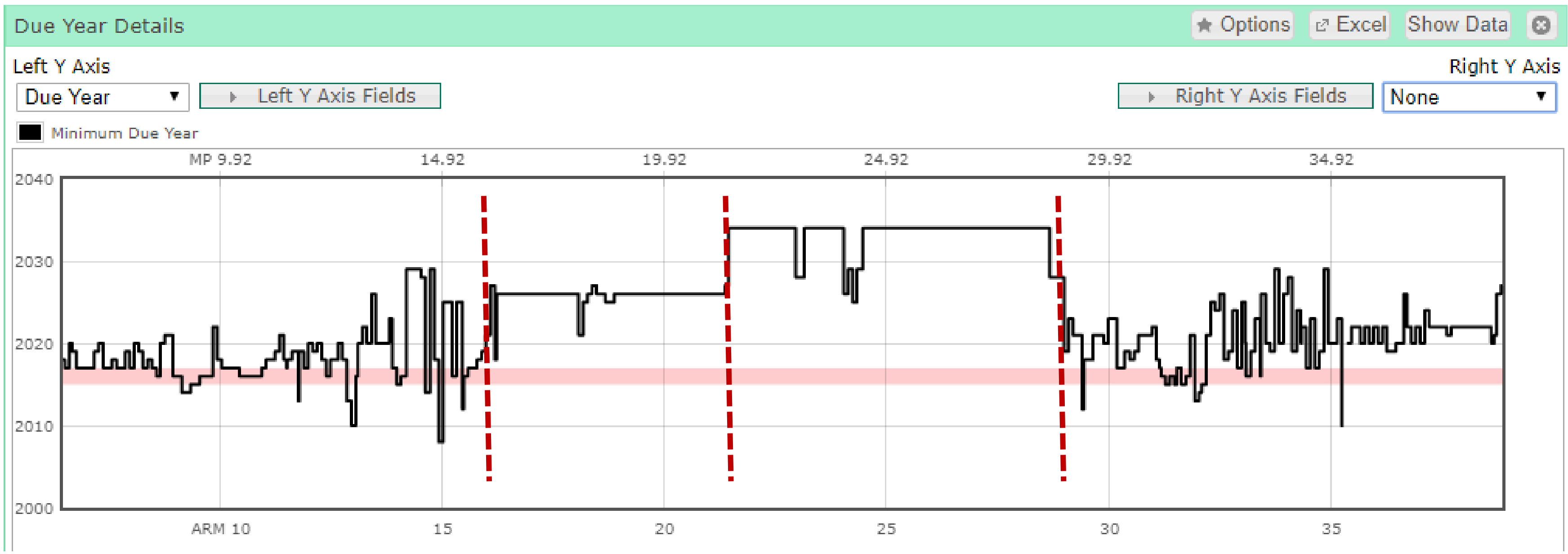
Curve Fitting



- The Due Year is the minimum of the three condition due years.

Segmenting into Project Units

Plot of Due Year for each 0.1 mile segment over 32 miles



Automated algorithm segments into units of similar condition

Maintenance Treatment Evaluation: Original Experimental Design Concept

Table 2. Maintenance Experiment—Primary and Secondary Factors

Climate (Region)	Traffic (ESALs per year)	Maintenance Treatments							
		Crack Sealing (Pavement Condition)			Crack Filling	Fog Seal	Patching	Chip Seal	Full Depth Digouts
Olympic	**Medium**	Poor	Fair	Good	...	...	...	...	...
		2	2	2	...	...	...	...	...
	High	Poor	Fair	Good	...	...	...	...	...
		2	2	2					
Eastern	**Medium**	Poor	Fair	Good	...	...	...	...	...
		2	2	2					
	High	Poor	Fair	Good	...	...	...	...	...
		2	2	2					

Notes
1. Total sections = 144 and 288 with control sections.
2. All primary and secondary "treatment" combinations have two replicate sections.
3. Reducing the pavement conditions from three to two will reduce the number of sections to 96.

Simplified Monitoring Approach

- Limited number of treatment types
- Modify treatments in segments (about ¼ mile) on same test section
- Repeat at different geographic areas
- Document and monitor
  - previous condition
  - treatment methods and materials
  - cost
  - performance

Monitoring of Treatment Segments

Take-Away

- Modeling is difficult, but can develop best models with Experimental Design (like AASHO Road Test).
- Lots of natural variability in pavement performance that is very difficult to model. Must monitor performance carefully.
- Empirical modeling approach works at WSDOT for rehabilitation decision making.
- Can develop simplified comparison of pavement performance variables by using side-by-side treatments.

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Developing Performance Curve of Rubberized Asphalt Concrete for Local Agencies

By Sui Tan

StreetSaver Program Manager

Metropolitan Transportation Commission

TRB Webinar: Developing Pavement Performance Models

October 11, 2017

Acknowledgments

- Funding for this project is provided by CalRecycle:
  - Special thanks go to Nate Gauff and Bob Fujii for their continued support
- California Pavement Preservation Center at California State University at Chico:
  - Professor Dingxin Cheng, Dr. Gary Hicks and graduate students

Why Rubberized Asphalt Concrete?

- California generates about 45 million reusable and waste tires every year
- State mandates CalRecycle to divert waste tires from landfills
- RAC has many benefits:
  - Cost effective
  - Safe
  - Quiet (noise reduction)
  - Environmentally friendly alternative
  - Durable

Anecdote:

" … it last 50% longer than conventional materials…"

Methodology

Gather Pavement Mangement System Information from three different regions within California

↓

Research applicable models that could be used for modeling Rubberized Asphalt Concrete

↓

Collect pavement performance modeling related data from each region and its respective database

↓

Filter data gathered for each model

↓

Adapt and determine data to fit each model requirement

↓

Conduct non-linear regression analysis

↓

Create preliminary Rubberized Asphalt Concrete models for each region

Data Mining of Resources

- CalRecycle local agency grant recipient list
- MTC StreetSaver database
- City and County of Sacramento
- Southern California projects

Model Studied

- StreetSaver Model:

