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Pavement Deterioration Prediction Model and Project Selection for Kentucky Highways

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Outline

- **Project Background**
- **AC Pavement Deterioration Prediction Models**
  - **Methodology**
  - **Results and discussions**
- **An Analytical Hierarchy Process for Project Selection**
  - **Methodology**
  - **Results and discussions**
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Background

- **The Kentucky Transportation Cabinet (KYTC)**
  - KYTC is an executive branch agency responsible for supervising the development and maintenance of a safe transportation system throughout the Commonwealth.
  - KYTC manages more than 27,000 miles of highways, including roughly 20,500 miles of secondary roads, 3,600 miles of primary roads, and more than 1,400 interstate and parkway miles.

- **Pavement management and preservation (PMP) has received growing attention by KYTC as an effective means to manage pavement assets.**

Problem Statement

- **KYTC has been collecting pavement condition data for over 10 years.**
- **There are 9 distress condition indices pertaining to 5 types of distress.**

- **This project aims to:**
  1. **Predict 9 distress condition indices for next year;**
  2. **Develop a prioritization method for selecting pavement projects based on the 9 predicted condition indices.**

Pavement Prediction Model – Condition Data

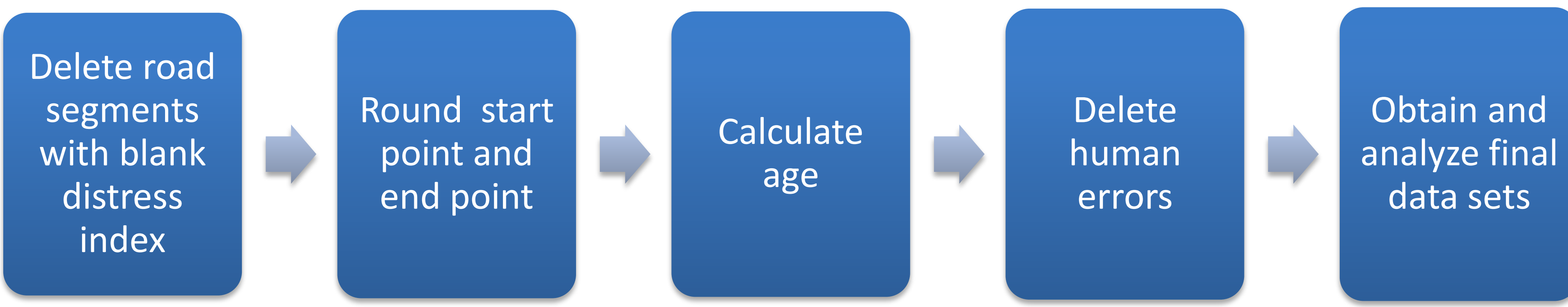
- **The raw data collected from KYTC contains 11-year (2003-2013) worth of data on Kentucky's interstate and parkways road condition.**

Distress Indices	Pavement Types
Wheel Path Cracking (Extent, Severity) 0-9	Asphalt (AC)
Raveling (Extent, Severity) 0-5	Concrete (PCC)
Other Cracking (Extent, Severity) 0-5	Composite (AC/PCC)
Out of Section (Extent, Severity) 0-3	
Appearance 0-3	

Pavement Prediction Model – Other Data

- **The entire data set (2003-2013) contains 58 columns (attributes) and 6,045 rows.**
- **For each road segment, it includes**
  - four types of distress indices in terms of extent and severity + appearance
  - pavement types
  - construction information, effective year
  - route ID, from and end point, and more …
- **A separate database contains information on contracts performed throughout the 11 years.**
  - route ID, from and end point
  - treatment type/coding
  - project approval and completion dates

Pavement Prediction Model – Data Processing



N=1,900

N'=1,300

Pavement Prediction Model – Sample Input Data

12 input variables + 1 target variable.

