

Development of AI-Based Prediction Models to Evaluate Long-Term Aged Cracking Resistance in Asphalt Mixtures Using SCB Jc Parameter



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Key Topics

- Background
- Objectives and Scope
- Development Prediction Models
 - Statistical Scaling Factor
 - AI-Based
- Results
- Key Takeaways
- Implementation



Pavement Performance

- Ability of a structure to satisfactorily serve traffic and environmental loading over a period of time



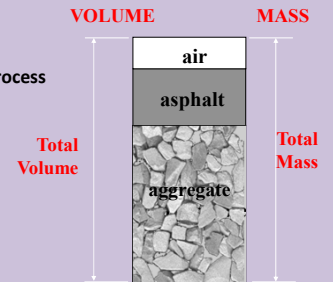
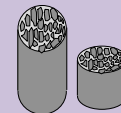
Asphalt Mixture Design

• Volumetrics

- Voids in the Total Mix, **VTM**
- Voids in the Mineral Aggregate, **VMA**
- Voids Filled with Asphalt, **VFA**

• Densification

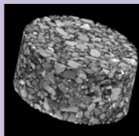
- Stages during lab compaction process



Concerns

• Optimum asphalt binder content

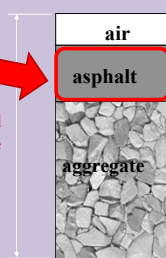
- Quantity
- **NOT QUALITY**
- **Aged Binders**
 - » Replace virgin binder
 - » RAP and/or RAS



VOLUME **MASS**

Total Volume

Total Mass



Durable Flexible Pavement

- Permanent deformation
- **Fatigue cracking – repeated load**
- Low temperature cracking
- Moisture induced damage
- Raveling
- etc ...

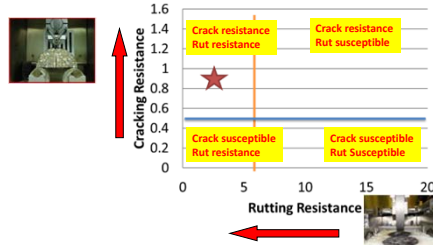


Durable

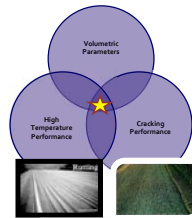
- ... able to exist for a long time without significant deterioration in quality or value."

Louisiana's Approach -- Durable Flexible Pavement Balanced Asphalt Mixture Design

- **Volumetric and Performance Mixture Testing**
 - Rutting (AASHTO T 324): LWT test (50°C, Wet)
 - Cracking (ASTM 8044): SCB test (25°C)



Asphalt Mixtures Stress Tests



LOUISIANA
STANDARD SPECIFICATIONS
FOR
ROADS AND BRIDGES

DOTD
LOUISIANA DEPARTMENT OF
TRANSPORTATION & DEVELOPMENT

2018
EDITION

STATE OF LOUISIANA
DEPARTMENT OF TRANSPORTATION
AND DEVELOPMENT

2016 Louisiana DOTD Specifications for Roads and Bridges

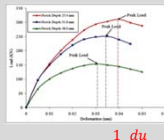
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SCB, min, Jc, kJ/m² @
25⁰ C, **Aged**

All mix design level 1 must meet minimum 0.5 Jc ,
All mix design level 2 must meet minimum 0.6 Jc.

Durable Flexible Pavement

- Permanent deformation
- **Fatigue cracking – repeated load**
 - Fracture mechanic-based test
 - Semi-Circular Bend (SCB) Test – ASTM D8044
 - Sample preparation
 - Aging (85°C for 5 days) **Not Practical Q/C**
 - Testing
 - Outputs
 - Load vs displacement curve
 - Compute cracking resistance parameter
 - Critical strain energy release rate (J_c)
 $J_c \geq 0.6 \text{ kJ/m}^2$ High volume traffic



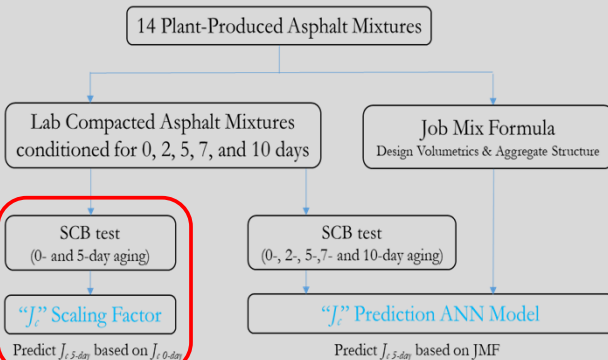
$$J_c = -\left(\frac{1}{b}\right) \frac{du}{da}$$

