Effects of Transit-Oriented Development on Trip Generation, Distribution, and Mode Share in Washington, D.C., and Baltimore, Maryland

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It is claimed that transit-oriented developments (TODs) have the ability to reduce the number and average lengths of auto trips by providing better nonautomobile accessibility to jobs and other destinations and to encourage sustainable modes (i.e., transit, walking, and biking) by facilitating a pedestrian-friendly environment and transit services. This paper presents a comprehensive analysis of TODs in the Washington, D.C., and Baltimore, Maryland, metropolitan areas that was performed to investigate whether TODs actually have those hypothesized impacts. Trip generation, trip length, and mode share were modeled in the two case study areas through the use of the most recent local household travel survey data and advanced econometric analysis methods. The findings showed that, overall, people living in TODs made more trips by all modes of transportation but fewer trips by auto. The results also showed that TOD residents tended to travel shorter distances by all modes of transportation, a finding that implies the selection of closer destinations for their activities. Trips originating from TODs had substantially higher nonauto mode shares in both Baltimore and Washington, D.C., after relevant socioeconomic and demographic factors were controlled for. Significant differences in the effectiveness of TODs in these two metropolitan areas were also found to be due to TOD locations, transit system availability and level of service, and TOD resident characteristics.

Transit-oriented development (TOD) continues to be a popular area of research because of the planning, implementation, and success aspects of it that are unknown and yet to be explored. It has also received much attention in the past few years after several government transportation agencies allocated funds and resources to promote and expand transit services and facilities. The most recent attempt by the federal government to achieve this goal was through the Moving Ahead for Progress in the 21st Century Act, which was signed into law on July 6, 2012.

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Several factors distinguish this study from previous studies. First, a scalable and quantitative method that considers all of the main factors of TODs, such as high density, pedestrian friendliness, and the presence of affordable housing near transit, was used to define TOD. Most of the studies performed previously analyzed the effects of the land use attributes of TODs, such as high density, proximity to transit, and mixed-use development, separately. However, the identification method proposed here evaluates the impact of TOD as a whole instead of the effect of each attribute individually. Second, in this study the authors comprehensively analyzed the most important indicators of travel behavior, including trip generation, distribution, and mode share. The authors believe that other characteristics, such as route and departure time choice, are not significantly influenced by living in a TOD and thus did not include them in this analysis. Moreover, the present study is one of the first studies to model how transit-oriented urban environments influence trip length for various trip purposes. The present empirical work also allows comparative analysis of two neighboring metropolitan areas with many similarities as well as differences.

The findings show that living in a TOD has a significant impact on both auto and nonauto trip generation. Living in a TOD is associated with shorter trips. However, this change does not necessarily affect travel time. The results indicate that only after socioeconomic factors are controlled for, the development of high-density mixed-use areas around transit stations leads to a more sustainable lifestyle with a higher nonauto mode share.

However, the results show that the effect of TOD is not the same in the metropolitan areas compared. In Washington, D.C., TODs seem to be more effective and promising at reducing auto trips and promoting transit than TODs in the Baltimore, Maryland, area. This might be because of the better transit system and the higher concentrations of jobs and retail spaces around transit in Washington, D.C.

LITERATURE REVIEW

For several decades, the concept of TOD has been proposed, planned, and studied by a significant number of planners, policy makers, and researchers who have tried to investigate and analyze the benefits and lack of benefits of this kind of development.

Cervero claimed that the placement of various destinations closer together by the development of high-density, mixed-use, and transit-friendly neighborhoods encourages less driving and promotes transit ridership, especially for commute trips (*1*). Several studies in the literature have focused on the effects of TOD and different types of land development on overall and mode-specific trip generation.

Lapham developed several regression models of trip generation using data from eight TODs in the Portland, Oregon, metropolitan region (*2*). In TCRP Report 128, the weighted average vehicle trip rate was computed for 17 TOD built projects in Philadelphia, Pennsylvania; Portland; Washington, D.C.; and the East Bay section of San Francisco, California (*3, 4*). The results of these studies showed that the average trip generation rate in areas with TOD is well below the trip generation rate proposed by ITE. According to a study by the San Francisco Bay Area Metropolitan Transportation Commission, TOD residents in the Bay Area made about 50% fewer vehicle trips than the region's average vehicle trip rate and nearly 50% to 200% more transit trips than the region's average transit trip rate (*5*). Chatman modeled the frequency of non–work trips by mode type using variables for the built environment and residential search criteria (*6*). Chatman also modeled weekly grocery trips by auto as a function of attributes of the built environment and transit proximity and found that the benefit of TODs does not much depend on rail access (*7*).

Also, elasticity factors described as the 5D's, including density, diversity, design, destination, and distance to rail mass transit stations, have been used to calculate auto trip generation (*8–10*). Colman et al. indirectly modeled auto trip generation rates in TOD zones of Sacramento County, California, using the change in vehicle ownership because of improvements in transit service and urban structure (*11*).

