Forecasting the Life of Asset Preservation Treatments: A Comparative Evaluation of Tools and Techniques

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Outline

- Introduction
- Study Objective
- Literature Review
- Methodology
- Case Study
- Concluding Remarks

Asset Performance Models

Why do we need to develop performance models for the highway assets?

- Describing and predicting the performance of in-service assets
  - Physical and financial needs assessment (project level and network level)
  - Project prioritization and programming
- Maintenance and Rehabilitation treatment evaluation (benefits assessment and cost analysis)
  - Effective planning and scenario analysis
  - Re-Evaluation of strategies and design guides

Problem Statement

- AM needs appropriate techniques to ascertain the effectiveness of their actions.

- Past or currently used methods for AM performance modeling and remaining service life prediction include:
  - Expert Opinion
  - Curve Fitting
  - Linear/Non-Linear Regression
  - Markov Chains
  - Artificial Neural Networks

- Most of the above methods raise issues regarding precision, practicality, and appropriateness for use **within an AM framework**.

Study Objective

- Develop an enhanced methodology for performance prediction that duly considers:
  - The challenging nature of data related to asset performance
  - The purposes for which the results will be used
  - Precision

- Use the developed methodology to:
  - Predict post-rehabilitation performance and estimate rehabilitation treatment service life for:
    - Existing (in-service) assets
    - Assets slated for future rehabilitation
  - Assess future needs of in-service rehabilitated pavements

Study Scope

- Highway Asset type: **Pavements**
- Preservation Treatment type: **Rehabilitation**
  - Typical Rehabilitation Treatments, Indiana DOT (1996-2006):

1. Thin HMA Overlay
2. HMA Overlay, Multiple Structural Layers
3. Mill Surface and HMA Overlay
4. Crack and Seat PCC and HMA Overlay
5. Repair PCC and HMA Overlay
6. Rubblize PCC/Composite and HMA Overlay
7. Concrete Overlay on PCCP

