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THE EFFECTS OF URBAN FORM ON WALKING TO TRANSIT

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THEME: Methodological Development and Modeling

ABSTRACT

This study analyzes an on-board transit survey conducted by the Atlanta Regional Commission in order to determine how far urban density, mixed land-uses, and street network connectivity are related to transit walk-mode shares to/from stations. The data are drawn from all the stations of Atlanta's rapid transit network (MARTA). Overall, the analyses presented in this study confirm the hypothesis that local conditions around MARTA rail stations are significantly related to riders' choice to walk to/from transit. The results emphasize the importance of including measures of street connectivity in transit-oriented studies. It is shown that street connectivity is strongly associated with walk-mode shares when controlling for transit service characteristics as well as population density, land-use mix and personal attributes. The research findings have several implications. They confirm that transit oriented policies are better supported by urban development policies and zoning and subdivision regulations that encourage transit-friendly urban forms. Findings also augment the knowledge base that supports transit oriented development by emphasizing the contribution of the spatial structure of the street network, over and above the impact of side-walk provision and design and pedestrian safety.

OBJECTIVES

The aim of this study is to determine how far urban density, mixed land-uses, and street network connectivity are related to transit walk-mode shares controlling for sociodemographic attributes and transit service features. The underlying hypothesis is that environments that are connected so as to support different kinds of walking also support public transportation. Using travel data from the 2001-2002 Atlanta Regional On-Board Transit Survey, multivariate regression equations are estimated within 0.25, 0.5, and 1 mile radii around MARTA rail stations predicting walk-mode shares. As such, this study aims to build upon the growing literature on walk-mode choice by investigating to what extent local conditions of station environments contribute to an explanation of variations in transit-access/egress walking shares, defined as the number of riders walking from within a range as a proportion of total ridership. This research represents an important contribution toward understanding the extent to which street network connectivity influences the choice to walk for transit –a critical dimension of overall quality of life.

RESEARCH BACKGROUND

Previous studies have used various measures of the built environment to capture the effects of urban form on travel mode choice, but most of the literature has been framed around three dimensions of urban form: *density*, diversity of *land-use* and *street network design*.

The "pro-density" argument considers density as the most important factor affecting travel choices (Smith 1984; Marshall and Grady 2005; Badoe and Miller 2000). A plethora of recent studies have suggested that compact developments with higher densities 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; Krizek 2003; Ewing et al. 1994). Conclusions regarding the relative importance of employment and population densities on commute mode choice provide some evidence that the probability of walking (both for work and non-work trips as well as walking for commute) increases at higher population densities (gross population density at trip origins and destinations) and at higher employment densities (gross employment density at origins only), controlling for a variety of socio-demographic factors that influence transport choice (Frank and Pivo 1994; Reilly and Landis 2002; Chatman 2003). On the other side of the debate, other studies contend that any association between urban form and travel behavior is due to the intervening relationship between density and various factors such as income levels, auto ownership rates, cost and efficiency of transit service, and the supply and price of parking (Meyer 1989; Parsons Brinkerhoff Quade and Douglas Inc. 1996b, Pushkarev and Zupan 1982; Gomez-Ibanez 1996). Thus, it seems imperative that conclusions regarding density should be considered in conjunction with transit service and socio-demographic attributes.

Recent studies exploring the land-use–transportation connection have verified high levels of land-use mix at the trip origins and destinations as the primary driver of mode choice (Bhat and Pozsgay 2002; Rodriguez and Joo 2004; Schwanen and Mokhtarian 2005). Studies regarding the measurable impacts of land-use characteristics on travel have shown that the proportions of trips by public transit and walking increase as the intensity and mixing of land-uses is higher (Cervero 1996; Cervero 2002; Cervero and Kockelman 1997; Frank and Pivo 1994). This is reflected in different trip generation rates and (sometimes) mode shares attributed to different land-use

development patterns. Thus, it is argued that improving the diversity of uses in neighborhoods through flexible zoning can reduce automobile dependence and encourage walking (Rajamani et al. 2003).

In contrast to the focus on the effect of density and land-use on travel behaviour, there has been relatively lesser attention on the importance attributed to street network design. For street network design, prevalent measures of connectivity have been limited to average measures of street networks, such as the number of intersections, percent of gridded streets, and average block sizes per area. 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 higher walking rates for transport (Kerr et al. 2007; Cervero and Gorham 1995) and increased proportion and number of utilitarian and non-work walk trips (Handy 1996; Moudon et al. 2006; Lee and Moudon 2006). Apart from average measures of street density, some studies have investigated the underlying differences of street types, such as the distinctions between traditional vs. suburban and grid vs. cul-de-sac, to show a statistically significant relationship between street design with a grid-like geometry and increased frequency of walking trips (Shriver 1997; Greenwald and Boarnet 2001; Handy 1992; Rajamani et al. 2002; Khattak and Rodriguez 2005).