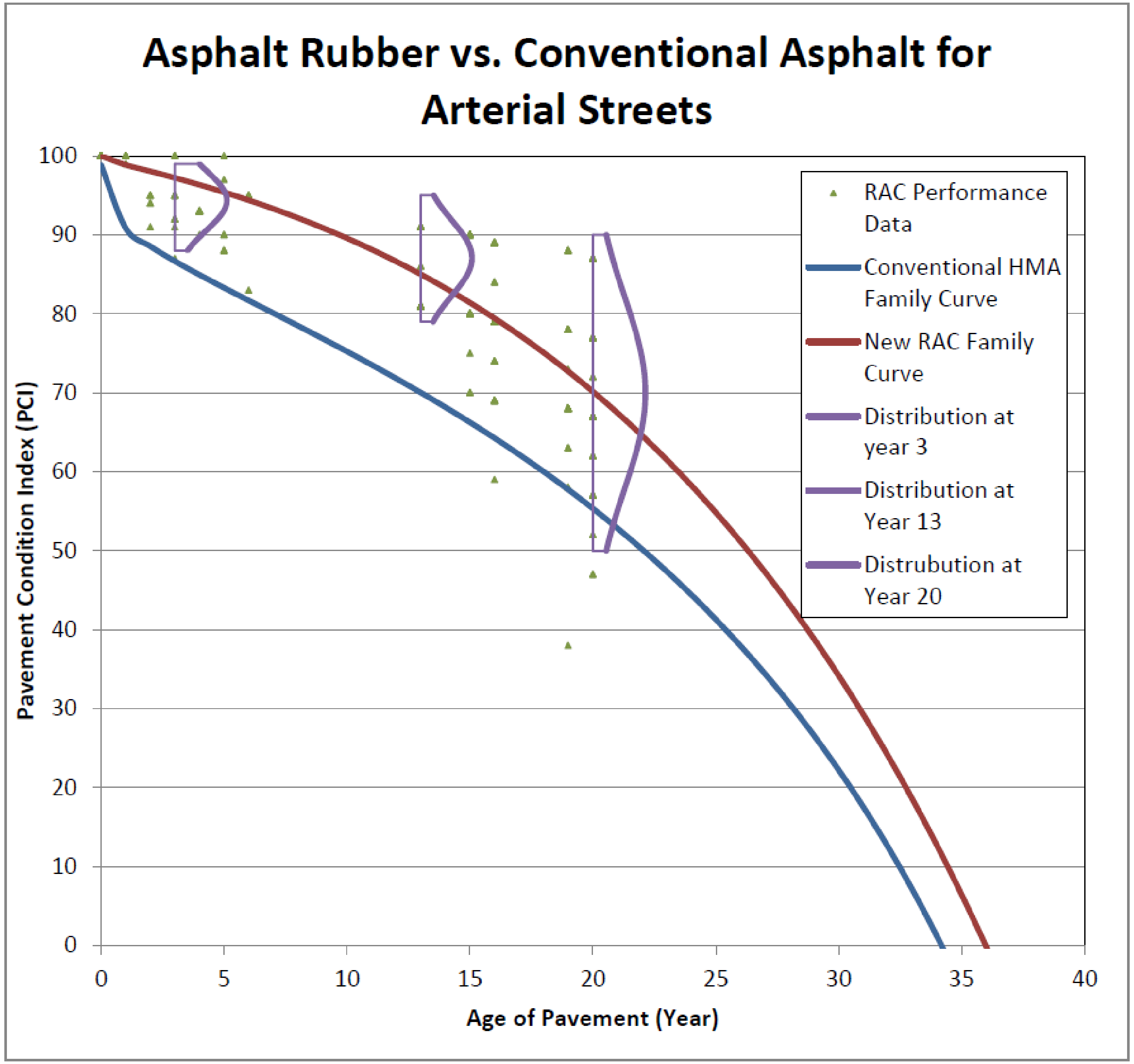
$$PCI = 100 - \frac{\rho}{\left[ln\left(\frac{\alpha}{Age}\right)\right]^{\frac{1}{\beta}}}$$

where:

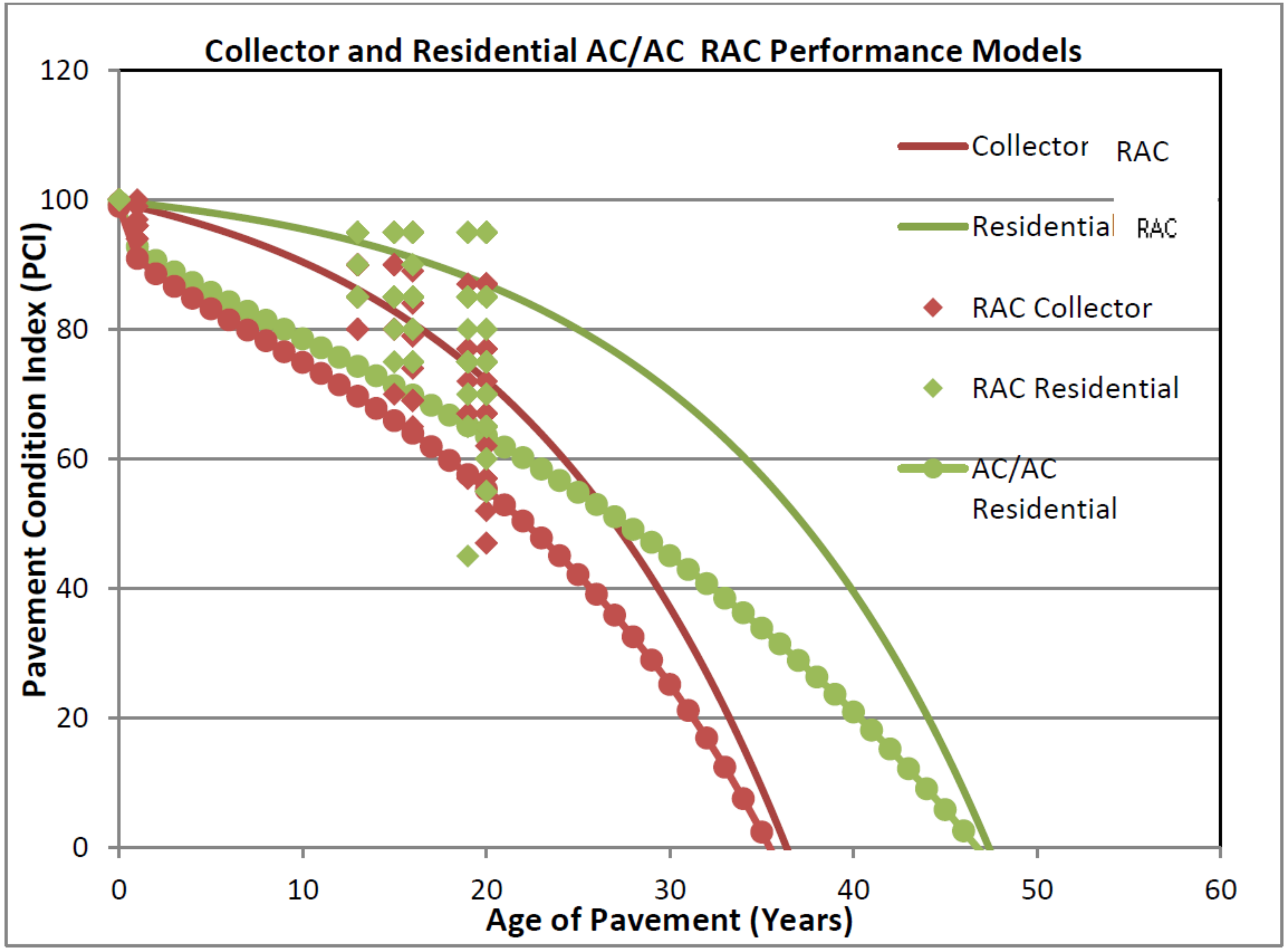
AGE is the age of the current pavement surface
ln is the natural logarithm
α, β, and ρ are regression constants.