Objective

- Develop *practical LTA SCB Jc prediction* models from short-term data available at the design and production phases
 - *Scaling factor*
 - » Forecast SCB Jc at 5 days (Jc 5-day) aging from asphalt plant produced SCB Jc (Jc 0-day)
 - *Machine learning prediction model* to obtain SCB Jc 5-days from parameters available in job mix formulas
 - » Facilitate implementation in QC/QA
 - » User-friendly GUI developed

Elnam, I., Mohammad, L. N., Cooper, III, S., and Cooper, Jr, S., "Development of Practical Prediction Models to Assess Long-Term Aged Cracking Resistance in Asphalt Mixtures Using the SCB Jc Parameter." *Journal of Construction and Building Materials*, Vol 491, 2025, pp. 142670: 1-9

Scope



Scope:

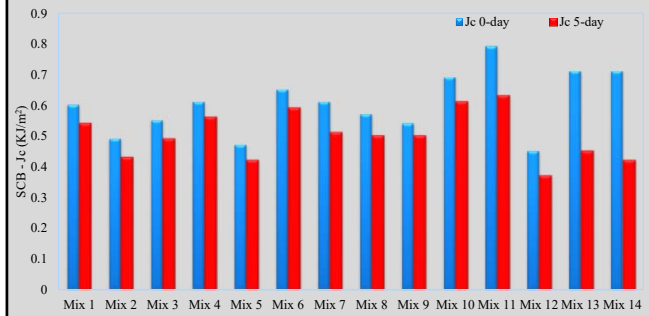
Materials

- ❑ **14 field projects**
 - **Asphalt Mixture Types**
 - SMA
 - Dense graded
 - **NMAS, mm**
 - ❖ 9.5, 12.5
 - ❖ **RAP Contents, %**
 - ❖ 0 - 26
 - ❖ **Asphalt Binder Type**
 - ❖ PG 67-22 (unmodified) -- 4
 - ❖ PG 70-22 (SBS modified) -- 4
 - ❖ PG 70-22 (Latex modified) -- 1
 - ❖ PG 76-22 (SBS modified) -- 4
 - ❖ PG 82-22 (Crumb Rubber modified) -- 1
 - ❖ **Asphalt Binder Source**

Scope

Mixture Number	RBR	Total %AC	Asphalt Binder PG	Modifier	NMAS, mm	Design Level*	V _a (%)	VMA (%)	VFA (%)	P _{bb} (%)	D/B
M1	0.14	5.0	70-22m	SBS	12.5	1	3.5	14.7	76	4.8	0.96
M2	0.00	6.0	82-22m	CR	12.5	SMA	3.5	16.3	79	5.5	1.31
M3	0.26	4.6	76-22m	SBS	19.0	2	3.5	13.2	73	4.1	1.02
M4	0.00	6.3	76-22m	SBS	12.5	SMA	3.5	17.0	79	5.9	1.29
M5	0.18	5.0	67-22	-	12.5	1	3.7	13.8	74	4.7	1.17
M6	0.16	5.0	76-22m	SBS	12.5	2F	3.5	14.7	76	4.8	0.96
M7	0.15	4.7	67-22	-	12.5	1	3.4	13.9	76	4.5	1.21
M8	0.15	4.7	70-22m	SBS	12.5	1	3.4	13.9	76	4.5	1.21
M9	0.28	4.6	67-22	-	19.0	1	3.6	13.1	72	4.1	1.20
M10	0.20	5.0	67-22	-	12.5	1	3.6	13.9	74	4.5	1.22
M11	0.21	4.7	70-22m	Latex	12.5	1	3.5	14.1	75	4.6	1.17
M12	0.20	5.1	70-22m	SBS	12.5	1F	3.5	13.8	75	4.4	1.18
M13	0.00	6.3	76-22m	SBS	12.5	SMA	3.7	16.5	78	5.6	1.47
M14	0.00	4.2	70-22m	SBS	19.0	1	3.5	12.5	72	3.8	0.92

Development Prediction Models – Scaling Factor

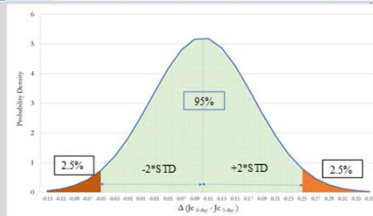


Development Prediction Models – Scaling Factor

Descriptive statistics

	J _c 0-day	J _c 5-day	Δ (J _c 0-day - J _c 5-day)
Maximum	0.79	0.63	0.29
Minimum	0.45	0.37	0.04
Average	0.603	0.501	0.101
STD	0.096	0.075	0.077
COV, %	16.6	15.6	78.3