Unlike trip generation, previous studies have not thoroughly evaluated the trip lengths and trip distributions of TOD residents. In theory, the development of high-density mixed-use neighborhoods brings destinations closer together and thus aims to reduce the average trip length (*12*). Empirically, most of the literature in this area includes only descriptive statistical analysis. McCormack et al. studied two mixed-use neighborhoods in Seattle, Washington, and showed that residents of these two areas traveled 28% to 120% fewer kilometers than residents of nearby suburbs (*13*). Lund et al. compared the mean commute time for residents of an area near a station and residents of surrounding cities and found that the residents of an area near a station spent twice as much time commuting to work as residents of the surrounding cities did (*14*). Another study in Austin, Texas, showed that the average length and duration of trips that originate or end in mixed-use developments are less than those of trips that start and end in other areas for both commuting and non–work trips (*15*). Muley et al. compared the mode share and the lengths of trips made by residents of a fully planned mixed-use development in Brisbane, Queensland, Australia, to those made by residents of Brisbane as a whole and found that the residents of the mixed-use area had a lower average trip length and that they used automobiles for trips to destinations farther away and public transport for trips to destinations that were relatively closer (*16*).

Several studies have evaluated the effect of living in TODs on modes of travel. Cervero and colleagues focused on the effect of TODs on commuting trips and found that residents of TODs were two to five times more likely than residents of other areas, on average, to take transit to work (*3, 14, 17*). More detailed studies tried to determine if characteristics of the built environment influence travel mode choice (*18*). Ewing and Cervero conducted a meta-analysis of the built environment and travel and concluded that although none of the variables for the built environment individually had great elasticity for mode choice, the combined effect was still quite large and significant (*19*). Therefore, proximity to transit should be accompanied by a pedestrian-friendly design and other factors related to the built environment (such as density) to decrease the auto mode share more successfully.

DATA AND METHODOLOGY

Characteristics of TODs and Framework for Identification

Researchers have defined the concept of TOD in various ways. In general, a TOD has been defined as a high-density, mixed-use neighborhood with easy access to transit for individuals in all age and income groups such that these individuals can easily reach various destinations by transit or nonmotorized modes in a timely manner (*14, 20, 21*).

Many definitions of TOD have used similar criteria with the aim of producing a walkable environment for people to access transit services. As a result, TODs are transit centers with specific urban design characteristics, such as high densities and mixed-use neighborhoods. In the framework for TOD identification proposed here, several land use factors as well as proximity to transit services were considered.

To identify TOD areas, the method proposed by Nasri and Zhang was used as the base (*22*). They quantitatively measured TODs by using factors such as population and employment densities, level of mixed-use development, and pedestrian friendliness in a half-mile buffer zone (straight line) around major rail transit stations. The authors revised their method by accounting for housing affordability criteria, in addition to other factors in their definition of TOD. Each traffic analysis zone (TAZ) is marked as a TOD if it meets the following conditions:

$$\text{TAZ} \in \text{TOD} \qquad \text{if} f$$

$$D^{\text{TAZ}}_{\text{residential}} \geq D^{\text{avg}}_{\text{residential}}$$

or

$$D^{\text{TAZ}}_{\text{employment}} \geq D^{\text{avg}}_{\text{employment}}$$

$$B_{\text{TAZ}} \leq B_{\text{avg}}$$

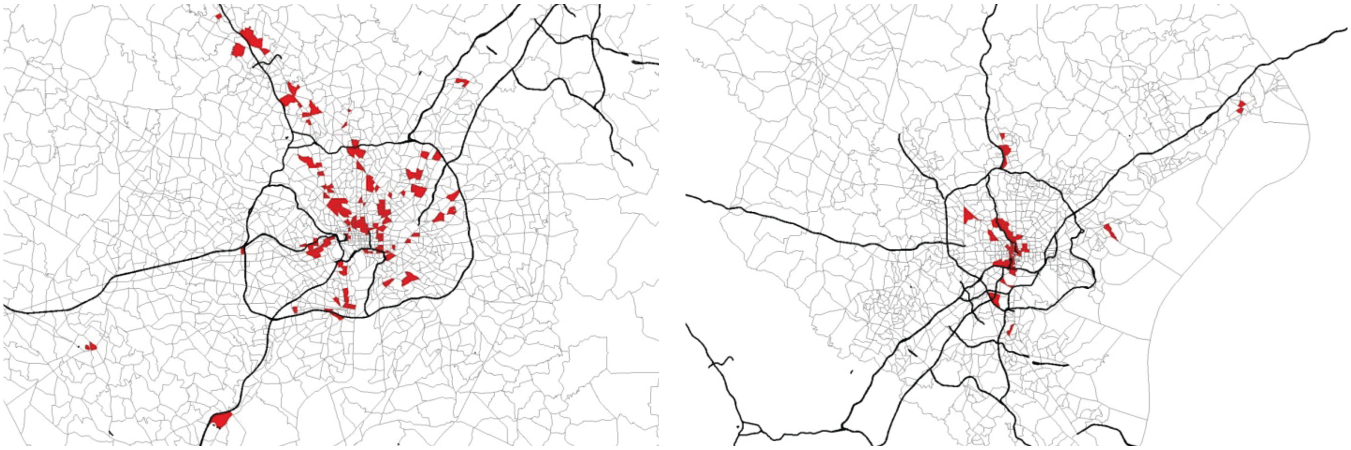
$$\frac{\text{rank}^{\text{entropy}}_{\text{TAZ}}}{n} \geq 0.30$$