Performance Curve for RAC :

Arterial



Collector & Residential Models



Statistical Analysis

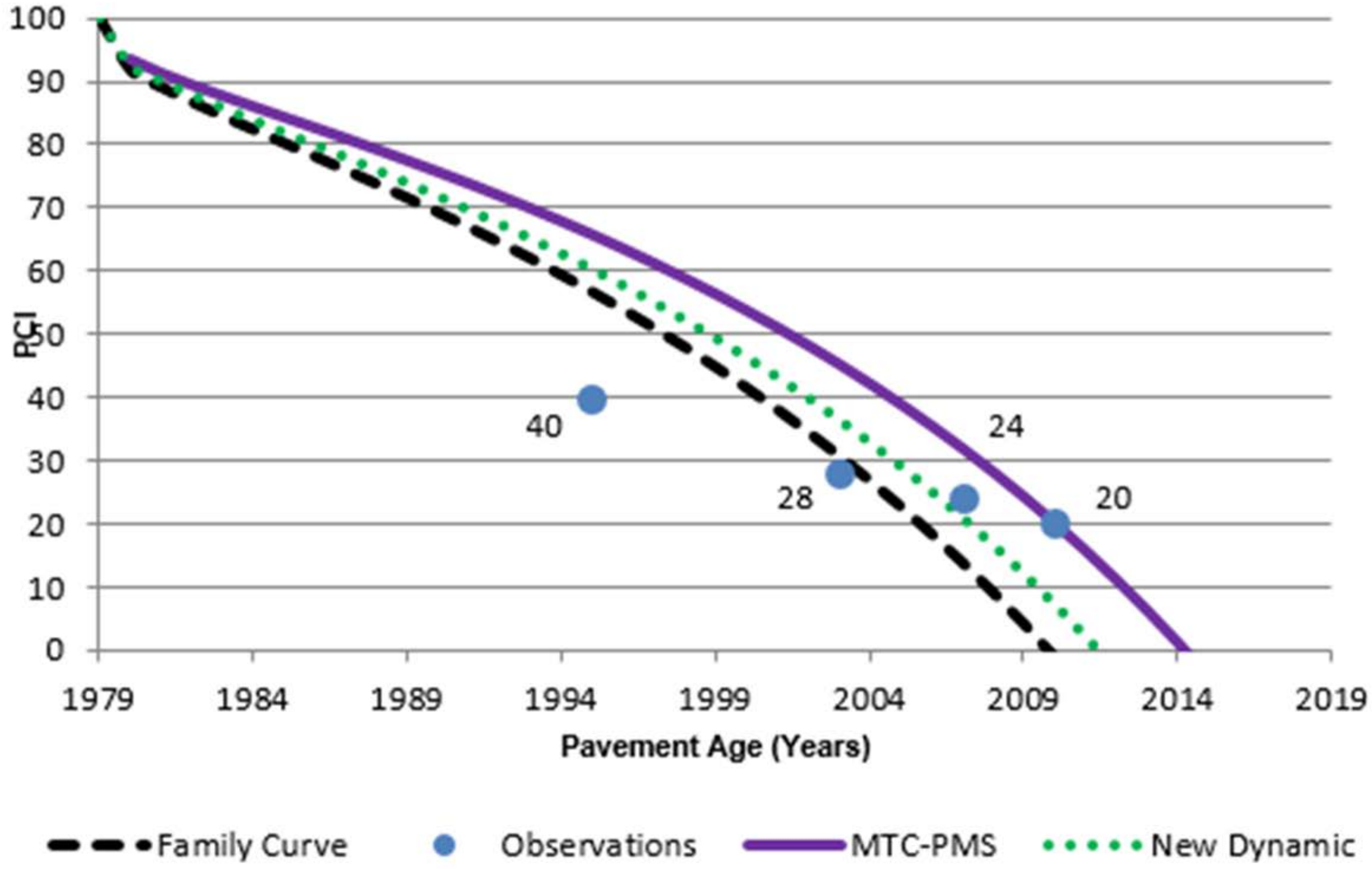
ANOVA[a]			
Source	Sum of Squares	Df [(1)]	Mean Squares
Regression	2282479.690	3	760826.563
Residual	18508.310	287	64.489
Uncorrected Total	2300988.000	290	
Corrected Total	36886.703	289	
Dependent variable: PCI			
a. R squared = 1 – (Residual Sum of Squares) / (Corrected Sum of Squares) = .498.			

(1) Degree of freedom

Conclusions

- Data points are from 0 to 6 years
- Longer term will improve R^2 value
- Research is on going