Normal Distribution for Δ values



Development Prediction Models – Scaling Factor

Scaling Factor

	Dataset Scaling Factor (J _c 5-day / J _c 0-day)	Recommended Scaling Factor (J _c 5-day / J _c 0-day)	95% Confidence Band of Recommended Scaling Factor
Maximum	0.93	0.93	
Minimum	0.59	0.80	95% CI = Average ± 1.96*STD
Average	0.84	0.87	95% CI = 0.87 ± 1.96*0.04
STD	0.10	0.04	95% CI = [0.79 - 0.94]
COV, %	12.3	4.5	

N = number of mixtures; CI = confidence interval

$$J_{c\ 5\text{-day}} = J_{c\ 0\text{-day}} * SF$$

Where:

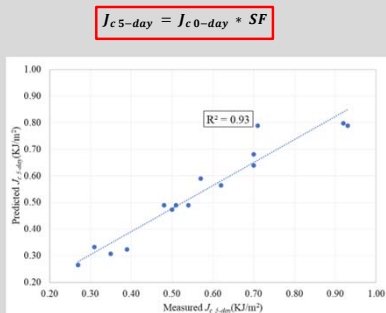
J_c 5-day: Predicted SCB J_c value at 5 days at 85°C, kJ/m²

J_c 0-day: Measured SCB J_c value, at 0 days, kJ/m²

SF: Scaling factor range [79% – 94%], with an average of 87%.

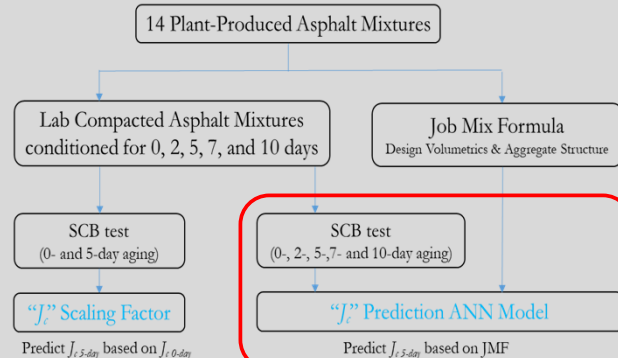
Development Prediction Models – Scaling Factor Results

Scaling Factor Validation (15 new mixtures)



Comparison of measured J_c 5-day and predicted J_c 5-day using the Scaling Factor developed

Scope



Development Prediction Models -- ANN

- 40 asphalt mixtures at different aging levels
 - 0-, 2-, 5-, 7-, and 10-day
- Diverse set of asphalt mixture component materials
 - unmodified, polymer modified, various recycled binder ratios (RBR)
 - different gradations
- 104 data points were used to select significant parameters in predicting SCB Jc
 - LL & PL specimens

Development Prediction Models -- ANN

- Artificial neural network (ANN) model
 - 12 variables were considered
 - readily available
 - » Volumetric properties of asphalt mixture
 - » aging level
 - » asphalt binder modification level.
 - Mixture Volumetric Properties --10
 - » %AC (asphalt content)
 - » %RAP and %RAS
 - » P_{be} (effective asphalt binder)
 - » P200 (%passing no. 200 sieve)
 - » P4 (%passing no.4 sieve)
 - » VMA (void in mineral aggregate)
 - » VFA (void filled with asphalt)
 - » SA (surface area, m²)
 - » FT (film thickness, μm)
 - » DB (dust to binder ratio)

Louisiana Department of Transportation and Development
JRP SUPERPAVE ASPHALT CONCRETE MIXTURES

Job No.	Section	Plant Name	Plant No.	Job Title	Job Date	Job Type	Job Status	Job Notes
101-00000001	101-00000001	101-00000001	101-00000001	101-00000001	101-00000001	101-00000001	101-00000001	101-00000001
101-00000002	101-00000002	101-00000002	101-00000002	101-00000002	101-00000002	101-00000002	101-00000002	101-00000002
101-00000003	101-00000003	101-00000003	101-00000003	101-00000003	101-00000003	101-00000003	101-00000003	101-00000003
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101-00000005	101-00000005	101-00000005	101-00000005	101-00000005	101-00000005	101-00000005	101-00000005	101-00000005
101-00000006	101-00000006	101-00000006	101-00000006	101-00000006	101-00000006	101-00000006	101-00000006	101-00000006
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Development Prediction Models -- ANN

