Impact of Metropolitan-level Built Environment on Travel Behavior

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Abstract

There has been a growing recognition about the significant impact of land use pattern on travel behavior and changes in built environment pattern could potentially be considered as a long-term solution to change people’s travel behavior and especially vehicle miles traveled (VMT). However, the existing literature has been mainly focused on local and neighborhood characteristics of the built environment and little is known about the unique or relative influence of the metropolitan-level built environment. In this empirical analysis we use an extensive database for six major metropolitan areas in the U.S to employ multilevel mixed effect model highlighting the impact of built environment characteristics on travel behavior at different scales.

Our findings show that changes in built environment measures not only at local and neighborhood levels but also at larger metropolitan/ regional levels could be very influential in changing people’s travel behavior. Specifically, promoting compact, mixed-use built environment with well-connected street network can help to reduce VMT and thus provide better solutions to transportation-related issues.

Key words: Built environment, Metropolitan level land use, Travel behavior, Vehicle miles traveled (VMT), Multilevel model, Mixed effect.

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1. Introduction

The linkage between built environment and travel behavior has been intensively studied since the 1980s and a lot of mixed findings have been published. Recent research suggests that people living in neighborhoods with pedestrian-oriented design, characterized by high street connectivity, mixed land use, and high population density, are encouraged to drive less. However, the existing research has mainly focused on built environment at local and neighborhood levels rather than at regional and higher levels.
The rapid process of urbanization in the U.S. is identified as a leading factor to increased automobile-based mobility (Berube, 2007; Ross, 2009). As a consequence of the increased mobility, individuals or households would no longer be restricted into opportunities located in their own residential neighborhoods and are more likely to travel to further destinations. Thus the physical form of metropolitan areas including their land use pattern, size, population, employment, and transportation infrastructure pattern could potentially have a significant impact on economic activities, housing, transportation, etc. Some empirical research suggests that metropolitan structure such as degree of concentration, decentralization, regional sub-centers, and job-housing balance could be more influential in travel than the typical neighborhood level built environment features (Newman and Kenworthy, 1999; Horner 2002; Shen 2000; Yang 2008; Yang and Ferreira 2008).

Given the lack of empirical research on the connection between travel behavior and metropolitan-scale built environment, this paper attempts to examine the statistical association between the two using multilevel mixed effect regression models.

2. Data and Model Specification

This project uses data for six metropolitan areas in the United States including Washington DC; Baltimore, MD; Seattle, WA; Atlanta, GA; Richmond-Petersburg, VA; and Norfolk-Virginia Beach, VA. For each metropolitan area, household travel information and the most recent land use data for the entire metro area obtained from various local MPOs, regional transportation planning agencies, and States DOTs has been used.

There are five built-environment factors at neighborhood level used in our model, including residential and employment densities, mixed use development (entropy), average block size, and distance to the city center. Our built environment measures at the neighborhood level have been directly taken from the analysis of Zhang, et al. 2011. The density variables are calculated by dividing the residential/employment population by the area size (acre) of each TAZ or census tract. Distance to the city center is simply the straight line from CBD and entropy is calculated using the following formula ranging from 0 to 1:

\[
\text{Entropy} = \sum_j \frac{P_j e^{\ln(P_j)}}{ln(J)}
\]

Where \( P_j \) is the proportion of land use in the \( j \)th use category and \( J \) is the number of different land use type classes in the area.

The factors we constituted to measure metropolitan level built environment capture residential and employment density, strength of city centers, and street network accessibility and connectivity. To measure each of these factors, we defined variables such as average population
and employment densities for each county in the metropolitan area, proportion of population living within 5 miles from CBD, and proportion of employment locating within 5 miles from CBD, average block size for each county in the metropolitan area, and average entropy (mixed use) also at the county level.

The dependent variable –VMT- is measured also by using the same method as Zhang et al. 2011 and calculated the weighted distance by dividing total travel distance for each reported trip by the number of people in the vehicle used for the trip. Table 1 shows the descriptive statistics for the households in each of the study area.

