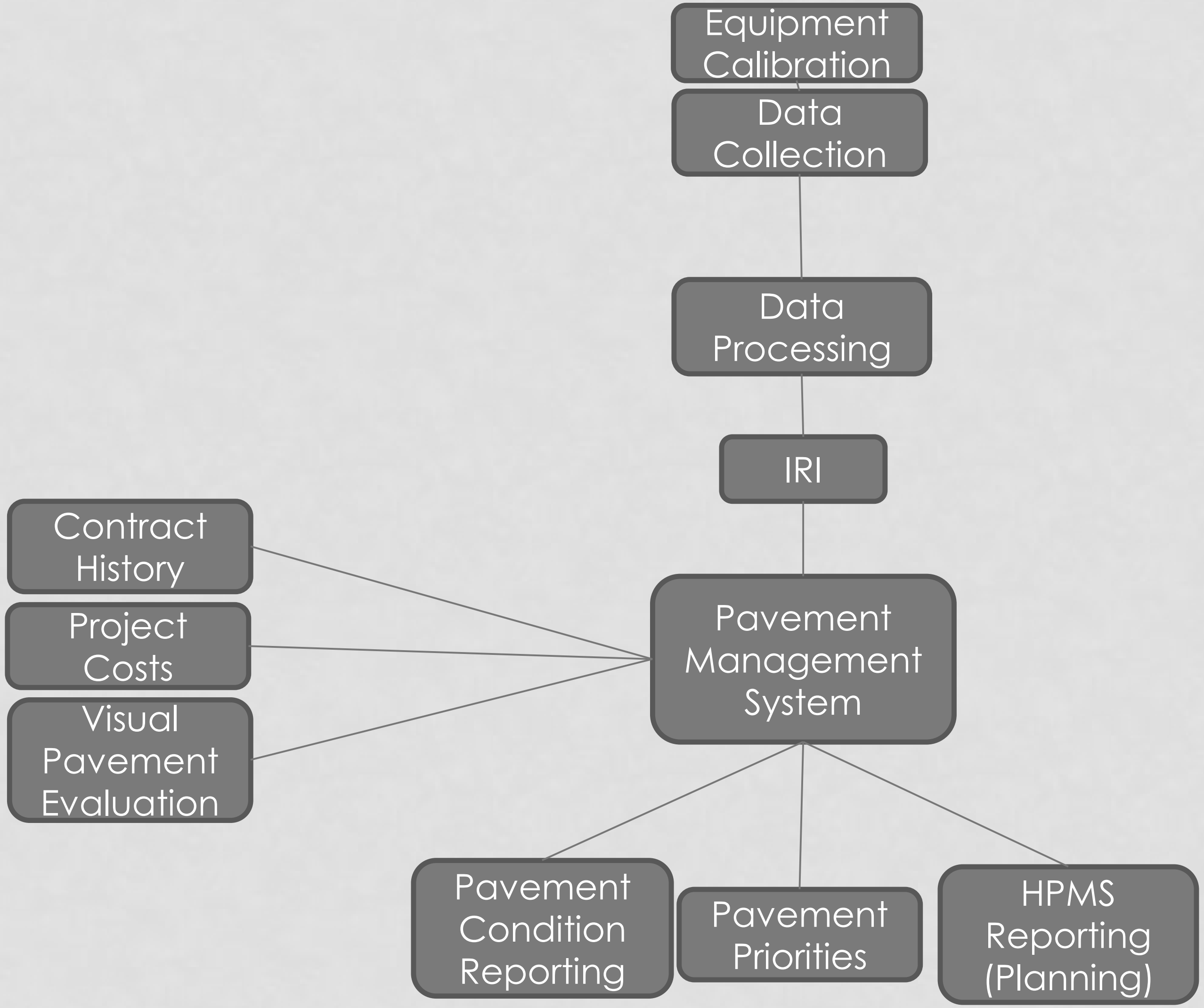
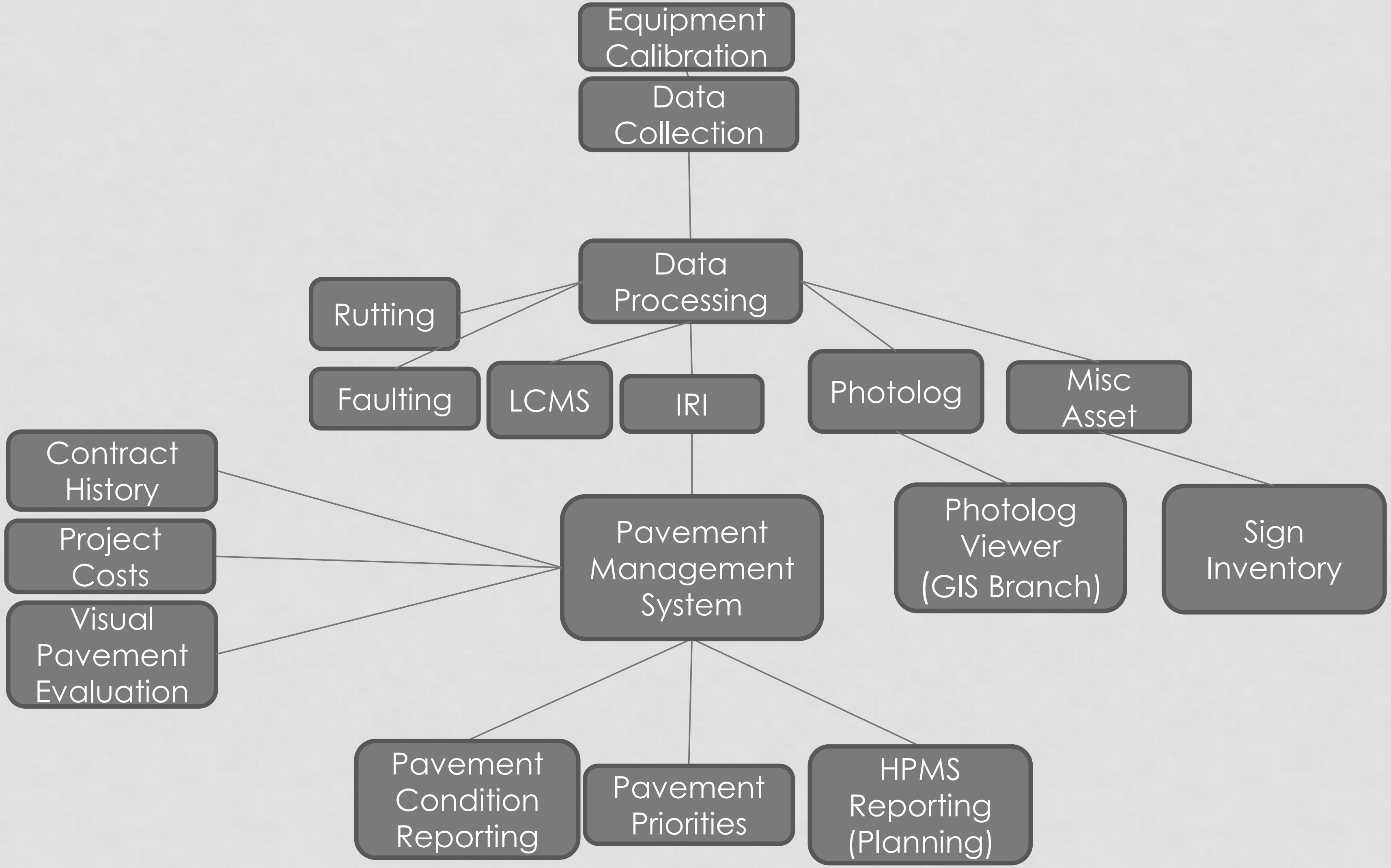
Modernizing Pavement Management in KY