In spite of the burgeoning literature concerned with street connectivity, conclusions about the relative importance of street network configuration in overall travel behavior remains unclear. One reason is the absence of commonly accepted measures that capture the internal structure of urban areas. The significance of spatial structure in affecting pedestrian movement has been addressed through the framework of configurational analysis of space syntax. Empirical studies have shown that road segments that are accessible from their surroundings with fewer direction changes tend to attract higher flows (Hillier 1996; Peponis and Wineman 2002). From a point of view of this study, the key implication of previous syntactic studies is that our understanding of how street networks impact behaviors and performances of different kinds is significantly improved when we apply stronger descriptive methods and better measures of spatial properties. A second reason for the weak explanatory power of street network design in urban models is the absence of rich land-use and urban design data. The models employed by the broader literature on urban form and pedestrian behavior have turned to relatively larger units of analyses, such as Traffic Analysis Zones (TAZs), census tracts, or block groups. These gross geographic units estimate average regional urban form characteristics, failing to capture fine-grained land-use and design aspects essential for understanding travel impacts of small-scale place-oriented projects. Another methodological dilemma of studying the travel impacts of street network design is the multicollinearity between urban features. Clearly, the foregoing findings point to the fact that urban form measures are interrelated since denser areas typically have higher land-use mixtures, on average higher street intersections per area with more gridiron street network patterns (Parsons Brinkerhoff Quade and Douglas Inc. 1996a).

This study attempts to overcome some of the methodological drawbacks underlined here in two aspects. First, using connectivity measures which are sensitive to both the sinuosity and the density of the network, the impacts of street layout on walking are assesed more rigorously, controlling for the multi-collinearity caused by various other aspects of the built environment. Second, the statistical models developed include highly disaggregate data at the segment and parcel level with respect to street network design and land-use data. These smaller units of analysis prevent the unfair advantage of density measures, generally measured at a precise metric scale, over land-use and design measures, computed through coarser indices, and detect walking impacts of urban form more clearly. Given the complexity of the factors reviewed here any attempt to develop alternative behavioral theories and to arrive at comprehensive explanatory models would exceed the scope of this study. Rather, the strategy in this research is to focus on some particular regularities of interest –how far do street networks encourage more people to walk to the station as a proportion of total ridership.

CASE CONTEXT AND DATA

MARTA stations are characterized not only by their own characteristics, including the frequency of service and ridership levels, but also by the properties of the surrounding areas. Surrounding areas of stations are identified as circles of 0.25, 0.5 and 1 mile radius to judge how the radius distance for the analysis affects results. This study relies on currently available data sources on socio-demographics, land-use compositions, gross densities, and street networks for such areas.

Definition of the study area

Figure 1 illustrates the geographically accurate representation of MARTA rail system overlaid on the map of Atlanta. As shown, the transit system is bounded within metro Atlanta; only 4 stations, namely Dunwoody, Sandy Springs, North Springs, and Indian Creek, lie beyond I-285.

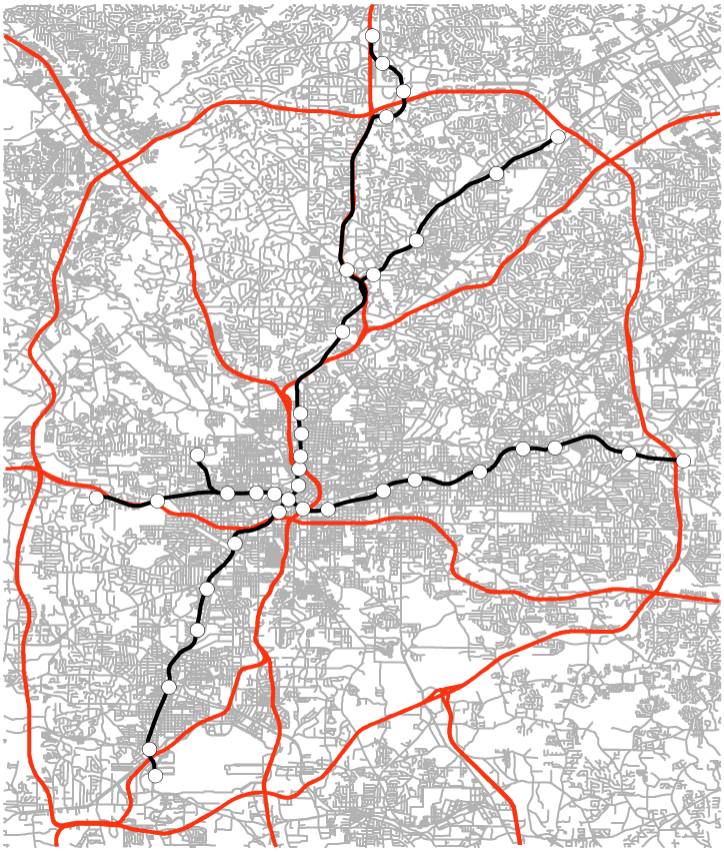

Figure 1. Real geometry of the system overlaid on the map of Atlanta within I-285. The grey lines represent roads while the red lines denote the freeway system.

