Prediction of Roadway Condition and Smoothness Using Neural Networks: Experience from Louisiana

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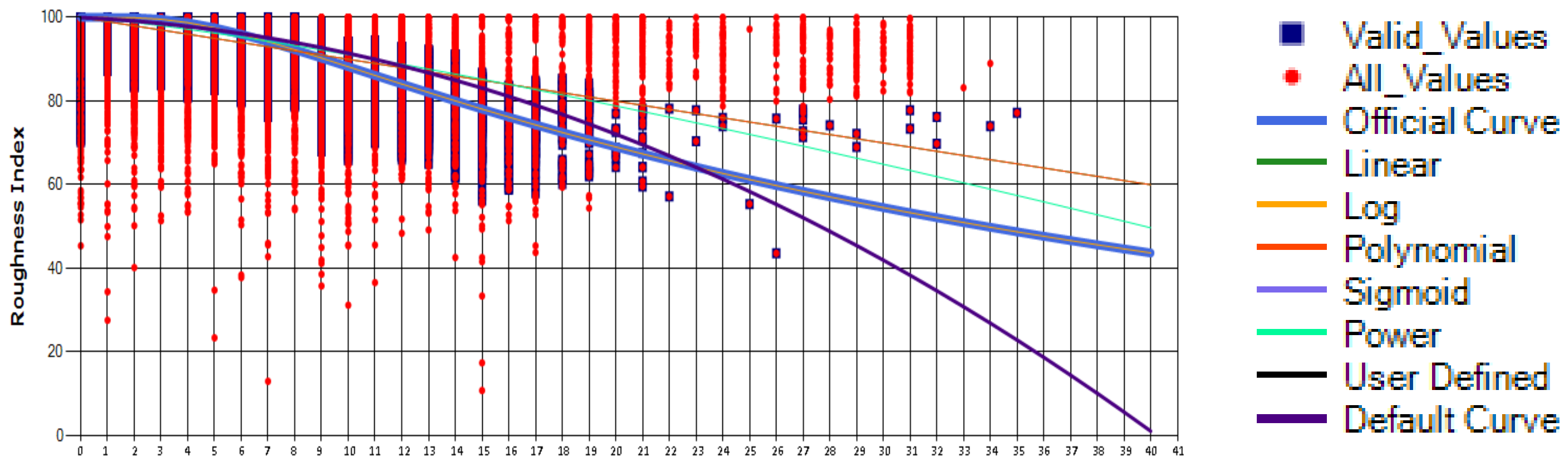
Problem Statement

- Pavement performance models are important for transportation asset management.
  - Select most cost-effective treatment
  - Determine project priority and improve budget allocation
- Huge amount of resource invested on M&R in Louisiana
  - $677 million from FHWA and the state matching funds for it,
  - Governor also raise nearly $700 million per year for transportation funding.
- Even a slight improvement in pavement performance modeling could save a lot of money for taxpayers

Problem Statement

- DOTD Pavement Management System (PMS)
  - Site-specific curves
  - Family curves



- There is a need of better performance models
  - Considering more parameters (traffic, structural info, and climate)
  - More accuracy and prediction power

Problem Statement

- Transportation Asset Management Plans (TAMP) Condition Targets
  - NHS performance targets, 2 year and 4 year
  - Federal goodness rating on IRI, rutting, cracking percent, and faulting

Federal Pavement Condition Criteria 23 CFR Part 490.313(b)			
Metric	**Good**	**Fair**	**Poor**
IRI (inches/mile)	<95	95 - 170	>170
Cracking (%)			
- Asphalt	<5	5 - 20	>20
- Jointed Concrete	<5	5 - 15	>15
- Continuously Reinforced Concrete	<5	5 - 10	>10
Rutting Asphalt (inches)	<0.20	0.20-0.40	>0.40
Faulting Jointed Concrete (inches)	<0.10	0.10-0.15	>0.15

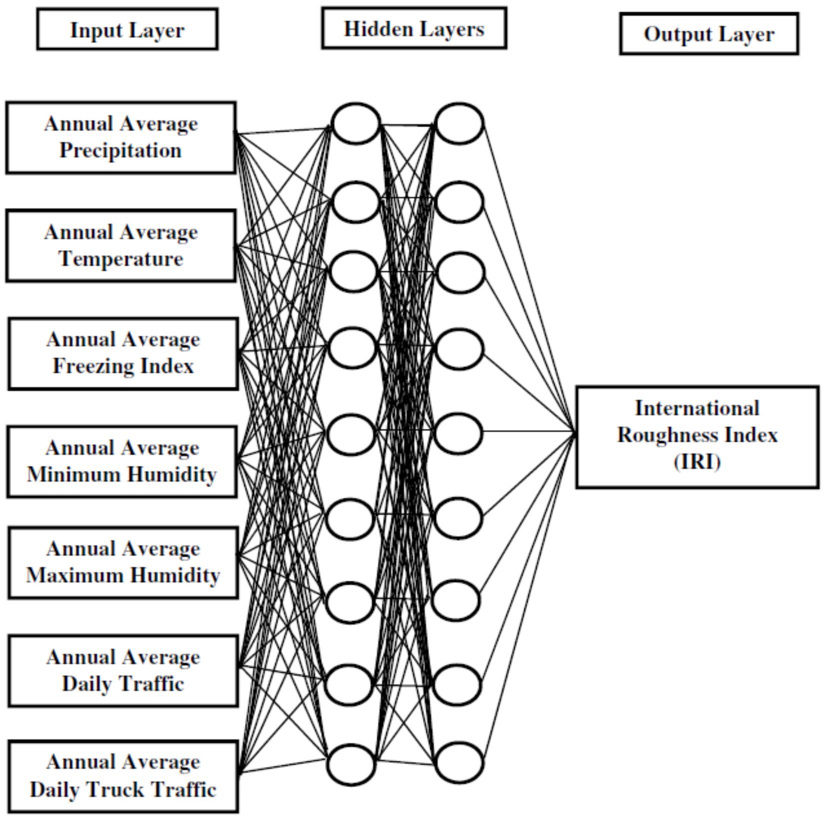
  - IRI and rutting are consistent with previous measurement
  - Cracking and faulting are different
- Only 4 years of Highway Performance Monitoring System (HPMS) data was available