$$X_{\text{HT}} \leq 0.45$$

$$\text{TAZ} \in \cup_{1 \leq i \leq n} \text{ball}^{T_i}_{0.5}$$

where

$D^{\text{TAZ}}_{\text{residential}}$ = residential density of TAZ = residential population area (acres);
$D^{\text{TAZ}}_{\text{employment}}$ = employment density of TAZ = employment population area (acres);
$D^{\text{avg}}_{\text{residential}}$ = average residential density for entire metropolitan area;
$D^{\text{avg}}_{\text{employment}}$ = average employment density for entire metropolitan area;
B_{TAZ} = average block size for each TAZ (mi^2);



(a) (b)

FIGURE 1 Locations of TOD zones in (*a*) Washington, D.C., and (*b*) Baltimore.

B_{avg} = average block size for entire metropolitan area (mi^2);
$\text{rank}_{\text{TAZ}}^{\text{entropy}}$ = the rank of entropy (TAZ) when sorted decreasingly according to entropy [the formula for entropy has been widely used in several land use– and transportation-related articles (*23, 24*)];
X_{HT} = housing and transportation affordability, which is housing and transportation cost as a percentage of household income;
$\text{ball}_{0.5}^{T_i}$ = circle with radius of 0.5 mi around point T_i; and
T_i, $1 \le i \le n$ = point where transit station is located.

By use of this method, 44 TOD sites were identified in the Washington, D.C., metropolitan area and 10 TOD sites were identified in the Baltimore metropolitan area. The areas highlighted in red in Figure 1 illustrate the TOD zones in the two cities and their positions with respect to the major arterials and roadways. Most of the TOD zones are concentrated either in downtown areas, where higher employment opportunities exist and better transit service is provided, or in close proximity to major roads and arterials, where access to various destinations is easy.

Data Collection and Processing

The 2007–2008 National Household Travel Survey data for the Washington, D.C., and Baltimore metropolitan areas were used for the household-level analysis. Table 1 provides summary statistics for the households living in the designated TOD areas in Washington, D.C., and Baltimore. In both metropolitan areas, people living in TODs have smaller household sizes, fewer automobiles, and lower levels of household income. This outcome is expected, as household sizes are smaller and less parking space is available in TOD areas than in suburban non–TOD areas, characteristics that attract smaller and lower-income households to live in TOD areas.

To calculate factors related to the built environment as part of the proposed definition of TOD, the most recent (2005) land use data for Washington, D.C., and Maryland with geographically coded population and employment information was obtained from the Metropolitan Washington Council of Governments and geographically coded census block data were downloaded from the TIGER database of the Bureau of the Census. Geographically coded rail transit station data were also obtained from the national TOD database.

To investigate the availability of affordable housing in TOD zones as part of the proposed definition of TOD, the location affordability index data set was used. The location affordability index includes the housing and transportation cost (which was developed by the U.S. Department of Housing and Urban Development) as a percentage of household annual income at the census block group level. The location affordability index was then aggregated to the TAZ level by the use of ArcGIS software.

TABLE 1 Summary Statistics for Households in TOD and Non–TOD Zones

Sociodemographic Variable	Washington, D.C.		Baltimore	
	TOD	Non-TOD	TOD	Non-TOD
Mean HH size	1.81	2.24	1.71	2.15
Mean HH vehicles	1.12	1.82	1.09	1.65
Mean HH students	0.35	0.54	0.38	0.5
Mean HH workers	1.13	1.22	0.97	1.13
Mean HH bikes	0.87	1.11	0.65	1.00
Mean HH income ($)	92,000	93,000	56,000	82,000
Number of observations	1,050	10,386	230	9,509

NOTE: HH = household.