National Pavement Preservation Conference
October 2016
Tracy Nowaczyk, P.E. & Chad Shive, P.E.

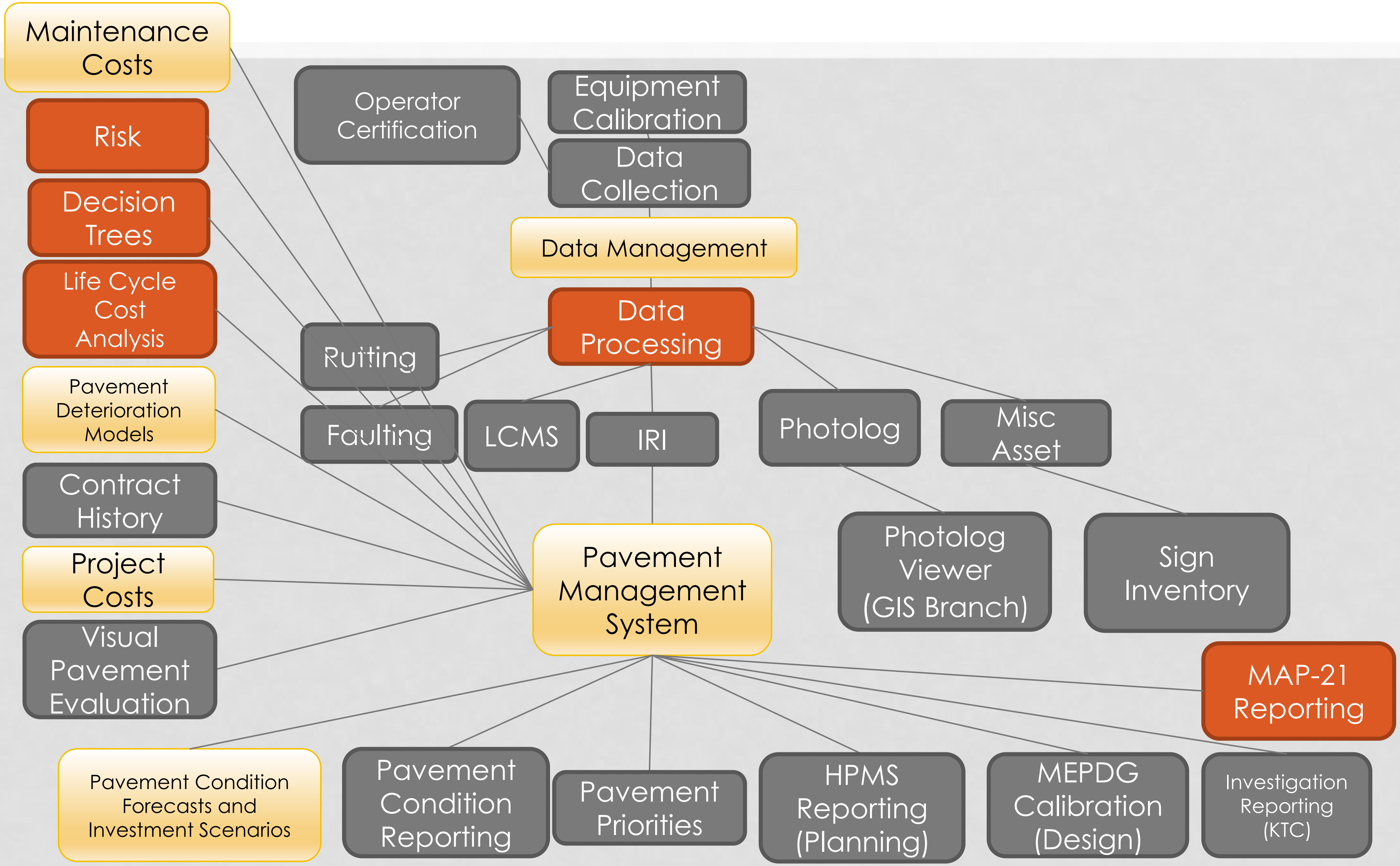
PAVEMENT MANAGEMENT FOUNDATION



INVESTMENT IN EQUIPMENT



MODERN PAVEMENT MANAGEMENT DEMANDS

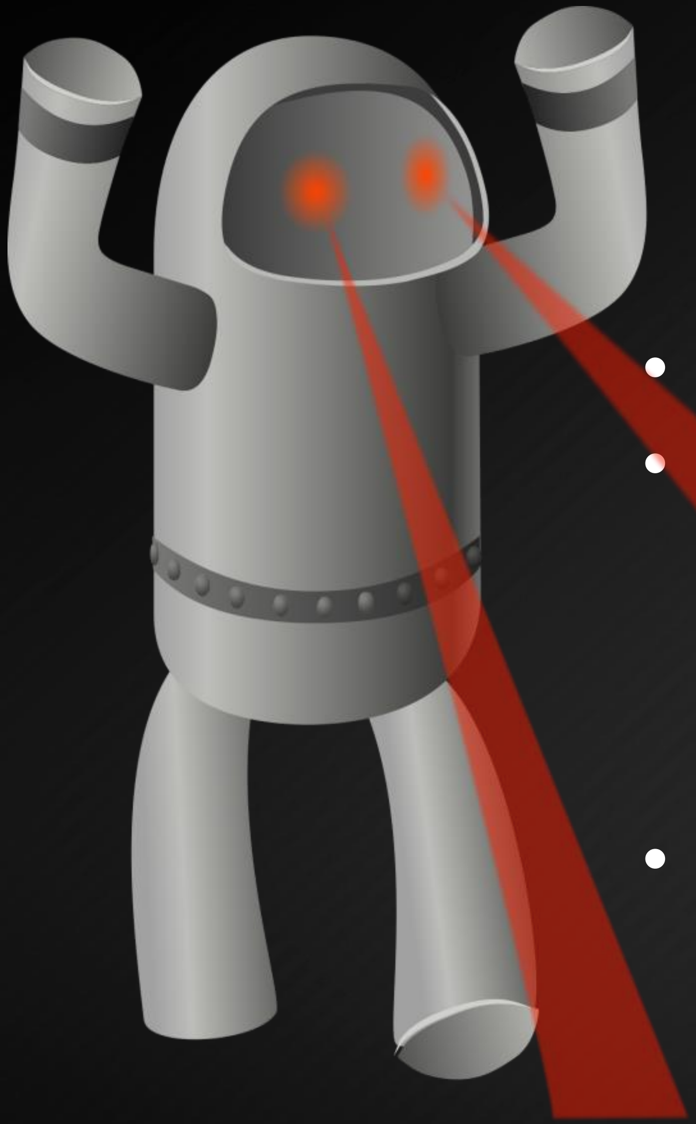


University of Louisville

- Began partnership in fall 2013
- Develop predictive models for asphalt pavement based on legacy data