Objectives

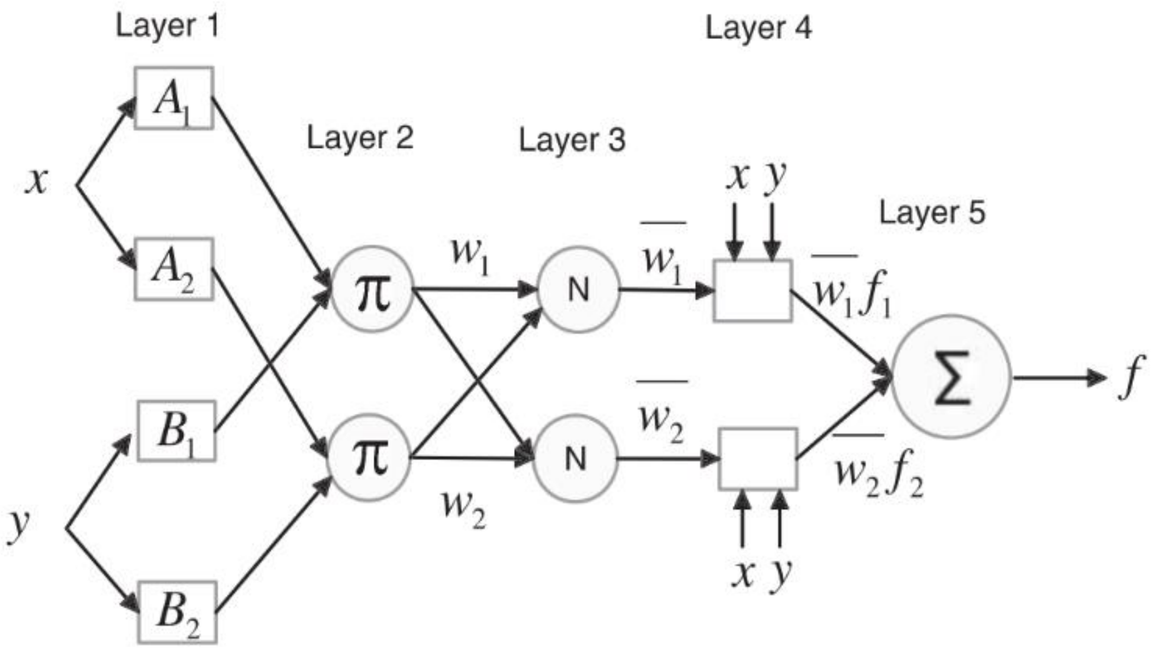
- Develop short-term pavement cracking forecasting models to predict two- and four-year cracking percent, based on 2017-2020 HPMS database;
- Establish a historical pavement condition database for all asphalt overlay projects constructed after 2009
  - Long-term model #1: Incremental model
    - ❖ Two previous pavement condition, mill/overlay thickness, traffic, climate
    - ❖ Incrementally predict future pavement performance up to 15 years
    - ❖ IRI, rutting, cracking %, ALCR, RNDM, PTCH, RUT, and RUFF
  - Long-term model #2: family curves
    - ❖ Project-based information of pavement age, functional class, thickness, and five weather related project data

Artificial Neural Networks (ANN)

- Feed-Forward Neural Network
- Adaptive Neuro-Fuzzy Inference System (ANFIS)

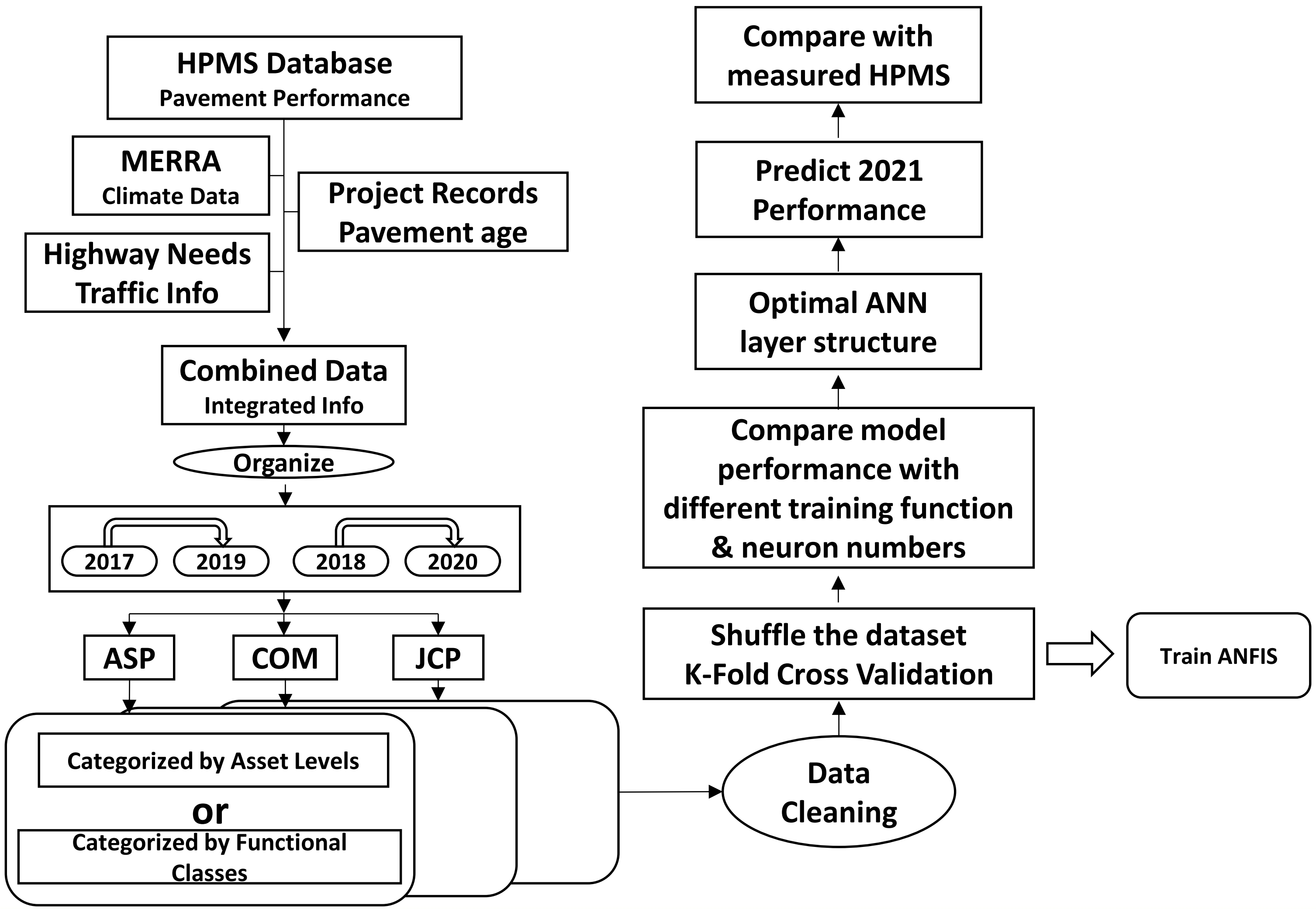


IRI Prediction (Hossain et al. 2017)



ANFIS Structure

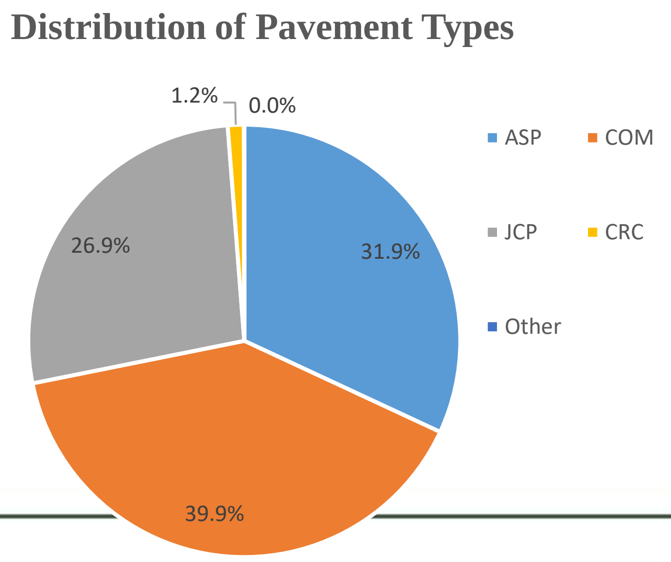
Short-term Pavement Performance Modeling