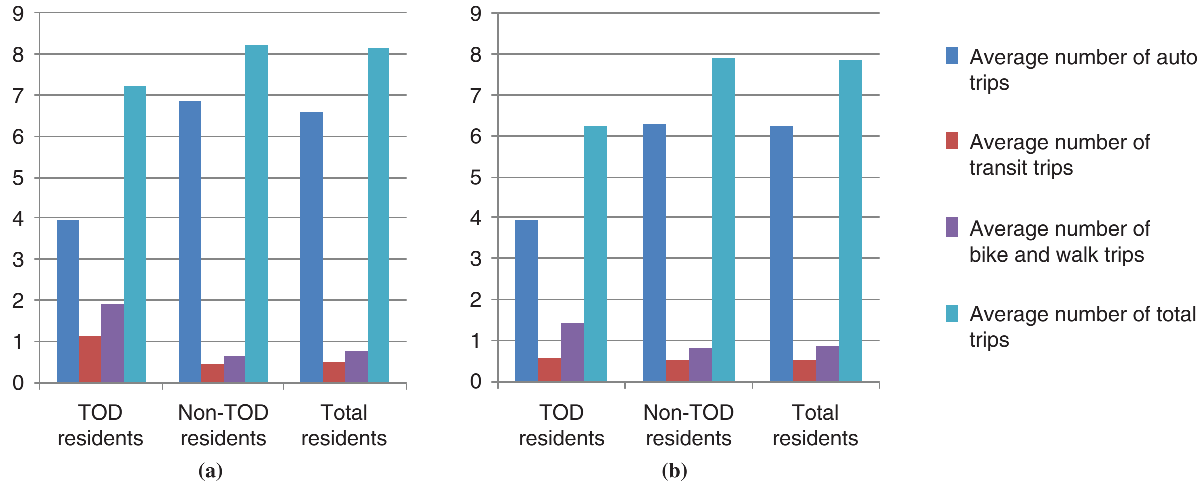


FIGURE 2 Descriptive statistics for number of trips by mode for (*a*) Washington, D.C., and (*b*) Baltimore.

Descriptive Statistics

Descriptive statistics on trip generation rates for total and mode-specific trips for households in Washington, D.C., and Baltimore are presented in Figure 2. In both case study areas, as expected, TOD areas have a lower number of auto trips, on average, than non–TOD areas. These statistics in general show that TOD promotes nonauto mode choices, such as the transit and the walk and bike modes.

The summary statistics for trip length and duration are presented in Table 2. Trips were divided into four categories: home-based work (HBW), home-based shopping (HBS), home-based other (HBO), and non–home-based (NHB) trips. The analysis excluded NHB trips, since the effect of living in a TOD on these trips was small and therefore negligible.

People living in TODs in both cities have shorter average trip lengths. For total trips, although the average trip length of TOD residents in Washington, D.C., is reduced by 40%, their travel duration is only slightly shorter than that of non–TOD residents. For the Baltimore area, the average travel time for trips is longer in TOD zones than non–TOD zones. This difference might be because of the higher nonauto mode share.

The statistics show in general that HBW trips are longer according to both travel distance and the amount of time spent on trips than other home-based trips, although in both cities, TOD residents seem to spend less time on commute trips. A comparison of HBW trips in Washington, D.C., with those in Baltimore showed that the overall trip length is shorter in Washington, D.C. However, the statistics show that this is not necessarily associated with a shorter trip time. In fact, the average travel time is approximately the same in both cities. This outcome might be because of the higher rate of transit use in Washington, D.C., which is a slower mode than the automobile. The descriptive statistics for mode share show that 39% of the commute trips of TOD residents in Washington, D.C., are made by transit, whereas this number is only 13% for Baltimore. Similarly, for HBS and HBO trips, it is observed that in most cases shorter trips are not associated with shorter travel times in either TOD areas or non–TOD areas.

The auto, transit, and walk and bike mode shares are compared in Figure 3 for TOD and non–TOD areas at the zone level. Non–TOD residents have a 17% higher auto mode share in Washington, D.C., and a 14% higher auto mode share in Baltimore. The summary statistics also confirm the hypothesis that proximity to transit stations and living in a mixed-use and high-density neighborhood result in higher rates of transit use. In general, Baltimore is shown to be a more auto-oriented city than Washington, D.C., probably because of the existence of a more efficient subway system in Washington, D.C. Descriptive statistics also indicate that among the three modes, walking or biking is the most influenced by the TOD designation. In both Washington, D.C., and Baltimore, living in transit-oriented neighborhoods results in an approximately 9% higher walk and bike mode share. However, these results show only the aggregate comparison between TOD and non–TOD areas and do not distinguish the effects of different land use and household characteristics.

TABLE 2 Summary Statistics for Trip Length and Duration

Development Type	Average Trip Length (mi)				Average Trip Time (min)			
	Total Trips	HBW Trips	HBS Trips	HBO Trips	Total Trips	HBW Trips	HBS Trips	HBO Trips
TOD								
Washington, D.C.	4.3	7.0	2.64	3.80	25.3	34.9	17.94	23.65
Baltimore	6.1	9.9	3.38	5.42	27.7	34.2	19.91	27.77
Non-TOD								
Washington, D.C.	7.6	12.6	4.83	6.31	25.8	37.8	18.25	22.71
Baltimore	6.9	11.5	4.41	5.94	26	36.9	18.86	23.75