ADT	WPC_E	WPC_S	R_E	R_S	OC_E	OC_S	OS_E	OS_S	APP	AGE	IRI
12517	0	0	0	0	1	1	0	0	0.5	5	54.131
11033	0	0	0	0	0	0	0	0	0	21	151.414
17493	5	5	2	2	2.5	1.5	0	0	0.5	7	72.428
17493	3	3	3	2.5	3.5	2.5	0	0	0.5	9	74.269
17493	4	6	3	3	3	2	0	0	1	10	79.771
17493	5	4	2	2	3	2	0	0	1.5	11	90.468
17493	7	5	3	4	4	3	0	0	2	12	93.167
17493	8	5	4	4	5	3	0	0	2.5	13	93.329
17493	5	6	5	5	3	4	3	3	3	15	93.439
18383	4	4	3	4	2.5	2.5	0.5	0.5	1	10	68.293

Note: WPC_E = extent of wheel path cracking; WPC_S = severity of wheel path cracking;
R_E = extent of raveling; R_S = severity of raveling;
OC_E = extent of other cracking; OC_S = severity of other cracking;
OS_E = extent of out of section; OS_S = severity of out of section;
APP = appearance;

Multiple Linear Regression Models

- **We used SAS Enterprise Miner 12.1 to perform the linear regression for predicting each of the 9 distress indices.**
- **“Data Partition” module is used to partition all final data set into 50% training, 25% validation and 25% testing data.**
- **The “Transform” module is used to handle ADT data.**
- **The stepwise regression is used as our selection model.**

Multiple Linear Regression Models

The following scenarios of using various sets of input variables are done for each distress index to be predicted.

- **S1: Total of 12 input variables, i.e., ADT, age, IRI, APPEAR, WPC_EXT, WPC_SEV, RF_EXT, RF_SEV, OC_EXT, OC_SEV, OS_EXT, OS_SEV.**
- **S2: A subset of the entire 12 input variables is used based on recommendations from KYTC experts.**
- **S3: Only use the target variable from the previous year as input variable to predict this variable for next year.**
- **S4: Only use the pavement age as input variable to predict any distress index for next year**

Multiple Linear Regression: AC_WPC_EXT

Scenarios	Model	ASE Training	ASE Validation	ASE Testing	ASE Average	R Squared
S 1	Polynomial 3	0.9582	1.3173	0.9147	1.0634	0.8848
	Polynomial 2	0.9911	1.2983	0.8888	1.0594	0.8809
	Linear	1.0388	1.2964	0.9214	1.0855	0.8751
S 2	Polynomial 3 SLCT	0.9803	1.2561	0.8956	1.0440	0.8821
	Polynomial 2 SLCT	1.0335	1.2919	0.886	1.0705	0.8757
	Linear SLCT	**1.0726**	**1.3123**	**0.9262**	**1.1037**	**0.8710**
S 3	WPC_EXT 3	1.0701	1.3420	0.8998	1.1039	0.8713
S 4	Age 3	4.0492	3.9725	4.1682	4.0633	0.5132

$$WPC_{EXT_{t+1}} = 0.493 + 0.0449\ \mathrm{Age} + 0.8612\ \mathrm{WPC_{EXT}} + 0.1\ \mathrm{WPC_{SEV}}$$

Multiple Linear Regression: AC_WPC_SEV

Scenarios	Model	ASE Training	ASE Validation	ASE Testing	ASE Average	R Squared
S 1	Polynomial 3	0.8745	1.0488	0.6919	0.8717	0.8529
	Polynomial 2	0.8999	1.0261	0.6591	0.8617	0.8486
	Linear	0.9558	1.0239	0.6554	0.8784	0.8392
S 2	Polynomial 3 SLCT	0.9186	0.9859	0.6767	0.8604	0.8455
	Polynomial 2 SLCT	0.9167	0.9916	0.6848	0.8644	0.8458
	Linear SLCT	**0.9707**	**1.0150**	**0.6714**	**0.8857**	**0.8367**
S 3	WPC_SEV 3	0.9899	1.0554	0.7159	0.9204	0.8335
S 4	Age 3	2.8684	2.7266	2.8023	2.7991	0.5176