- Create objective composite pavement distress index
- Map LCMS data to legacy data

Legacy Data

- Visual evaluation system (VES)
- Distresses measured based on overall extent and most common severity
- Year of recommended treatment
- Measured distresses
  - IRI
  - Rutting

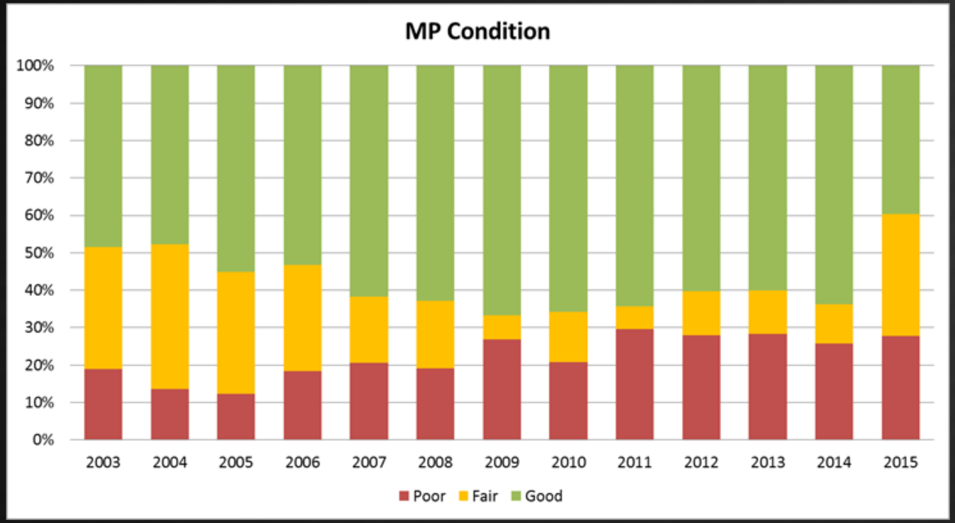


Laser Crack Measurement System (LCMS)