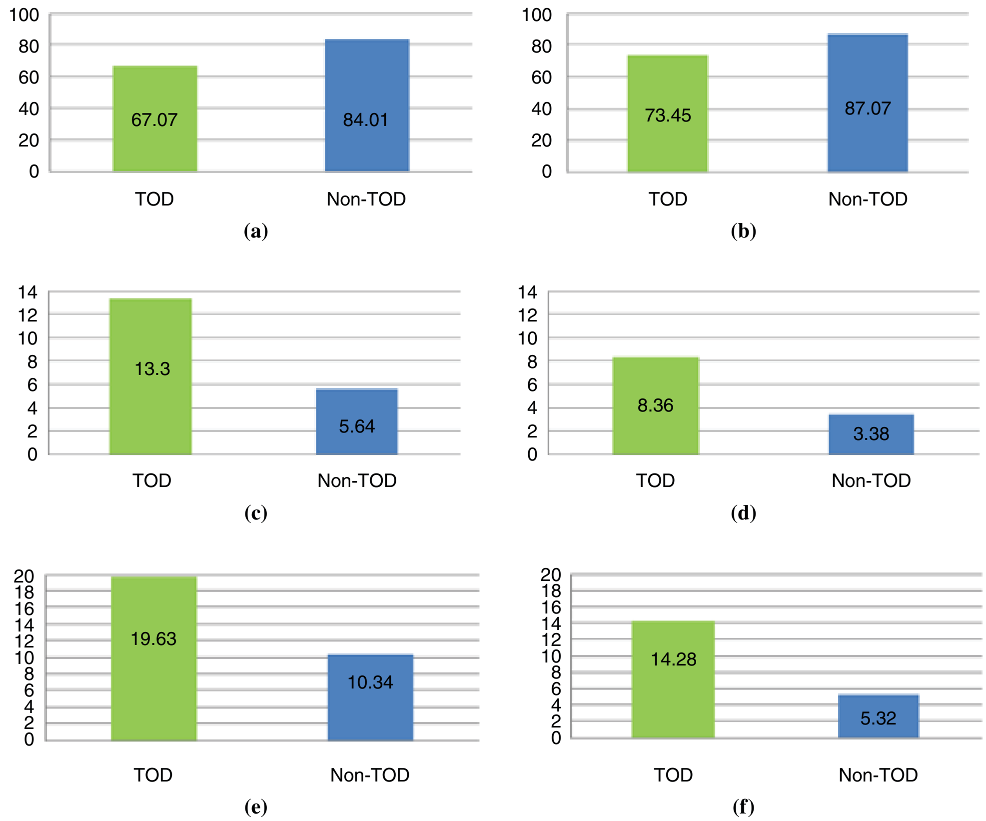


FIGURE 3 Mode share (percentage) distribution: auto mode share for (*a*) Washington, D.C., and (*b*) Baltimore; transit mode share for (*c*) Washington, D.C., and (*d*) Baltimore; and walk and bike mode share for (*e*) Washington, D.C., and (*f*) Baltimore.

Modeling Approach

Trip Generation and Trip Distribution and Length Model

The multiple-regression method was used to model trip generation with two sets of predictors: household characteristics and whether the household's residence location was in a TOD. Inclusion of household characteristics in the model controls for the possible effects of those variables and also can provide better estimates of the effects of variables for the built environment on travel behavior in TOD areas. It makes the results more reliable than those from previously performed analyses that did not include these factors because of either a lack of data or the scope of the analysis.

Equation 1 presents the structure of the trip generation model. The dependent variables include the number of auto, nonauto, and total trips. The socioeconomic variables included in the models are household size, number of vehicles, household annual income, number of children, and number of workers in the household.

$$\text{trips} = f\left(\text{SES}_{ij}, \text{TOD}_j\right) \tag{1}$$

where

trips = number of trips by mode,
SES_{ij} = socioeconomic attributes of household i living in zone j, and
TOD_j = dummy variable indicating whether zone j is a TOD.

The model specification for the trip length model is similar to that of the trip generation model and uses the sociodemographic characteristics of households and a binary variable indicating whether a zone is a TOD.

Mode Share Model

The seemingly unrelated regression method at the zone level was used to model mode share through the use of three primary modes: auto, transit, and walk and bike. The percentage of the mode share of all trips originating from each TAZ is the dependent variable, and the independent variables include land use variables and the average household characteristics of the zone (Equation 2).

$$\text{auto} = \alpha_1\left(\text{SES}_j\right) + \beta_1\left(\text{BE}_j\right) + \varepsilon_1$$

$$\text{transit} = \alpha_2\left(\text{SES}_j\right) + \beta_2\left(\text{BE}_j\right) + \varepsilon_2$$

$$\text{walk and bike} = \alpha_3\left(\text{SES}_j\right) + \beta_3\left(\text{BE}_j\right) + \varepsilon_3 \tag{2}$$

subject to

$$\alpha_1 + \alpha_2 + \alpha_3 = 0$$

$$\beta_1 + \beta_2 + \beta_3 = 0$$

where

auto = percentage of auto mode share originating from zone j;
transit = percentage of transit mode share originating from zone j;
walk and bike = percentage of walk and bike mode share originating from zone j;
SES_j = socioeconomic attributes of a household living in zone j;
BE_j = attributes of built environment in zone j, including residential density, employment density, entropy, and TOD binary variable; and
α, β, and ε = parameters.