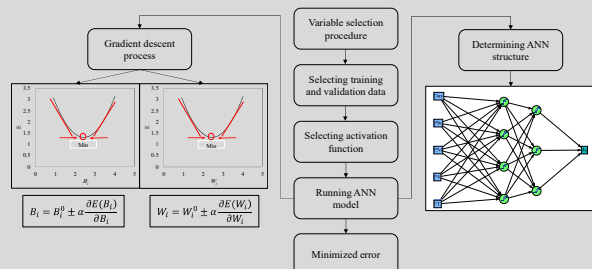
- Artificial neural network (ANN) model
 - 12 variables were considered
 - readily available
 - » Volumetric properties of asphalt mixture
 - » aging level
 - » asphalt binder modification level.
 - Asphalt Binder Properties
 - » asphalt binder modification level
 - 0 = PG 67-22; 1 = PG 70-22; 2 = PG 76-22
 - Aging Level
 - » Days
 - 0-, 2-, 5-, 7-, and 10-days
- Stepwise Regression Analysis
 - building a model by successively adding or removing independent variables
 - » based on F-statistics of estimated coefficients
 - significant variables to predict the SCB

Development Prediction Models -- ANN

Step	Parameter	Action	F-value	R ²	No. of parameters in model
1	Surface Area	Entered	0.0000	0.3210	2
2	Aging Days	Entered	0.0000	0.5086	3
3	Polymer modification level	Entered	0.0000	0.6105	4
4	%Passing from sieve #4	Entered	0.0000	0.6769	5
5	Effective Asphalt Binder	Entered	0.0149	0.6961	6
6	Surface Area	Removed	0.7551	0.6958	5
7	Film Thickness	Entered	0.0226	0.7118	6
8	Surface Area	Entered	0.0187	0.7280	7
9	Recycled Asphalt Shingle	Entered	0.0772	0.7368	8
10	AI	Removed	0.0000	0.7368	7
11	Surface Area	Entered	0.0000	0.3210	2
12	Aging Days	Entered	0.0000	0.5086	3
13	Polymer modification level	Entered	0.0000	0.6105	4
14	%Passing from sieve #4	Entered	0.0000	0.6769	5
15	Effective Asphalt Binder	Entered	0.0149	0.6961	6
16	Surface Area	Removed	0.7551	0.6958	5
17	Film Thickness	Entered	0.0226	0.7118	6
18	Surface Area	Entered	0.0187	0.7280	7

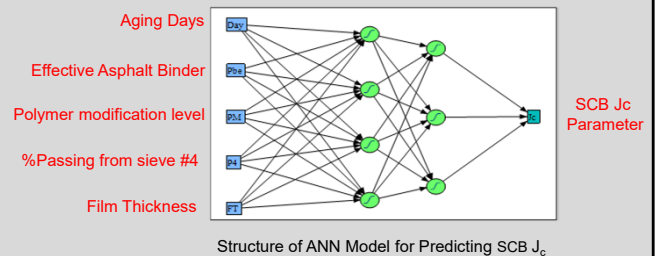
Development Prediction Models -- ANN

- Model Development
 - » R-studio software – Training 70% and Validation 30%
 - » Sample size should be more than 10*parameters studied (6) = 60 < 104 used



Development Prediction Models -- ANN

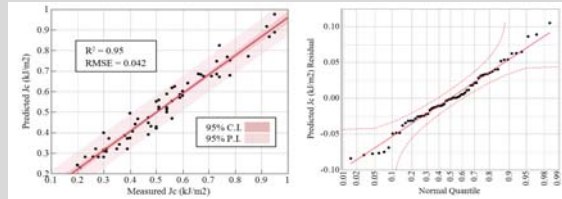
- Model Development
 - » R-studio software – Training 70% and Validation 30%
 - » Sample size should be more than 10*parameters studied (6) = 60 < 104 used



Development Prediction Models -- ANN

Model Development

- R-studio software – Training 70% and Validation 30%
- Sample size should be more than 10*parameters studied (6) = 60 < 104 used

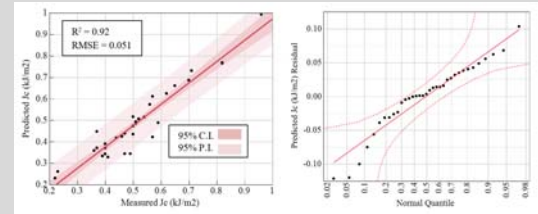


Training Result (a) Predicted versus Measured SCB Jc, (b) Residual Normal Quantile Plot