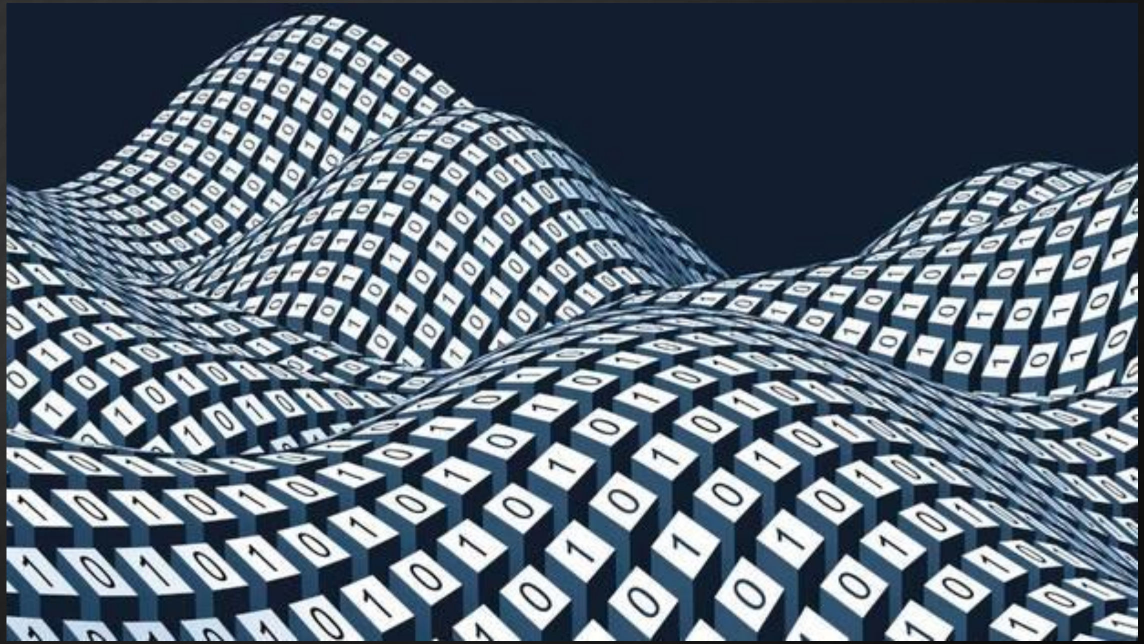
- Objective assessment of pavement condition
- Captures more factors
  - High detail of Rutting, Macrotexture, Cracking, Potholes, Patches, Sealed Cracks, Vehicle Orientation
  - ~95% accuracy for Longitudinal Cracks, ~90% accuracy for Transverse Cracks
- Shifts needs
  - Much less field time for engineers
  - Some of that times shifts to data processing
  - Once data is processed, entire system can be evaluated

Data Mountain

VES – High level data with low resolution



LCMS – Detailed low level data with high resolution



Pilot Case Study

LCMS → VES → PMS

Pilot Case Study

Need to relate new method to legacy data

From

RT UNIQUE ID	FROM POINT	TO POINT	LANE DIR	WPC JD EXT	WPC JD SEV	R F EXT	R F SEV	OC EXT	OC SEV	OS P EXT	OS P SEV	APP
122-KY-9000	0	3.648	L	9	7	5	5	5	5	0	0	3
122-KY-9000	3.648	11.913	L	6	5	3	4	5	2	3	1	3
122-KY-9000	11.913	16.02	L	3	1	2	2	1	1	0	0	1
122-KY-9000	16.02	19.15	L	3	1	1	1	1	1	0	0	1
122-KY-9000	19.15	22.307	L	1	1	0	0	1	1	0	0	0.5
...	...	...	...	...	...	...	...	...	...	...	...	...

To

Session Name	Begin MP	End MP	LEN (mile)	DIR	CWBS TypA Sev (in)	CWBS TypA Low (ft)	CWBS TypA Med (ft)	CWBS TypA High (ft)	...
15-KY-1494N	6.6	6.7	0.1	N	0.690	89.383	62.992	15.632	...
15-KY-1494N	6.7	6.8	0.1	N	0.426	154.435	130.666	3.121	...
15-KY-1494N	6.8	6.9	0.1	N	0.421	199.566	140.278	3.534	...
15-KY-1494N	6.9	7	0.1	N	0.544	256.281	371.720	23.269	...
15-KY-1494N	7	7.1	0.1	N	0.458	134.963	89.799	4.914	...
...	...	...	...	...	...	...	...	...	...

Pilot Case Study

Too Much Data!!!

LCMS reports 176 fields, where do we start?