Dependent variable: proportion of riders walking

Using travel data from the 2001-2002 Regional On-Board Transit Survey, the walk-mode share data was extracted from the travel data of individual riders (n=13,751). It is the ratio of total walk trips to the total ridership by station. In other words, it represents the percent of walking, including both access and egress walk-mode shares.

Independent variables

The independent variables employed in the models were selected from a multitude of factors that were shown to be significantly related to mode choice by the literature, and were grouped into the following six categories:

1. Connectivity:

The measures of connectivity applied in this research have been developed at GaTech to allow for the analysis of standard GIS-based representations of street networks according to street centerlines (Peponis et al. 2008). 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. Figure 2 illustrates the new unit of analysis by clarifying the difference between road segments and line segments.

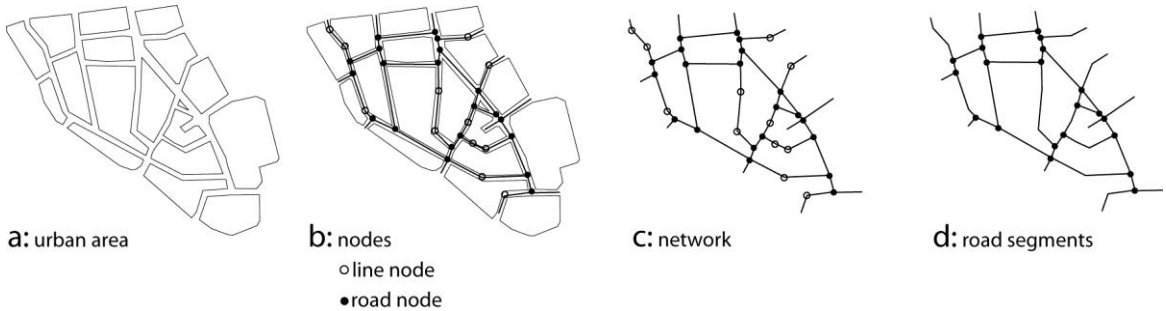

Figure 2. Definition of line segments and road segments. Source: Peponis et al. 2008.

Metric reach captures the density of streets and street connections accessible from each individual road segment. This is measured by the total street length accessible from each road segment moving in all possible directions up to a parametrically specified metric distance threshold. *Directional reach* measures the extent to which the entire street network is accessible with few direction changes. This is measured by the street length which is accessible from each road segment without changing more than a parametrically specified number of directions. Figure 3 illustrates the two measures. In this research metric reach was computed for 1, 0.5 and 0.25 mile walking distance thresholds. Directional reach was computed for two direction changes subject to a 10° angle threshold. A *composite connectivity measure* (metric reach divided by the corresponding directional distance, subject to a 10°

angle threshold) was also added to calculate the ratio of metric reach to the average directional distance associated with it. This composite variable takes higher values as street density increases and as access to streets becomes more direct. In other words, road segments from which more street length is accessible within the walking radius, taking fewer turns to get everywhere, draw greater volumes of pedestrians.