Ongoing R&D:
Dynamic Adjustment



Ongoing R&D:
Probability-based performance curves

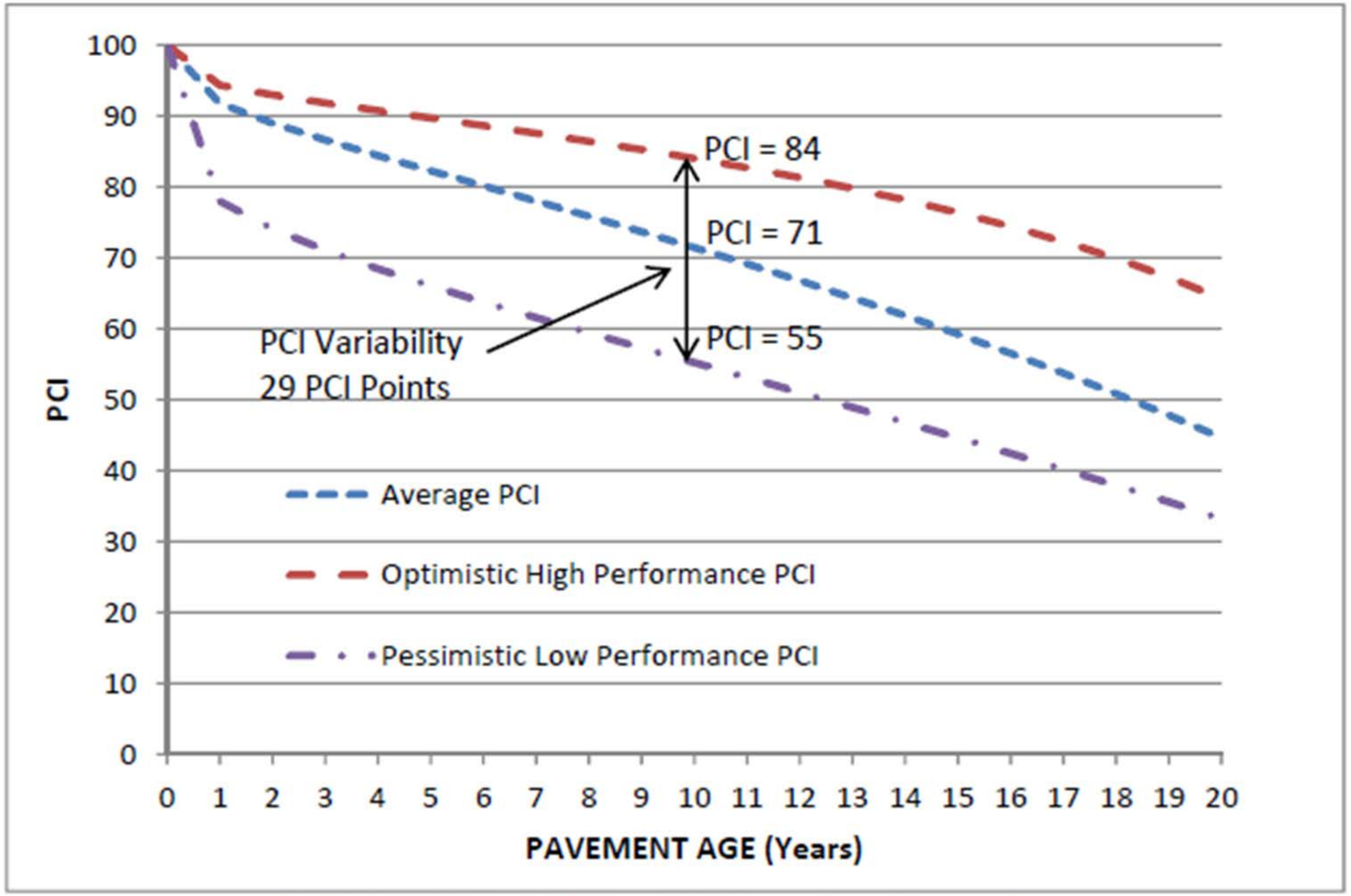
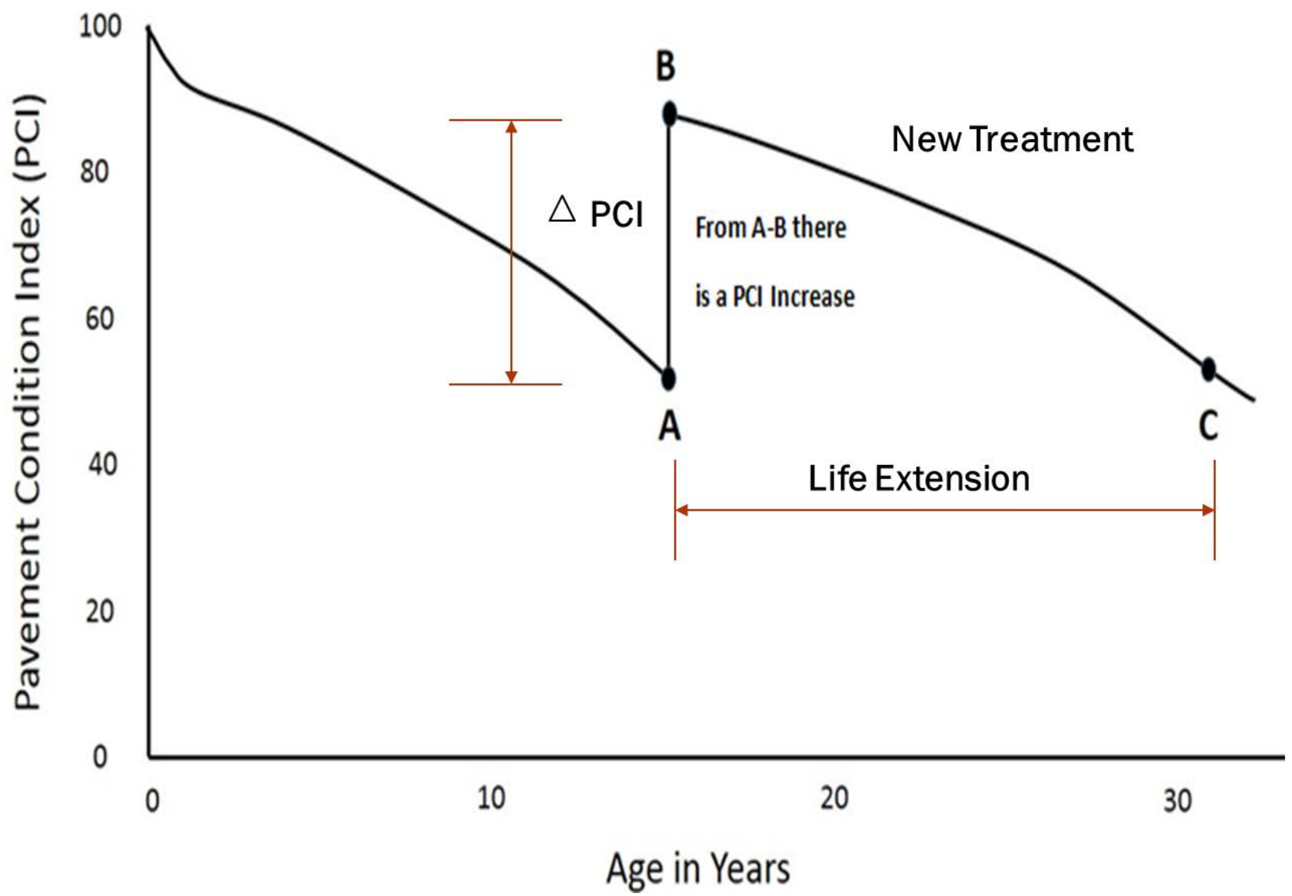


FIGURE 1 Variability of PCIs projected over time

Ongoing R&D:
PCI increase and life extension due to surface treatment



Summary

- Illustrates the process of performance model development using RAC
- RAC performance models for various functional classes were developed for the MTC StreetSaver program.
- Dynamic adjustment of the performance curve based on real pavement condition survey results is being developed.
- Next generation of performance models would be probability-based performance curves, which will increase the reliability and accuracy of the performance prediction.
- Performance of surface treatments with initial PCI jumps and life extension predictions are being investigated.

Development of Performance Models for Urban Pavement Management

Alelí Osorio Lird

Researcher

Pontificia Universidad Católica de Chile

Oct 11st, 2017

Outline

1. **Experimental Designs and Data Collection**
2. **Urban Pavement Condition Evaluation**
3. **Urban Pavement Performance Models**

Experiment: Calibration and Validation Performance Models

1. Dependent Variable: UPCI

2. Independent Variables: Distresses measured in the field and time

3. Scenarios: Fixed independent variables
    - Pavement Type: asphalt and concrete
    - Climate: Dry, Mediterranean and Humid
    - Structural Design
        - Hierarchy: traffic and pavement thickness, based on functional classification (express, trunk, collector, service, and local and laneways)
        - Design: Under design or Over design

4. Relationship: UPCI deterioration over time for each scenario

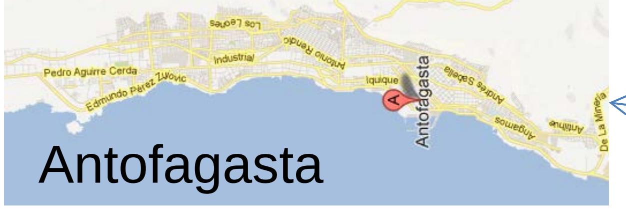
Factorial Design for Calibration and Validation of Performance Models