- Leading Factors Identification for each visual index
- Clustering Analysis (Verifying data integrity / Outlier detection)
- Factorial Analysis (Significance testing for regressor variables)
- Principal Component Analysis (exploratory)
- Regression Modeling

  Linear Regression

  Ordinal Logistic Regression

Pilot Case Study

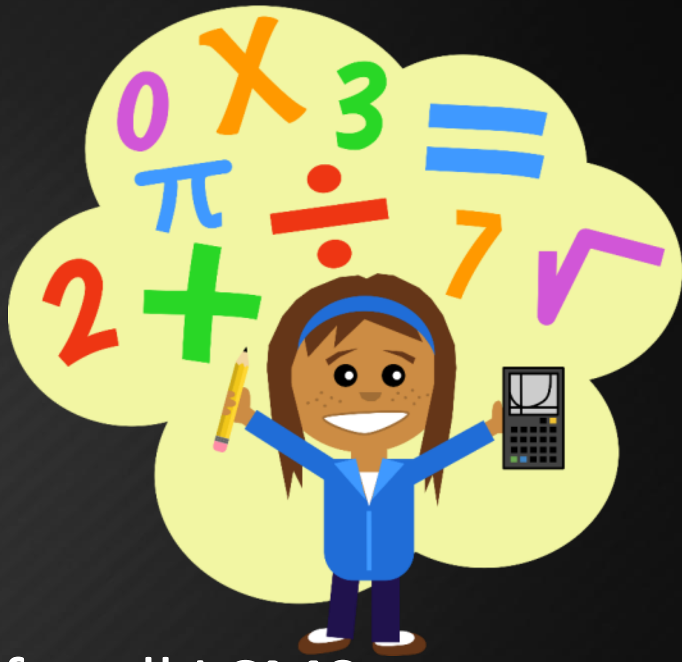
Formal Approach

- Step 1: Factors Identification
- Step 2: Data Consolidation and Preprocessing
- Step 3: Data Quality Check
- Step 4: Factorial Analysis using Analysis of Variance (ANOVA)
- Step 5: Linear Regression Model for Data Mapping

Pilot Case Study

Factor Identification

Wheel Path Cracking Extent (WPC^e)	Wheel Path Cracking Severity (WPC^s)	Appearance (APP)	Other Cracking Extent (OC^e)
Fatigue Type A EXT	Fatigue Type A SEV	Fatigue Type A SEV	Edge Crack EXT
Fatigue Type A LOW	Fatigue Type B SEV	Fatigue Type B SEV	Edge Crack LOW
Fatigue Type A MED	Fatigue Type C SEV	Fatigue Type C SEV	Edge Crack MED
Fatigue Type A HIGH	Fatigue Type D SEV	Fatigue Type D SEV	Edge Crack HIGH
Fatigue Type B EXT	Non WP Long SEV	Non WP Longitudinal SEV	Transverse Crack EXT
Fatigue Type B Area EXT		Edge Crack SEV	Transverse Crack LOW
Fatigue Type C EXT		Transverse Crack SEV	Transverse Crack MED
Fatigue Type C Area EXT		Sealed Crk Fatigue A LENGTH	Transverse Crack HIGH
Fatigue Type D EXT		Sealed Crk Long LENGTH	Transverse Crack Count LOW
Fatigue Type D Area EXT		Sealed Crk Edge Length	Transverse Crack Count MED
Non WP Longitudinal EXT		Sealed Crk Transverse Length	Transverse Crack Count HIGH
Non WP Longitudinal LOW		Sealed Crk Transverse Count	Unclassified Crack LOW
Non WP Longitudinal MED		Sealed Crk Unclassified Length	Unclassified Crack MED
Non WP Longitudinal HIGH			Unclassified Crack HIGH
Sealed Crk Fatigue A LENGTH			Unclassified Crack Count LOW
Sealed Crk Long LENGTH			Unclassified Crack Count MED
			Unclassified Crack Count HIGH
			Sealed Crk Edge Length
			Sealed Crk Transverse Length
			Sealed Crk Transverse Count
			Sealed Crk Unclassified Length



Pilot Case Study

Data Consolidation and Preprocessing

- Summarize LCMS data for each VES segment
  - Two methods, Average & Max
    - Average method uses length weighted average for all LCMS values that cover a VES section
    - Max method uses maximum LCMS value within a VES section
- Use additional factors from LCMS data
  - Weighted Cracking Extent
  - Pattern Density

