The Effects of Street Configuration on Transit Ridership

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Abstract
This study examines the impact of street network connectivity on transit patronage. The aim is to better understand how connectivity affects the decision to use public transportation after we control for population density and the effect of walking distance from the transit station. Data on population densities, transit service features, and annual average daily station boardings are drawn from Chicago (CTA), Dallas (DART), and Atlanta (MARTA). Results suggest that metric reach, which measures the street length that is accessible within a walking range, has significant impact on ridership levels jointly with population density and two attributes of transit service features. In particular, the estimates indicate that metric reach is a stronger predictor of transit use than station area population densities.

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Empirical research dealing with how built environments can influence travel behavior has been framed around three properties of environment: *density*, *land use* and *the design of street network*. There is a substantial amount of literature that has acknowledged *density* as a significant predictor of travel choice (Pushkarev and Zupan 1977, 24-43; Smith 1984, 521; Marshall and Grady 2005, 44; Badoe and Miller 2000, 235). A plethora of recent studies have suggested that compact developments with higher densities generate fewer vehicle trips and encourage non-motorized travel by reducing the distance between origins and destinations; by offering a wider variety of choices for commuting and a better quality of transit services; and by triggering changes in the overall travel pattern of households (Cervero and Kockelman 1997, 199; Krizek 2003, 265; Holtzclaw 1994; Ewing et al. 1994, 53). A number of empirical studies have identified threshold densities to give planners a sense of whether there is a reasonable possibility for transit to work in different settings. Newman and Kenworthy (1989, 8) recommend densities above 30 to 40 persons per hectare (12 to 16 persons per acre) for public transit-oriented urban developments.

Studies regarding the measurable impacts of *land-use characteristics* on transit use and mode of access to transit have verified that high land-use mix at the trip origins and destinations yield in increase in transit shares and non-auto commuting (Cervero 1996, 361; Holtzclaw 1994; Cervero 2006, 285) and induce walking (Frank and Pivo 1994, 351.1; Cervero 1988, 429). The general inferences that can be drawn from these studies are that the characteristics of areas around stations strongly influence the ways in which patrons travel to and from transit: in employment centers land-use mix is found to contribute to increasing use of transit; while, in residential neighborhoods urban design that supports pedestrians is shown to influence the mode of access to transit, that is whether people walk or drive to the station. Pedestrian-friendly neighborhoods are claimed to be more congenial to transit use as well as to walking.

Empirical investigations evaluating how the built environment shapes travel choices have mainly focused on *road network designs*, characterized by local street connectivity, block sizes, the density and pattern of intersections and block face lengths among other factors (Southworth and Owens 1993, 271; Cervero and Kockelman 1997, 199; Siksna 1997, 19; Boarnet and Crane 2001, 85). Pertinent analysis has computed higher NA (neighborhood accessibility) levels for communities with higher street intersection densities or lower average block areas (Krizek 2000, 48; Krizek 2003, 265). A common theme of this body of research is that inordinate size of street blocks or the lack of a fine-grained urban network of densely interconnected streets fails to promote walking (Ewing et al. 2003, 47; Hess et al. 1999, 9).

In spite of the plethora of studies on the influences of land use, density, and urban form on transit use, no conclusions emerge on the relationships between street networks and travel. A limitation of these studies is the difficulty to develop well-specified statistical models that allow researchers to accurately evaluate the individual effect of street network. Part of the reason is due to collinearity between density, land use mix and urban form. Fairly compact neighborhoods in US cities generally have more varied land-uses, on average shorter block lengths with more grid-like street patterns. Thus, the effect of street network design on overall travel remains unclear.

The connectivity measures used in this research (Peponis et al. 2008, 881) offer a systematic framework for evaluating impacts of the layout of streets on ridership, controlling for the multi-collinearity caused by various other aspects of the built environment. The analysis is based on standard GIS-based representations of street networks according to street center-lines. The unit of analysis is the road segment. Road segments extend between choice nodes, or street intersections at which movement can proceed in two or more alternative directions. Road segments may contain one or more line segments. A line segment is the basic unit of the map drawn and is always defined as a single straight line. Thus, unlike the axial line map, this analysis treats the unit of analysis (the road segment, for which the individual values are computed) and the unit of computation (the line segment which provides the base metric for values) as different entities. Figure 1 illustrates the new unit of analysis by clarifying the difference between road segments and line segments.

