Regional LCA Tool Development and Applications

Pavement LCA Symposium 2017

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“Where Excellence and Transportation Meet”
Acknowledgments

- Illinois Tollway Authority
- Joep Meijer (theRightenvironment)
- At UIUC:
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  - Drainage team: Professor Jeremy Guest and Diana Byrne
- And Alejandro Salinas
Illinois Tollway LCA Tool

Development of a complete roadway/roadside LCA tool

- Pavement LCA
- Landscape LCA
- Drainage LCA
- Lighting LCA
- Structures LCA
- Roadway/Roadside LCA

Illinois Tollway Network
Tollway’s Sustainability Goals

- Communicate environmental performance of roadway/roadside elements built/maintained by Tollway to all stakeholders
- Monitor achievements by establishing a baseline
- Identify hot-spots and develop cost-effective strategies to achieve the sustainability goals
UIUC’s Goal and Approach

- Develop an easy-to-use and representative LCA tool to meet the needs of Illinois Tollway

UIUC’s approach to accomplish the goal:
- High quality and representative data
- Inclusiveness with roadway/roadside features
- Consistent with agency procurement practices
- Use stage modeling and integration
- Compatibility with ISO
System Boundaries

Material Production & Acquisition
- Recycled, co-product, waste material processing
- Plant operations
- Raw material production

Initial Construction
- Initial construction

Use
- Rolling resistance
- Albedo & carbonation
- Work Zone

Maintenance & Rehabilitation
- Maintenance activities
- Rehabilitation activities

End-of-Life
- Removal activities
- Landfilling

Out of Scope
- Transported

Reuse/recycle into new systems

Construction equipment
Inventory Analysis

- Compile data to best represent the region and time period of interest (Illinois, 1999-2014)
- Create models of major unit processes

Primary Sources

Secondary Sources

Unit Processes

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Inventory Data

- Total 591 materials are included in the inventory database
- 114 of these are related to pavements
- Primary data were sought for:
  - Aggregates
  - Asphalt binder
  - Cement and ready-mix concrete
  - Emulsions
  - Asphalt and concrete plant operations
- Secondary data for upstream processes
Use of Pay Items

- Use of pay items as the **basis unit** in all phases except the use stage
- **This facilitates** implementation of LCA using existing procurement framework
- Improves inventory data quality

**Pay Item**

- General Characteristics
- Materials
- Equipment
- Mix Designs
Importance of Pay Items

- Almost 2,000 pay items with 603 of them are related to pavements
- Including **top pay items (95% of cost)** capturing most impacts
Impact Assessment

- Four major metrics
  - Global Warming Potential (GWP)
  - Total Primary Energy (TPE)
  - Primary Energy as Fuel (PEF)
  - Single Score (SS)

- Other relevant metrics
  - Recycled Content (%)
  - Renewable Content (%)
  - Transportation Intensity (ton-mile)

Weighted and normalized TRACI impacts:
- Ozone depletion
- Smog
- Acidification
- Fossil fuel depletion
- Eutrophication
- Respiratory effects
- Non carcinogenics
- Carcinogenics
- Ecotoxicity
- Global warming
# Data Quality Assessment

| Time-Period       | • Data collected from 2012  
|                  | • Time-sensitive equipment and electricity databases |
| Geography        | • Northern Illinois region  
|                  | • Inventory models for electricity mix, asphalt binder, hauling trucks |
| Technology       | • Includes warm mix technology  
|                  | • Recent IDOT/Tollway standards |
| Representativeness | • Actual pay items, mixes, standards  
|                  | • Surveys to Tollway contractors/plants |
| Completeness     | • Use of pay items allows for supporting items (i.e., markings, signs, etc.) |
Use Stage Models

- Developed models for rolling resistance and included albedo and lighting in the use stage.