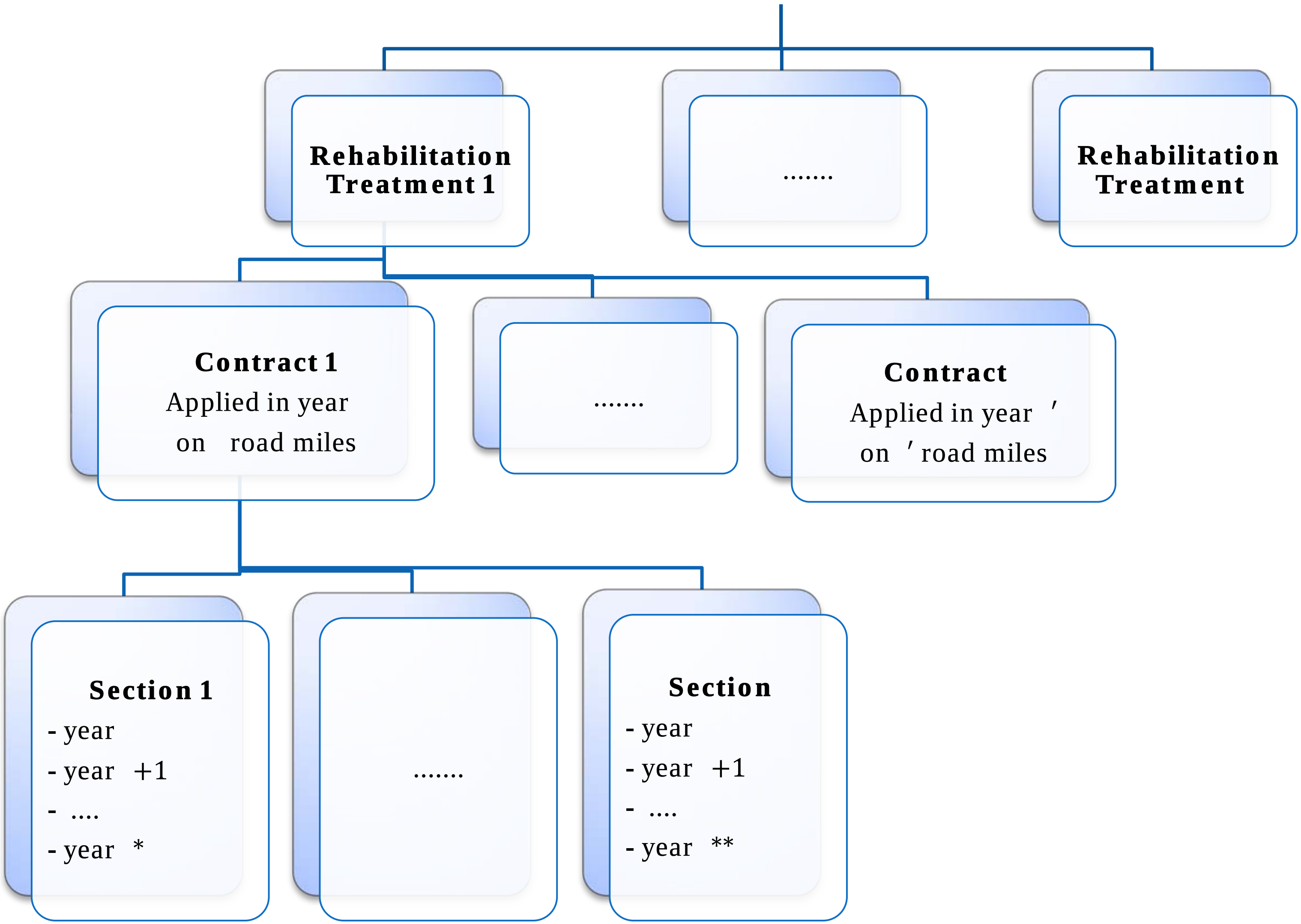
Literature Review

Methods proposed by researchers:

- Incremental Models (Abu-Lebdeh et al, 2003; Prozzi and Madanat, 2003)
- Bayesian Regression (Hajek and Bradbury, 1996; George, 2000; Hong and Prozzi, 2006; Amador and Mrawira, 2011)
- Survival Analysis (Paterson, 1987; Prozzi and Madanat, 2000, Romanoschi and Metcalf, 2000; DeLisle et al., 2003; Gharaibeh and Darter, 2003; Wang et al, 2005; Yang, 2007; Wang and Allen, 2008; Yu et al, 2008; Morian et al., 2011)
- Mixed Models (Madanat and Shin, 1998; Yu et al, 2007; Chu and Durango-Cohen, 2008; Nakat et al, 2008; Hong and Prozzi, 2010; Aguiar-Moya et al, 2011)
- Simultaneous Equations (Mohamad et al. 1997)
- Seemingly Unrelated Equations (Prozzi and Hong, 2008; Anastasopoulos et al, 2011)

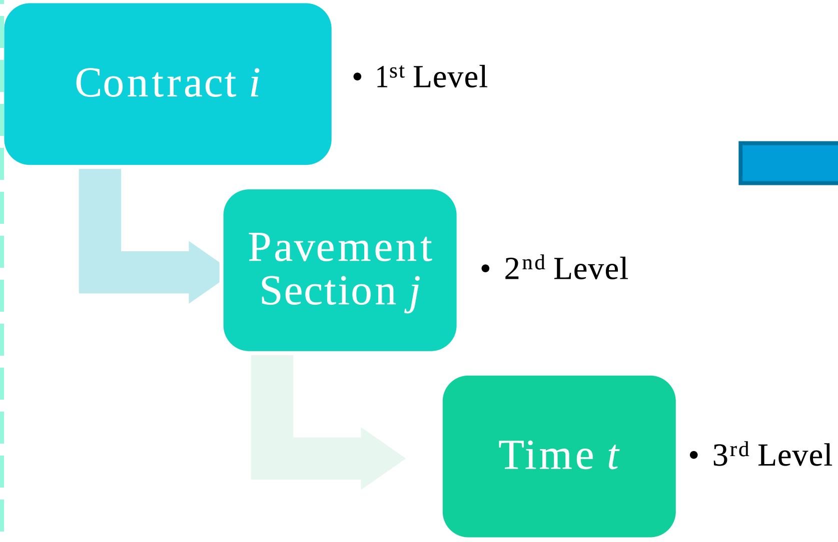
These methods have seen little or no practical application in agencies.