This modeling approach allows the analysis to be performed with a set of simultaneous equations and preset constraints. The main constraint used in the model is that the coefficients for each variable in each row should sum to zero. This constraint was added to capture the changes in different modes simultaneously. Furthermore, mode-specific variables can be used in this approach.

Modeling of mode share was done in two steps: (*a*) only household characteristics were controlled for so that the TOD variable captures all the effects of the built environment and transit proximity at the same time, and (*b*) land use variables were added to the model to distinguish the effect of the built environment from other factors in TOD, such as transit proximity.

RESULTS AND DISCUSSION OF RESULTS

Trip Generation Modeling Results

The results of trip generation for total trips, nonauto trips (including transit, bike, and walk), and auto trips are presented in Table 3. Table 3 shows that when the socioeconomic attributes of households are controlled for, living in TODs is associated with higher numbers of total trips. This result confirms that people living in TOD areas do not make fewer trips, but, rather, switch to other modes (e.g., transit) to make trips. The results indicate that TOD residents make about 0.51 and 0.28 more trips in Washington, D.C., and Baltimore respectively.

Households living in TOD areas make about 1.71 and 0.74 more nonauto trips in Washington, D.C., and Baltimore, respectively. The regression model for auto trips shows that households living in a TOD make about 1.2 and 0.6 fewer auto trips in Washington, D.C., and Baltimore, respectively. These numbers divided by the average number of auto trips obtained from descriptive statistics (6.6 for Washington, D.C., and 6.2 for Baltimore) give reductions in auto trips for households in TODs of about 10% and 18% in Washington, D.C., and Baltimore, respectively. Overall, the results indicate that TODs in Washington, D.C., are more successful at reducing the auto mode share and promoting nonauto modes than TODs in Baltimore.

All socioeconomic variables have the expected sign for and direction of influence on trips made by various modes. Larger households with higher annual incomes tend to make more trips regardless of mode choice. Vehicle ownership and number of children both have positive effects on the number of auto trips and negative effects on the number of nonauto trips, since the presence of children makes it harder to coordinate transit trips and car ownership inevitably encourages driving. Households with higher numbers of commuters make fewer auto trips and use transit more often. This outcome could be because transit systems are more efficient during the morning and evening commuting hours and the use of transit for commuting is easier than the use of transit for other trip purposes.

Trip Distribution Modeling Results

Table 4 presents the results of the regression model for trip length for all trips and HBW, HBS, and HBO trips. The results show that living in TODs significantly decreases the trip length by 40% for TOD residents in Washington, D.C., and by 25% for TOD residents of Baltimore. The results suggest that this effect is larger in magnitude than the effect of the household's socioeconomic characteristics, although they are all statistically significant. HBW trips are 40% shorter for TOD residents in Washington, D.C., and 37% shorter for TOD residents in Baltimore.

Living in a TOD reduces the average length of HBS trips by 46% for TOD residents in Washington, D.C., and by 41% for TOD residents in Baltimore. For HBO trips, these values are 40% and 18% for Washington, D.C., and Baltimore, respectively. Vehicle ownership and income have a positive effect on the length of all trips. This result is reasonable, since the auto is a more convenient mode for longer trips and lower-income families prefer not to travel to destinations far away because of the corresponding costs.

The disparities in the model coefficients and descriptive statistics for trip length observed between the two metropolitan areas might

TABLE 3 Trip Generation Model of Households

	Total Trips		Transit, Bike, and Walk Trips		Auto Trips	
Dependent Variable	Washington, D.C.	Baltimore	Washington, D.C.	Baltimore	Washington, D.C.	Baltimore
Household size	2.51	2.3	0.65	0.81	1.82	1.44
Household's income	0.21	0.23	0.11	0.15	0.10	0.08
Number of children	0.88	0.97	–0.33	–0.41	0.75	1.03
Number of vehicles	0.23	0.32	–0.83	–1.05	1.06	1.38
Number of workers	—[a]	0.11	0.33	0.28	–0.34	–0.18
Household living in TOD	0.51	0.28[b]	1.71	0.74	–1.22	–0.59
R^2	.81	.81	.34	.32	.74	.73

NOTE: Unless otherwise designated, all coefficients are significant at the 95% level.
[a]Coefficient not statistically significant; variable deleted from the model.
[b]Coefficient not statistically significant at 95% level.