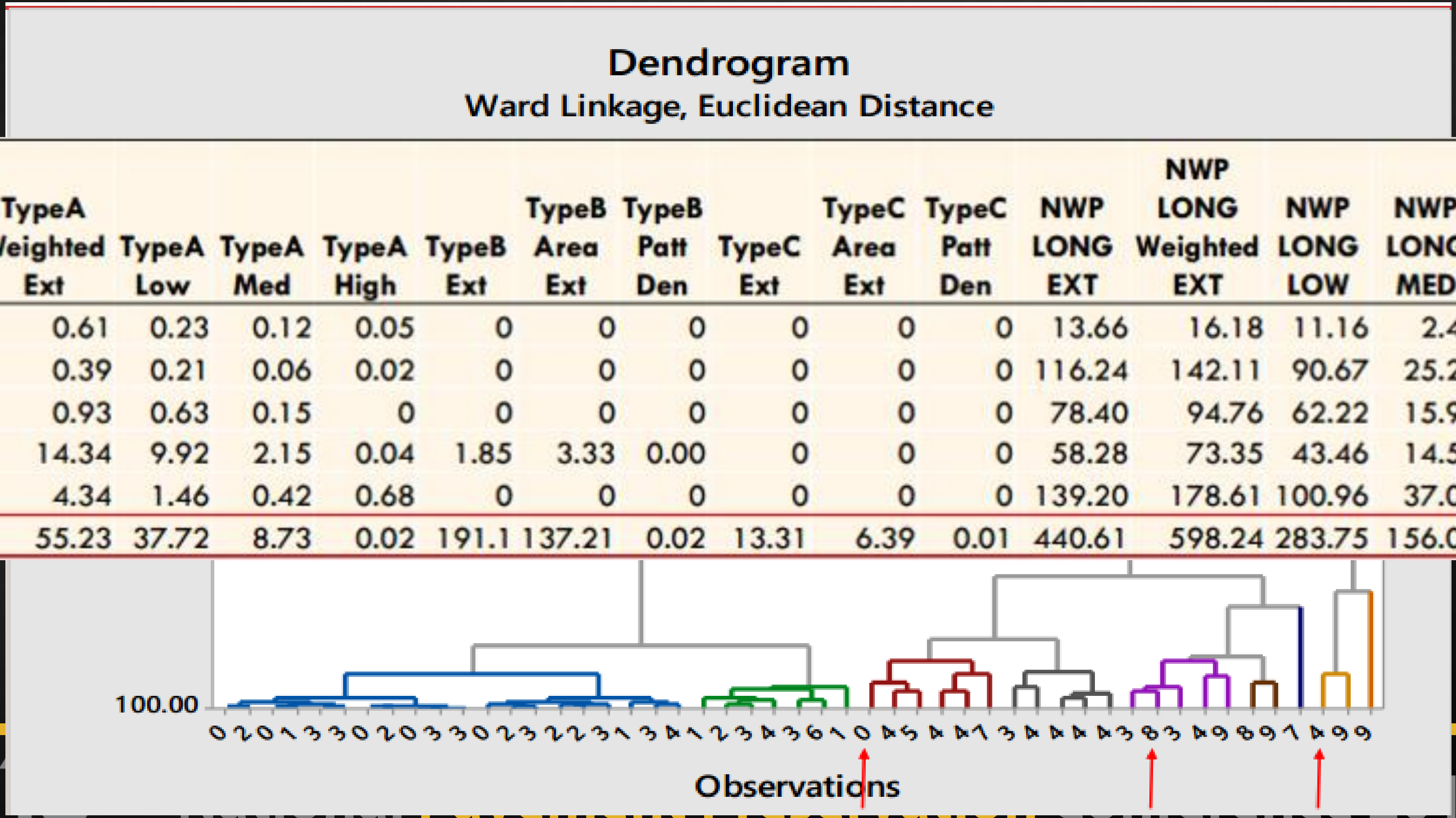
Pilot Case Study

Data Quality Check

- Clustering Analysis
  - Agglomerative Hierarchical Clustering
    - All samples start as separate individual clusters
    - Build hierarchy from individual elements by progressively merging the clusters
    - Based on desired distance level (dk), user can choose set of clusters

Pilot Case Study

Data Quality Check



WPC EXT	TypeA Ext	TypeA Weighted Ext	TypeA Low	TypeA Med	TypeA High	TypeB Ext	TypeB Area Ext	TypeB Patt Den	TypeC Ext	TypeC Area Ext	TypeC Patt Den	NWP LONG EXT	NWP LONG Weighted EXT	NWP LONG LOW	NWP LONG MED	NWP LONG HIGH
0	0.40	0.61	0.23	0.12	0.05	0	0	0	0	0	0	13.66	16.18	11.16	2.47	0.03
0	0.29	0.39	0.21	0.06	0.02	0	0	0	0	0	0	116.24	142.11	90.67	25.26	0.30
0	0.78	0.93	0.63	0.15	0	0	0	0	0	0	0	78.40	94.76	62.22	15.99	0.19
0	12.11	14.34	9.92	2.15	0.04	1.85	3.33	0.00	0	0	0	58.28	73.35	43.46	14.56	0.26
0	2.56	4.34	1.46	0.42	0.68	0	0	0	0	0	0	139.20	178.61	100.96	37.09	1.16
0	46.47	55.23	37.72	8.73	0.02	191.1	137.21	0.02	13.31	6.39	0.01	440.61	598.24	283.75	156.09	0.77

Pilot Case Study

Factorial Analysis

- Fit various combinations of the LCMS input variables to the VES output variable and study the Analysis of Variance (ANOVA) results to determine the significant and non-significant factors
- Low p-value (<0.05) is desired for any factor to be significant in the model
- The R2 value shows how close the data is fitted to the regression line
- Sequentially remove factors with large p-values from the model until all factors are significant

Pilot Case Study

Factorial Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS
Regression	12	236.649	19.7207
Fat_Crk_TypeA_Low	1	0.528	0.5280
Fat_Crk_TypeA_Med	1	6.471	6.4714
Fat_Crk_TypeA_High	1	8.740	8.7405
Fat_Crk_TypeB_Ext	1	18.701	18.7009
Fat_Crk_TypeB_Area_Ext	1	15.013	15.0126
TypeB_PattDen	1	7.062	7.0624
Fat_Crk_TypeC_Ext	1	0.405	0.4052
Fat_Crk_TypeC_Area_Ext	1	1.556	1.5561
TypeC_PattDen	1	2.703	2.7027
NON_WHEEL_LONG_LOW	1	5.205	5.2046
NON_WHEEL_LONG_MED	1	1.247	1.2467
NON_WHEEL_LONG_HIGH	1	16.209	16.2086
Error	36	75.555	2.0988
Total	48	312.204	