$$WPC_{SEV_{t+1}} = 0.4495 + 0.034\,Age + 0.2705\,OS_{SEV} + 0.0883WPC_{EXT} + 0.807WPC_{SEV}$$

Recommended MLR Models

$$\boldsymbol{RF\_EXT\_(t+1)} = 0.3436 + 0.0257x_1 + 0.7064x_2 + 0.1216\mathrm{x}_3 + 0.0358x_4,$$
$$where\ x_1{:}\,age, x_2{:}\,RF\_EXT, x_3{:}\,RF\_SEV, x_4{:}\,WPC\_EXT$$

$$\boldsymbol{RF\_SEV\_(t+1)} = 0.4331 + 0.0207x_1 + 0.2442x_2 + 0.5657\mathrm{x}_3 + 0.0459x_4$$
$$where\ x_1{:}\,age, x_2{:}\,RF\_EXT, x_3{:}\,RF\_SEV, x_4{:}\,WPC\_EXT$$

$$\boldsymbol{OC\_EXT\_(t+1)} = 0.3156 + 0.0178x_1 + 0.8588x_2 + 0.0575,$$
$$where\ x_1{:}\,age, x_2{:}\,OC\_EXT, x_3{:}\,WPC\_EXT$$

$$\boldsymbol{OC\_SEV\_(t+1)} = 0.2037 + 0.0162x_1 + 0.1186x_2 + 0.7265\mathrm{x}_3 + 0.0621x_4$$
$$where\ x_1{:}\,age, x_2{:}\,OC\_EXT, x_3{:}\,OC\_SEV, x_4{:}\,RF\_SEV$$

$$\boldsymbol{OS\_EXT\_(t+1)} = -0.0751 + 0.0794x_1 + 0.9372x_2 + 0.0297x_3x_4 - 0.2177x_1x_3 + 0.051x_5x_6 - 0.0252x_3^2x_5 + 0.0857x_3^2x_1 - 0.051x_3^2x_7,$$
$$where\ x_1{:}\,OC_{SEV}, x_2{:}\,OS_{EXT}, x_3{:}\,appearance, x_4{:}\,LG10_{ADT}, x_5{:}\,OC_{EXT}, x_6{:}\,WPC_{SEV}, x_7{:}\,OS\_SEV$$

Recommended MLR Models

$$\boldsymbol{OS\_SEV\_(t+1)} = -0.00473 + 0.615x_1 + 0.1332x_2 + 0.0317x_3x_4 - 0.3157x_4x_5 + 0.0307x_1x_3 + x_4^2x_6 - 0.00103x_3^2x_4 - 0.00796x_3x_4x_6 - 0.00254x_4x_7x_8 + 0.000826x_4x_6x_7 + 0.0595x_4x_5^2 + 0.0014x_2^2x_3 - 0.00000518x_7^2x_9 + 0.0104\mathrm{x}_5x_{10}^2 + 0.0227x_8x_{10}^2 - 0.0103x_6x_9x_{10} - 0.00585x_6x_{10}x_{11} - 0.0134x_5x_9x_{11} - 0.00615x_1x_{11}^2 + 0.0119x_6^2x_9 - 0.00182x_6^3,$$

$where\ x_1: OS\_SEV, x_2: WPC\_SEV, x_3: age, x_4: appearance, x_5: OC\_SEV,$
$x_6: WPC\_EXT, x_7: CUR\_IRI, \mathrm{x}_8: OS\_EXT, x_9: RF\_EXT, x_{10}: LG10\_ADT, x_{11}: WPC\_SEV$

$$\boldsymbol{APPEAR\_(t+1)} = 0.2191 + 0.8479x_1 + 0.00932x_2 + 0.035\mathrm{x}_3,$$