Pavement-tire interaction

Rolling Resistance

Rolling Direction

Electricity usage

Higher Albedo
Lower Albedo

Albedo

Use Phase

Lighting
Roughness-Speed-Impact Model

- An analytical standalone model was needed
- Impacts are based on vehicle type, speed, roughness
- RSI model can be easily integrated to any LCA software

Model Development Approach

Inputs
- Roughness
- Speed/Congestion
- Vehicle Efficiency

Methodology
- HDM-4 Model (Constant Speed)
- Vehicle Specific Power Model
- MOVES (Constant Roughness)

Model
- Roughness-Speed Impact (RSI) Model
- Energy Consumption and Emissions for Vehicle Miles Traveled
- Validation
RSI Model Verification

- Total fuel consumption according to the RSI model as a function of speed is in the range

![Graph showing fuel consumption as a function of speed for different models: ORNL, NCHRP (HDM-4), MOVES, RSI Model. The graph indicates that RSI Model shows higher fuel consumption compared to the others, with a peak around 50-60 MPH and a drop afterwards. The graph also highlights the differences between models, with RSI Model showing a more significant drop at higher speeds.](image-url)
RSI can report incremental impacts per change in IRI

Percent Change in Fuel Consumption for One unit Change in IRI (m/km), %

- Proposed RSI
- HDM4 (Chatti and Zaabar, 2012)
- MOVES (U.S. EPA, 2015)
- Taylor & Patten (2006)
- Sandberg (1990)
- Hammistrom (2008)
- Delanne (1994)
- Amos (2006)
- Heffernan (2006)
LCA Software

- MS Excel/VBA
- Follows life-cycle stages
- Modular design for consistency to allow for other roadway/roadside elements
- Pay items are used throughout to facilitate agency use
Life-Cycle Assessment Tool for the Illinois Tollway - Prototype Version (April 2016)

This life-cycle assessment (LCA) tool was developed for the Illinois State Toll Highway Authority to calculate life-cycle environmental impacts for various roadway/roadside components on the Tollway road network. These components include Drainage, Landscaping, Lighting, Pavements, and Structures. One of these components will be loaded as module into the tool. The tool was developed using graphical interfaces, so the user will only engage with interactive controls on the spreadsheet - no direct input will be allowed on the spreadsheet.

The following life-cycle stages can be toggled off or on by clicking on the corresponding buttons.

*Note: the life-cycle stages are chronologically interdependent, so making changes in any stage will require the user to re-confirm all relevant subsequent stages.
Mix Level and Pay Items Analysis
Project Level LCA and Interpretation
14 Case Study Projects

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range of Values in Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1999 – 2013</td>
</tr>
<tr>
<td>Pavement type</td>
<td>12” JPCP, 12” CRCP, 12 – 15” HMA, 11.25” JPCP composite, HMA overlays</td>
</tr>
<tr>
<td>Project type</td>
<td>Widening, reconstruction, resurfacing, new construction, new ramp construction</td>
</tr>
<tr>
<td>Traffic level</td>
<td>20,000 to 70,000</td>
</tr>
<tr>
<td>% Truck</td>
<td>7% – 29%</td>
</tr>
<tr>
<td>Cost</td>
<td>$6.7M – $50M</td>
</tr>
<tr>
<td>Length</td>
<td>1.5 mi – 12.8 mi</td>
</tr>
<tr>
<td>Analysis Period</td>
<td>44 – 78 yrs</td>
</tr>
</tbody>
</table>
Key Assumptions

- Tollway LCA software is capable of performing **comparative analysis** between projects and modules
- **Unique attributes** in projects make it challenging to draw comparisons or trends
- Reports results based on **total project impacts** as well as the **functional unit chosen as vehicle-miles-travelled**
  - More on Thursday presentation…
Summary of Projects - GWP

PCC Recons.  HMA Recons.  New  Reh*

*Rehabilitation/Resurfacing
A Bit of Nostalgia!!!

- Let’s check where we are at since 2009!