Analysis is based on finding the subset of street center-lines and parts of lines that can be reached subject to some limitation. When the limitation is metric distance, the total length of street reached is called metric reach, R_v, and the set of segments S_v. When the limitation is a number of permissible direction changes, the total length of streets reached is called directional reach, R_u, and the set of street segments S_u.

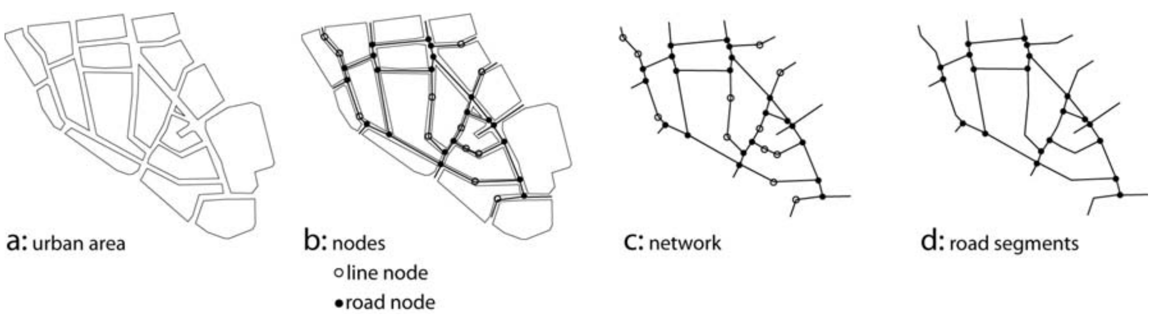

Figure 1
Definition of Road Segments.

We analyzed average annual daily station boardings for the year 2007 per transit station in Chicago (CTA), Dallas (DART), and Atlanta (MARTA). In order to judge how the radius distance for the analysis affects results, all areas were analyzed at 0.25, 0.5 and 1 mile radii. Similarly, we established population densities for the same surrounding areas using US 2000 census data. We measured street connectivity using metric and directional reach based on ESRI Streetmap 2003 maps. We also factored in transit service features, namely supply of park-and-ride facilities, availability of feederbus services, and service potential that is the number of intersecting rail routes at each station. When multivariate regressions are run for 3 ranges separately, street connectivity is found to be a rather significant predictor of ridership levels in all three catchment areas when controlling for population density and transit station measures. However, the best results are obtained for the 0.5 mile range. This supports the findings of various studies which suggest that within short distances people will walk to transit regardless of local street connectivity (Cervero 1993, 130; Lund et al. 2004, 71-72). In other words, people residing within 0.25 mile distance from a station are inclined to use transit irrespective of the street connectivity levels of the station area. Higher correlation coefficients within the 0.5 mile buffer suggest that the decision to walk a slightly longer but still very manageable distance is strongly affected by the density of street connections. The effect becomes weaker when we look at 1 mile radius, because the extra effort to walk a considerably longer distance begins to overpower the positive influence of connectivity.

We then produced "standard", "urban form", and "reduced" models for average annual daily boardings for 0.5 mile wide ring to identify the statistical significance levels of all variables and to capture the unique contributions of connectivity measures to the overall model. The "standard" model includes control variables, which are the city variable, distance to CBD from each station, transit service features, and station-area population densities. The "urban form" model is constructed by the inclusion of connectivity measures, metric reach (avg Reach) and 2-directional reach (avg R_2), in addition to controls. The "reduced" model shows the extracted measures which are statistically significant at the 0.01 level in the "urban form" model. Table 1 presents the results of effect tests for the three models. Consistent with theory, ridership levels are sensitive to the population density around stations. However; the high positive coefficients on the park-and-ride and service potential variables support the argument that residential density thresholds are interrelated with various factors such as measures of transit operational levels and the supply and price of parking (Pushkarev and Zupan 1982, 342-43; Parsons Brinckerhoff Quade & Douglas, Inc. et al. 1996, 9). When we introduce control variables, 31% of the variation in transit ridership is explained. When the "urban form" model is examined, connectivity measures, metric reach and 2-directional reach, add moderate explanatory power of 5% point to the "standard" model. However; for the "urban form" model only metric reach entered as a significant connectivity measure. There was no significant correlation between ridership levels and 2-directional reach. This somewhat surprising finding suggests that even though direction changes appear to have significant impact on movement within an urban environment as suggested by standard syntax theory, decision to use transit does not depend on them. The explanation may be quite simple. We can distinguish between two kinds of walking. Directed walking aimed at moving from a familiar origin to a known destination, and walking which involves different degrees of exploration (looking for something to buy in a familiar area or exploring an unfamiliar area) or different degrees on wandering (recreational walking). Direction changes are a cognitive variable and are likely to influence the latter kind of walking which involves cognitive decisions, overt or latent. Directed walking is likely to follow an established route without much ongoing cognitive effort and can thus be independent of directional reach or traditional syntactic integration.