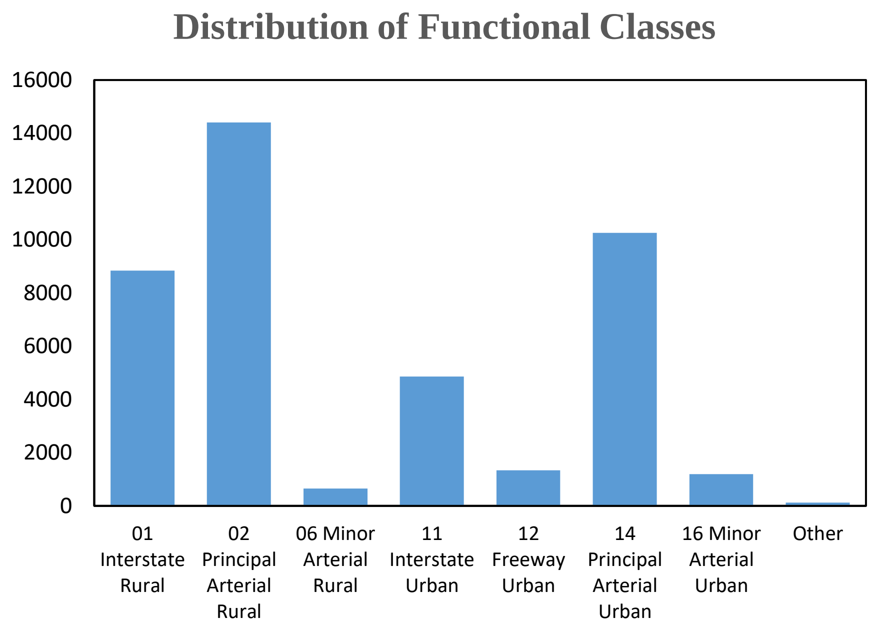


Data Collection for Crack% Modeling (Short-term)

- Highway Performance Monitoring System (HPMS) Database
  - Similar to PMS, focused on NHS
  - Purpose: PMS are to supervise and forecast pavement conditions and select the optimal treatment and timing; HPMS monitors network level condition of NHS pavements and identifies the overall.
  - Measurement: Cracking percent and faulting
  - Only 2017 to 2020 HPMS data was available

Example: 2017 HMPS Data (41,679 rows)





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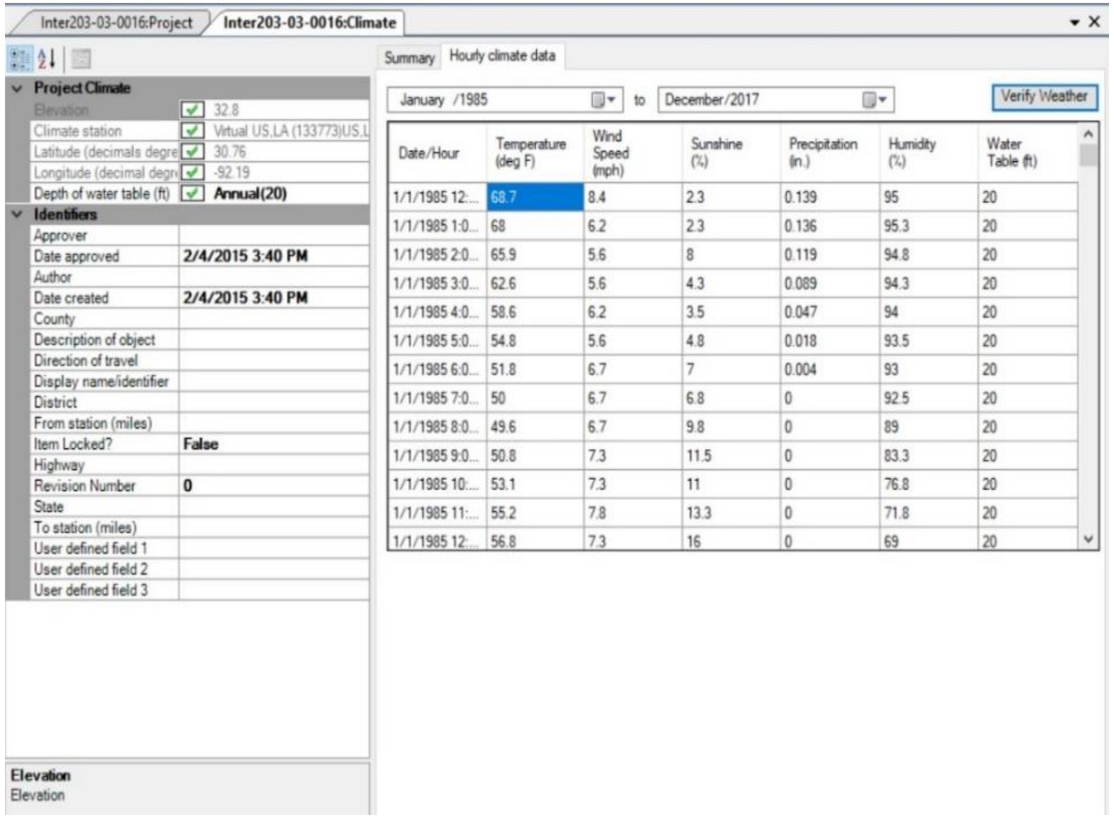
Data Collection for Crack% Modeling (Short-term) (Cont.)

- The Modern Era Retrospective-Analysis for Research and Applications (MERRA) Climate Data
  - Annual air temperature (AAT),
  - Annual precipitation (AP),
  - Freezing index (FI),
  - Annual number of freeze-thaw cycles (AFC)
  - Annual number of wet days (AWD)

Average Climate Input by District

District	AAT	AP	FI	AFC	AWD
2	69.7	49.3	1.2	3.3	305.2
3	67.9	48.7	4.0	11.3	307.2
4	65.5	52.0	13.3	28.9	293.2
5	65.3	53.0	18.3	31.2	287.6
7	67.7	50.9	3.5	12.9	308.7
8	66.2	52.2	8.1	23.4	302.0
58	66.0	51.8	13.0	26.2	297.0
61	67.6	50.7	4.2	14.0	308.6
62	67.7	52.5	3.4	12.9	308.4



MERRA in Pavement-ME

Data Collection for Crack% Modeling (Short-term) (Cont.)