TABLE 4 Regression Model Results for Trip Length

	ln(avg. trip length per HH)		ln(avg. length of HBW trips per HH)		ln(avg. length of HBS trips per HH)		ln(avg. length of HBO trips per HH)	
Dependent Variable	Washington	Baltimore	Washington	Baltimore	Washington	Baltimore	Washington	Baltimore
Household size	–0.09	–0.08	–0.05	–0.05	—[a]	—[a]	–0.09	0.04[b]
Ln(household's income)	0.12	0.1	0.16	0.15	0.05	0.04	0.12	0.08
Number of children	—[a]	—[a]	0.13	0.13	—[a]	—[a]	—[a]	–0.17
Number of vehicles	0.18	0.21	0.2	0.24	0.27	0.28	0.18	0.19
Number of workers	0.2	0.19	—[a]	—[a]	–0.08	–0.07	0.2	–0.04
Household living in TOD	–0.5	–0.28	–0.5	–0.46	–0.6	–0.52	–0.5	–0.2
R^2	.79	.77	.84	.81	.45	.4	.79	.57

NOTE: Unless otherwise designated, all coefficients are significant at the 95% level. Avg. = average.
[a]Coefficient not statistically significant; variable deleted from the model.
[b]Coefficient not statistically significant at 95% level.

exist for several reasons. First, both population and employment densities are higher in Washington, D.C., and more people may be attracted to live and work in the Washington, D.C., area to enjoy its various benefits. In fact, many people living in Baltimore travel to Washington, D.C., on a daily basis. This portion of the Baltimore population must drive to Washington, D.C., as a fast and efficient transit service connecting downtown Washington, D.C., to Baltimore does not exist. That fact could be a probable cause of the longer trip length for TOD residents of Baltimore. However, HBW trips in Baltimore are shorter in duration, probably because of the higher share of auto mode (which is faster).

Second, parking space is not as limited and expensive in Baltimore as it is in the Washington, D.C., area, and neighborhoods in Baltimore are not as pedestrian friendly and do not have as great a level of mixed use as those in Washington, D.C. Thus, people make fewer walking trips—which, as intuition would suggest, are shorter than trips by other modes—and more auto trips to reach destinations farther away. Lastly, in general, trips are longer in the Baltimore area in part because more people who favor driving choose to live in Baltimore, where policies are more supportive of driving than are policies in the Washington, D.C., area (the issue of self-selection). Moreover, the transit system in Washington, D.C., is more efficient than that in Baltimore because it provides more frequent service and provides greater coverage to different parts of the city. The average trip length for shopping is shorter for residents of TODs in Washington, D.C., than residents of TODs in Baltimore because of the existence of more shopping opportunities near transit.

Mode Share Modeling Results

The results for mode share in Table 5 indicate that trips originating from TODs in Washington, D.C., have significantly higher transit and walk and bike mode shares. In the first step, after sociodemographic factors are controlled for, the results indicate that living in a TOD is correlated with a 12.13% decrease in auto mode share and 4.72% and 7.4% increases in transit and walk and bike mode shares, respectively. Household size does not significantly affect the mode share of trips, whereas the number of workers in the household has a positive effect on transit mode share. This outcome is because of the convenience of transit use among commuters in the Washington, D.C., area. The modeling results also confirmed the hypothesis that higher rates of car ownership increase auto dependency and lower transit ridership.

In the second step of modeling of the mode share for Washington, D.C., residents, after land use variables were separated from living in TODs, the TOD coefficient shows that living in TODs results in a 7.3% reduction in auto mode share and 3.75% and 3.55% increases in transit and walk and bike mode shares, respectively. The coefficients for the land use variables show that, as expected, in high-density mixed-use urban areas, more sustainable and environmentally friendly modes of transit and walking and biking are encouraged and automobile use is discouraged. A one-unit increase in residential density would result in 0.24% and 0.12% increases in walk and bike mode share and transit mode share, respectively.

The results indicate that in Baltimore, trips originating from TODs have a 8.95% lower auto mode share and 2.46% and 6.49% higher transit and walk and bike mode shares, respectively. The average number of workers has a positive influence on transit mode share, and if average car ownership increases by one unit, auto mode share would increase by 7.52% and transit and walk and bike mode share would decrease by 3.39% and 4.14%, respectively.

In the second step of modeling of the mode share for Baltimore residents, the results have trends different from those of modeling of the mode share for Washington, D.C. residents. The effect of TOD on mode share is not statistically significant in Baltimore. This result may be because of the weak performance of the transit systems in Baltimore and their relative inefficiency compared with that of the transit systems in Washington, D.C. In the second step, household size has a significant impact on mode share. An increase in household size results in a higher level of use of nonauto modes.

The direction but not the magnitude of the effect of socioeconomic and demographic variables is the same in both metropolitan areas. The income factor has a significant positive effect on the walk and bike mode share. A justification for this result may be that high-income groups use the nonauto mode share for recreational purposes. After auto ownership is controlled for, income does not have a significant effect on auto mode share in either Baltimore or Washington, D.C. As expected, car ownership is the most influential factor determining the mode of travel in both Washington, D.C., and Baltimore.

The results for land use coefficients are inconsistent, and to some extent, the results for the effect of entropy are unexpected.