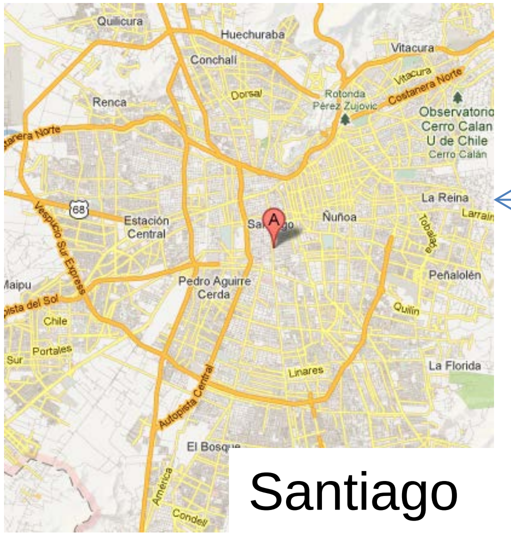
Concrete

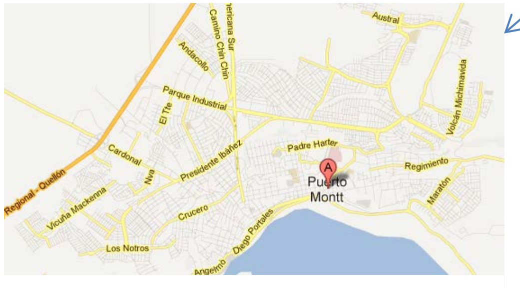
Asphalt										
Climate		Dry			Mediterranean			Humid		
Time		1	2	3	1	2	3	1	2	3
Hierarchy	Express	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3
	Trunk	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3
	Collector	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3
	Service	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3
	Local	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3	UPCI 1	UPCI 2	UPCI 3

Network Evaluated

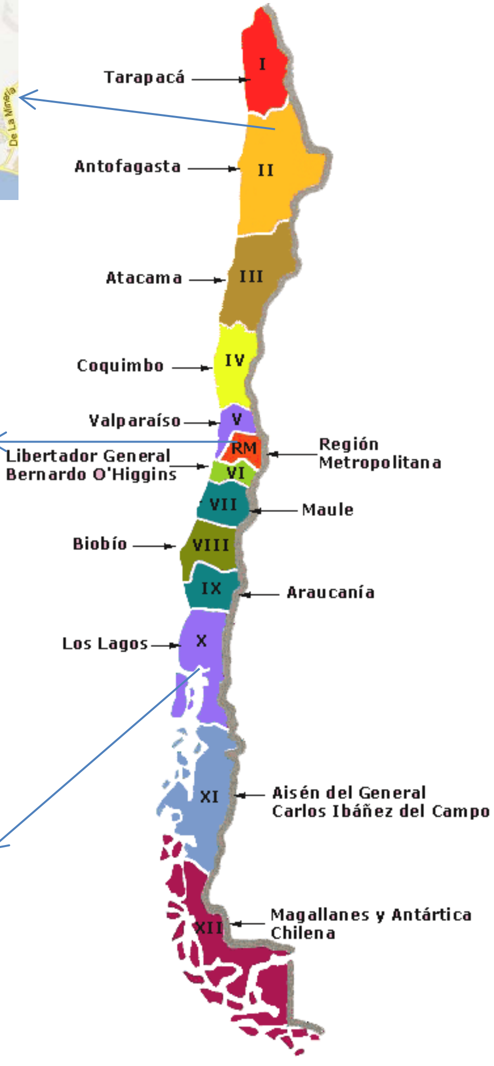
- Dry Climate
  - AMMP < 20 mm
  - Rainy Season < 4 months
  - Asphalt: 122 sample units
  - Concrete: 10 sample units
- Mediterranean Climate
  - AMMP: 20 - 200 mm
  - Rainy Season: 4 -8 months
  - Asphalt: 214 sample units
  - Concrete: 159 sample units
- Humid Climate
  - AMMP > 200 mm
  - Rainy Season > 8 months
  - Asphalt: 34 sample units
  - Concrete: 99 sample units







Puerto Montt



Urban Pavement Condition Index

$$\text{Asphalt UPCI}_{MANUAL} = 10 - 0.038\ FC - 0.049\ TRC - 0.046\ DP - 0.059\ R - 0.237\ P$$

$$\text{Asphalt UPCI}_{AUTO} = 10 - 0.031\ FC - 0.040\ TRC - 0.028\ DP - 0.082\ R - 0.143\ IRI$$

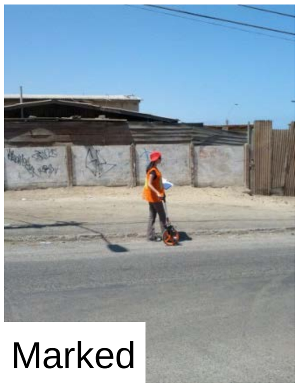
$$\text{Concrete UPCI}_{MANUAL} = 10 - 0.042\ LC - 0.025\ TC - 0.063\ DP - 0.263\ F - 0.038\ COB - 0.018\ JD$$

Where:

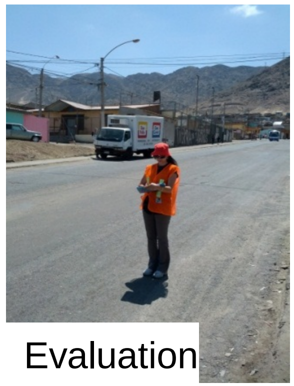
- FC: Fatigue cracking (%)
- TRC: Sum of transversal and reflection cracking (%)
- DP: Deteriorated Patch (%)
- R: Rutting in mm
- P: Potholes (%)
- LC: Longitudinal cracking (%)
- TC: Transversal cracking (%)
- DP: Deteriorated Patch (%)
- F: Faulting in mm, calculated as the average of faulting of each slab in the sample unit
- COB: Sum of corner and oblique breaks (%)
- JD: Joint Damage in percentage of the total meters of joins existing in the sample unit