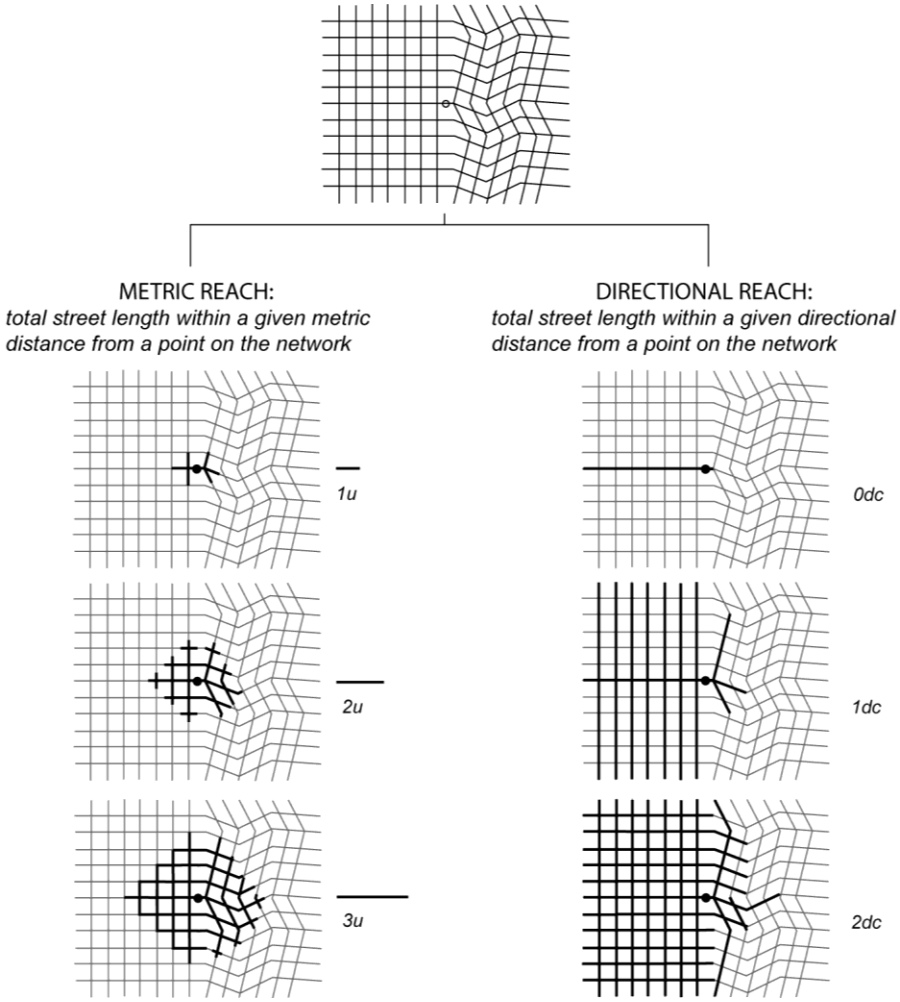

Figure 3. Diagrammatic definition of segment-based connectivity measures. Source: Peponis et al. 2008.

2. Accessibility:

Sidewalk availability measuring the percentage of streets with sidewalk that are accessible to pedestrians within walking ranges of stations.

3. Density:

Population density (people in gross acres) within 1, 0.5, and 0.25 mile radii of stations were established using US 2000 census data.

4. Land-Use:

Mixed-use entropy index[1], based on a formula derived from Cervero and Kockelman (1997), Cervero (2006), and Greenwald (2006), was computed using parcel-based land-use data acquired from the data-base developed at the Center for GIS at Georgia Tech for the SMARTRAQ program (Goldberg et al. 2006). Separate entropy indices were computed for 0.25, 0.5, and 1 mile radii around each MARTA rail station.

5. Transit service features:

Transit service features, namely supply of park-and-ride facilities[2], service frequency[3], feeder bus services[4], and station structures[5] were included in order to control for the impacts of transit operational and design factors on walking levels.

6. Socio-demographics:

A composite socio-demographic variable was developed to control for personal and household characteristics. Auto ownership relativized by per-capita income measures the ratio of auto-ownership to per-capita income (annual household income divided by household size).

MODELING WALKING AS TRANSIT ACCESS/EGRESS MODE CHOICE

We produced "standard" regression models and "reduced" models for walk-mode shares within 1 mile range 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 all independent variables. The "reduced" model shows the extracted measures which are statistically significant at 5% level in the "standard" model. The non-urban form variables were entered into the regression first to allow for the evaluation of urban form variables in context relative to other factors affecting travel behavior. Urban form measures were then added into the model respectively to demonstrate the effect of adding each to the model and to infer whether some variables could be eliminated in the final model without noticeably increasing the residual sum of squares. When multivariate regressions are run for three ranges separately, the coefficient of determination is found to be considerably higher for 1 mile range. Even though the relative effect size of metric reach is consistent across all ranges, ¼ of a mile appears to be an overly limited distance threshold since it fails to capture the effects of land-use mix. Thus, results at 1 mile range are reported here. Table 1 shows the results of "standard" regression models for 1 mile radii including the connectivity measure metric reach as the street connectivity variable.

From the relative effect sizes it is clear that the primary factors in explaining predictability are metric reach and land-use mix. This result indicates that the decision to walk to/from transit is significantly associated with the

[1] $$Mixed-use\ entropy = -1 \times \left(\frac{\left(\sum_{i=1}^{k} p_i \times \ln(p_i) \right)}{\ln(k)} \right)$$

[2] number of station parking spaces
[3] number of inbound trains in am peak hour (7am-9am)
[4] availability and number of feeder buses arriving at station
[5] types of station structure: at-grade, elevated, underground

density of available streets and mixing of land-uses within a larger surrounding context of stations. Somewhat surprisingly, the population density coefficient is positive but not significant. This might be supportive of the argument that employment density exerts a stronger influence on the variation in mode choice for walking (Frank and Pivo, 1994), and that combined population and employment densities has a greater degree of explanatory power over mode shares (Parsons Brinkerhoff Quade and Douglas Inc., 1996a). Thus, future research should take into account employment density in addition to population density.

"Standard" models also point to statistically significant associations between non-urban variables and walking shares. Consistent with theory, walk-mode shares are sensitive to transit service levels and personal attributes. The coefficient on the feeder bus variable indicates that the availability of feeder bus services at stations is negatively associated with the proportion of walking, with more people choosing to ride the bus to/from stations than to walk.

