Impacts of Network Connectivity on Passenger Vehicle Use and Greenhouse Gas Emissions

Technical Background Document

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Study Selection

No studies were identified that directly test the effect of a change in network connectivity on vehicle miles traveled (VMT) or greenhouse gas (GHG) emissions, though network connectivity has been considered in several studies that examine the association between the built environment and travel behavior. Connectivity in these cases is measured for residential neighborhoods, from the perspective of households, but not for areas around transit stations or trip destinations. Measuring the impact of connectivity on VMT and GHGs, while controlling for socio-demographic characteristics (e.g. income, household size), population density, and land-use mix, is challenging.

The key criterion for including studies in the policy brief was reporting of the effects of network connectivity on VMT and GHG emissions while controlling for socio-demographic characteristics and built environment characteristics. Additional considerations included U.S. location for the data (though studies in other developed countries were also considered), published since 1990, and data collected from a sample of residents of both areas with transit supply and areas without it. There are no available studies that provide direct evidence on the effect of connectivity on GHG emissions.

Studies meeting the criteria were Boarnet et al. (2004), Bento et al. (2003), Cervero and Kockelman (1997), Chapman and Frank (2004), Zhang et al. (2013), Khan et al. (2013), and the meta-analysis study by Ewing and Cervero (2010). Fan and Khattak (2008) reports person miles of travel (PMT) rather than VMT, but was included because of its U.S. location and because it is the only study to control for attitudes, in this case meaning one's beliefs about and feelings towards transportation. Hedel and Vance (2007) was also considered but excluded since it focuses on a non-U.S. location and does not report an average value of VMT that would enable calculation of the change in VMT associated with an increase in connectivity (though an elasticity for this study is reported in Ewing and Cervero (2010)). Specific measures used in each study and important considerations with respect to these measures are noted in Table 1.

Table 1: Network Connectivity and VMT or PMT

Study	Connectivity Measures	Travel Behavior Measures	Elasticity	Notes
Cervero and Kockelman, 1997	Proportion of neighborhood blocks that are quadrilaterals (i.e. 4 straight sides, square or rectangle), based on randomly sampling 20 blocks per sampled neighborhood	Personal VMT per household (VMT per household divided by vehicle occupancy), from 1990 Bay Area Travel Survey (BATS) - For all trips - For non-work trips	Reported in Table 14 in cited paper: 0.185 0.463	Uses ordinary least-squares regression
	Proportion of intersections that are four-way (e.g. not T or Y intersections)	- For all trips - For non-work trips	No effect -0.592	
Bento et al., 2003	Road density (lane miles per square mile); area over which connectivity is measured is not specified	VMT per person, from Nationwide Personal Transportation Survey	-0.07 Reported in Table 10 in cited paper, for total impact excluding New York City, as 0.7% increase in VMT for 10% increase in road density	Based on sample that excludes New York City. Uses a two-step model: multinomial logit model for the number of cars per household and a set of ordinary least-squares regression model for VMT per vehicle, with separate models for each category of car ownership (e.g. 1, 2, or 3 or more vehicles per household)
Boarnet et al., 2004	Number of 4-way intersections within a mile of the household	VMT for non-work purposes only, from the 1994 Portland Travel diary survey	-0.06 Reported in Table A-3 in Ewing and Cervero (2010)	Uses ordinary least squares regression
	Number of intersections within 1 mile buffer		-0.19 Reported in Table A-3 in Ewing and Cervero (2010)	

Study	Connectivity Measures	Travel Behavior Measures	Elasticity	Notes
Chapman and Frank, 2004	Number of intersections with three or more road approaches intersecting within 1 km road network-based buffer around each home	VMT per person, from the 2001-2002 Atlanta Region travel survey	-0.08 Calculated based on regression coefficient (β) (see Table 114 in cited paper), average intersection density (x_o) and average VMT (y_o) (see Table 113 in cited paper): β=-0.06405 x_o=33.893 y_o=28.236 elasticity = $\beta * x_o / y_o$ = -0.0769	Uses ordinary least squares regression
Hedel and Vance, 2007	Street density measured as kilometers of street links per square kilometer	Person kilometers of travel; from the German mobility panel, collected between 1996 and 2003	-0.04 Reported in Table A-3 in Ewing and Cervero (2010)	Study reports coefficients from VMT models, but not average VMT needed to calculate percent reduction in VMT associated with increases in connectivity
Fan and Khattak, 2008	Percent of intersections in the household's neighborhood that are not dead ends; dead ends are counted as intersections	Person miles of travel (daily travel distance by all modes) from the 2006 Greater Triangle Travel Study	-0.26 Calculated based on log-linear regression coefficient (β) (see Table 2 in cited paper) and average intersection density (x_o) (see Table 1 in cited paper): β=-0.389 x_o=0.665 elasticity = $\beta * x_o$ = -0.2587	Survey included only workdays and therefore over-represents commute travel. Uses ordinary least squares regression