Table 2 shows the effect levels of statistically significant variables included in the "reduced" model. The signs of control variables are consistent with a priori expectations; for example, boarding levels increase with the availability of parking. The model shows that ridership levels are most sensitive to service potential of a station along with the city variable that captures the variations in-between cities. Figure 2, which shows the prediction equations for each variable in the model, clearly demonstrates the variations between 3 cities. Figure 3 illustrates the scatter plot showing the natural log of annual average daily station boardings as affected by variables in the "reduced" model. Metric reach appears to be a reasonably significant predictor of transit ridership. In fact, the model suggests that density of street connectivity impacts the probability of using transit more than population density within 0.5 mile of transit.

Dependent variable: natural log of annual average daily station boardings									
	standard model			urban form model			reduced model		
	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F
Explanatory variables									
City*	**20.225**	**19.175**	**0.000**	**22.727**	**22.619**	**0.000**	**30.907**	**30.210**	**0.000**
Distance to CBD†: miles between station and center	1.665	3.158	0.077	0.321	0.640	0.425	—	—	—
Park-and-ride (no, yes)	1.915	3.630	0.058	**4.513**	**8.984**	**0.003**	**5.429**	**10.613**	**0.001**
Feederbus services (no, yes)	1.564	2.965	0.087	*2.916*	*5.805*	*0.017*	—	—	—
Service potential: number of intersecting rail routes at station	**16.259**	**30.830**	**0.000**	**13.460**	**26.792**	**0.000**	**13.572**	**26.533**	**0.000**
Population density: persons per gross acre within 0.5 mile of station	*2.602*	*4.934*	*0.027*	**3.919**	**7.802**	**0.006**	*2.682*	*5.244*	*0.023*
avg R_2‡				0.742	1.478	0.226	—	—	—
avg Reach				**5.791**	**11.528**	**0.001**	**6.668**	**13.035**	**0.000**
Number of cases	219			219			219		
R squared	**0.31**			**0.35**			**0.33**		

Note: Numbers in bold

* City was entered as a categorical variable into the equation to capture the differences that are due to cities.

† Measures the crow-fly distance between transit station and city center in CBD.

‡ Average 2-directional reach expresses the average length of streets within 0.5 mile radius of station that is up to 2 direction changes away from the station.

Table 1

Effect tests for multivariate regressions estimating natural log of annual average daily station boardings.

Dependent variable: natural log of annual average daily station boardings			
	Reduced model		
	B	t	std β
Explanatory variables			
constant		0.000	
city [atlanta]	**0.791**	**0.000**	**0.518**
city [chicago]	**-0.267**	**0.008**	**-0.233**
city [dallas]	**-0.523**	**0.000**	**-0. 325**
Park-and-ride (no)	**-0.238**	**0.001**	**-0.241**

Table 2

Parameter estimates for multivariate regressions estimating natural log of annual average daily station boardings.

Our work is still in progress and conclusions are, at this stage, tentative. We have not considered any cross-effects. Even though the correlations between our effect variables are low; arguably the overall co-efficient of determination could be increased by a model that includes the cross-effects. However, our intention here was to primarily examine the comparative significance of variables derived from connectivity networks, not so much to develop the best model. The variables to be included in such models would vary from case to case. To the extent that the results of this study hold more generally, we confirm the importance of including the density of street connections in transit-oriented studies. The empirical model developed in this research is based on the hypothesis that environments that are connected so as to support different kinds of walking also support public transportation. Within this framework our study shows that street connectivity has significant effects on transit ridership when controlling for population density, transit service features, and distance to CBD. The high positive standardized coefficient of metric reach is systematically high in all 3 catchment areas when control variables are introduced. Consistent with studies (Bernick and Cervero 1997, 37-73; Untermann 1984, 29; Pettinga 1992) that consistently report exponential decline in transit patronage with distance from a station, correlations appear to diminish starting from 0.5 mile buffer range. In other words, while configuration of street network within 0.25 and 0.5 mile radius of rail stations acts as an incentive to transit riding, between a distance of 0.5 and 1 mile, the proportion of transit riders who walk to or from transit steadily decreases. These results suggest that street connectivity measured at the appropriate range can add explanatory power for accurate forecasting models.