- Project Records
  - All overlay projects
  - Log mile info and final inspection data were extracted
- Highway Needs
  - ADT, Truck%, number of lanes
- Assign these info to HPMS based on CST and log miles
  - A program in Matlab was complied to add these info to HPMS 0.1-mile sections

Project/Highway Info, from 1990 to present

LADOTD Projects - 6/21/2023

Final_Inspect_date >= '1990-01-01' and Final_Inspect_date <= '2999-12-31' and Work_Type1 in 'A1, A2, A3, A4, A5, A6, A7, A8, C1, C2, C3, C4, C5, M1, M2, M3, M4, Z9, ZA'

Project	Control Section	ERP Project	Proj Status	Contract Amt	Cost to Date	Pct Complete	District	Parish	Bid Date	Contract Date	Final Inspect date	Route1	Project Name	Begin Log Mile	End Log Mile	Work Type1	Work Cat1	map	PS
H.000126.6	001-06		C	11,413,917	11,718,525	99	04	7	12/11/2013	2/6/2014	10/20/2016	US 80	KCS Railroad Overpass near ADA	4.19	4.99	A1-Asphalt New Pvt	300	map	PS
H.000140.6	001-08		C	1,442,463	1,298,207	99	05	31	1/25/2012	2/29/2012	9/19/2012	US 80	EAST RUSTON CITY LIMITS TO EAST CHOUDRANT CITY LIMITS	2.52	8.78	A3-Asph Ovly Asph Pvmt	300	map	PS
H.000143.6	001-08		C	609,471	616,641	99	05	31	6/27/2012	8/1/2012	12/10/2012	US 80	U.S. 80 INTERSECTION IMPROVEMENTS @ U.S. 167	0.54	0.66	A6-AC Ovly Rubblized Pvt	300	map	PS
H.000173.6	002-01		C	4,572,771	3,979,928	96	05	37	12/14/2016	2/7/2017	11/6/2019	US 80	US 80: MCQUILLER RD. - RICHLAND P/L	8.30	10.26	A5-AC Ovly/Inplace Base	300	map	PS
H.000195.6	003-10		C	2,531,199	2,606,657	99	03	1	9/28/2011	10/27/2011	8/13/2012	US 90	US 90: LA 3076 - LA 719	6.28	11.38	A3-Asph Ovly Asph Pvmt	300	map	PS
H.000314.6	007-02		C	2,040,713	1,838,277	99	02	26	12/12/2012	2/14/2013	6/12/2014	US 61	US 61: LABARRE RD - TRANSCONTINENTAL BLVD	1.56	3.61	A3-Asph Ovly Asph Pvmt	300	map	PS
H.000320.6	007-03		C	4,765,432	4,606,440	97	02	45	11/13/2019	1/30/2020	11/9/2022	US 61	JEFFERSON PARISH LN. - LA 50	0.00	1.68	A3-Asph Ovly Asph Pvmt	300	map	PS
H.000329.6	007-07		C	9,182,214	11,213,080	99	61	3	12/14/2011	1/30/2012	9/25/2013	US 61	US 61: LA 22 - LA 74	0.00	6.47	A8-Asph Ovly Conc Pvmt	300	map	PS
H.000336.6	414-03		C	3,968,969	4,533,826	99	61	3	9/12/2012	11/21/2012	7/31/2015	LA 30	LA 431 INTERSECTION IMPROVEMENTS	10.66	10.74	A2-Asph Wdn + Ovly	300	map	PS
H.000393.6	010-03		C	2,621,679	2,660,254	99	04	41	4/10/2013	5/23/2013	12/3/2013	US 71	RESURFACING ON US 71, US 84 & LA 5	0.00	10.96	A3-Asph Ovly Asph Pvmt	300	map	PS
H.000403.6	010-06		C	1,645,336	1,653,889	99	04	8	6/27/2012	8/16/2012	5/1/2013	US 71	US 71: LA 612 TO LA 3032 LA 72: LA 3 TO I-20	8.11	13.15	A3-Asph Ovly Asph	300	map	PS

Highway Needs File, 2019

LADOTD Highway Needs File - (2019 Summary Log) (as of December 2019)

Sorted by District,Parish

map / pms links	control section	sub sec	begin log mile	end log mile	dist rict	parish	route number	length	F system	urban rural	num lanes	surface type	adt	level of service
map pic ivision	870-35	0	0.000	0.045		17-E Baton	LA3290-2	0.045	7-Local	U	2	8-bitcon		
map pic ivision	005-10	1	0.000	3.410	02	26-Jeffers	US0090	3.410	3-PrArt	U	4	8-bitcon	24,333	B-good
map pic ivision	005-10	2	3.410	3.800	02	26-Jeffers	US0090	0.390	3-PrArt	U	4	8-bitcon	33,519	F-worst
map pic ivision	005-10	3	3.800	4.220	02	26-Jeffers	US0090	0.420	3-PrArt	U	4	8-bitcon	33,519	F-worst
map pic ivision	005-10	4	4.220	6.010	02	26-Jeffers	US0090	1.790	3-PrArt	U	4	8-bitcon	35,969	F-worst
map pic ivision	005-10	5	6.010	6.934	02	26-Jeffers	US0090	0.924	3-PrArt	U	4	8-bitcon	37,182	F-worst
map pic ivision	006-01	1	0.000	1.770	02	26-Jeffers	US0090	1.770	3-PrArt	U	4	9-pcc	44,560	D-poor
map pic ivision	006-01	2	1.770	2.503	02	26-Jeffers	LA3152	0.733	3-PrArt	U	6	2-graded	53,329	E-bad
map pic ivision	006-02	1	0.000	1.680	02	26-Jeffers	US0090	1.680	3-PrArt	U	6	8-bitcon	38,114	C-avg

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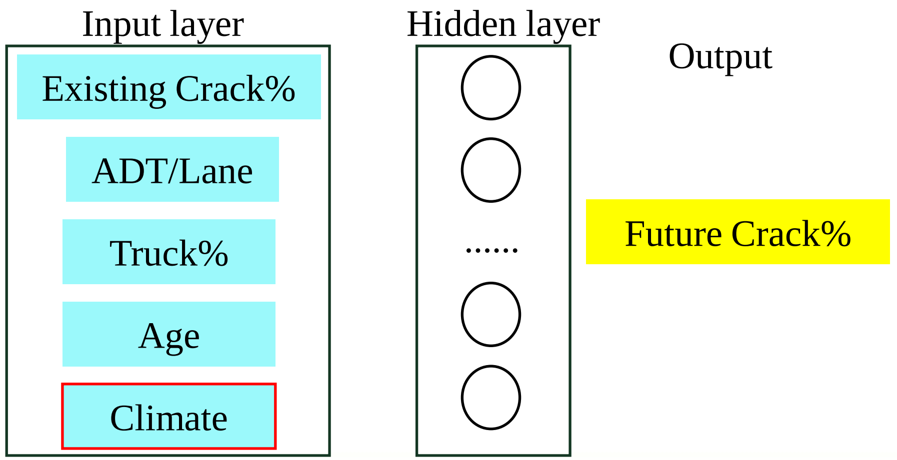
Build Database for Crack% Model (Short-term)

- Data Combining, Cleaning and Organizing
  - Intersection of 4 years' HPMS data (35,913 tenth miles)
  - Remove data without pavement age or measurement
- Organize Data
  - Predict future 2 years Crack %
  - Five inputs, one outputs
- Find out climate factors with most contribution
  - Correlation Matrix



Example of Climate Correlation Matrix (ASP Inter Rural)

	Crack%	Temp	Percip.	FreezeIndex	F-T cycle	WetDays
Crack%	1	0.0128	0.005	**0.0166**	0.014	0.0144
Temp		1	0.2932	0.9121	0.9976	0.8522
Percip.			1	0.1266	0.2827	0.0985
FreezeIndex				1	0.9304	0.988
F-T cycle					1	0.8772
WetDays						1

