Policy Brief on the Impacts of Network Connectivity Based on a Review of the Empirical Literature

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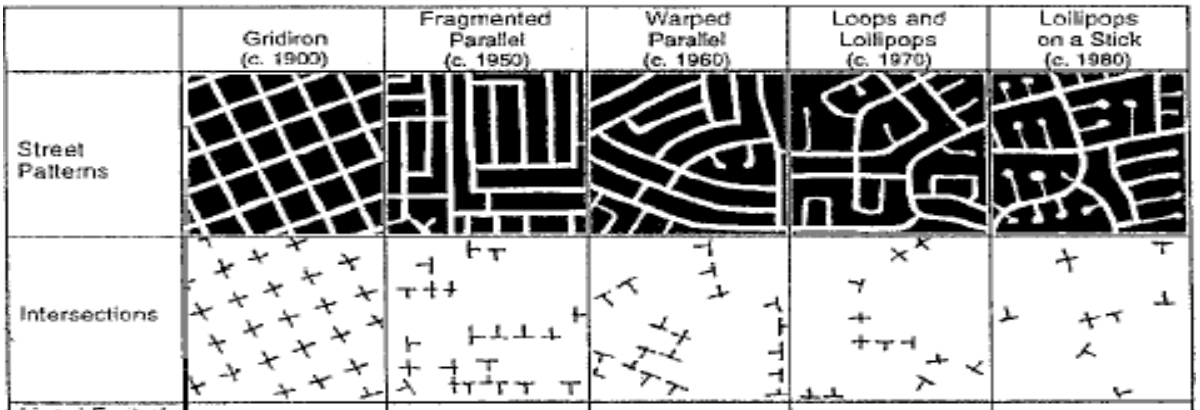
Policy Description

Network connectivity describes the quality of the connections that link each of the points in a community with one another. The structure of the street network, defined in terms of the patterns of streets and intersections, determines the directness of these connections, which often differ by mode (Handy, et al. 2003). Because, from the transportation standpoint, connections to destinations are most important, network connectivity in this case is defined with respect to land use patterns and the locations of potential destinations.

Network connectivity is shaped by local codes and standard practices. Subdivision ordinances, in particular, often set standards that encourage street networks with relatively low connectivity (Handy, et al. 2003). Professional guidelines, such as those adopted by the Institute of Transportation Engineers, have also encouraged development patterns characterized by low-connectivity networks for many decades (Southworth and Ben-Joseph 1997). As a result, the structure of residential street networks in the United States has evolved over time, as illustrated in Figure 1, from “grids,” which were common prior to World War II, to networks dominated by cul-de-sacs. Over the last decade, however, many communities throughout the United States have revised their standards to encourage a return to grid networks (Handy, et al. 2003).



	Gridiron (c. 1900)	Fragmented Parallel (c. 1950)	Warped Parallel (c. 1960)	Loops and Lollipops (c. 1970)	Lollipops on a Stick (c. 1980)
Street Patterns					
Intersections					
Lineal Feet of Streets	20,800	19,000	16,500	15,300	15,600
# of Blocks	28	19	14	12	8
# of Intersections	26	22	14	12	8
# of Access Points	19	10	7	6	4
# of Loops & Cul-de- Sacs	0	1	2	8	24

Figure 1: Residential Streets Patterns in the United States (Source: Southworth and Owens, in Southworth and Ben-Joseph 1997)

Because of the strong association between the era of development and the layout of the street network, connectivity is likely to be correlated with other characteristics of the built environment. For example, pre-World War II neighborhoods tend to have grid networks, small

neighborhood stores, and narrower streets, and are located closer to the center of the city, while subdivisions developed during the 1980s are characterized by cul-de-sacs, strip malls and “big box” stores, and wider streets, and are located farther from the center. Therefore, the year in which a neighborhood was first developed often serves as a good proxy for connectivity (with older neighborhoods having greater connectivity), and connectivity, in turn, often serves as a useful proxy for a broader set of characteristics typical of that era. Separating the effect of connectivity on vehicle miles traveled (VMT) and greenhouse gas emissions from the effect of these other characteristics can be difficult.

Impacts of Connectivity

Connectivity is important for travel in two ways. First, it determines the directness of the connection between one point and another. A straight line between points, “as the crow flies,” yields the shortest travel distance. Second, network connectivity determines the number of possible routes between one point and another. Having multiple routes of similar distance gives a traveler the opportunity to vary his route, whether out of a desire for variety or to avoid occasional obstacles. It also enables traffic to spread more efficiently through the network, reducing traffic on any individual street.