<table>
<thead>
<tr>
<th>Metropolitan Area</th>
<th>Sample Size</th>
<th>Atlanta</th>
<th>Baltimore</th>
<th>Norfolk- &amp; Richmond</th>
<th>Seattle</th>
<th>Washington</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Size</td>
<td>2079</td>
<td>3991</td>
<td>4352</td>
<td>3945</td>
<td>8537</td>
<td></td>
</tr>
<tr>
<td>Household Size</td>
<td>Mean 2.28</td>
<td>2.29</td>
<td>2.49</td>
<td>2.26</td>
<td>2.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std. Dev. 1.18</td>
<td>1.22</td>
<td>1.21</td>
<td>1.22</td>
<td>1.22</td>
<td></td>
</tr>
<tr>
<td>Number of Workers</td>
<td>Mean 1.12</td>
<td>1.24</td>
<td>1.11</td>
<td>1.17</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std. Dev. 0.73</td>
<td>0.87</td>
<td>0.89</td>
<td>0.84</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>Number of vehicles</td>
<td>Mean 1.91</td>
<td>1.89</td>
<td>2.32</td>
<td>1.92</td>
<td>1.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std. Dev. 0.93</td>
<td>1.04</td>
<td>1.13</td>
<td>1.04</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>Household Income</td>
<td>Mean $50,000-$59,999</td>
<td>$60,000-$74,999</td>
<td>$60,000-$64,999</td>
<td>$70,000</td>
<td>$75,000-$99,999</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std. Dev. -</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Summary Statistics of Built Environment Measures

<table>
<thead>
<tr>
<th>Metropolitan Area</th>
<th>Atlanta</th>
<th>Baltimore</th>
<th>Norfolk- &amp; Richmond</th>
<th>Seattle</th>
<th>Washington</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Std. Dev.</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>Population density</td>
<td>4.37</td>
<td>2.47</td>
<td>8.83</td>
<td>9.32</td>
<td>3.14</td>
</tr>
<tr>
<td>Employment density</td>
<td>2.26</td>
<td>2.47</td>
<td>4.72</td>
<td>17.22</td>
<td>1.25</td>
</tr>
<tr>
<td>Entropy</td>
<td>0.71</td>
<td>0.24</td>
<td>0.47</td>
<td>0.21</td>
<td>0.60</td>
</tr>
<tr>
<td>Average block size</td>
<td>0.087</td>
<td>0.082</td>
<td>0.097</td>
<td>0.145</td>
<td>0.143</td>
</tr>
<tr>
<td>Distance to CBD</td>
<td>14.53</td>
<td>7.73</td>
<td>13.18</td>
<td>8.75</td>
<td>18.15</td>
</tr>
</tbody>
</table>
Table 2 reports means and standard deviations of the TAZ and census tract–level variables for all the cases represented in this study. These statistics indicated considerable variation in neighborhood characteristics.

The mixed model is well suited for our analysis as on the one hand, there are households of the same category (i.e., live in the same TAZ or census tract), but on the other hand, they have different characteristics (i.e., different socioeconomic status). The mixed effect model allows us to have different coefficients by subject groups. Subjects in the same level/group are likely to be similar to each other in terms of their observable characteristics. Consequently, there are two sources of variation: variation between different TAZs or census tracts (inter-subject variance) and variation within a particular TAZ or census tract (intra-subject variance).

The mixed model can be represented as:

\[ y = X\beta + Zu + \varepsilon \]

Where:

- \( y \) is a vector of observations, with mean \( E(y) = X\beta \)
- \( \beta \) is a vector of fixed effects
- \( u \) is a vector of independent identically-distributed random effects with mean \( E(u) = 0 \) and variance-covariance matrix \( \text{var}(u) = G \)
- \( \varepsilon \) is a vector of random error terms with mean \( E(\varepsilon) = 0 \) and variance \( \text{var}(\varepsilon) = R \)
- \( X \) and \( Z \) are matrices of regressors relating the observations \( y \) to \( \beta \) and \( u \)

3. Results

The results from the multilevel mixed-effect model show a strong association between VMT and built environment characteristics at both neighborhood and metropolitan levels. Table 3 attempts to summarize the empirical evidence for all six metropolitan areas included in our model which was discussed earlier in more details. The table is divided into three main categories: Households’ socio-economic variables impacts, neighborhood-level land use factors impacts, and metropolitan-level built environment impacts.

We controlled for the potential effects of socioeconomic status using households’ size, annual income, number of workers, and vehicle ownership in the model. The results show that except household size, other socio-demographic variables proved to be significantly influencing VMT with a positive direction, though the impacts of number of workers and car ownership are much more considerable compared to households’ annual income. It is reasonable as larger households with higher income tend to have more cars and thus drive more.
As it is shown in Table 3, all land use variables at the neighborhood and local level have negative relationship with VMT except the distance from CBD, which is positively linked to VMT. This result is consistent with the previous studies as well.

The results of the model at neighborhood level show that people living in areas with compact development pattern, higher employment opportunities, and better mixed neighborhoods tend to drive less. Distance to central business district has a negative association with VMT meaning people living farther from CBD have to drive more to reach various destinations. The average block size as a measure of street network connectivity has a positive significant relationship with households’ VMT also because with lower block size - higher street connectivity- distance to various types of destinations would be lower and as a result people drive less to reach those destinations.

At the metropolitan level, the influence of built environment measures is much lower than that at the neighborhood level in terms of magnitude, though the directions of the relationship are the same. However, the impact of metropolitan-level average entropy seems to be much higher than
that of local level which is not statistically significant either. These results claim that the metropolitan-level population and employment density could also be very influential on driving behavior of the households in addition to these factors at the neighborhood and local level. Average entropy seems to be the most important land use factor at the metropolitan level, which is correlated to households’ VMT. Better mixed used development through the whole metropolitan area influences VMT and driving behavior of the residents.

Furthermore, the proportion of population and employment locating in the 5-mile buffer zone of the downtown area is a significant factor in predicting driving behavior and households’ VMT. This measure of metropolitan built environment could be interpreted as an indicator of strength of city centers as downtowns with higher population and employment concentrated within the five-mile buffer zone are considered stronger and could potentially influence the driving behavior of the people living the whole metropolitan area. This impact is larger in terms of magnitude compared to the average population and employment densities which confirms the significant role of city centers in the metropolitan areas.

These results clearly confirm the previous findings saying that people living in more compact/mixed-development neighborhoods with higher street connectivity tend to drive less. However, providing additional case study areas is needed in order to assess a better and more reliable model on the potential impacts of metropolitan level built environment on travel behavior and VMT.

4. Conclusion

The relationships found between local and metropolitan-level built environment and VMT show that transportation-related problems would be much less in better mixed areas with higher population density, better street connectivity and less sprawl even when controlling for income, household size, and other households socioeconomic characteristics. While these findings may seem obvious, this is one of the first studies to explicitly measure metropolitan-level built environment and relate it to household’s VMT. Thus, looking at not only the land use characteristics of the immediate neighborhoods of residence in the analysis, but also considering the position of the neighborhoods in the large metro areas has been the main contribution of this analysis.

Our findings clearly show that measures of urban form have a significant association with VMT among households of all studied metropolitan areas, adjusting for households’ socio-demographic characteristics. Households living in neighborhoods with higher population and employment densities, better mixed land development, and closer to city centers tend to drive significantly lower.
As a next step, we are expanding this analysis by adding about 15 more case study areas across the country and also improving our model by adding a measure of transit accessibility in the neighborhoods of study. This makes our model even more comprehensive and thus can help policy and decision-makers to evaluate land use plans and policies according to their impact on vehicle miles traveled.

References:


McCann, B. A., and Ewing, R., Measuring the Health Effects of Sprawl; A National Analysis of Physical Activity, Obesity and Chronic Disease, 2003