Table 1. Effect tests for multivariate regressions estimating the proportion
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tests for multivariate regressions estimating the proportion of walking

	Controls			+ Land Use			+ Connectivity			+Accessibility			+ Density		
total riders walked / total ridership per station	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F
auto ownership relativized by per-capita income*	**0.051**	**8.844**	**0.006**	0.002	0.567	0.458	0.008	2.748	0.109	*0.0095*	*3.0113*	*0.094*	0.0094	2.8784	0.1017
station structure type[b]	0.023	1.994	0.154	0.016	1.931	0.163	*0.020*	*3.220*	*0.055*	0.0199	3.1619	0.0584	*0.020*	*3.030*	*0.066*
service frequency[‡]	0.002	0.395	0.535	0.003	0.805	0.377	**0.031**	**10.215**	**0.003**	**0.032**	**10.168**	**0.0036**	**0.028**	**8.637**	**0.007**
feederbus services (no)	**0.111**	**19.360**	**0.000**	**0.044**	**10.458**	**0.003**	**0.030**	**9.641**	**0.004**	**0.0303**	**9.6295**	**0.0045**	**0.027**	**8.255**	**0.008**
parking supplies	**0.053**	**9.346**	**0.005**	0.009	2.133	0.155	0.000	0.060	0.809	0.000	0.0061	0.9381	0.000	0.008	0.928
mixed-land use index[†]				**0.048**	**11.350**	**0.002**	**0.046**	**14.967**	**0.001**	**0.044**	**13.965**	**0.001**	**0.039**	**11.942**	**0.002**
avg. Reach (1mile)							**0.037**	**12.201**	**0.002**	**0.029**	**9.307**	**0.005**	**0.018**	**5.512**	**0.027**
sidewalk availability[a]										0.001	0.338	0.566	0.001	0.304	0.586
population density: persons per gross acre within 1 mile of station													0.000	0.004	0.949
N=37															
R^2		**0.69**			**0.77**			**0.84**			**0.84**			**0.84**	
R^2 *adjusted*		**0.62**			**0.72**			**0.80**			**0.79**			**0.78**	
std. error, S_e		**0.08**			**0.07**			**0.06**			**0.06**			**0.06**	
Prob>F														**0.00**	
coefficient of residual variability, V_e														**39.17**	

Numbers in bold = p< 0.05; numbers in italics = p<0.10

Notes:
[a] proportion of roads with sidewalk

$$\dagger\, Mixed-use\ entropy = -1 \times \left(\frac{\left(\sum_{i=1}^{k} p_i \times \ln(p_i) \right)}{\ln(k)} \right)$$

[b] types of station structure: at-grade, elevated, underground
[‡] number of inbound trains in am peak hour (7am-9am)
* ratio of average auto-ownership to average per-capita income calculated per station

Multivariate regression models estimated by including the composite connectivity measure, metric reach divided by the corresponding average directional distance based on metric reach (10°), follow similar patterns with the earlier models including metric reach. Table 2 reports the results of "standard" regression model for 1 mile radii. Results reveal that aside from street density and land-use mix, spatial structure of urban areas also mattered. The standardized coefficient for the composite connectivity measure is positive and statistically significant. The sign and significance of the coefficient remains consistent even after the inclusion of other urban form measures,

controlling for non-urban form factors. This indicates that the configuration of street networks at the scale of an individual area is a reasonably significant predictor of the variation in walk-mode shares at stations. More particularly, the composite connectivity measure, which takes into account both street density and the shape and alignment of streets as indexed by the direction changes needed to navigate the system, is clearly associated with riders' choice to walk for transit.

Table 2. Effect tests for multivariate regressions estimating Effect tests for multivariate regressions estimating the for multivariate regressions estimating the proportion of multivariate regressions estimating the proportion of walking

	Controls			+ Land Use			+ Connectivity			+ Accessibility			+ Density		
total riders walked / total ridership per station	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F	sum of squares	F ratio	prob>F
auto ownership relativized by per-capita income*	**0.051**	**8.844**	**0.006**	0.002	0.567	0.458	0.007	2.359	0.136	0.0067	2.287	0.142	0.0066	2.157	0.154
station entrance type[b]	0.023	1.994	0.154	0.016	1.931	0.163	*0.018*	*3.173*	*0.057*	*0.0184*	*3.117*	*0.061*	*0.018*	*3.010*	*0.067*
service frequency[‡]	0.002	0.395	0.535	0.003	0.805	0.377	**0.030**	**10.410**	**0.003**	**0.03**	**10.19**	**0.004**	**0.028**	**9.310**	**0.005**
Feederbus services (no)	**0.111**	**19.360**	**0.000**	**0.044**	**10.458**	**0.003**	**0.047**	**16.561**	**0.000**	**0.0472**	**16.03**	**4E-04**	**0.047**	**15.462**	**0.001**
parking supplies	**0.053**	**9.346**	**0.005**	0.009	2.133	0.155	0.001	0.363	0.552	0.0012	0.423	0.521	0.001	0.414	0.526
mixed-land use index[†]				**0.048**	**11.350**	**0.002**	**0.047**	**16.437**	**0.000**	**0.042**	**14.318**	**0.001**	**0.036**	**11.691**	**0.002**
avg.metric reach(1mile) / directional distance (10°)							**0.043**	**15.241**	**0.001**	**0.035**	**11.723**	**0.002**	**0.023**	**7.687**	**0.010**
sidewalk availability[a]										0.000	0.108	0.745	0.000	0.044	0.835
population density: persons per gross acre within 1 mile of station													0.000	0.064	0.802
N=37															
R^2		**0.69**			**0.77**			**0.85**			**0.85**			**0.85**	
R^2 *adjusted*		**0.62**			**0.72**			**0.81**			**0.81**			**0.80**	
std. error, S_e		**0.08**			**0.07**			**0.05**			**0.05**			**0.06**	
Prob>F														**0.00**	
coefficient of residual variability, V_e														**37.89**	