$where\ x_1: appearance, x_2: age, x_3: WPC\_EXT$

Integrating AHP & Pavement Prediction Models

Collect pavement condition data in the past planning cycle

↓

Run regression models to predict 9 distress indices

↓

Perform AHP analysis for weights for 11 criteria

↓

Calculate composite condition index for all road segments

↓

Rank all projects based on composite condition index

A Composite Pavement Distress Index

- **The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology.**

- **In practice, AHP has been used by companies and organizations including Intel, Apple, NASA and Xerox to make decisions on choice, prioritization, resource allocation, etc.**

The Curent Rating Method

Total Score
=WPC_EXT
+WPC_SEV
+RF_EXT
+RF_SEV
+OC_ECT
+OC_SEV
+OS_EXT
+OS_SEV
+APPEAR
+JS
+SIRI

IRI	Points	IRI	Points	IRI	Points
<=53	0	94-96	13	135-138	26
54-57	1	97-99	14	139-141	27
58-61	2	100-102	15	142-144	28
62-64	3	103-106	16	145-148	29
65-67	4	107-109	17	149-151	30
68-70	5	110-112	18	152-154	31
71-74	6	113-115	19	155-157	32
75-77	7	116-118	20	158-160	33
78-80	8	119-122	21	161-163	34
81-83	9	123-125	22	164-167	35
84-86	10	126-128	23	168-170	36
87-90	11	129-131	24	171-173	37
91-93	12	132-134	25	>=175	38

Composite Pavement Distress Index

- **Pairwise comparison**

WPC_EXT	5	RF_EXT	1

- **There are 11 criteria and 55 pairwise comparisons.**

Intensity of importance	Definition
1	"factor A" and "factor B" are equally important
3	"factor A" is moderately favored than "factor B"
5	"factor A" is strongly favored than "factor B"
7	"factor A" is very strongly favored than "factor B"
9	"factor A" is extremely favored than "factor B"
2,4,6,8	Ratings are between two adjacent judgments

Calculated Priority

	WPC_EXT	WPC_SEV	RF_EXT	RF_SEV	OC_EXT	OC_SEV	OS_EXT	OS_SEV	APPEAR	IRI	JS	Calculated Priority
WPC_EXT	1	1/3	3	3	1	1/3	5	3	5	1/2	1	0.0995
WPC_SEV	3	1	5	4	5	2	7	5	7	2	3	0.2423
RF_EXT	1/3	1/5	1	1	1/5	1/5	1	1/3	2	1/3	1	0.0376
RF_SEV	1/3	1/4	1	1	2/3	1/3	4	2	2	1	1	0.0646
OC_EXT	1	1/5	5	3/2	1	1/3	4	2	3	1	1	0.0894
OC_SEV	3	1/2	5	3	3	1	5	3	4	2	2	0.1710
OS_EXT	1/5	1/7	1	1/4	1/4	1/5	1	1/3	1	1/4	1/3	0.0244
OS_SEV	1/3	1/5	3	1/2	1/2	1/3	3	1	3	1/2	1/3	0.0521
APPEAR	1/5	1/7	1/2	1/2	1/3	1/4	1	1/3	1	1/8	1/3	0.0242
IRI	2	1/2	3	1	1	1/2	4	2	8	1	3	0.1204
JS	1	1/3	1	1	1	1/2	3	3	3	1/3	1	0.0745

Results

- **We conducted a pilot study using two subsets of road segments to compare the recommendations from the current rating system and those from the proposed rating system using AHP.**

- **Two subsets are randomly selected from the 2010 pavement condition database, whose conditions need treatments.**