Increased connectivity within residential areas has the potential to reduce VMT, though it might also increase VMT in some situations. The net effect of connectivity on VMT depends on its direct effect on travel distances and the potential indirect effects on trip frequency, destination choice, and mode choice. All else being equal, greater connectivity means shorter travel distances and thus less VMT. However, if greater connectivity results in residents making more frequent trips (because distances are shorter and trips are easier and less costly) or choosing more distant destinations (because now they can get there for the same amount of travel time as before), the net effect could be an increase in VMT. On the other hand, greater connectivity could encourage residents to walk or bicycle instead of drive by reducing travel distances to destinations and increasing the variety of possible routes.

Effect Size

Five studies provide evidence on the effect of connectivity on VMT. One study reports the effect on person miles of travel (PMT). It is not possible to directly compare the estimated effect sizes, as connectivity is measured differently in each study, and VMT is also not measured in a consistent way. Studies tend to use one of two types of network connectivity measures, and researchers do not agree as to which is most appropriate. The first type looks at facility design, such as the ratio of the number 4-way or 3-way intersections to all intersections, the ratio of the number of intersections to the number of street segments (“nodes” to “links”), or the share of blocks created by the street pattern that are square or rectangular. The second type factors in land area to calculate intersection density (e.g. intersections per square mile) or street density (e.g. lane miles of street per square mile). The effect of street connectivity is measured either as percent change in vehicle miles of travel (VMT) or person miles of travel (PMT) for a 1 percent increase in connectivity.

The studies summarized in Table 1 suggest a high level of uncertainty about the effect of connectivity. One study, for example, found a negative effect for one measure of connectivity, as expected, but a *positive* effect for a second measure, and found more substantial differences in effect sizes for VMT for all travel than for VMT for non-work trips only

(Cervero and Kockelman 1997). The higher estimated effects are likely to reflect differences between neighborhoods beyond just connectivity, as noted earlier. However, the study by Fan and Khattak controls for differences in socio-economic characteristics and attitudes of residents, as well as differences in built environment characteristics between neighborhoods, but still has the highest effect size for travel for all purposes. Unfortunately, this study measures person miles of travel (PMT) and not VMT (though in suburban settings, the effect is likely to be similar given the low use of modes other than driving), and its measure of connectivity, focusing on the prevalence of dead-ends, is useful for comparing cul-de-sac networks to grid networks, but not different grid networks to one another.

Table 1: Network Connectivity and VMT or PMT

Study	**Study Location**	**Study Year**	**Results**		
			Connectivity Variable	*VMT Variable*	*VMT Reduction for 1% Increase in Connectivity*
Boarnet et al. (2004)	Portland, OR	1994	Number of 4-way intersections within 1 mile of household	VMT per person, non-work only	-0.06%
			Number of intersections within 1 mile of household		-0.19%
Bento et al. (2003)	Nationwide	1990	Road density (lane miles per square mile)	VMT per person, all purposes	-0.07%
Chapman and Frank (2004)	Atlanta Region, GA	2001-2002	Intersection density (number of intersections within 1km around each home)	VMT per person, all purposes	-0.08%
Ewing and Cervero (2010)	Multiple locations	Multiple years	Percent – or 4-way intersections	Various measures, including VMTfor all purposes, commute only, and non-work only	-0.12%
			Intersection or street density		-0.12%
Cervero and Kockelman (1997)	Bay Area, CA	1990	Proportion of intersections that are 4-way	VMT per household for all purposes	No effect
				VMT per household for non-work only	-0.59%
			Proportion of neighborhood blocks that are quadrilaterals (i.e. four straight sides, shaped as either a square or rectangle)	VMT per household for all purposes	0.18%
				VMT per household for non-work only	0.46%

Study	Study Location	Study Year	Results		
			Connectivity Variable	*VMT Variable*	*VMT Reduction for 1% Increase in Connectivity*
Fan and Khattak (2008)	Triangle Area, NC	2006	Percent of intersections that are not dead-ends	Person miles of travel for all purposes and all modes	-0.26%

The meta-analysis by Ewing and Cervero (2010) of multiple studies may provide a reasonable estimate of effect size for typical conditions and is near the middle of the range of estimates presented in Table 1. However, because the studies they analyzed use different measures of connectivity and different measures of VMT, an averaging of their estimated effect sizes may gloss over important nuances in the relationship between connectivity and VMT. Little is known about how the effect might vary across urban or rural areas, as the evidence in this body of literature is largely from within metropolitan regions.