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.44871	75.80%	67.73%	0.00%

WPC_JD_EXT = 1.349 + 0.0100 Fat_Crk_TypeA_Low - 0.0
+ 0.926 Fat_Crk_TypeA_High - 0.0522 Fat_Crk_TypeB_E
+ 0.0510 Fat_Crk_TypeB_Area_Ext + 98.0 TypeB_PattDe
- 0.0204 Fat_Crk_TypeC_Ext + 0.090 Fat_Crk_TypeC_Area_Ext
- 261 TypeC_PattDen + 0.00498 NON_WHEEL_LONG_LOW
+ 0.00450 NON_WHEEL_LONG_MED + 0.0734 NON_WHEEL_LONG_HIGH

Better model fit but less terms are significant

AFTER SELECTING MAJOR CONTRIBUTING FACTORS FROM ABOVE ANALYSIS

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	6	222.78	37.129	17.44	0.000
Fat_Crk_TypeA_Med	1	11.84	11.841	5.56	0.023
Fat_Crk_TypeA_High	1	23.77	23.771	11.16	0.002
Fat_Crk_TypeB_Ext	1	39.37	39.366	18.49	0.000
Fat_Crk_TypeB_Area_Ext	1	27.19	27.195	12.77	0.001
TypeB_PattDen	1	30.51	30.514	14.33	0.000
Non_WP_LONG_Weighted_EXT	1	45.19	45.194	21.23	0.000
Error	42	89.43	2.129		
Total	48	312.20			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.45919	71.36%	67.26%	60.62%

Regression Equation

WPC_JD_EXT = 1.192 - 0.0589 Fat_Crk_TypeA_Med
+ 1.054 Fat_Crk_TypeA_High - 0.0646 Fat_Crk_TypeB_Ext
+ 0.0600 Fat_Crk_TypeB_Area_Ext + 144.5 TypeB_PattDen
+ 0.00512 Non_WP_LONG_Weighted_EXT

Pilot Case Study

Factorial Analysis

AFTER SELECTING MAJOR CONTRIBUTING FACTORS FROM ABOVE ANALYSIS

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-V
Regression	3	155.084	51.695	2
Fat_Crk_TypeB_Sev	1	15.739	15.739	
Fat_Crk_TypeC_Sev	1	19.013	19.013	1
NON_WHEEL_LONG_SEV	1	7.839	7.839	
Error	45	80.549	1.790	
Total	48	235.633		

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.33790	65.82%	63.54%	55.48%

Regression Equation

WPC_JD_SEV = 0.141 + 1.703 Fat_Crk_TypeB_Sev +
+ 0.955 NON_WHEEL_LONG_SEV

AFTER SELECTING MAJOR CONTRIBUTING FACTORS FROM ABOVE ANALYSIS

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	173.08	86.538	63.63	0.000
Fat_Crk_TypeB_Sev	1	20.97	20.970	15.42	0.000
NON_WHEEL_LONG_SEV	1	12.95	12.948	9.52	0.003
Error	46	62.56	1.360		
Total	48	235.63			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.16616	73.45%	72.30%	68.39%

Regression Equation

WPC_JD_SEV = -0.753 + 8.78 Fat_Crk_TypeB_Sev + 5.93 NON_WHEEL_LONG_SEV

Pilot Case Study

Factorial Analysis

VES Indices	AVG method		MAX method	
	No. of Significant Factors	Model Fit (Adj R^2)	No. of Significant Factors	Model Fit (Adj R^2)
Wheel Path Cracking Extent (WPC_EXT)	**6 /16**	**67.26 %**	2 / 16	66.06 %
Wheel Path Cracking Severity (WPC_SEV)	**2 / 4**	**72.30 %**	3 / 4	63.54 %
Other Cracking Extent (OC_EXT)	**7 / 10**	**65.35 %**	3 / 10	57.63 %
Other Cracking Severity (OC_SEV)	**1 / 1**	**74.23 %**	1 / 1	39.54 %
Raveling Extent (R_F_EXT)	**4 / 5**	**70.39 %**	3 / 5	57.37 %
Appearance (APP)	1 / 5	43.52 %	**2 / 5**	**54.09 %**

Pilot Case Study

Next Steps

- Larger data samples
  - Entire dataset of 2015/2016 testing
- Ordinal logistic regression to model dependent variables as Integer values (for the visual indices)
- Use of Clustering analysis to develop separate regression models for various clusters
  - Different models for newer (less distressed) pavements vs older

Path to Prioritization

- Collect pavement condition data in the past planning cycle
- Run regression models to predict distress indices
- Perform AHP analysis for weights for criteria
- Calculate composite condition index for all road segments
- Rank all projects based on composite condition index

Existing Project Prioritization

- Composite pavement scores derived from distress indices
- Large emphasis on roughness of the road
- Projects prioritized based on roughness instead of pavement deterioration

Analytic Hierarchy Process

- Structured Technique for organizing complex decisions
- Based on mathematics and psychology
- Interviews with panel of experts
- Weights for individual indices calculated and validated
- Each project receives single overall priority score