Numbers in bold = p< 0.05; numbers in italics = p<0.10

Notes:

[a] proportion of roads with sidewalk

$$^{\dagger}Mixed-use\ entropy = -1 \times \left(\frac{\left(\sum_{i=1}^{k} p_i \times \ln(p_i) \right)}{\ln(k)} \right)$$

[b] types of station entrances: at-grade, elevated, underground

[‡] number of inbound trains in am peak hour (7am-9am)

* ratio of average auto-ownership to average per-capita income calculated per station

Table 3 shows the results of "reduced" models by including metric reach (1mile) and the composite connectivity measure, metric reach divided by the corresponding average directional distance based on metric reach (10°), for 1 mile radii. Comparisons of coefficients within the "reduced" models provide useful insights about the individual contribution of urban form measures. Results suggest that the primary factors in explaining predictability are connectivity measures and land-use mix. Stations with higher metric and directional accessibility as well as maximally mixed uses within their catchment areas attract more walk-on riders, even when controlling for other factors. In fact, street network overpowers the effects of socio-demographic characteristics and transit features. Therefore it would appear that in addition to street density, spatial structure based on directional bias is indeed implicated in the way in which street networks function to support walking.

Table 3. Parameter estimates and residual plots for the "reduced" models by including (a) metric reach (1mile) and (b) the composite connectivity measure, estimating the proportion of walking within 1 mile buffer for all stations considered as a single set.

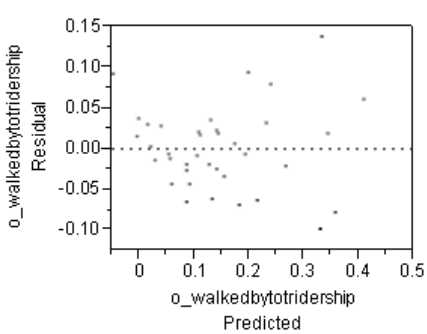
(a) Reduced Model

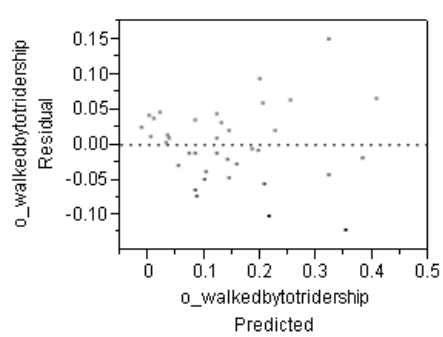
total riders walked / total ridership per station	B	t	std β
constant		-0,94	
station structure type[b] (elevated)	**-0,03**	**-2,25**	**-0,21**
service frequency[‡]	**0,00**	**-2,88**	**-0,32**
feederbus services (no)	**0,05**	**2,72**	**0,24**
mixed-land use index[†]	**0,77**	**6,36**	**0,60**
avg. Reach (1mile)	**0,01**	**3,48**	**0,46**
N		37	
R^2		**0,83**	
R^2 *adjusted*		**0,79**	
std. error, S_e		**0,06**	
Prob>F		**0,00**	

(b) Reduced Model

total riders walked / total ridership per station	B	t	std β
constant		0,15	
service frequency[‡]	**0,00**	**-2,47**	**-0,26**
feederbus services (no)	**0,06**	**3,33**	**0,28**
mixed-land use index[†]	**0,77**	**6,80**	**0,61**
avg.metric reach(1mile)/ directional distance(10°)	**0,02**	**3,91**	**0,42**
N		37	
R^2		**0,81**	
R^2 *adjusted*		**0,79**	
std. error, S_e		**0,06**	
Prob>F		**0,00**	

Numbers in bold = p< 0.05; numbers in italics = p<0.10





DISCUSSION

Overall, the analyses presented here confirm the hypothesis that local conditions around MARTA rail stations are significantly associated with increased transit access/egress walk-mode shares. Statistical models developed reveal that measures of street network design and land-use mix are most strongly associated with walking shares, when controlling for population density, transit service characteristics, and personal attributes. While mixed-use neighborhoods around stations increase the odds of walking to/from transit, street networks with denser and more direct connections are associated with higher proportion of walking shares among station patrons. Importantly, the results presented here also underscore the significance of the spatial structure of street networks, specifically the alignment of streets and the directional distance hierarchy engendered by the street network. Directional accessibility plays as significant a role as metric accessibility in affecting the proportion of riders walking for transit. The spatial structure of street network does not work independently of land-use. On the contrary, based on the standardized coefficients estimated in regression models, street network and land-use mix have comparably high positive impacts on transit walk-mode shares.