17 Crack% Models (Short-term)

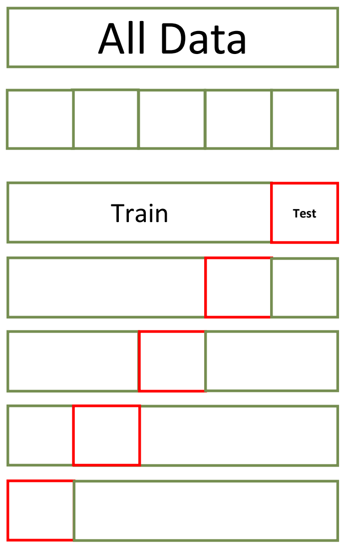
- Divide Database into Categories
  - Pavement Type
  - Functional Classification
- Datasets for 17 Models

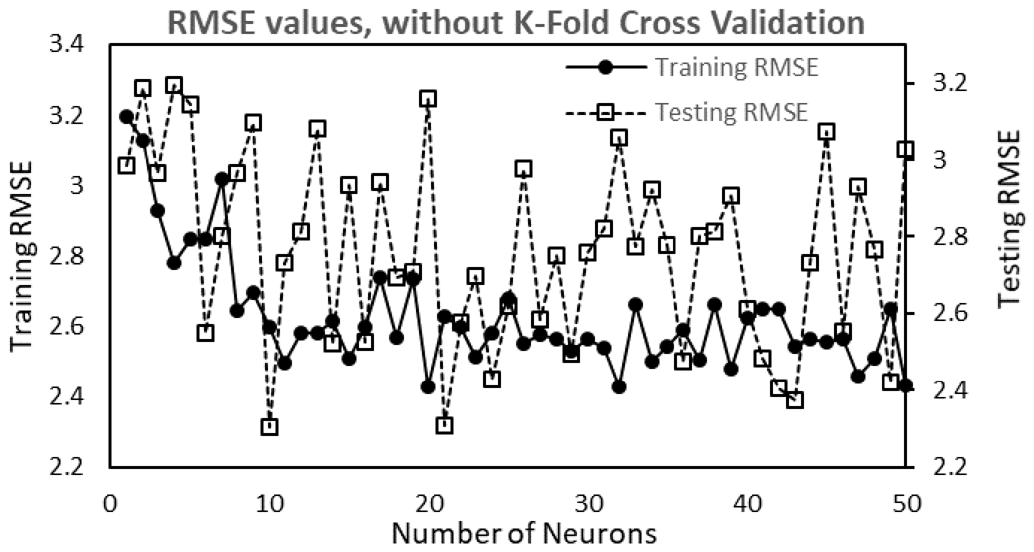
ASP			COM			JCP		
FUN	Rows	Weather Input	FUN	Rows	Weather Input	FUN	Rows	Weather Input
01	3879	AAFI	01	4317	AAP	01	4641	AAP
02	9469	AAFI	02	9825	AAFI	02	4566	AAFTC
06	2	-	06	4	-	06	-	-
11	1728	AAFTC	11	1840	AAWD	11	2738	AAT
12	469	AAWD	12	183	AAP	12	561	AAT
14	1840	AAP	14	4982	AAWD	14	3656	AAWD
16	486	AAFTC	16	104	AAT	16	17	-

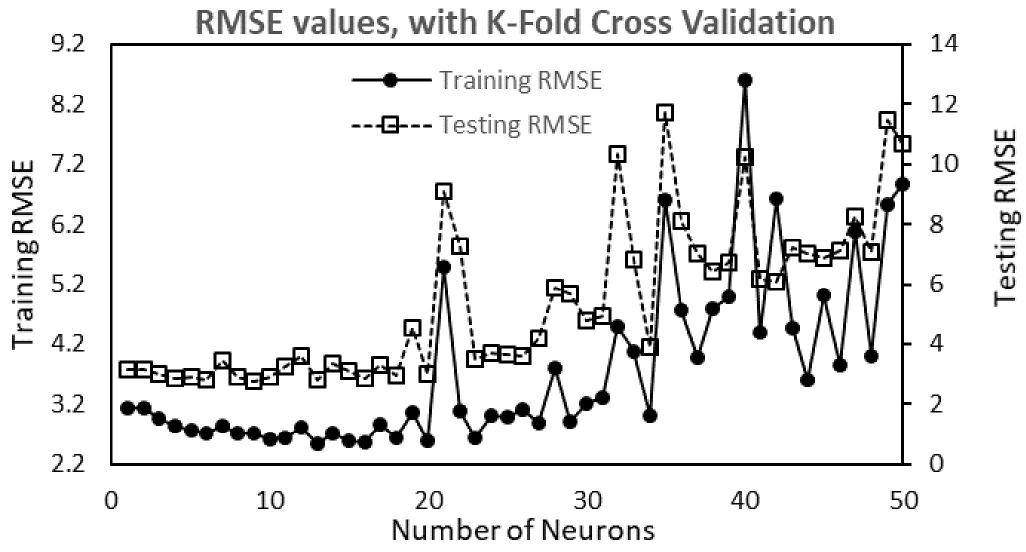
*AAT - Average annual air temperature
AAP - Average annual precipitation
AAFI - Average annual freeze index
AAWD - Average annual wet days
AAFTC - Average annual freeze/thaw cycles

K-fold Cross Validation

- Data Cleaning and K-Fold Validation
  - Remove data with cracking percent <-5%
- K-fold Cross Validation
  - Shuffle dataset first
  - Divide into 5 folds
  - Same folds of data were saved for training other ANN