Evidence Quality

The studies in Table 1 use accepted statistical methods to analyze high quality data for individual households. Although they provide the best available evidence of the effect of connectivity on VMT, the cited studies have notable limitations. The estimated effects in all studies are based on a comparison between neighborhoods at one point in time (e.g. a cross-sectional design) rather than changes in VMT that result from a change in connectivity (e.g. a "before-and-after" design). Fan and Khattak (2003) control for more factors than the other studies. By controlling for attitudes, the study reduces the possibility that the differences in VMT between neighborhoods with different levels of connection stem from the "self-selection" of residents who prefer to drive less into neighborhoods with higher connectivity.

In addition, 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. Only Cervero and Kockelman (1997) use data from California exclusively, and the estimated effect sizes of the others may not be accurate for California communities.

Caveats

When applying the results of the cited studies, it is important to note that they mostly focus on street connectivity in residential areas. Connectivity in residential areas is likely to have the greatest effect on short distance trips, particularly when increased connectivity puts schools, stores, and other potential destinations within walking distance. Residential connectivity can also reduce VMT by reducing distances to destinations for driving trips, but the reduction is likely to be small compared to the total length of the trip. It is possible that connectivity around transit stations and mixed-use centers, where it is easier to use modes other than driving, would have a greater effect on VMT than connectivity in residential areas. In addition, the connectivity of the pedestrian network might be different from the connectivity of the street

network, owing to pedestrian connections (e.g. trails, cut-throughs) and barriers (e.g. freeways), and should be considered in efforts to reduce VMT that encourage a shift from driving to walking.

Greenhouse Gas Emissions

No available studies provide direct evidence on the effect of connectivity on greenhouse gas (GHG) emissions. Translating VMT reductions into GHG emissions reductions depends on the nature of the VMT eliminated (e.g. speeds, acceleration, deceleration, times vehicle is started) and the types of vehicles owned by residents who decrease their driving. The direct impact of connectivity on trip distances is likely to be relatively uniform for all residents in an area, but they may differ in their propensity to shift from driving to walking and bicycling in response to an increase in connectivity. Apart from those particular considerations, one would generally expect GHG reduction to be similar to VMT reduction, if vehicle fleet composition and driving patterns are unchanged. While the pattern of such changes in response to connectivity has not been documented, it is reasonable to expect that policies that reduced VMT will also lead to reductions in GHG emissions.

Co-benefits

Higher connectivity contributes to shorter distances to destinations, which encourages walking and bicycling rather than driving for short trips (Saelens and Handy 2008). The substitution of walking and bicycling for driving leads to a reduction in air pollution and health-related impacts. Non-motorized travel is an important source of physical activity and contributes to many health benefits as well (Handy 2009). A recent study shows that grid-networks, characterized by high connectivity, produce fewer accidents overall than cul-de-sac neighborhoods bounded by high-speed arterial streets (Dunbaugh and Rae 2009). In addition, a shift from driving to walking or bicycling could reduce the need for parking spaces, which may result in economic and environmental benefits.

Examples

A number of cities across the U.S. have adopted changes in their subdivision ordinances to promote greater street network connectivity (Handy, et al. 2003). Eugene, Oregon and Corvallis, Oregon, for example, have maximum block lengths at 600 feet, with requirements for pedestrian connections at least every 300 feet. Several cities in North Carolina have adopted requirements based on the ratio between intersections (nodes) and street segments (links). Some communities have restricted the use of cul-de-sacs in residential subdivisions. Retrofitting communities to increase connectivity is more challenging than requiring high levels of connectivity when a neighborhood is first built, but examples can be found throughout California. The cities of Berkeley and Davis, for example, have increased pedestrian and bicycle connectivity by constructing a bridge over and a tunnel under, respectively, Interstate 80. The effects of these policies and programs on VMT and greenhouse gas emissions have not been measured.

Suggested Further Reading

Bento, A.M., Cropper, M.L., Mobarak, A.M., and 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., and Smith, C. S. (2004). Comparing the influence of land use on nonwork trip generation and vehicle distance traveled: An analysis using travel diary data. Paper presented at the 83rd annual meeting of the Transportation Research Board, Washington, DC.

Cervero, R. and 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.

Dumbaugh, E. and Rae, T. (2009). Safe Urban Form: Revisiting the Relationship Between Community Design and Traffic Safety. *Journal of the American Planning Association*, 75(3): 309-329.

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