Data Collection

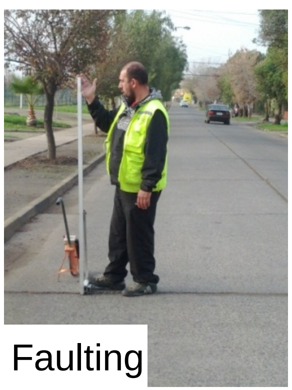
- Manual



Marked



Evaluation



Faulting

Rutting

- Automated

Laser Profilers

Roughometer III

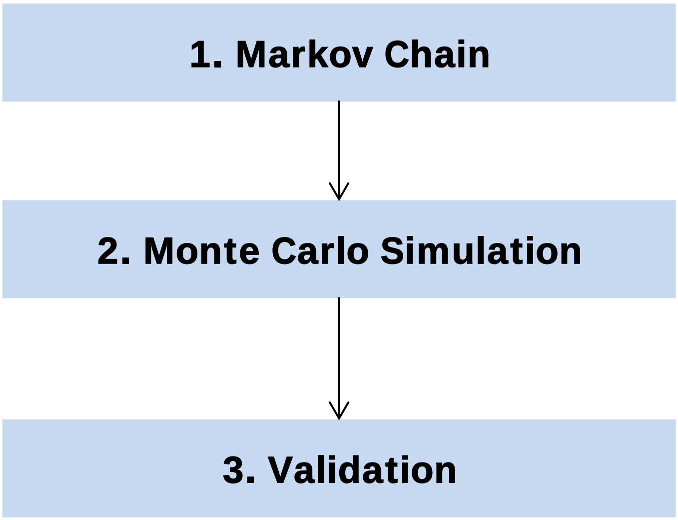
Pave Inspect

FWD

British Pendulem

Calibration of Performance Models

1. Technique: Markov Chain Models with Monte Carlo simulations
   - Probabilistic nature of pavements performance
   - Capture non-linear and stocastic behaviours
   - Not require comprehensive historical data
   - Calibrated with expert surveys or historical data
2. Deterioration Trend: observed after 1 year of service life
3. Service life: 25 years
4. Sections not maintained



Markov Chain

- Condition Summary Table (m)

	Future Condition j (After 1 year) – Asphalt Pavement, Mediterranean Climate										
Current Condition i	Range	10 - 9	8.9 - 8	7.9 - 7	6.9 - 6	5.9 - 5	4.9 - 4	3.9 - 3	2.9 - 2	1.9 - 1	Total (m)
	10 - 9	25,384	5,881	2,767	900	0	0	0	0	0	34,932
	8.9 – 8	0	5,951	4,658	100	612	0	0	0	0	11,321
	7.9 – 7	0	0	6,284	3,908	1,756	0	0	0	0	11,948
	6.9 – 6	0	0	0	3,458	1,902	1,129	311	0	0	6,800
	5.9 – 5	0	0	0	0	2,659	894	397	0	0	3,950
	4.9 – 4	0	0	0	0	0	2,578	231	678	0	3,487
	3.9 – 3	0	0	0	0	0	0	840	632	536	2,008
	2.9 – 2	0	0	0	0	0	0	0	1,162	1,350	2,512
	1.9 - 1	0	0	0	0	0	0	0	0	1,377	1,377

- Cumulative TPM (%)

	Future Condition j (After 1 year) – Asphalt Pavement, Mediterranean Climate									
Current Condition i	Range	10 - 9	8.9 - 8	7.9 - 7	6.9 - 6	5.9 - 5	4.9 - 4	3.9 - 3	2.9 - 2	1.9 - 1
	10 - 9	73	90	97	100	100	100	100	100	100
	8.9 – 8	0	53	94	95	100	100	100	100	100
	7.9 – 7	0	0	53	85	100	100	100	100	100
	6.9 – 6	0	0	0	51	79	95	100	100	100
	5.9 – 5	0	0	0	0	67	90	100	100	100
	4.9 – 4	0	0	0	0	0	74	81	100	100
	3.9 – 3	0	0	0	0	0	0	42	73	100
	2.9 – 2	0	0	0	0	0	0	0	46	100
	1.9 – 1	0	0	0	0	0	0	0	0	100

Montecarlo Simulation

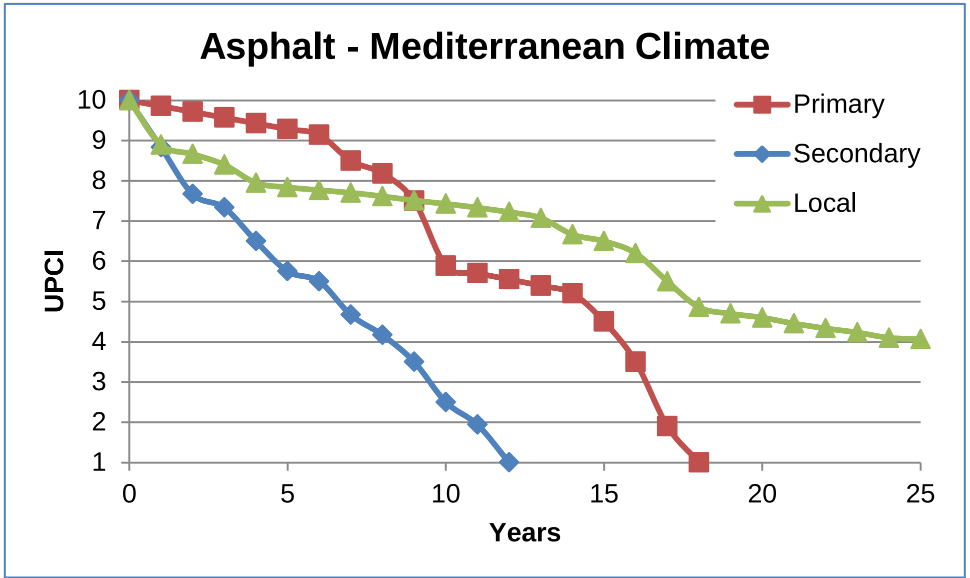
- Trial: Set of 25 random numbers between 0%-100%, for asphalt/concrete pavements representative of the pavement cycle life ⟹ 10,000 trials
- Random number: cumulative probability that a pavement in a condition "i" will be in condition "j" after one year
- Initial condition "i" = 10 (first row of the Cumulative PTM)
- Condition "j" after one year, given by the first cumulative probability higher than the random number