Development Prediction Models -- ANN

Model Validation

- R-studio software – Training 70% and Validation 30%

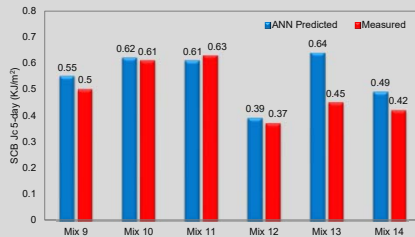


Validation Result (a) Predicted versus Measured SCB Jc, (b) Residual Normal Quantile Plot

Development Prediction Models -- ANN

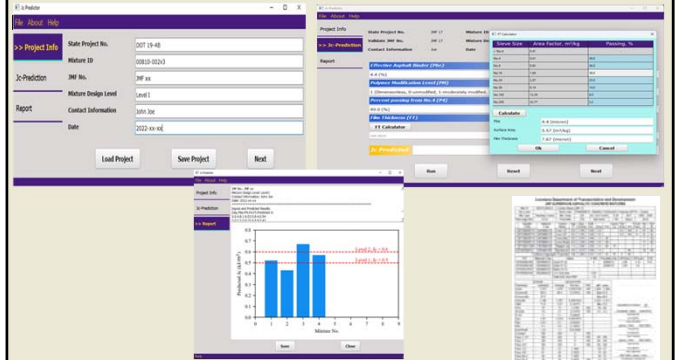
Model Validation

- R-studio software – Training 70% and Validation 30%



Validation Result (a) Predicted versus Measured SCB Jc, (b) Residual Normal Quantile Plot

SCB Jc Prediction - ANN Model

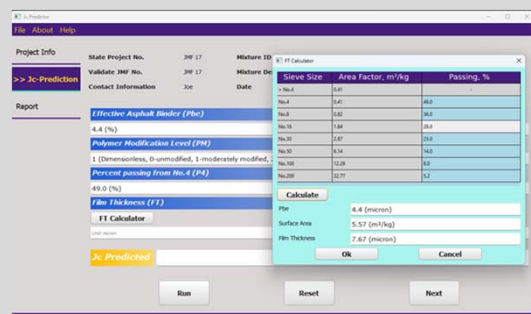


Mohammad, L., et al., FHWA/LA.23/685, Implementation of Semi-circular Bend (SCB) Test for QC/QA of Asphalt Mixtures. 2023, Louisiana Transportation Research Center.

Results of Prediction Models

2. Results of ANN Prediction Model

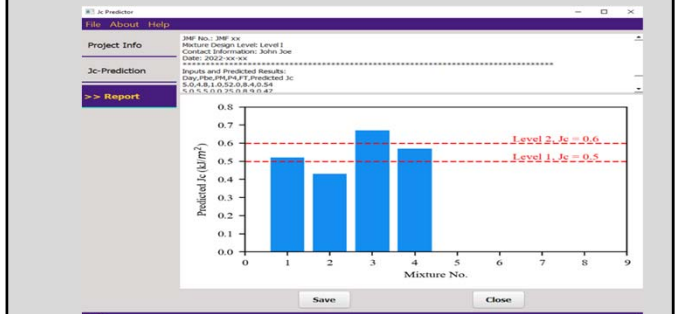
– 2.4. User Interface



Results of Prediction Models

2. Results of ANN Prediction Model

– 2.4. User Interface

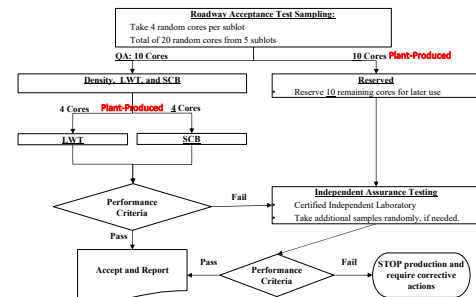


Key Takeaways

- SCB Jc parameter was effective in capturing the effect of progressive aging
- Scaling factor [87%] was developed to forecast SCB Jc 5-day at 85°C aging from SCB Jc 0-day aging (i.e., plant-produced mixtures).
– $R^2 = 0.93$
- ANN prediction model for SCB Jc 5-day value based on data available in the JMF.
– $R^2 = 0.92$
- A user-friendly interface was developed for evaluation and implementation in the Louisiana DOTD's asphalt mixture QA programs.

Proposed Implementation

• Acceptance Testing Plan



Mohammad, L.N., et. al., "Development Of Performance Based Specifications For Louisiana Asphalt Mixtures." Report No. FHWA/LA.14/558. Baton Rouge, LA, 2016

Proposed Implementation

- Pilot Specification for 2026
 - Link interface to production QC data submitted through LaPAVE (DOTD Mix Design and Production Database)
 - Monitor real time variation in model output.



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Photo: Jim Gaffney, Office of Public Affairs