Composite Pavement Distress Index

- Pairwise comparison

WPC_EXT	5	RF_EXT	1

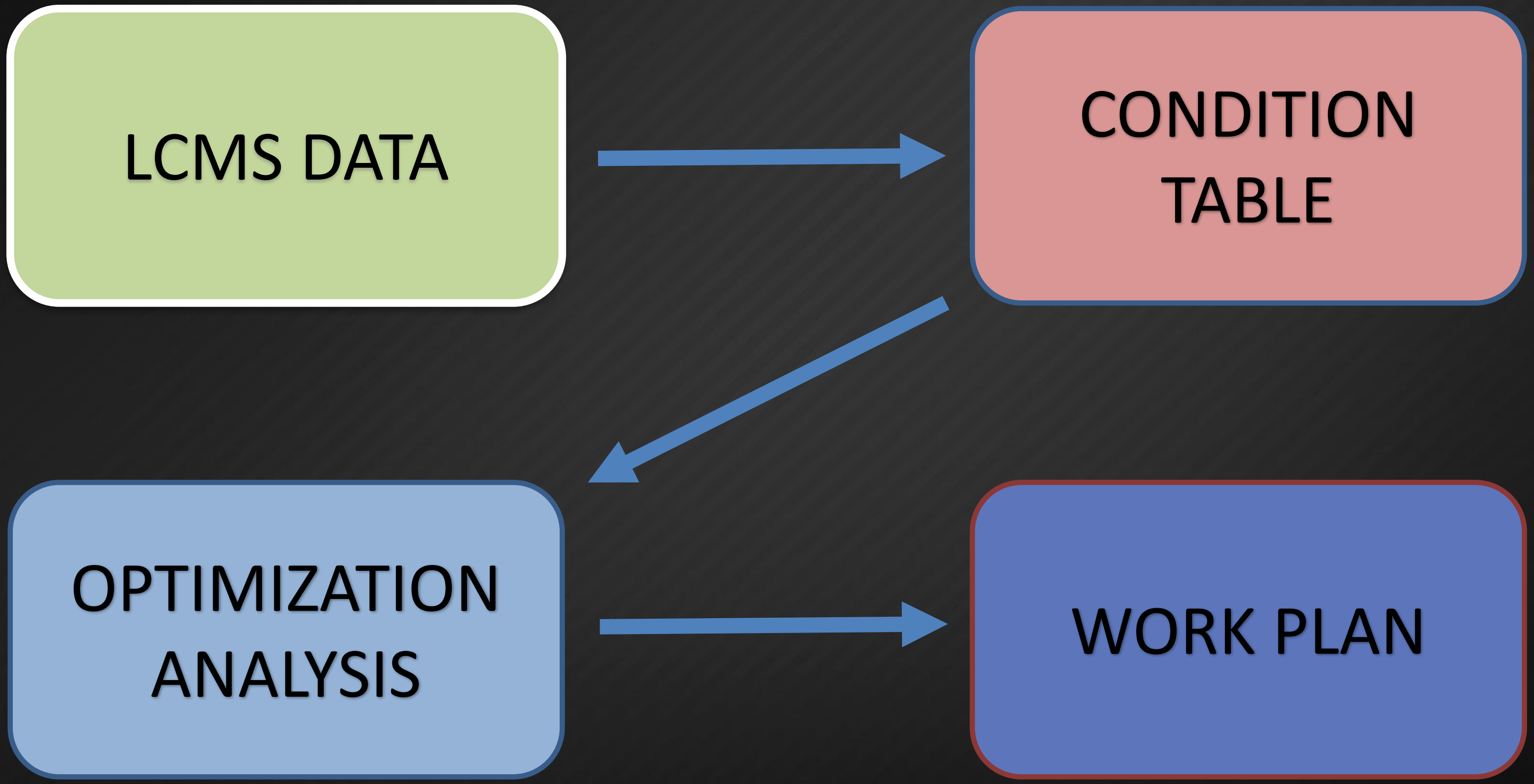
INTENSITY OF IMPORTANCE	DEFINITION
1	“factor A” and “factor B” are equally important
3	“factor A” is moderately favored than “factor B”
5	“factor A” is strongly favored than “factor B”
7	“factor A” is very strongly favored than “factor B”
9	“factor A” is extremely favored than “factor B”
2,4,6,8	Ratings are between two adjacent judgements

	WPC_EXT	WPC_SEV	R_EXT	R_SEV	OC_EXT	OC_SEV	PAT_EXT	PAT_SEV	APPEAR	IRI	JS
WPC_EXT	1	1/3	3	3	1	1/3	5	3	5	1/2	1
WPC_SEV		1	5	4	5	2	7	5	7	2	3
R_EXT			1	1	1/5	1/5	1	1/3	2	1/3	1
R_SEV				1	2/3	1/3	4	2	2	1	1
OC_EXT					1	1/3	4	2	3	1	1
OC_SEV						1	5	3	4	2	2
PAT_EXT							1	1/3	1	1/4	1/3
PAT_SEV								1	3	1/2	1/3
APPEAR									1	1/8	1/3
IRI										1	3
JS											1

Pavement Distress Index (PDI)

- Matrix exercise produced new set of weightings
- New system provides 0-1 scale for each section
- Pilot study comparison of prioritization projects
- Successfully addressed the overemphasis of IRI

Future PMS Map



Special Thanks

- Dr. Lihui Bai
- Dr. Zhihui Sun
- Guanyang xu
- Prajwal khadgi
- Peiyu luo