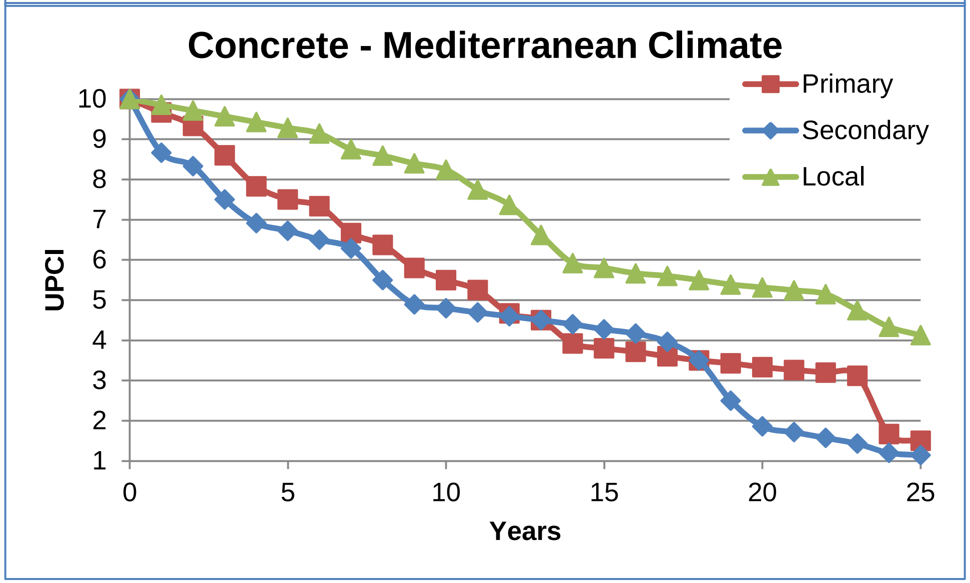
1st period: 88%

2nd period: 70%

Current Condition i	Future Condition j (After 1 year) – Asphalt Pavement, Mediterranean Climate									
	Range	10 – 9	8.9 - 8	7.9 - 7	6.9 - 6	5.9 - 5	4.9 - 4	3.9 - 3	2.9 - 2	1.9 – 1
	10 - 9	73	90	97	100	100	100	100	100	100
	8.9 – 8	0	53	94	95	100	100	100	100	100
	7.9 – 7	0	0	53	85	100	100	100	100	100
	6.9 – 6	0	0	0	51	79	95	100	100	100

Performance Models by Hierarchies

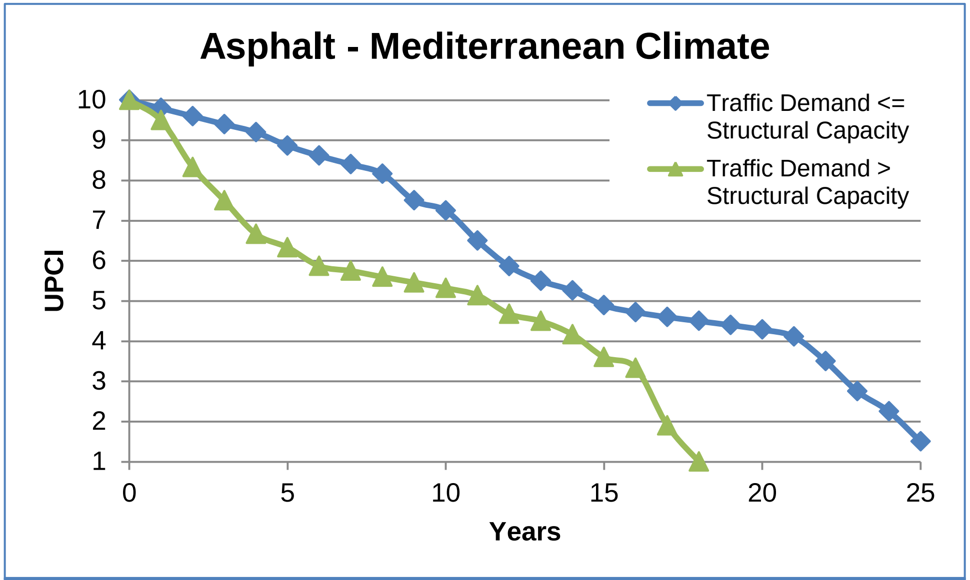


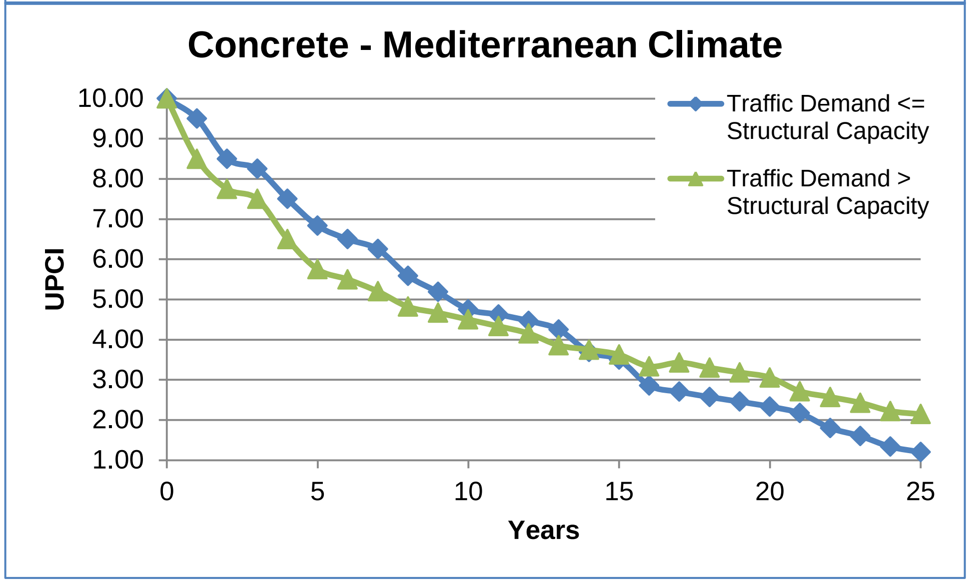


Findings

1. Primary network for asphalt pavements consistent with design.
2. Secondary network for asphalt pavements shows more rapid deterioration than expected.
3. Primary and secondary networks for concrete pavements show similar performance.
4. Local networks for asphalt and concrete pavements have a low deterioration rate.