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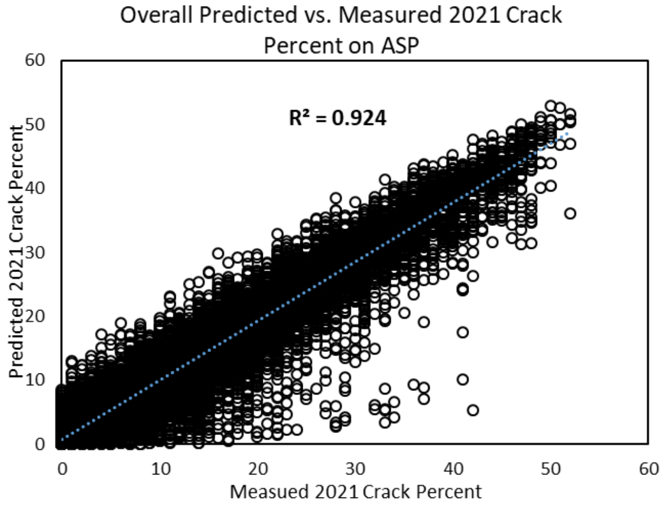
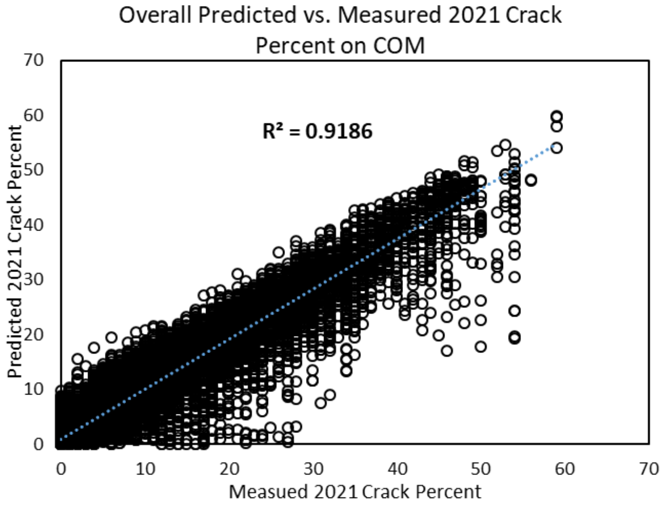
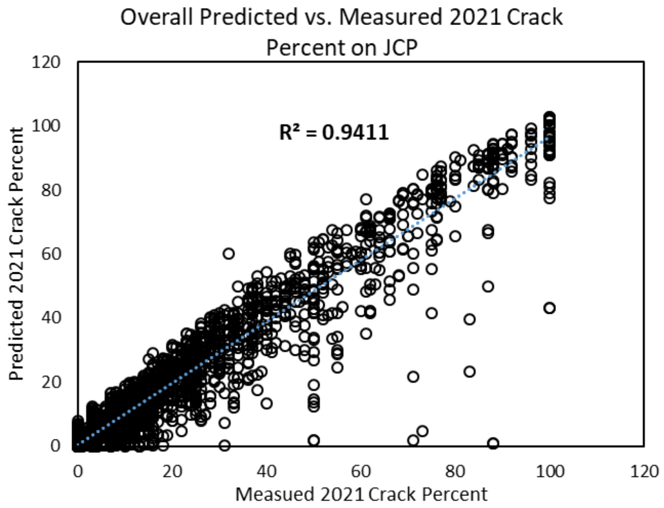
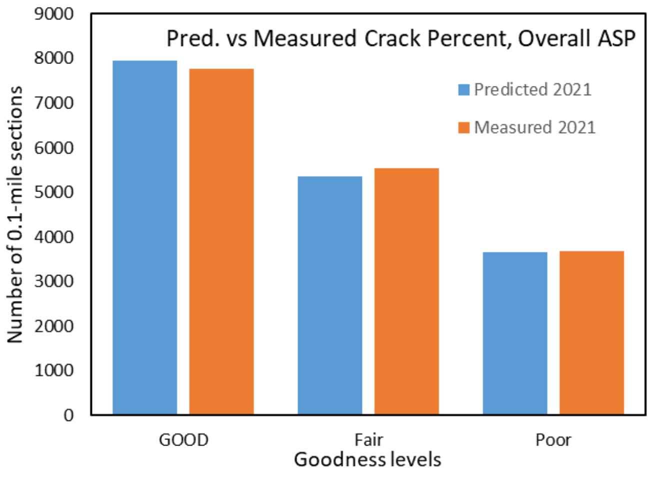
Test Crack% Models: Validate with 2021 Data

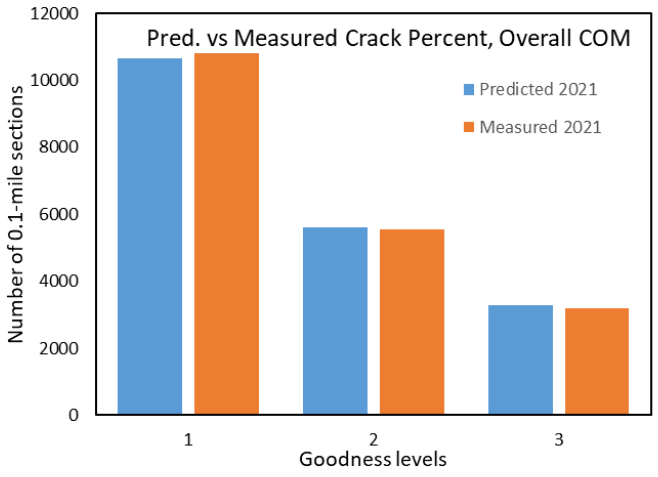
- Overall comparison between Predicted and Measured 2021 values

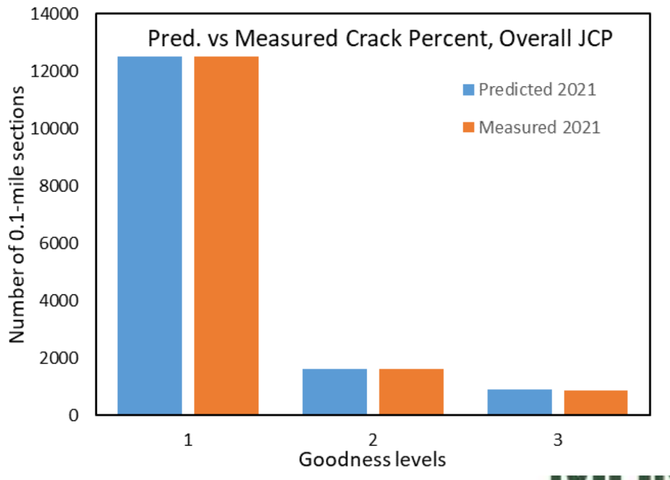












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Long-term Pavement Performance Modeling

- PMS Treatment History
  - Previous treatment activities for 0.1-mile sections
  - Extract overlay projects numbers and related Element ID
  - Verify projects and obtain design traffic and structural info in FileNet

PMS_TREATMENT_HISTORY

Length	CreatedOn	CreatedBy	LAST_PROJ_	LAST_PROJ_	LAST_PROJ_	LAST_PROJ_	LAST_PROJ_	LAST_RECON_YEA	LAST_TREAT_2009	LAST_TREAT_2011	LAST_TREAT_2013	LAST_TREAT_2015	LAST_TREAT_2017
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882			TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882			TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO
0.1	8/19/2021 6:36	DTIMS_dbo		H.000882	H.000882	H.000882	H.000882	1991		TO	TO	TO	TO