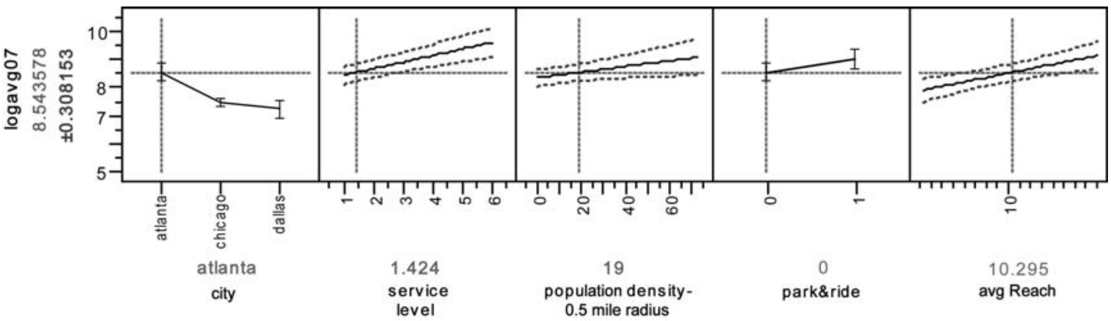

Figure 2
Prediction equations for the variables in "reduced" model.

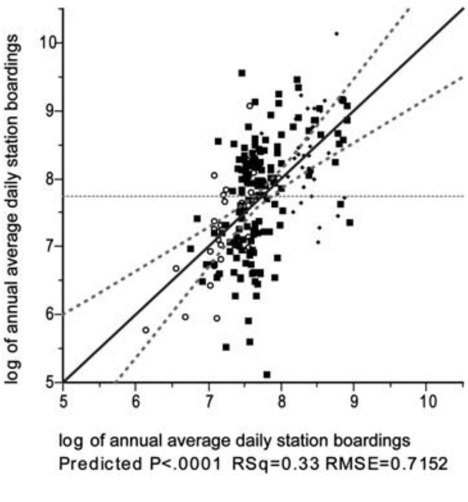

Figure 3
Scatter plot showing the natural log of annual average daily station boardings by the "reduced" model.

Our research supports the previous finding that increased transit patronage is provided by higher population densities within walkable rings around stations. The impact of population density is fairly consistent within all buffers. However; our estimated linear model demonstrates that population densities of station catchment areas have less impact on ridership than street connectivity at the 0.5 mile radius. Importantly, when distance between station and CBD is excluded from the equation, significance of population density is reduced notably. Moreover, consistent with theory, the service potential of stations and the supply of park-and-ride proved to be the most significant correlates of ridership. Thus, it seems imperative that conclusions regarding the effects of density should be considered in conjunction with the degree to which stations are differentiated according to their service features.

Besides these primary findings, we gained several additional insights through this research. Our analysis indicates that there is noteworthy variation among the cities selected. Particularly, Atlanta is significantly different from Dallas and Chicago. Partly, this is due to the fact that station area densities in Atlanta vary in a rather small range. (Minimum and maximum population densities within 0.5 mile of station are 0.8 and 15 persons per gross acre respectively.) This much smaller variation among population densities of station catchment areas obliterated the predictive advantage of this variable in the case for Atlanta.

Lastly, the absence of land-use data at the road segment scale was a limitation of this analysis. While we currently have land use data at the parcel level for Atlanta, we lack access to similar data for other cities. More work is needed to determine if land use can be suitably incorporated in the model at this stage. The US census contains information on population densities, housing, and socio-demographic characteristics at the tract-level and the census block-group level. Very little information is available on specific land-use compositions. This is a significant barrier to carrying out small scale studies at the neighborhood level on how the design of street network shapes non-motorized travel.

In conclusion we note that our results, at this stage, largely confirm and complement existing models that have been reviewed above. Finer grain research, including parcel information on land use as well as field studies of pedestrian movement are needed before we can inform design and planning decisions aimed at increasing the likelihood of transit usage through the creation of lively walkable environments around transit stations. This indicates that further research that focuses on measures of land-use mix and walking at a smaller geographic unit of analyses (i.e. road segment scale) might more clearly detect relationships with transit riding. This finer grain research would require a generous budget to collect rich parcel-level land use data and to obtain more detailed information on pedestrian movement than is generally available from travel surveys. Based on the presented evidence in our study, we believe such research refinements to be worthwhile pursuing. We hope to incorporate such data in our future prospective work to complement our model.

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