Impact Ranges Based on Actual Data

- Material and construction stages are not always as small as we think (~5-50%)
- Roughness and work zone are the largest contributors
- Large variations in all impacts from projects to projects
# Case Study – Low Volume

<table>
<thead>
<tr>
<th>Project Year &amp; Cost</th>
<th>2013-2014 &amp; $29.5 million ($4.9 million for pavement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>New JPCP Ramp I-57</td>
</tr>
<tr>
<td>Analysis Period</td>
<td>62 years</td>
</tr>
<tr>
<td>Length/Lanes</td>
<td>1.2 mi</td>
</tr>
<tr>
<td>Traffic</td>
<td>4,100 ADT with 22.1 % truck (2013)</td>
</tr>
</tbody>
</table>

![Graph showing contributions to SS, GWP, TPE, and PEF]
Use Stage Breakdown

- Roughness governs the use stage impact

No work zone closures due to new construction
Case Study – High Volume

<table>
<thead>
<tr>
<th>Project Year &amp; Cost</th>
<th>2004-2006 &amp; $36.7 million ($31 million for pavement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Widening with CRCP</td>
</tr>
<tr>
<td>Analysis Period</td>
<td>78 years</td>
</tr>
<tr>
<td>Length/Lanes</td>
<td>4.6 mi</td>
</tr>
<tr>
<td>Traffic</td>
<td>70,000 ADT with 7.6 % truck (2006)</td>
</tr>
</tbody>
</table>

![Chart showing contributions to SS, GWP, TPE, PEF with EOL, Use, M&R, M&C]
Use Stage Breakdown

- Work zone and roughness may be competing with each other
Final Remarks

- A ready-to-use tool was developed for an agency use
- Required data quality can be achieved using inventory modeling
- Completeness of an LCA analysis is critical to report most accurate impacts (importance of pay items)
Final Remarks

- Materials and construction stages can be as important as use stage for low volume roads.
- Roughness impact should be captured with proper models and traffic volume/composition.
- Work zone contribution to LCA may not be ignored; especially for high volume roads.
Thank you for your time!
Sensitivity: Cut-off Criteria

- Including **top pay items** capturing most impacts
- Considering only top 70% vs. 95% pay items omits 2-3% life-cycle impacts (7-12% of M&C)

![Diagram](image)

- **PCC Recon**
- **New PCC**
- **HMA Recon**
- **HMA Resurf**

**Impact**

- **Lower impact items**
- **Higher impact items**

**Cost**

- **High cost items**
- **Low cost items**
Sensitivity Analysis

- Systematic evaluation of the effect of methodological choices on life-cycle impacts

<table>
<thead>
<tr>
<th>Issue</th>
<th>Effect on Life-Cycle (LC)</th>
<th>Individual LC Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>M&amp;C cut-off criteria</td>
<td>2 – 3%</td>
<td>7 – 12%</td>
</tr>
<tr>
<td>Substitution allocation for EOL</td>
<td>small</td>
<td>39 – 76%</td>
</tr>
<tr>
<td>M&amp;C round trip hauling</td>
<td>--</td>
<td>10%</td>
</tr>
<tr>
<td>Random traffic growth</td>
<td>+/- 20% STDEV</td>
<td>--</td>
</tr>
<tr>
<td>Impact assessment</td>
<td>35%</td>
<td>--</td>
</tr>
</tbody>
</table>
## Sensitivity Analysis

- **Systematic evaluation of the effect of important parameters on life-cycle impacts**

<table>
<thead>
<tr>
<th>Issue</th>
<th>Effect on Life-Cycle</th>
<th>Excluding Use-Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder allocation</td>
<td>0.8 – 2%</td>
<td>2 – 8%</td>
</tr>
<tr>
<td>Progressive material LCI</td>
<td>small</td>
<td>2 – 6%</td>
</tr>
<tr>
<td>Progressive equipment LCI</td>
<td>small</td>
<td>0 – 3.4% REP*</td>
</tr>
<tr>
<td>Improved technology</td>
<td>50%</td>
<td>--</td>
</tr>
</tbody>
</table>

*Respiratory Effects*

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Mix Level and Pay Items Analysis
Contribution of Energy Items

Energy (MJ/SQ YD)

Percentage Energy Contribution

- Paved Shoulder Rem.
- Granular Embank.
- Pavement Rem.
- WMA Subbase 3"
- HMA Shoulders 6"
- WMA Shoulders 9"
- FDHMA 12"
- FDHMA 15"

Pay Items: Project-Level* View

- Cost-environment relationship for pay items
- Potential tradeoffs to optimize multi-objectives

*Composite PCC reconstruction project