ECONOMETRIC MODELS FOR PAVEMENT ROUTINE MAINTENANCE EXPENDITURE

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Introduction

• Change in Focus of US Transportation Agencies
  – Historically: design/construction
  – Recent past and currently: preservation

• US Transportation Agencies increasingly face:
  – Decreasing or uncertain financial resources
  – Increasing costs/rate of deterioration
Outline

• Problem Statement and Objectives
• Database
• Methodology
• Results
  – AMEX OLS Model
  – AMEX Tobit Model
  – AveAMEX OLS Model
• Conclusions
Problem Statement and Objectives
Problem Statement

• In-house (force-account) Pavement Maintenance
  – Often of a routine, not periodic, nature
  – Significant impact on an asset’s life-cycle cost
  – Rough approximations
    • Difficulty in acquiring data
    • Inconsistency (referencing and reporting periods)
Objectives

• Develop models to help agencies predict levels of **annual routine maintenance expenditure** using statistical and econometric techniques

• Types of models sought:
  – Annual maintenance expenditure (AMEX) and
  – Average annual maintenance expenditure (AveAMEX) models,

• Other study objectives:
  - Identify the segment-specific characteristics and operating features that significantly influence annual maintenance expenditures
  - Input for LCCA

  AMEX and AveAMEX models can be used by highway agencies in life-cycle cost analysis to help make investment decisions
Pavement Maintenance Taxonomy

Category by Function

Corrective
Minor Preventive
Moderate Preventive
Major Preventive

Category by Funding Source

Contract
Force Account

Category by Cycle Length

Routine Maintenance
Periodic Maintenance
Context of the Study: Life-cycle Cost Analysis

• Traditionally, LCCA practice/research considers:
  – Initial (re)construction actions
  – Rehabilitation actions
  – Major or periodic maintenance actions

• In-house or Routine maintenance?
  – Typically not included in LCCA
  – Problem: Difficulty of measurement; lack of data; assumed negligible; etc.

• What is desirable: to program not a specific treatment, but an annual amount of in-house maintenance
Typical Pavement Activity Profile

- **HMA (Full Depth)**
- **HMA Overlay (Prev. Mnt.)**
- **HMA Overlay (Structural)**

End of Service Life: 42
Typical Representation

HMA (Full Depth)

HMA Overlay (Prev. Mnt.)

HMA Overlay (Structural)

Crack Sealing

End of Service Life

0 3 6 9 12 15 18 21 24 27 30 33 36 39 42
ECONOMETRIC MODELS FOR PAVEMENT ROUTINE MAINTENANCE EXPENDITURE
We want a function instead of a constant.
Database
Database

- Developed Dataset (Indiana pavement segments)
  - 90% of the 11,300 centerline miles
- Acquisition of all data items are vital for model development.
- Data requirements:
  - location,
  - size,
  - surface type,
  - rehabilitation history,
  - traffic volumes,
  - functional classification,
  - climate, and
  - pavement condition
Database

• Challenges
  – Inconsistency in pavement section referencing system between databases
    • State mileposts
    • County mileposts
    • Descriptive start and endpoints
  – Inconsistency in reporting periods
    • Calendar year
    • Fiscal year
  – Merging Databases
Developing Segments for the Study
Developing Segments for the Study
Developing Segments for the Study

Interstate - 65

Asset

Mile Marker

S0019003-ML

2003 Rehab

Major Rehabilitation Activities

1996 Rehab

1999 Rehab

1989 Rehab

Study Segments

1 2 3 4

Year of Rehabilitation

1980 1990 2000 2010
Methodology
(Modeling Approaches)
Modeling

- Response Variable (In-house Maintenance Expenditure)
  - Annual Maintenance Expenditure (AMEX)
  - Average Annual Maintenance Expenditure (AveAMEX)
Modeling Approach

• The response variable is continuous, censored at zero, and does not have an upper bound

• Models investigated
  – Ordinary Least Squares
  – Tobit
  – 2 Stage Discrete/Continuous
  – Panel
Modeling Approach

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  Has been applied
  Has been discussed
  Has not been discussed
Modeling

- Historical Limitations with In-house Maintenance Expenditure Models:
  - OLS → Utilized a limited number of variables
  - Tobit → Mnt. Exp. = f(P.C.) and P.C. = f(load and non-load factors)

- Pavement Condition Will Not be Used as an Explanatory Variable in Any of the Discussed Models
Results
Model Results

1) Ordinary Least Squares
   - OLS with and without temporal effects

2) Tobit
   - Tobit with and without spatial effects

3) 2-Stage (Discrete/Continuous)
   - Discrete outcomes are not feasible (due to the disparity in outcome frequencies (Cramer, 1999)
   - Likelihood outcomes currently being investigated