Case Study 1: a Subset of 10 Road Segments

Current system

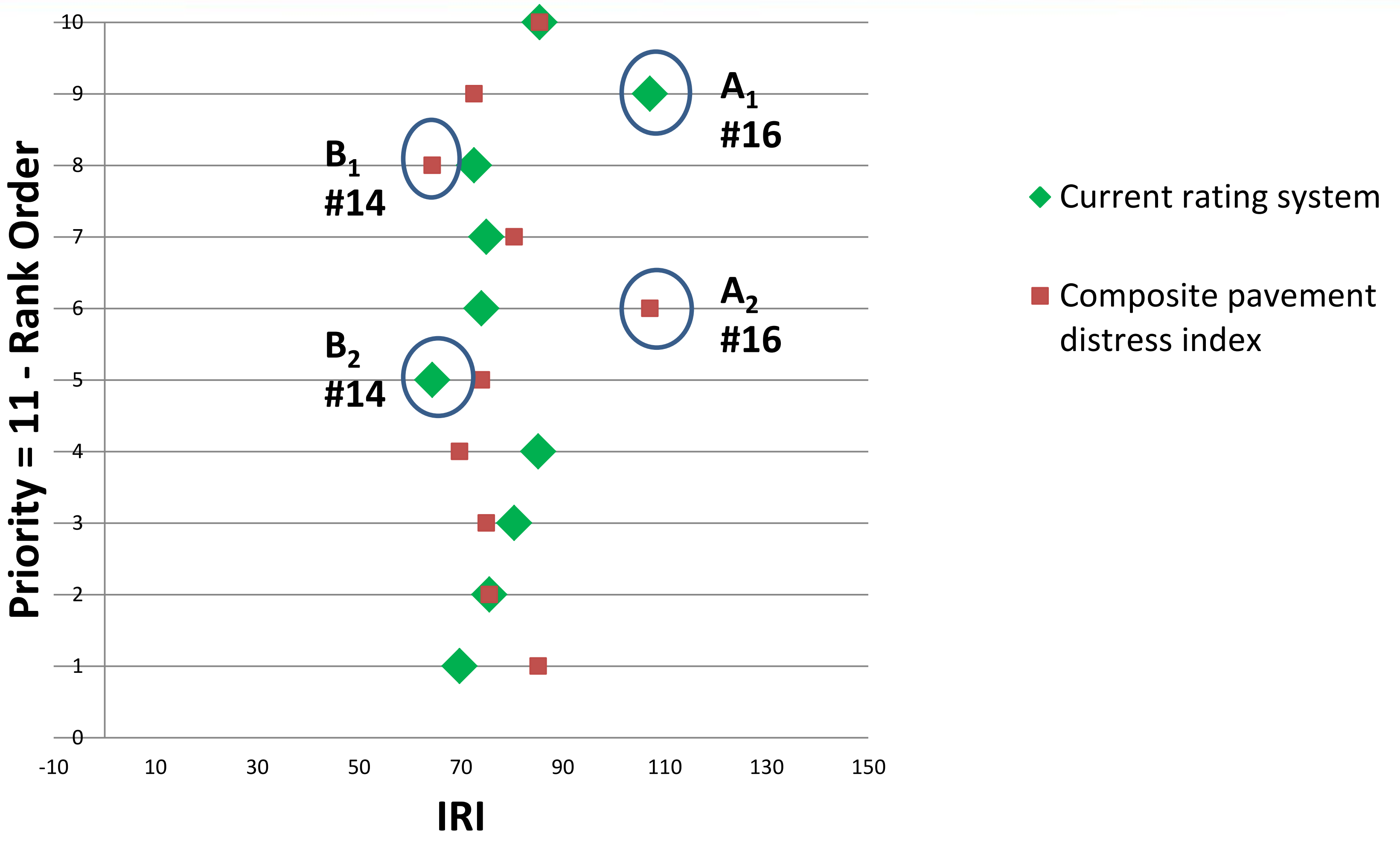
Road #	WPC_E	WPC_S	RF_E	RF_S	OC_E	OC_S	OS_E	OS_S	APPEAR	JS	IRI	Total Score
4	9	9	4	4	5	4	0.5	1	3	1	85.442	49.5
16	**4**	**6**	**4**	**4**	**3**	**3**	**0**	**0**	**2**	**5**	**107.111**	**47**
15	8	7	4	4	2	3	1.5	1.5	2.5	3	72.54	41.5
5	8	6	4	4	5	2	0	0	2	1	74.989	38
6	8	7	4	3	5	2	0	0	2	1	74.021	37
14	**6**	**5**	**4**	**4**	**3**	**4**	**1.5**	**1**	**2.5**	**4**	**64.355**	**37**
26	**7**	**4**	**3**	**2**	**4**	**2**	**1**	**1**	**2**	**2**	**85.144**	**37**
7	6	8	2	2	4	3	1	1	1.5	1	80.442	36.5
29	7	5	4	3	2	3	0	0	2	3	75.578	35
17	**7**	**7**	**2**	**2**	**4**	**2**	**1**	**1.5**	**2**	**1**	**69.702**	**33.5**