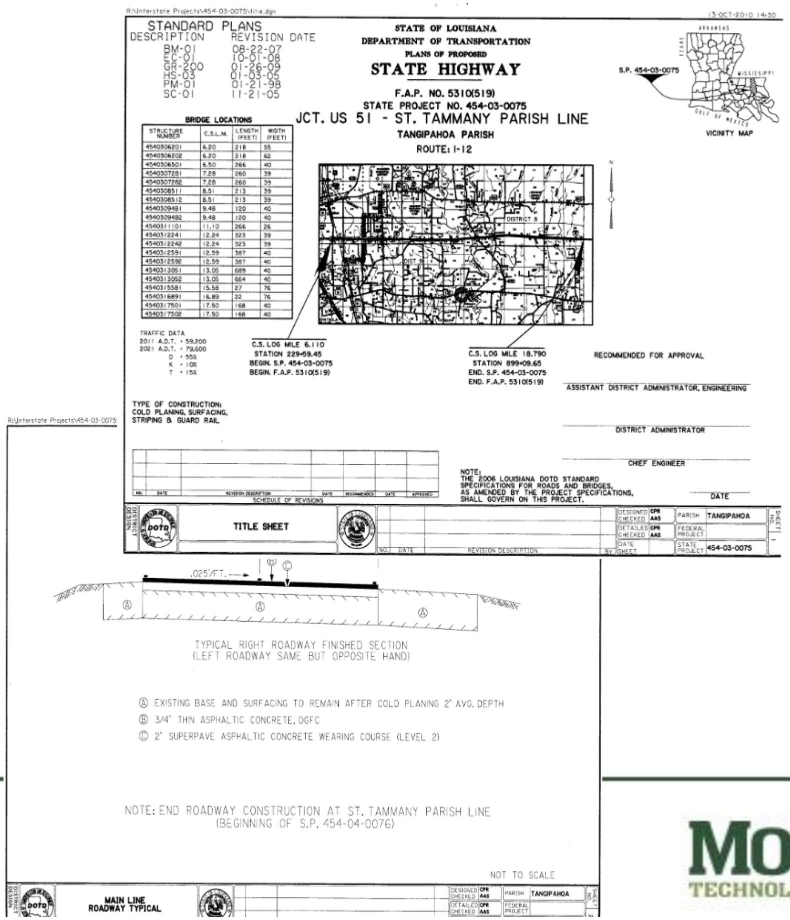
DOTD Design Projects - Search

Search Criteria: Class: DOTD Design Projects including subclasses Search in: FN DOTD Search options: Released version, Both property and text criteria Property options: Match all

Search Results

Showing results for: DOTD Design Projects - Search

Project Na...	Project Num...	Legacy Project Nu...	Document ...	Type of Docum...	Route Num...	File Number	Remarks
	H.000882	024-05-0047	TRAN		US 171		PRELIMINARY PLANS
	H.000882	024-05-0047	PVMT				TYICAL SECTION REVIEW
	H.000882	024-05-0047	TRAN		US 171		ADVANCED CHECK PRINTS
	H.000882	024-05-0047	mis	CLOSE OUT			file closeout
	H.000882	024-05-0047	TRAN		US 171		REVISION
	H.000882	024-05-0047	TRAN		US 171		REVISION
	H.000882	024-05-0047	TRAN		US 171		STORM WATER POLLUTION PREVENTION PLAN
	H.000882	024-05-0047					final plans



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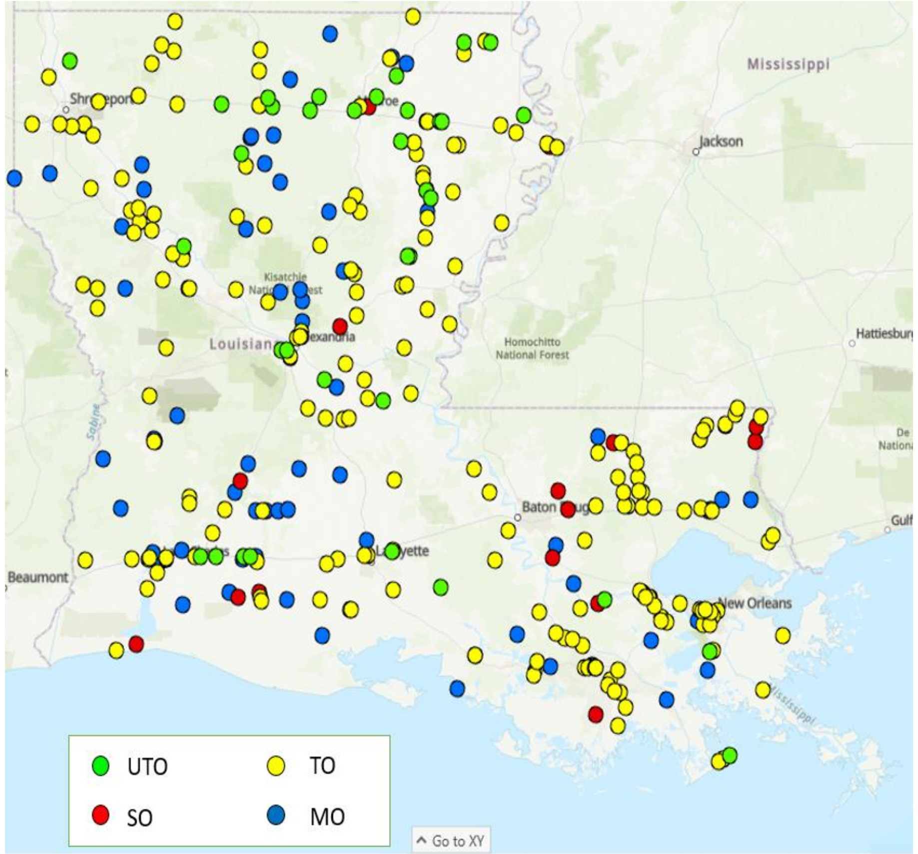
Location and Summary of Selected Projects

- Build up database
  - With obtained Element IDs, extract all historical condition in PMS
  - Combine age, traffic and climate info
  - Remove records before treatments
  - Average condition data for projects
  - Location of the overlay projects



Summary of overlay PMS database

Type	Projects	mileage	Age	ADT range	Truck%	Milling depth	Overlay thickness	Number of data
UTO	37	171.2	0-12.6	400-37,300	5-34	0-2	0.75-1.0	147
TO	230	746.6	0-14.8	75-66,700	3-34	0-4	1.5-2	1,236
MO	79	374.3	0-15.1	100-28,600	7-25	0-4	2.5-4	340
SO	17	56.4	0.4-11.1	650-23,600	5-40	0-2	2-8	71
Total	363	1348.5		75-66,700	3-40			1,794

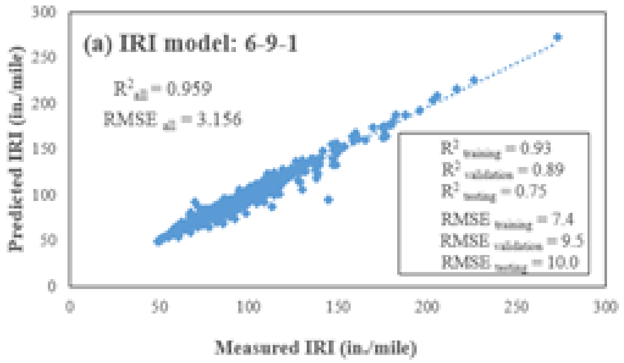
Long-term Model: Incremental Models

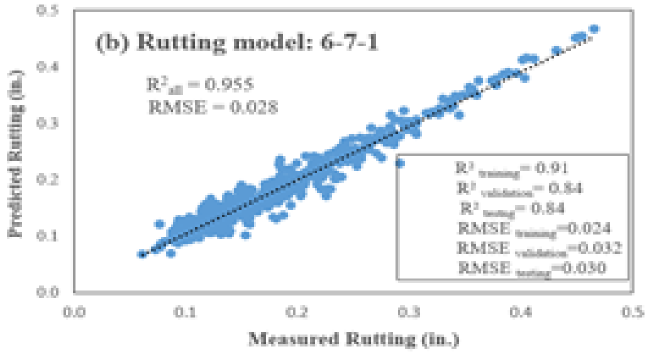
- Incremental Performance Models
  - Use previous two pavement conditions to predict next same condition
  - 8 incremental models: IRI, Rutting, alligator crack% and 5 distress indices
- Input Parameters used in long-term performance modeling