4) Panel Models
   - One-way fixed effects
   - Two-way fixed effects
   - One-way random effects
   - Two-way random effects
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**AMEX OLS**  
\[ y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \epsilon_i \]

**Response Variable = sq. rt. [Annual Maintenance Expenditure (in 2007 dollars)]**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Without Temporal Effects</th>
<th>With Temporal Effects</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>14.46 (2.61)</td>
<td>11.43 (2.05)</td>
<td></td>
</tr>
<tr>
<td>Age of pavement segment (in years)</td>
<td>0.30 (4.47)</td>
<td>0.31 (4.65)</td>
<td>10.66</td>
</tr>
<tr>
<td>AADT for the pavement segment (in thousands of vehicles)</td>
<td>0.10 (2.54)</td>
<td>0.10 (2.54)</td>
<td>11.89</td>
</tr>
<tr>
<td>Number of Commercial Vehicles (in thousands per day)</td>
<td>1.09 (6.66)</td>
<td>1.10 (6.71)</td>
<td>2.17</td>
</tr>
<tr>
<td>Average Annual Precipitation (in years)</td>
<td>-0.54 (-4.19)</td>
<td>-0.54 (-4.19)</td>
<td>39.84</td>
</tr>
<tr>
<td>Urban arterial indicator (1 if road segment is an u. arterial, 0 otherwise)</td>
<td>5.93 (5.20)</td>
<td>5.93 (5.21)</td>
<td>0.18</td>
</tr>
<tr>
<td>Reconstructed road indicator (1 if most recent rehab. was recon., 0 ow)</td>
<td>3.43 (2.16)</td>
<td>3.34 (2.11)</td>
<td>0.08</td>
</tr>
<tr>
<td>New road indicator (1 if most recent rehab. was new constr.*, 0 ow)</td>
<td>-4.47 (-2.34)</td>
<td>-4.51 (-2.37)</td>
<td>0.05</td>
</tr>
<tr>
<td>Square Root of Length of pavement segment (in miles)</td>
<td>21.98 (41.00)</td>
<td>21.99 (41.08)</td>
<td>1.5</td>
</tr>
<tr>
<td>Number of lanes in the pavement segment (both directions)</td>
<td>1.29 (2.91)</td>
<td>1.28 (2.88)</td>
<td>2.99</td>
</tr>
<tr>
<td>2005 Indicator (1 if data is from 2005, 0 otherwise)</td>
<td>N/A</td>
<td>2.80 (2.76)</td>
<td>0.33</td>
</tr>
<tr>
<td>2006 Indicator (1 if data is from 2006, 0 otherwise)</td>
<td>N/A</td>
<td>5.81 (5.73)</td>
<td>0.33</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>10228</td>
<td>10228</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.157</td>
<td>0.160</td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.156</td>
<td>0.159</td>
<td></td>
</tr>
</tbody>
</table>

* new road construction includes; new road, new road pavement only, and added travel lanes
### AMEX Tobit

\[ Y_i^* = \beta x_i + \varepsilon_i \quad i = 1, 2, \ldots, N \]

\[ Y_i = 0 \quad \text{if } Y_i^* = 0 \]

\[ Y_i = Y_i^* \quad \text{if } Y_i^* > 0 \]

**Response Variable** = Annual Maintenance Expenditure (in 2007 dollars)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1496.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age of pavement segment (in years)</td>
<td>82.65</td>
<td>4.12</td>
<td>10.66</td>
</tr>
<tr>
<td>AADT for the pavement segment (in thousands of vehicles)</td>
<td>19.53</td>
<td>1.71</td>
<td>11.89</td>
</tr>
<tr>
<td>Number of Commercial Vehicles for the pavement segment (in thousands of vehicles)</td>
<td>265.99</td>
<td>5.61</td>
<td>2.17</td>
</tr>
<tr>
<td>Average Annual Precipitation (in inches)</td>
<td>-141.86</td>
<td>-3.69</td>
<td>39.84</td>
</tr>
<tr>
<td>Urban arterial indicator (1 if road segment is an urban arterial, 0 otherwise)</td>
<td>1226.43</td>
<td>3.62</td>
<td>0.18</td>
</tr>
<tr>
<td>Length of the segment (in miles)</td>
<td>1141.93</td>
<td>25.26</td>
<td>2.91</td>
</tr>
<tr>
<td>Reconstructed road indicator (1 if most recent rehab. was reconstruction, 0 otherwise)</td>
<td>981.32</td>
<td>2.114</td>
<td>0.08</td>
</tr>
<tr>
<td>Concrete indicator (1 if roadway is concrete, 0 otherwise)</td>
<td>-789.49</td>
<td>-1.71</td>
<td>0.09</td>
</tr>
</tbody>
</table>