TABLE 5 Mode Share Model Results

Dependent Variable	Mode Share Percentage, Washington, D.C.: Mode Share Model, First Step			Mode Share Model, Second Step			Mode Share Percentage, Baltimore: Mode Share Model, First Step			Mode Share Model, Second Step		
	Auto	Transit	Walk and Bike	Auto	Transit	Walk and Bike	Auto	Transit	Walk and Bike	Auto	Transit	Walk and Bike
Avg. household size	−0.54[a]	−0.70	1.24	−1.14	−0.55[a]	1.69	−1.16[a]	−0.41[a]	0.75[a]	−1.80	0.52	1.28
Avg. income	−0.29[a]	−0.48[a]	0.77	−0.08[a]	−0.54	0.62	−0.23[a]	−0.32	0.086[a]	−0.05[a]	−0.24	0.29
Avg. number of vehicles	10.37	−5.08	−5.29	7.91	−4.26	−3.65	7.61	−3.43	−4.18	3.08	−1.91	−1.17
Avg. number of workers	−3.30	2.52	0.78[a]	−2.24[a]	2.23	0.01[a]	−1.08[a]	1.27	0.19[a]	0.92[a]	0.60[a]	−1.52
Residential density	—[b]	—[b]	—[b]	−0.36	0.12	0.24	—[b]	—[b]	—[b]	−0.75	0.24	0.51
Employment density	—[b]	—[b]	—[b]	−0.10	0.02	0.08	—[b]	—[b]	—[b]	−0.12	0.05	0.07
Mixture–entropy	—[b]	—[b]	—[b]	1.78[a]	−2.10[a]	0.34[a]	—[b]	—[b]	—[b]	−4.1	−0.83[a]	4.88
Constant	72.11	17.32	10.57	77.46	16.45	6.09	77.92	10.25	11.83	96.19	5.37	0.58
Household living in TOD	−12.13	4.72	7.41	−7.30	3.75	3.55	−8.95	2.46	6.49	−0.86[a]	0.28[a]	0.58[a]
R^2	.61	.39	.31	.53	.29	.23	.54	.34	.26	.48	.30	.21

NOTE: Unless otherwise designated, all coefficients are significant at the 90% level.
[a]Coefficient not statistically significant at 90% level.
[b]Coefficient not statistically significant; variable deleted from the model.

In Washington, D.C., the level of mixed use (entropy) has a positive but statistically insignificant influence on auto mode share. In contrast, in Baltimore, entropy has a significant and negative influence on auto mode share.

To check the reliability of the model, a TAZ with an extreme case consisting of a residential density and employment density of 100 people per acre was assumed. When these numbers were placed into the model for Washington, D.C., and averages for the other variables were used, the results showed a 35% auto mode share, 28% transit mode share, and 37% walk and bike mode share. These results show that even in extreme cases, the model generates reasonable outputs.

On the basis of the modeling results, residential density and employment density both have a significant effect on increasing the nonauto mode share. Furthermore, when only household characteristics are controlled for, trips originating from TODs have an auto mode share that is about 10% less than that of trips originating from non-TODs.

CONCLUSION

As part of an ongoing analysis of TODs in the greater Washington, D.C., area, this study used advanced modeling methods to explore the impacts of living in TODs on several travel behavior indicators. Trip generation, trip length, and the mode share of trips in TOD areas were modeled on the basis of the observed data. The research offers some insightful results for Washington, D.C., and Baltimore and show that TOD is associated with an overall higher level of trip generation, increased transit ridership, and shorter trip lengths.

The statistical models indicated that TOD residents make about 4% to 6% more trips, a finding that implies that TODs provide a more active lifestyle and a higher quality of life and result in more vibrant and livable communities. TOD residents take transit more often than residents of non–TOD zones, and their trips are, on average, 25% to 40% shorter in length than those of residents of non-TODs. However, the duration of trips is, on average, higher in some cases, probably because of the higher share of transit, bike, and walk modes. Trips by transit require longer access, transfer, and waiting times. When these results are combined with the findings from the mode share models, one can understand how and to what extent factors like transit proximity, residential density, and employment density encourage nonauto trips and transit ridership.

The different results of the mode choice model for Baltimore and Washington, D.C., indicate the importance of transit accessibility, urban form, and the distribution of jobs and houses as determinants of the mode of travel. Further studies are needed to investigate other factors to make TODs effective and successful.

Some differences in the results of the two cases analyzed were found. In Washington, D.C., the effect of TOD on the promotion of transit is much higher, and TOD leads to less driving for residents of TODs in Washington, D.C., than residents of TODs in Baltimore. The descriptive statistics and models developed for trip length also indicate that TOD residents in Washington, D.C., make shorter trips.

This study opens the opportunity for future research, such as (*a*) the development of more sophisticated models and the generation of improvements to the various models developed in this research by consideration of the effect of self-selection (this research might require the collection of additional data on attitudes and data from other household travel surveys); (*b*) the use of more advanced methods to model the travel behavior indicators studied; and (*c*) enhancement of the definition of TOD and regression models through the addition of accessibility measures and indicators of transit performance, such as frequency.

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