AHP system

Road #	WPC_E	WPC_S	RF_E	RF_S	OC_E	OC_S	OS_E	OS_S	APPEAR	JS	IRI	Total Score
4	10	10	5	5	6	5	1.5	2	4	1	85.442	0.8419
15	9	8	5	5	3	4	2.5	2.5	3.5	3	72.54	0.7134
14	**7**	**6**	**5**	**5**	**4**	**5**	**2.5**	**2**	**3.5**	**4**	**64.355**	**0.6716**
7	7	9	3	3	5	4	2	2	2.5	1	80.442	0.6507
16	**5**	**7**	**5**	**5**	**4**	**4**	**1**	**1**	**3**	**5**	**107.111**	**0.6501**
6	9	8	5	4	6	3	1	1	3	1	74.021	0.6015
17	**8**	**8**	**3**	**3**	**5**	**3**	**2**	**2.5**	**3**	**1**	**69.702**	**0.5997**
5	9	7	5	5	6	3	1	1	3	1	74.989	0.5880
29	8	6	5	4	3	4	1	1	3	3	75.578	0.5515
26	**8**	**5**	**4**	**3**	**5**	**3**	**2**	**2**	**3**	**2**	**85.144**	**0.5475**

Comparison on Priorities

Priority = 10 receives treatment first



Case Study 2: a Subset of 30+ road segments

TOTAL POINTS RANK	AHP POINTS RANK	IRI	CONDITION POINTS
1	1	179.97	43.5
1	1	179.97	43.5
2	5	88.282	49
6	2	81.151	48.5
3	3	92.987	47
3	3	92.987	47
4	4	88.779	47
4	4	88.779	47
5	26	107.32	41
2	5	88.282	49
6	2	81.151	48.5
9	6	81.017	46.5
7 (Rt.A)	14	102.13	42
31 (Rt.B)	7	53.309	47
8	9	89.625	45.5
26	8	60.967	46
9	6	81.017	46.5
8	9	89.625	45.5
10	13	91.822	43
27	10	62.386	45

TOTAL POINTS RANK	AHP POINTS RANK	IRI	CONDITION POINTS
11	28	98.94	41 (Rt.C)
22	11	71.917	44 (Rt.D)
12	19	87.218	43.5
33	12	42.064	46.5
13	16	76.09	47
10	13	91.822	43
14	22	90.601	42
7	14	102.13	42
15	20	73.83	46
17	15	74.3	44.5
16	25	78.507	44
13	16	76.09	47
17	15	74.3	44.5
25	17	58.106	47
18	32	84.201	41.5
21	18	73.5	44
19	23	91.322	39
12	19	87.218	43.5
20	30	82.606	42
15	20	73.83	46

Conclusions

- **We developed multiple linear regression models for KYTC to predict 9 distress indices for AC pavement for Kentucky Interstate parkways.**
- **The R^2 values of all the MLR models are larger than 0.85 except OS_SEV. Meanwhile, the average ASE from the MLR models is fairly small (~0.1)**
- **AHP-based composite distress index seems to address the overemphasis on IRI by the current rating method.**

Consistency Ratio

- **Consistency ratio for the above pairwise comparison matrix is 0.0482 << 0.1, a threshold value for AHP to be valid.**

Further Processing

- **Normalize each distress index to [0,1].**

$$Normalized(X_i) = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

where: X_i = *distress index;*

X_{min} = *the minimum value for the distress index;*

X_{max} = *the maximum value for the distress index.*