Pavement Rehabilitation Data



Model Formulation

Unbalanced Panel Data Structure for a Specific Treatment



Mixed Linear Model Formulation

- Pavement Performance Y_{ijt}:

$$Y_{ijt} = \boldsymbol{X_{ijt}\beta} + a_i + u_{j(i)} + e_{t(ij)}$$

$$i = 1, \dots, N \quad j = 1, \dots, S_i \quad t = 1, \dots, T_{ij}$$

- a_i : effect of the ith contract
- $u_{j(i)}$: effect of the jth pavement section from the ith contract
- $e_{t(ij)}$: residual

Three-Level Nested Linear Model

$$Y_{ijt} = \boldsymbol{X}_{ijt}\boldsymbol{\beta} + \alpha_i + u_{j(i)} + e_{t(ij)}$$

$$i = 1, \ldots, N \quad j = 1, \ldots, S_i \quad t = 1, \ldots, T_{ij}$$

$$\alpha_i \sim N(0, \sigma_a^2) \qquad u_{j(i)} \sim N(0, \sigma_u^2) \qquad e_{t(ij)} \sim N(0, \sigma_e^2)$$

- The deterioration process is represented by performance indicator Y_{ijt}
- Pavement deterioration is caused by aging, traffic loading, climate ($\boldsymbol{X}_{ijt}$)
- Deterioration levels that cannot be fully explained by $\boldsymbol{X}_{ijt}$ happen because of:
    - Characteristics of a specific contract that we "failed" to observe (a_i)
    - Characteristics of a specific pavement section within a contract ($u_{i(j)}$)
    - Random variation ($e_{i(jt)}$)
- All unobserved terms are normally distributed with zero mean and constant variance

Applicability of the Proposed Method to a Highway Agency

- In-Service pavements, rehabilitated in the past
  - Performance prediction *conditional* on a specific pavement section within a specific contract (Best Linear Unbiased Predictor)
    - Highly Accurate Short-Term/Long-Term Performance Predictions
    - Future Needs Assessment

- Future rehabilitation activities
  - Average (Population-Wide) Performance prediction
    - Unbiased Performance and Service Life predictions regarding future activities on a specific pavement
    - Unbiased Average Treatment Service Life estimation

On-Going Research: Indiana DOT, Service Life Estimation of Selected Rehabilitation Treatments

- Preliminary Results from the analysis of the **Interstate** rehabilitated sections
- Performance Indicator used: International Roughness Index (**IRI**)
- Other Available Information: Traffic, Treatment Age, Pre-Treatment IRI, Climate

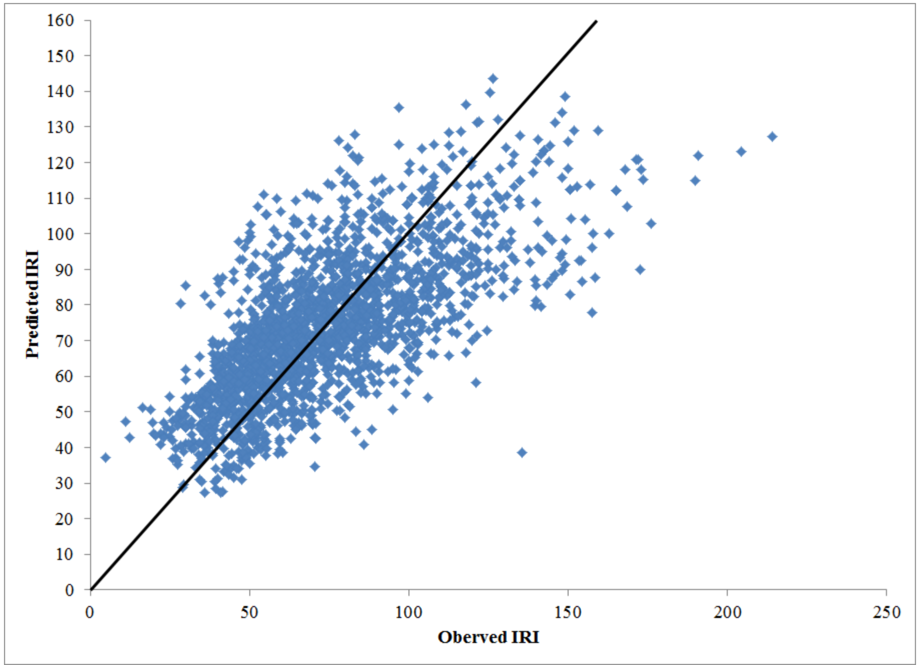
Treatment	# Contracts	Proposed Method
Thin HMA Overlay	10	✓
HMA Overlay, Multiple Structural Layers	5	✓
Mill Surface and HMA Overlay	36	✓
Crack and Seat PCC and HMA Overlay	2	x
Repair PCC and HMA Overlay	12	✓
Rubblize PCC/Composite and HMA Overlay	4	x
Concrete Overlay on PCCP	2	x

