How Built Environment Affects Travel Behavior

A Comparative Analysis of the Connections between Land Use and Vehicle Miles Traveled in U.S. Cities

Lei Zhang¹, Jin Hyun Hong², Arefeh Nasri¹, Qing Shen²

1. Department of Civil and Environmental Engineering
   University of Maryland

2. Department of Urban Design and Planning
   University of Washington
Acknowledgement

Data Sources

- Federal Highway Administration
- More than 15 Metropolitan Planning Organizations and State Departments of Transportation across the U.S.

Sponsors*

- Federal Highway Administration
- U.S. Department of Transportation University Transportation Center Program: CITSM at UMD

* Views herein do not necessarily represent agency views. The authors are responsible for all statements.
The LU-VMT Project

General Research Question

- What is the impact of land use policies (e.g. high density, compact, mixed, and transit-oriented development; neighborhood/street design innovations) on travel behavior, vehicle miles traveled (VMT), energy consumption, and emissions?

Background

- Mixed findings reported in previous research often based on inconsistent methods
- Most studies focus on a single metropolitan area
- Not clear why the estimated impact of built environment on VMT varies across urban areas
- Decision-makers need quantitative decision-support tool
Research Objectives

- Consider land use in long-term VMT forecasting

- Develop models with consistent specifications and datasets to compare the effects of built-environment factors on VMT in various U.S. urban areas

- Identify factors that explain the variation of the impact of built environment on VMT

- Provide a decision support tool for government agencies to quantify the impact of proposed land use changes and smart growth developments
Case Study Areas

Completed

- Washington, DC; Seattle, WA; Baltimore, MD; Richmond, VA; and Virginia Beach-Norfolk, VA.

Ongoing

- Chicago, IL; Phoenix, AZ; Philadelphia, PA; Minneapolis-St. Paul, MN; Atlanta, GA; San Francisco, CA; New York, NY; Buffalo, NY

Planned

- ~10 additional urban areas of various sizes in the U.S./Canada
Data Sources

Travel Behavior and VMT

- National and local household travel surveys
- Highway performance monitoring system

Land Use and Smart Growth

- Population and employment data
- Other socio-economic and demographic data
- Defined smart growth projects/areas

Street Networks and Distance Measures

- TIGER network and MPO/DOT networks
- Location information of urban centers and transit stops
Emerging Data Sources

Data Collection based on Innovative Technologies

- Web-based revealed and stated preference surveys
- Computer-aided interactive surveys/experiments
- GPS-based travel behavior and location surveys
- Smart-phones with GPS tracking applications
Defining Built Environment Factors

Density
- Residential density
- Five categories of employment density: commercial, industrial, office, government and others

Mixed Development
- Entropy
- $0$ for single-type land use; $1$ for perfectly mixed land use

Compact Development
- Distance to downtown and city centers

Transit-Oriented Development
- Distance to nearest transit stops
- Average block size
Consistent Urban Form Index (UFI)

A Comprehensive Measure of Smart Growth

- Conduct principal component analysis, and derive a single density factor representing density information for the six categories.

- Standardize the four built environment factors: density factor, entropy, average block size and distance to center.

- Urban Form Index = Standardized Density Factor + Entropy – Average block size – Distance to Center

- Higher UFI values imply more efficient land use patterns from smart growth point of view.
Methodology

Issues

- Causality (self-selection)
- Spatial autocorrelation
- Inter-trip dependency (tour and trip-chaining)
- Geographic units of analysis

Methods Employed in this Research

- Multilevel Bayesian model with control for travel attitude
- Structural equation model with control for self-selection and spatial autocorrelation
- Comparison among metropolitan areas that have different land use characteristics and policies using the same analytical approach
Bayesian Model Overview

Specification

\[ y_i \sim N(\alpha_{j[i]} + \beta_{SES} X_{iSES}, \sigma_y^2), \text{ for } i = 1, \ldots, n \]
Where:
\[ \alpha_j \sim N(\gamma + \gamma_{BE} X_{jBE}, \sigma_\alpha^2), \text{ for } j = 1, \ldots, J \]

Priori Distributions

- Non-informative prior for beta and gamma
- Uniform prior for variances

Posterior Distributions

\[
P(\alpha, \beta_{SES}, \gamma_{BE}, \sigma_y, \sigma_\alpha | y, X_{SES}, X_{BE}) \propto \prod_{j=1}^{J} \prod_{i=1}^{n_j} N(y_{ij} | \alpha_j + \beta_{SES} X_{ijSES}, \sigma_y^2) \prod_{j=1}^{J} N(\alpha_j | \gamma + \gamma_{BE} X_{jBE}, \sigma_\alpha^2)
\]
Structural Equation Model Overview
## Impact of Land Use on VMT/Person

<table>
<thead>
<tr>
<th>Land Use Variables</th>
<th>Seattle</th>
<th>Baltimore</th>
<th>DC</th>
<th>Virginia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential density</td>
<td>-0.308</td>
<td>-0.344</td>
<td>-0.444</td>
<td>-0.262</td>
</tr>
<tr>
<td>Employment density</td>
<td>-0.071</td>
<td>-0.085</td>
<td>-0.010</td>
<td>0.034</td>
</tr>
<tr>
<td>Mixed development</td>
<td>-0.149</td>
<td>-0.074</td>
<td>-0.195</td>
<td>-0.003</td>
</tr>
<tr>
<td>Average block size</td>
<td>0.153</td>
<td>0.089</td>
<td>0.021</td>
<td>0.220</td>
</tr>
<tr>
<td>Distance from CBD</td>
<td>0.331</td>
<td>0.264</td>
<td>0.456</td>
<td>-0.043</td>
</tr>
<tr>
<td>Distance to transit</td>
<td>0.036</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

Person-level socio-demographic variables not shown.
This table shows the percentage changes in VMT per person in response to one-standard-deviation increase of build-environment variable values from their respective sample means in different urban areas. For instance, the mean residential density in Seattle is 4,017 persons/sq-mile (numbers in red font). If the residential density in an average Seattle neighborhood is increased by 109%, we can expect the VMT/person to decrease in that neighborhood by 14.3%.
Proposed smart growth plan (20% increase in residential density and 20% improved mixed development) would lead to 7% reduction in VMT/person (1% + 6%) in a DC neighborhood with 3,000 persons/sqm existing residential density and 0.65 current index of mixed development.
Impact of Self Selection

% of VMT Reduction Explained by Land Use Changes
(The rest is explained by self-selection)
Conclusions

- Various land use policies can be effective in reducing VMT and consequently congestion, energy consumption, and emissions.

- The effectiveness of these policies varies greatly across urban areas, and within the same urban area.

- Policy effectiveness depends on the type and amount of land use change, existing built environment status, transit service, urban area size, and possibly land use decision-making process.
Future Research

- Additional case study areas (25~30 urban areas)
- Model-based meta-analysis revealing why the travel impact of built environment factors varies across different urban areas and within the same urban area
- Decision support tool that helps government agencies evaluate the effectiveness of proposed smart growth and other land use plans/policies, covering major regions/cities in the U.S.
Thank You!

Questions, Comments, and Suggestions are Welcome. Please Contact:

Lei Zhang
Ph.D., Assistant Professor
Department of Civil and Environmental Engineering
1173 Glenn Martin Hall, University of Maryland
College Park, MD 20742
Email: lei@umd.edu
Phone: 301-405-2881
Web: http://www.lei.umd.edu