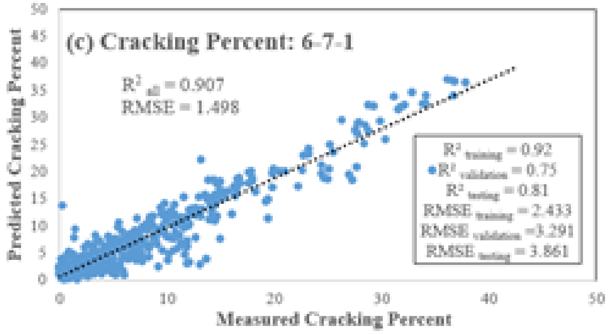
Model name	Input Parameters	Output
IRI	$IRI_{(i-4)}$, $IRI_{(i-2)}$, age $_{(i)}$, accumulative truck, overlay_h, mill_h	IRI $_{(i)\ year}$
Rutting	$RD_{(i-4)}$, $RD_{(i-2)}$, age $_{(i)}$, accumulative truck, overlay_h, mill_h	RD $_{(i)\ year}$
Percent of Alligator Cracking	$CK_{(i-4)}$, $CK_{(i-2)}$, age $_{(i)}$, accumulative truck, overlay_h, mill_h	CK $_{(i)\ year}$
ALCR	$ALCR_{(i-4)}$, $ALCR_{(i-2)}$, age $_{(i)}$, accumulative truck, overlay_h, mill_h	ALCR $_{(i)\ year}$
RNDM	$RNDM_{(i-4)}$, $RNDM_{(i-2)}$, age $_{(i)}$, accumulative truck, overlay_h, mill_h	RNDM $_{(i)\ year}$
PTCH	PTCH $_{(i-4)}$, PTCH $_{(i-2)}$, age $_{(i)}$, accumulative truck, overlay_h, mill_h	PTCH $_{(i)\ year}$
RUT	$RUT_{(i-4)}$, $RUT_{(i-2)}$, age $_{(i)}$, accumulative truck, overlay_h, mill_h	RUT $_{(i)\ year}$
RUFF	RUFF $_{(i-4)}$, RUFF $_{(i-2)}$, age $_{(i)}$, accumulative truck, overlay_h, mill_h	RUFF $_{(i)\ year}$

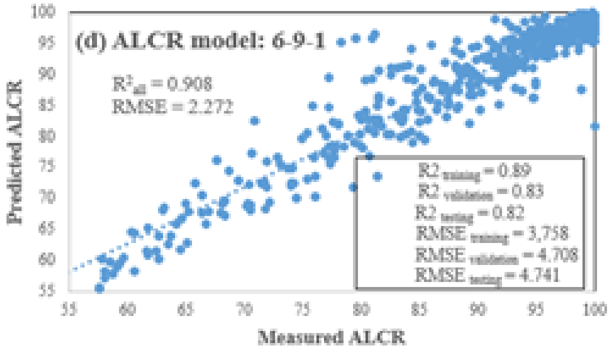
Long-term Model: Incremental Models (Cont’)

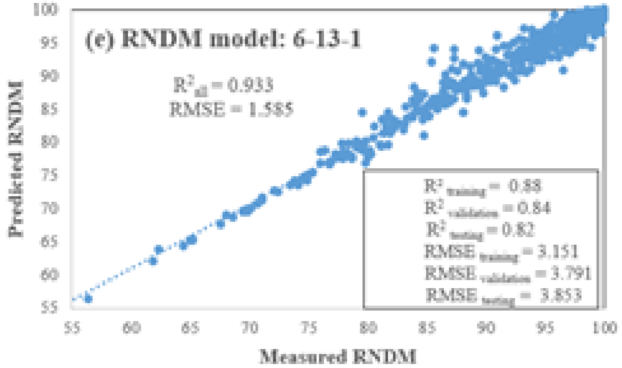
- Structures and performances

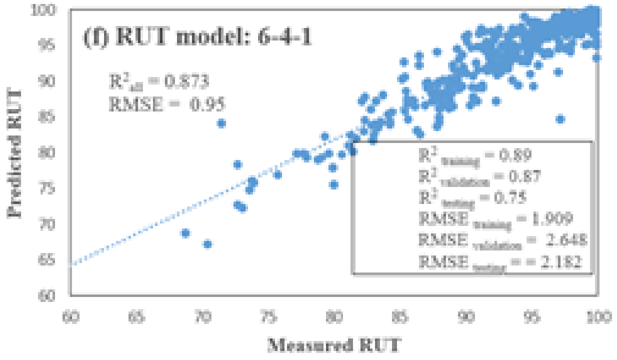


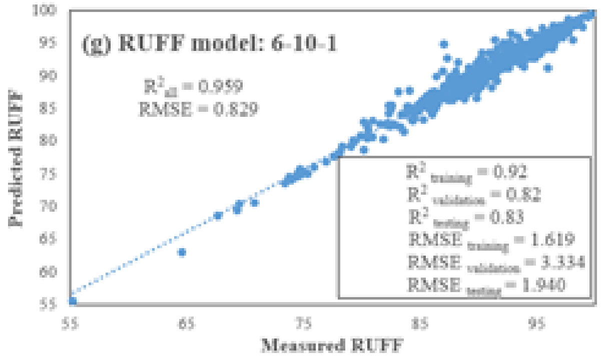


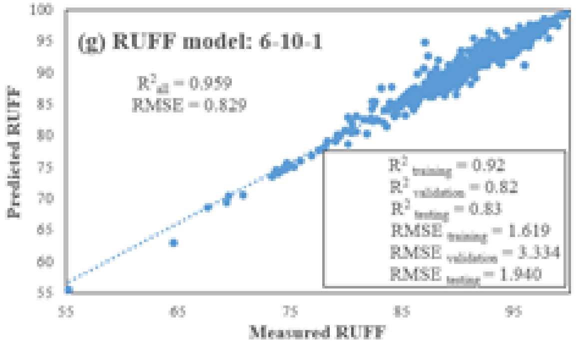











(g) RUFF model: 6-10-1
R^2_{all} = 0.959
RMSE = 0.829
$R^2_{training}$ = 0.92
$R^2_{validation}$ = 0.82
$R^2_{testing}$ = 0.83
RMSE $_{training}$ = 1.619
RMSE $_{validation}$ = 3.334
RMSE $_{testing}$ = 1.940
Predicted RUFF
Measured RUFF

Conclusions

- In this study, a methodology for developing short-term and long-term ANN-based pavement performance models was established.
  - Two network-level database
  - Three types of performance models
    - 17 Crack% Models (short-term)
    - 8 Incremental models (long-term)
- Following observations were drawn from this research
  - ANN-based pavement performance models were capable of produce greater accuracy compared with statistical regression models (higher R2 and lower RMSE); Also, easy to be implemented;
  - Both the feedforward ANN and ANFIS approaches were suitable for short-term crack% prediction; ANN is better in some pavement categories and easier to be implemented
  - Similar approach was used in developing long-term pavement performance models. These developed incremental models are capable of making prediction for many distress values, and can be a goof alternative when data is not sufficient for building site-specific curves;

Questions?