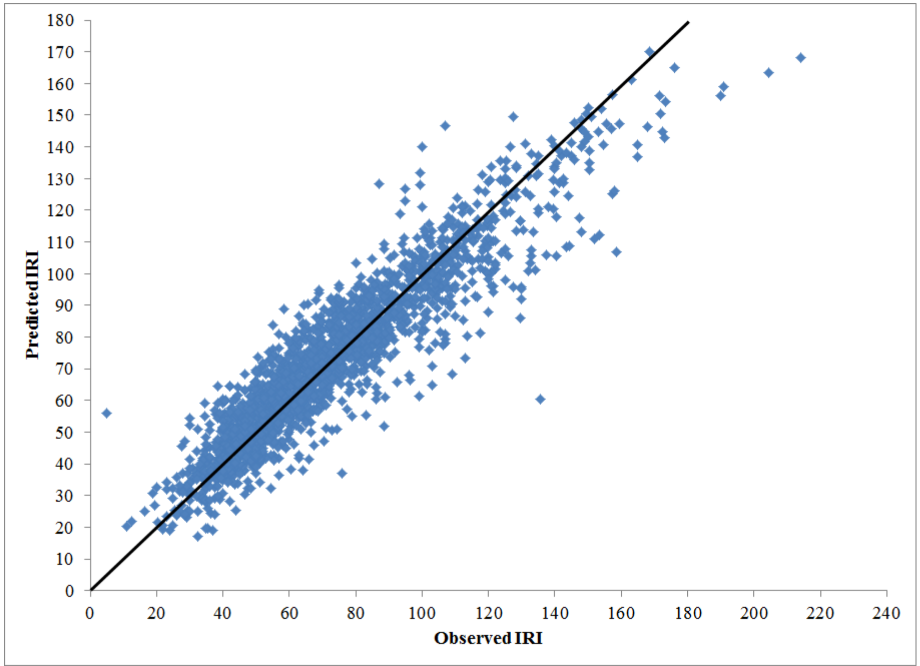
Prediction Methods Comparison

- Comparison of the actual and the predicted values
- Data: Mill Surface and HMA Overlay

Linear Regression

3-Level Nested Linear Model



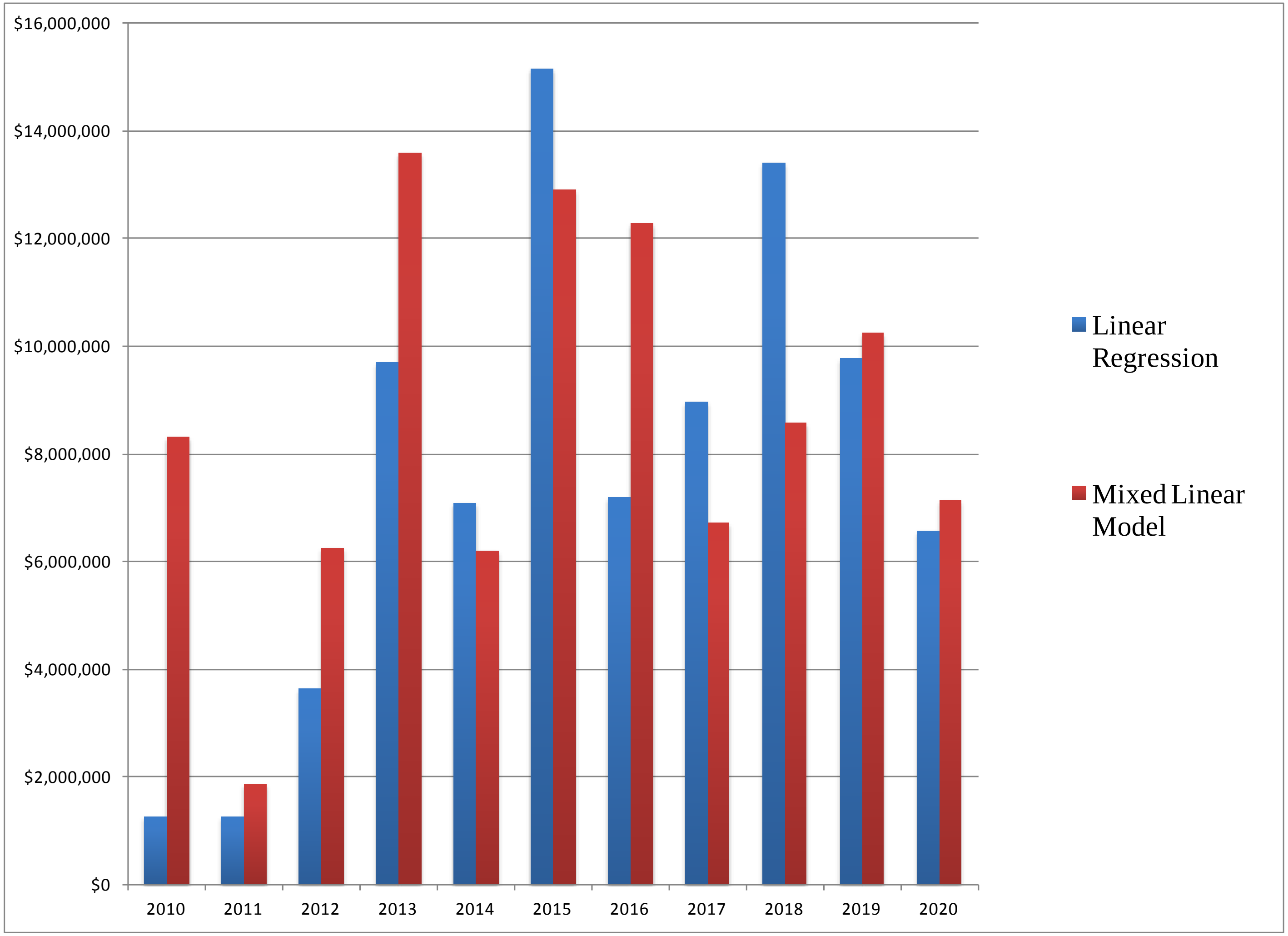


Prediction Methods Comparison

- Example: I-94, milepost 32-35 rehabilitated in 2005
  - Predictions for mile 32-33:

Year	Actual IRI	Predicted IRI (Linear Regression)	Predicted IRI (Mixed Linear Model)
2006	101	68	100
2007	114	73	106
2008	116	77	110
2009	119	80	115
2010		84	120
2011		89	125
2012		93	130
2013		97	134

Assessing the Future Needs of Rehabilitated Interstate Pavements, Indiana



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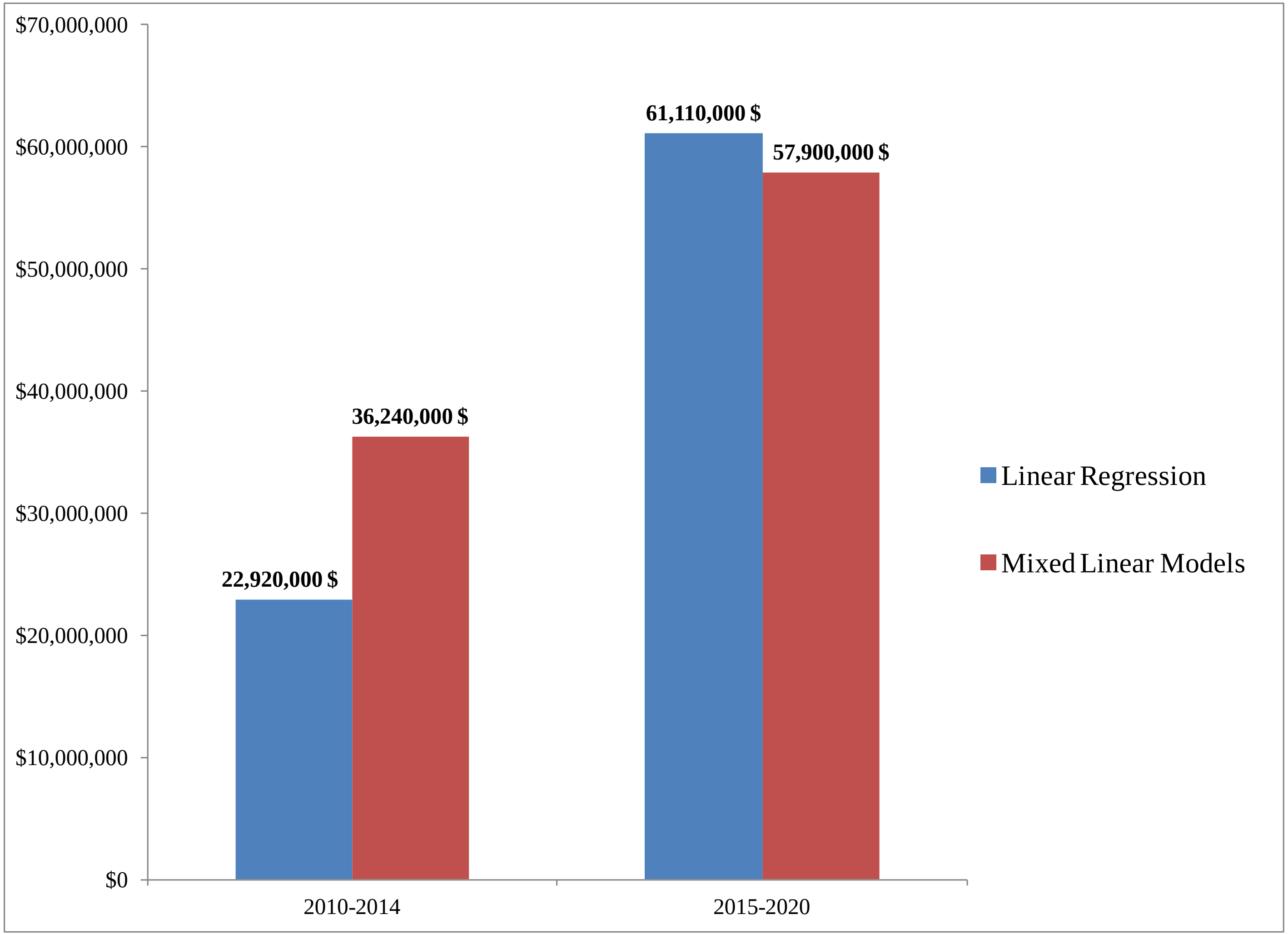
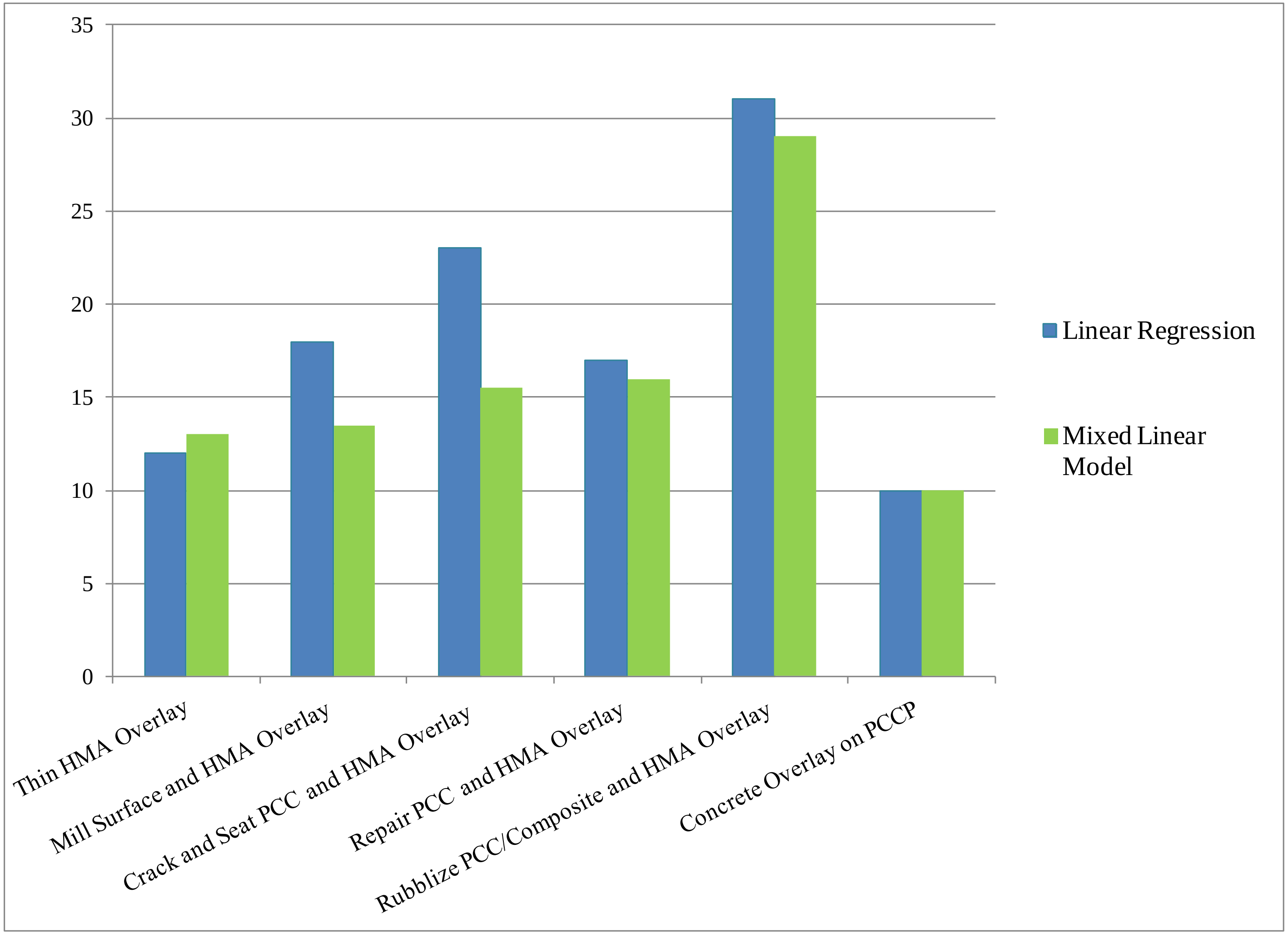


Average Treatment Service Life Estimation: Interstate Pavements, Indiana

Rehabilitation Treatment	Linear Regression			Mixed Linear Model		
	Lower	**Mean**	**Upper**	**Lower**	**Mean**	**Upper**
Thin HMA Overlay	11	**12**	13	10.5	**13**	15.5
HMA Overlay, Multiple Structural Layers	>40	**>40**	>40	22	**32**	40
Mill Surface and HMA Overlay	17	**18**	19	15	**13.5**	16.5
Crack and Seat PCC and HMA Overlay	17	**23**	29	12.5	**15.5**	19.5
Repair PCC and HMA Overlay	16	**17**	18	13.5	**16**	17.5
Rubblize PCC/Composite and HMA Overlay	27	**31**	35	26.5	**29**	29.5
Concrete Overlay on PCCP	9	**10**	11	7	**10**	13

Average Treatment Service Life Estimation: Interstate Pavements, Indiana



Conclusions

- Good Asset Management requires methods that combine **accuracy** with **practicality**.

- The presented methodology:
  - Takes into account the challenging structure of pavement rehabilitation data
  - Can provide accurate deterministic results at the project and at the network level
  - Can provide conditional and population-wide predictions which are both necessary in pavement management
  - Can provide unbiased average treatment service life estimates

- The presented model formulation:
  - Can be applied for **continuous** performance indicators (IRI, rutting, PCR)
  - Can be easily modified to incorporate **non-linear functions**
  - Does not correct for **self-selective samples**

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Questions?

Case Study: Functional HMA Overlay, Interstates, Indiana

Dependent Variable: International Roughness Index (IRI)

Independent Variable	Linear Regression	One-Way Random Effects Model *	3-Level Nested Linear Model*
Constant	-186.902 (-20.52)	-185.530 (-7.89)	-254.59 (-6.99)
Treatment Age [years]	3.600 (23.39)	4.354 (43.94)	4.418 (43.44)
Commercial Vehicles [1000vehicles/day]	0.957 (14.24)	0.743 (5.63)	0.608 (3.63)
Precipitation [in/year]	1.038 (6.92)	0.787 (1.99)	1.381 (1.72)
Log(Pre-Treatment IRI)	96.395 (29.69)	101.390 (12.26)	125.760 (14.88)
Model Statistics			
Observations: 1955 Pavement Sections: 232 Contracts: 36			
Contract Variance, σ_a^2	-	-	345.82 (3.57)
Pavement Section Variance, σ_u^2	-	311.32 (10.06)	122.43 (8.56)
Random Error Variance, σ_e^2	409.47	132.42	132.32
Restricted Log-Likelihood	-8652.6	-7892.7	-7838.2

*** Assuming Compound Symmetry as the covariance structure**