- Number of Observations: 10228
- Log Likelihood Function: -84112
- Restricted Log Likelihood Function: -109024
- \( \rho^2 \): 0.229
**AMEX Tobit Marginal Effects**

**Response Variable** = *In-house pavement maintenance expenditure*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Marginal Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>802.27</td>
</tr>
<tr>
<td>Age of pavement segment (in years)</td>
<td>44.32</td>
</tr>
<tr>
<td>AADT for the pavement segment (in thousands of vehicles)</td>
<td>10.47</td>
</tr>
<tr>
<td>Number of Commercial Vehicles for the pavement segment (thousands)</td>
<td>142.63</td>
</tr>
<tr>
<td>Average Annual Precipitation (in inches)</td>
<td>-76.07</td>
</tr>
<tr>
<td>Urban arterial indicator (1 if road segment is an urban arterial, 0 otherwise)</td>
<td>657.64</td>
</tr>
<tr>
<td>Length of the segment (in miles)</td>
<td>612.33</td>
</tr>
<tr>
<td>Reconstructed road indicator (1 if most recent work was reconstruction, 0 otherwise)</td>
<td>529.43</td>
</tr>
<tr>
<td>Rigid indicator (1 if roadway is rigid, 0 otherwise)</td>
<td>-423.34</td>
</tr>
</tbody>
</table>
### AveAMEX OLS

**Response Variable = sq.rt. [Annual Maintenance Expenditure (in 2007 dollars)]**

<table>
<thead>
<tr>
<th>Variable</th>
<th>District Effects</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coeff. t-stat</td>
<td>Coeff. t-stat</td>
</tr>
<tr>
<td>Constant</td>
<td>26.44 -10.11 -1.57</td>
<td>-10.11 -1.57</td>
</tr>
<tr>
<td>Length of pavement segment (miles)</td>
<td>6.67 31.66</td>
<td>6.69 31.20</td>
</tr>
<tr>
<td>Age of pavement segment (years)</td>
<td>0.17 1.84</td>
<td>0.24 2.41</td>
</tr>
<tr>
<td>AADT for the pavement segment (thousands)</td>
<td>0.25 6.75</td>
<td>0.24 6.37</td>
</tr>
<tr>
<td>Percentage of commercial vehicles (from 0 to 100)</td>
<td>0.39 7.05</td>
<td>0.45 7.99</td>
</tr>
<tr>
<td>Rural indicator (1 if road segment is rural, 0 otherwise)</td>
<td>-3.54 -2.33</td>
<td>-5.21 -3.39</td>
</tr>
<tr>
<td>Number of wet days (number of days with precipitation)</td>
<td>-0.08 -1.32</td>
<td>0.23 4.53</td>
</tr>
<tr>
<td>Replacement indicator (1 if most recent work was pavement replacement, 0 otherwise)</td>
<td>-13.45 -1.88</td>
<td>-12.57 -1.72</td>
</tr>
<tr>
<td>New road indicator (1 if most recent work was new construction*, 0 otherwise)</td>
<td>-5.08 -2.74</td>
<td>-5.81 -2.09</td>
</tr>
<tr>
<td>Rigid pavement indicator (1 if segment is rigid pavement, 0 otherwise)</td>
<td>-1.84 -0.73</td>
<td>-3.74 -1.65</td>
</tr>
<tr>
<td>Crawfordsville Indicator (1 if segment is in Crawfordsville, 0 otherwise)</td>
<td>3.10 1.82</td>
<td></td>
</tr>
<tr>
<td>LaPorte Indicator (1 if pavement segment is in LaPorte, 0 otherwise)</td>
<td>12.30 7.72</td>
<td></td>
</tr>
<tr>
<td>Vincennes Indicator (1 if pavement segment is in Vincennes, 0 otherwise)</td>
<td>-12.34 2.00</td>
<td></td>
</tr>
</tbody>
</table>

| Number of Observations | 3384 | 3397 |
| R2                    | 0.272 | 0.246 |
| Adjusted R2           | 0.270 | 0.244 |

* new road construction includes; road, road pavement, and added travel lanes
Conclusions

• AMEX
  – OLS may suffer from too many zeros
  – Tobit model had intuitive results and good overall fit
  – 2 Stage discrete/continuous model was unreliable due to outcome frequencies
  – Panel Models useful to describe multi-dimensional variance in dataset. Not practical for application

• AveAMEX
  – Fewer zeros lead to better OLS model specification
  – Spatial effects (district boundaries) have high influence
Future Work

• There is a need to investigate:
  – Other modeling techniques (Random Parameters)
  – New variables in the database (subsurface characteristics)
  – Updated Maintenance Expenditures
  – Applications outside of Indiana
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Thank You

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