Apart from theory building, this research also holds validity for more practical implications. The findings confirm the hypothesis that well structured and differentiated street networks affect transit access/egress walk-mode shares. These results are likely to guide future efforts to integrate subdivision provisions and regulations with zoning regulations in developing currently sparse suburban areas towards dense transit-oriented urban hubs. Traditional models estimating development impacts are based on the consideration of socio-demographic factors and transit service related features, but they do not take into account the structural qualities of street networks. The evidence in this study confirms the premise that the demand for public transport-related walking is significantly influenced by the configuration of street layout. Thus, incorporating measures of street density and measures of directional accessibility in transit-oriented studies can lead to enhanced models of urban form and function, which, in return, can inform specific urban design and urban master planning decisions. Findings also suggest that transit oriented policies are compatible with policies aimed at the enhancement of health and the reduction of obesity through daily physical activity –walking to/from the station can contribute a significant part of the daily activity recommended by Healthy Living Guidelines (US Department of Health Services 1996). Finally findings augment the knowledge-base that supports transit oriented development by emphasizing the contribution of the spatial structure of the street network, over and above the impact of side-walk provision and design and pedestrian safety.

REFERENCES

Badoe, D. & Miller, E. (2000). Transportation-land-use interaction: empirical findings in North America, and their implications for modeling. *Transportation Research Part D: Transport and Environment,* 5**,** 235-263.

Bhat, C.R. & Lockwood, A. (2004). On Distinguishing Between Physically Active and Physically Passive Episodes and Between Travel and Activity Episodes: An Analysis of Weekend Recreational Participation In the San Francisco Bay Area. *Transportation Research Part A: Policy and Practice*, 38 (8), 573-592.

Bhat, C.R. & Srinivasan, S. (2005). A Multidimensional Mixed Ordered-Response Model for Analyzing Weekend Activity Participation. *Transportation Research Part B*, 39(3), 255-278.

Bhat, C.R., & Pozsgay, M.A. (2002). Destination Choice Modeling for Home-Based Recreational Trips: Analysis and Implications for Land-use, Transportation, and Air Quality Planning. *Transportation Research Record: Journal of the Transportation Research Board,* 1777, 47-54.

Bhat, C.R., & Zhao, H. (2002). The Spatial Analysis of Activity Stop Generation. *Transportation Research B,* 36 (7), 593-616.

Boarnet, M.G. & Crane, R. (2001). *Travel by design: The influence of urban form on travel*, Oxford University Press, USA.

Boarnet, M.G., & Sarmiento, S. (1998). Can Land Use Policy Really Affect Travel Behavior? A Study of the Link between Nonwork Travel and Land Use Characteristics. *Urban Studies,*35 (7), 1155-1169.

Cervero, R. & Gorham, R. (1995). Commuting in transit versus automobile neighborhoods. *Journal of the American Planning Association,* 61**,** 210-225.

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

Cervero, R. (1996). Mixed land-uses and commuting: evidence from the American Housing Survey. *Transportation Research Part A: Policy and Practice,* 30**,** 361-377.

Cervero, R. (2002). Built environments and mode choice: toward a normative framework. *Transportation Research Part D: Transport and Environment,* 7**,** 265-284.

Cervero, R. (2006). Alternative approaches to modeling the travel-demand impacts of smart growth. *Journal of the American Planning Association,* 72**,** 285-295.

Chatman, D.G.. (2003). How Density and Mixed Uses at the Workplace Affect Personal Commercial Travel and Commute Mode Choice. *Transportation Research Record: Journal of the Transportation Research Board,* 1831, 193-201.

Ewing, R.H., Haliyur, P. & Page, G. (1994). Getting around a traditional city, a suburban PUD, and everything in-between. *Transportation Research Record: Journal of the Transportation Research Board,* 1466**,** 53–62.

Frank, L. & Pivo, G. (1994). Relationships between land use and travel behavior in the Puget Sound Region. *Final Summary Report, prepared for the Washington State Transportation Commission*.

Goldberg, D., Chapman, J., Frank, L., Kavage, S. & Mccann, B. (2006). New Data for a New Era: A Summary of the SMARTRAQ Findings; Linking Land Use, Transportation, Air Quality and Health in the Atlanta Region. *SMARTRAQ Summary Report* SmartTraq and Smart Growth.

Gomez-Ibanez, J. (1996). Big-City Transit Rider snip, Deficits, and Politics: Avoiding Reality in Boston. *Journal of the American Planning Association,* 62**,** 30-50.