Study	Connectivity Measures	Travel Behavior Measures	Elasticity	Notes
Ewing and Cervero, 2010	Percent 3- or 4-way intersections	Studies analyzed reported VMT per person or per household, for total VMT, commute VMT, or non-commute VMT	-0.12 Reported in Table 3 in cited paper.	Meta-analysis of 9 studies, all using different measures of connectivity and VMT; individual elasticities weighted by sample size and averaged
	Intersection (number per area) or street density (street length per area)		-0.12 Reported in Table 3 in cited paper.	
Zhang et al., 2012	Average block size (the larger the block, the lower the street connectivity)	VMT per person, for all purposes	Computed from the ratio of the percentage change in VMT divided by the percentage change in average block size by metropolitan area: Seattle: 0.0454 Virginia: 0.1029 Baltimore: 0.0303 Washington: 0.0048 Note: Increase in block size equates to decrease in connectivity, which results in an increase in VMT	Uses a Bayesian multilevel model to estimate the effects of average block size and other variables in each metropolitan area
Khan et al., 2013	Number of 3-way intersections within ½ mile of the household	VMT per household, for all purposes	-0.0886 Calculated based on marginal effects reported in Table 6 and values of mean and standard deviation of the independent variables in Table 1 in cited paper	Uses Tobit model to predict VMT and non-motorized miles traveled, using data from the Puget Sound Regional Council 2006 Household Travel survey

Study	Connectivity Measures	Travel Behavior Measures	Elasticity	Notes
	Number of 4-way intersections within ½ mile of the household		-0.0306	

Effect Size, Methodology and Applicability Issues

In applying the estimated effects, several methodological limitations should be considered.

First, every study uses a different measure of connectivity. Little work has been done to compare different measures or to assess their ability to distinguish different types of networks. Thus, it is not possible to favor one study over another based on the connectivity measure it uses. In addition, the effect of connectivity on VMT likely depends on connectivity to destinations, rather than connectivity in and of itself. The studies do not all control for land use patterns in the same way. Because the studies use different connectivity variables and do not control for the same factors, it is not possible to determine whether the differences in the estimated effects accurately reflect the range of effects under different conditions or simply reflect the differences in the connectivity variables and the control variables.

Second, all of the studies base their measures of network connectivity on the street network only. Pedestrian/bicycle network connectivity can be significantly different than street network connectivity in some places, depending on connections and barriers that affect pedestrians and bicyclists only (Tal and Handy, 2012). In places where connectivity has a significant effect on walking and bicycling, the use of a street network connectivity measure could under-represent the importance of connectivity for VMT.

Third, most of the cited studies focus on street connectivity in residential areas. However, connectivity around destinations is also likely to be important. For example, increased connectivity around transit stations at the destination-end of a trip could put more destinations within walking distance of the station and increase the feasibility of using transit. As another example, connectivity around worksites could reduce VMT during the work day by making it easier for workers to walk to restaurants and other services on their lunch hours. Incorporating destination connectivity into analyses of VMT is not straightforward, as most people visit multiple destinations each day. Chapman and Frank (2004) measured destination connectivity, as well as residential connectivity, and included this measure in mode choice models (as a component of a “destination walkability” variable), but not VMT models.

Finally, the studies all use cross-sectional designs that compare VMT for neighborhoods with different connectivity at one point in time, rather than longitudinal designs that measure changes in VMT in response to changes in connectivity within a neighborhood.

Cross-sectional designs leave open the possibility that the observed effects are partly attributable to the "self-selection" of residents who prefer to drive less into neighborhoods with higher connectivity. By controlling for attitudes, the study by Fan and Khattak (2008) at least partially controls for self-selection.

References

Bento, A.M., Cropper, M.L., Mobarak, A.M., & Vinha, K. (2003) The impact of urban spatial structure on travel demand in the United States. World Bank policy research working paper, 3007.

Boarnet, M. G., Nesamani, K. S., & Smith, C. S. (2004). *Comparing the influence of land use on nonwork trip generation and vehicle distance traveled: An analysis using travel diary data.* UCI-ITS-AS-WP-03-1, Institute of Transportation Studies, University of California, Irvine. Available: http://www.its.uci.edu/its/publications/papers/CASA/UCI-ITS-AS-WP-03-1.pdf

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: density, diversity, and design. *Transportation Research D*, *2*(3), 199-219

Chapman J. and Frank, L. (2004). *Integrating Travel Behavior and Urban Form Data to Address Transportation and Air Quality Problems in Atlanta*. SMARTRAQ full final technical report, Georgia Tech Research Institute, Atlanta, GA. Available: http://www.act-trans.ubc.ca/smartraq/files/GDOT_final_report.pdf

Ewing, R. and Cervero, R. (2010) Travel and the Built Environment: A Meta-Analysis. *Journal of American Planning Association*, 76(3): 265-294.

Fan, Y. and Khattak, A.J. (2008). Urban Form, Individual Spatial Footprints, and Travel: Examination of Space-Use Behavior. *Transportation Research Record,* 2082: 98–106.

Hedel, R., and Vance, C. (2007). *Impact of urban form on automobile travel: Disentangling causation from correlation*. Paper presented at the 86th annual meeting of the Transportation Research Board, Washington, DC.

Khan, M., K. M. Kockelman and X. Xiong (2013). Models for Anticipating Non-motorized Travel Choices, and the Role of the Built Environment. Paper presented at the 92nd annual meeting of the Transportation Research Board, Washington, DC.

Tal, G. and Handy, S. (2012). Measuring non-motorized accessibility and connectivity in a robust pedestrian network. *Transportation Research Record* 2299, 48-56.

Zhang, L., J. H. Hong, A. Nasri and Q. Shen (2012). How built environment affects travel behavior: A comparative analysis of the connections between land use and vehicle miles traveled in US cities. *Journal of Transport and Land Use,* 5(3): 40-52.

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