Performance Models by Real Traffic Demand

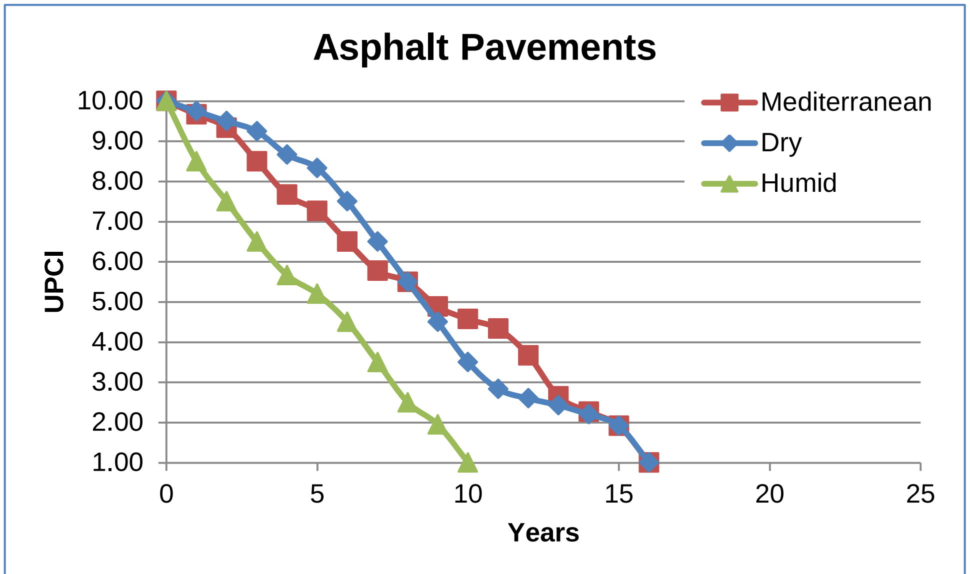


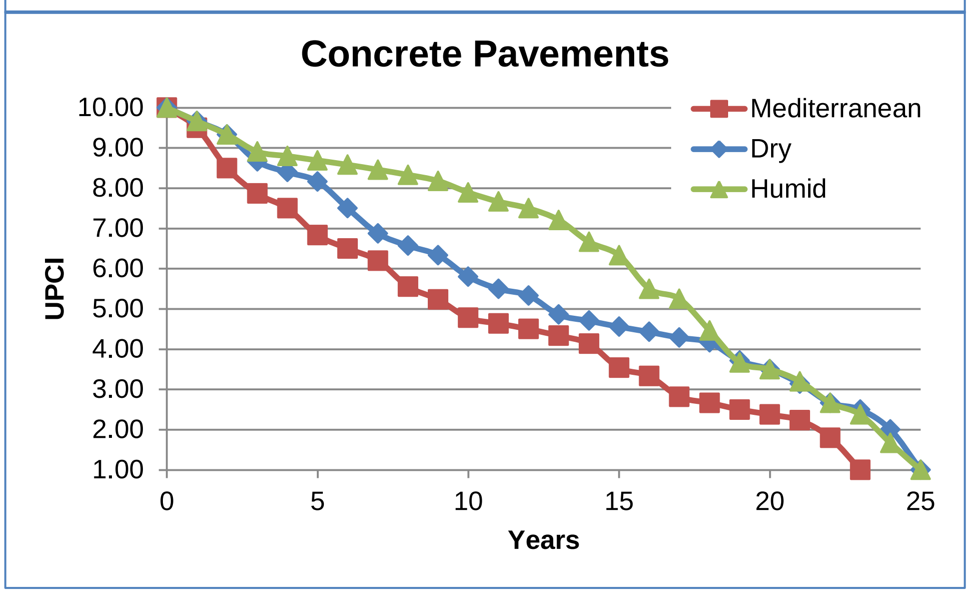


Findings

1. Relation between traffic demand and structural capacity shows
   - Under design of asphalt pavements results in rapid deterioration.
   - Concrete pavements deterioration is not effected by type of design.
2. Asphalt pavements are recommended when information about traffic and structure is available

Performance Models by Climates



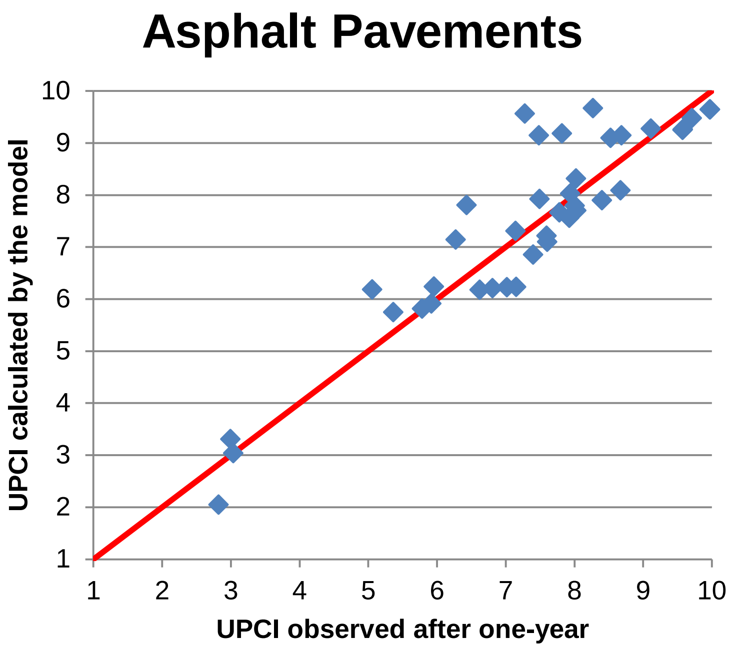


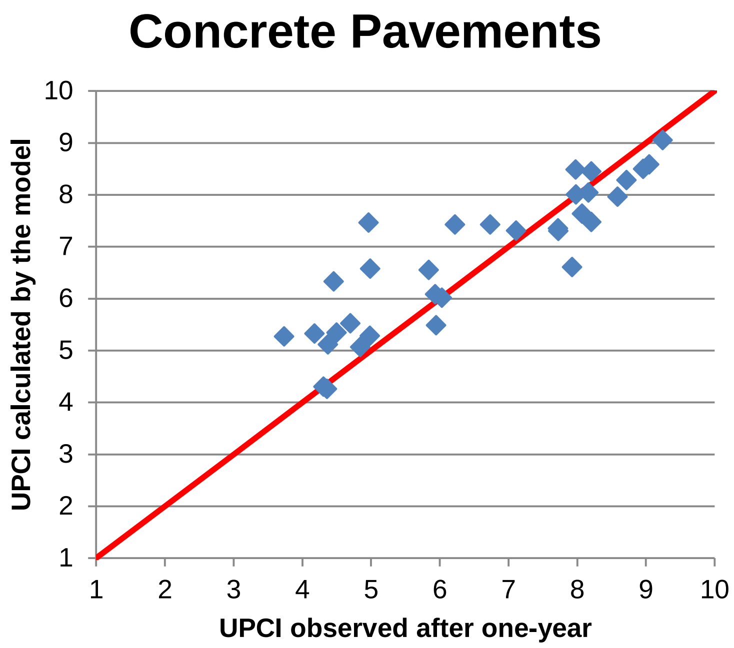
Findings

1. Dry vs. Mediterranean:
   - Similar deterioration for asphalt and concrete
   - Rate of deterioration is larger for asphalt pavements
2. Humid vs. Mediterranean:
   - Larger rate of deterioration for asphalt pavements
   - Lower deterioration rates for concrete pavements

Validation of Performance Models

1. Extrapolation to other cases (25%)
2. Extrapolation in time





Findings

- Calibrated performance models were successfully validated
- Perfomance models for mediteranean climate were validated in time

Poor Condition

Thanks!

Good Condition

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- David Luhr, *Washington State Department of Transportation,* luhrd@wsdot.wa.gov
- Yichang (James) Tsai, *Georgia Institute of Technology,* james.tsai@ce.gatech.edu
- Aleli Osorio, *Pontifical Catholic University of Chile,* aosoriol@ing.puc.cl

Panelists Presentations

http://onlinepubs.trb.org/onlinepubs/webinars/171011.pdf

After the webinar, you will receive a follow-up email containing a link to the recording

Get Involved with TRB

- Getting involved is free!
- Join a Standing Committee (http://bit.ly/2jYRrF6)
  - Search for AFD10 (Standing Committee on Pavement Management Systems)
- Become a Friend of a Committee (http://bit.ly/TRBcommittees)
  - Networking opportunities
  - May provide a path to become a Standing Committee member
- For more information: www.mytrb.org
  - Create your account
  - Update your profile

97th TRB Annual Meeting: January 7-11, 2018

Take Part in the *Careers in Motion* Networking Fair

http://bit.ly/CareersInMotionFair