Greenwald, M.J. (2006). The relationship between land use and intrazonal trip making behaviors: Evidence and implications. *Transportation Research Part D: Transport and Environment,* 11**,** 432-446.

Greenwald, M.J. & Boarnet, M.G. (2000). Built environment as determinant of walking behavior: analyzing nonwork pedestrian travel in Portland, Oregon. *Transportation Research Record : Journal of the Transportation Research Board,* 1780, 33–42.

Handy, S. (1992). Regional versus local accessibility: neo-traditional development and its implications for non-work travel. *Built Environment,* 18**,** 253-267.

Handy, S. (1996). Understanding the link between urban form and nonwork travel behavior. *Journal of Planning Education and Research,* 15**,** 183-198.

Hillier, B. (1996). *Space is the machine: a configurational theory of architecture*, Cambridge University Press.

Kerr, J., Frank, L., Sallis, J. & Chapman, J. (2007). Urban form correlates of pedestrian travel in youth: Differences by gender, race-ethnicity and household attributes. *Transportation Research Part D: Transport and Environment,* 12**,** 177-182.

Khattak, A.J. & Rodriguez, D. (2005). Travel behavior in neo-traditional neighborhood developments: A case study in USA. *Transportation Research Part A*, 39 ,481–500.

Krizek, K. (2003). Residential relocation and changes in urban travel: Does neighborhood-scale urban form matter? *Journal of the American Planning Association,* 69**,** 265-281.

Lee, C. & Moudon, A. (2006). The 3Ds+ R: Quantifying land use and urban form correlates of walking. *Transportation Research Part D: Transport and Environment,* 11**,** 204-215.

Marshall, N. & Grady, B. (2005). Travel demand modeling for regional visioning and scenario analysis. *Transportation Research Record: Journal of the Transportation Research Board,* 1921**,** 44-52.

Meyer, M. (1989). *A Toolbox for alleviating traffic congestion*, Institute of Transportation Engineers.

Moudon, A., Lee, C., Cheadle, A., Garvin, C., Johnson, D., Schmid, T., Weathers, R. & Lin, L. 2006. Operational definitions of walkable neighborhood: theoretical and empirical insights. *Journal of Physical Activity & Health,* 3**,** 99-117.

Parsons Brinkerhoff Quade and Douglas Inc. (1996a). *TCRP Report 16: Transit and Urban Form.* Washington, D. C: TRB, National Research Council.

Parsons Brinkerhoff Quade and Douglas Inc. (1996b). Influence of land-use mix and neighborhood design on transit demand. *Unpublished report for TCRP H-1 project).* Washington, D.C.: Transit Cooperative Research Program, Transportation Research Board.

Parsons Brinkerhoff Quade and Douglas Inc., Cambridge Systematics & Calthorpe Associates. (1993). Making the Land Use, Transportation, Air Quality Connection (LUTRAQ). Portland, OR: 1000 Friends of Oregon.

Peponis, J. & Wineman, J. (2002). Spatial structure of environment and behavior. *In:* Bechtel, R., and Churchman, A. (ed.) *Handbook of environmental psychology.* New York: John Wiley and Sons.

Peponis, J., Bafna, S. & Zhang, Z.Y. (2008). The connectivity of streets: reach and directional distance. *Environment and Planning B-Planning & Design,* 35**,** 881-901.

Pushkarev, B. & Zupan, J. (1982). Where Transit Works: Urban Densities for Public Transportation. *In:* Levinson, H.S., Weant, R.A . (ed.) *Urban Transportation: Perspectives and Prospects.* Westport, CT: Eno Foundation.

Rajamani, J., Bhat, C.R., Handy, S., Knaap, G.,& Song, Y. (2002). Assessing the impact of urban form measures in nonwork trip mode choice after controlling for demographic and level-of-service effects. *Paper presented at TRB Annual Meeting*.

Reilly, M. & Landis, J. (2002). The Influence of Built-Form and Land Use on Mode Choice Evidence from the 1996 Bay Area Travel Survey. *Final Report, prepared for the Institute of Urban and Regional Development University of California*, Berkeley, WP 4(1).

Rodriguez, D. & Joo, J. (2004). The relationship between non-motorized mode choice and the local physical environment. *Transportation Research Part D: Transport and Environment*, 9 (2), 151-173.

Schwanen, T. & Mokhtarian, P.L. (2005). What affects commute mode choice: neighborhood physical structure or preferences toward neighborhoods? *Journal of Transport Geography*, 13, 83-99.

Shriver, K. (1997). Influence of environmental design on pedestrian travel behavior in four Austin neighborhoods. *Transportation Research Record: Journal of the Transportation Research Board,* 1578**,** 64-75.

Smith, W. (1984). Mass transport for high-rise high-density living. *Journal of Transportation Engineering,* 110**,** 521-535.

U.S. Department of Health and Human Services. (1996). *Physical Activity and Health: A Report of the Surgeon General.* Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion.