Understanding Transit Ridership Demand for a Multi-Destination, Multimodal Transit Network in an American Metropolitan Area: Lessons for Increasing Choice Ridership While Maintaining Transit Dependent Ridership

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REPORT 11-06

UNDERSTANDING TRANSIT RIDERSHIP DEMAND FOR A MULTI-DESTINATION, MULTIMODAL TRANSIT NETWORK IN AN AMERICAN METROPOLITAN AREA: LESSONS FOR INCREASING CHOICE RIDERSHIP WHILE MAINTAINING TRANSIT DEPENDENT RIDERSHIP

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16. Abstract

This study examines the factors underlying transit demand in the multi-destination, integrated bus and rail transit network for Atlanta, Georgia. Atlanta provides an opportunity to explore the consequences of a multi-destination transit network for bus patrons (largely transit-dependent riders) and rail patrons (who disproportionately illustrate choice rider characteristics). Using data obtained from the 2000 Census, coupled with data obtained from local and regional organizations in the Atlanta metropolitan area, we estimate several statistical models that explain the pattern of transit commute trips across the Atlanta metropolitan area.

The models show that bus riders and rail riders are different, with bus riders exhibiting more transit-dependent characteristics and rail riders more choice rider characteristics. However, both types of riders value many of the same attributes of transit service quality (including shorter access and egress times and more direct trips) and their use of transit is influenced by many of the same variables (including population and employment). At the same time, the factors that influence transit demand vary depending on the type of travel destination the rider wishes to reach, including whether it is the central business district (CBD) or a more auto-oriented, suburban destination.

The results of the study offer new insights into the nature of transit demand in a multi-destination transit system and provide lessons for agencies seeking to increase ridership among different ridership groups. The results suggest that more direct transit connections to dispersed employment centers, and easier transfers to access such destinations, will lead to higher levels of transit use for both transit-dependent and choice riders. The results also show that the CBD remains an important transit destination for rail riders but not for their bus rider counterparts. Certain types of transit-oriented development (TOD) also serve as significant producers and attractors of rail transit trips.

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EXECUTIVE SUMMARY

INTRODUCTION

There is a growing body of evidence, including earlier Mineta Transportation Institute-sponsored research, showing that multi-destination transit systems are far more effective in attracting passengers and more efficient in use of resources to carry each passenger than central business district (CBD)-focused systems. At the same time, however, evidence is beginning to show that multi-destination transit systems appeal largely to transit-dependent riders (also called captive riders), whose demand for transit service appears to be highly elastic with respect to the shortening of transit travel time between origin and destination. Given the interest in using transit investments to lure people from their automobiles in order to reduce greenhouse gas emissions and reduce congestion, it is imperative that the appeal of such systems to choice riders (also called discretionary riders) also be understood. However, this issue remains as yet relatively unexplored.

In this study, we examine the Atlanta region's transit system, and we derive lessons that can be applied to transit systems elsewhere that would like to increase ridership among choice and transit-dependent riders by better serving increasingly dispersed travel destinations through a multi-destination transit network. Atlanta provides an opportunity to explore the consequences of a multi-destination transit network for bus patrons (largely transit-dependent riders) and rail patrons (who disproportionately illustrate choice rider characteristics). This study is an extension of earlier work by the authors on the determinants of transit ridership demand for an overwhelmingly transit-dependent rider population in Broward County, Florida, whose transit agency (Broward County Transit, BCT) operates a bus-only multi-destination transit system. Atlanta provides an opportunity to extend this work to a metropolitan area with a much larger, multimodal, multi-destination transit system (Metropolitan Atlanta Rapid Transit Authority, MARTA) and to explore differences in the determinants of transit rider demand for different groups of transit riders.

DATA SOURCES AND METHODOLOGY

The method used in this research is to specify and estimate several statistical models that predict bus and rail transit work trips (the dependent variable) from one part of a metropolitan area (traffic analysis zone or TAZ) to another. In other words, we develop statistical equations that allow us to explain the influence of different types of variables on transit ridership. Explanatory variables include describing demographic and land use characteristics in zones where trips begin and end, as well as those describing the general cost of making the trip in terms of travel time. Our resulting models fall within a category of models known as direct demand models. The models use travel time estimates from the Atlanta regional transportation demand model runs for 2002, but the models used in this study are not sub-models of the models used by the ARC.

In this study, we employ two sets of models. For one set of models, the dependent variable consists of transit users who identified themselves as "bus or trolley bus" riders in the 2000 Census Transportation Planning Package (CTPP). For the other set of models, the dependent variable consists of transit users who identified themselves as "subway or elevated" riders in the 2000 CTPP. Many respondents undoubtedly used a combination of bus and rail modes to complete their trips, but the 2000 CTPP did not give such transit users a box to check. Multimodal respondents were forced to identify themselves as either "bus or trolley bus" or "subway or elevated" riders. Therefore, we treat the former group as (self-identified) bus riders and the latter group as (self-identified) rail riders, although many riders in either category undoubtedly use multiple modes for their trips. The explanatory variables used in the models include socioeconomic variables from the 2000 CTPP, land use variables defined by the local metropolitan planning organization (MPO), and variables that measure transit service quality (broken into three components: in-vehicle, out-of-vehicle, and transfer time) obtained from the travel time skims of the regional travel demand model.

RESULTS

Bus riders were overwhelmingly transit-dependent riders, and rail riders included a disproportionate number of choice riders. By and large, rail riders tend to come from zones with high levels of vehicle access and bus riders from zones with low levels of vehicle access. The model results highlight important similarities as well as differences between the two rider groups. In terms of similarities, both bus and rail trips are produced in larger numbers in zones with higher populations and higher population densities, and attracted to destinations with larger numbers of jobs, but generally not areas with the highest densities of employment. Both bus and rail riders are also generally quite sensitive to in-vehicle travel time and transfer time.

In terms of differences between bus and rail riders, bus riders tend to come from zones with lower income, lower vehicle access (as noted above), and higher minority populations. While rail riders also disproportionately come from minority zones, they come from zones with high levels of vehicle access and the income variable is not significant, except in the cases of rail riders destined to more dispersed destinations, who tend to come from zones with lower incomes, but also relatively high levels of vehicle access. Bus riders do not place the same importance on out-of-vehicle travel time to transit as do rail riders, suggesting that bus stops are distributed in such a way that most patrons can easily access the stops to board a bus and then exit the vehicle to reach their final destination. Rail riders, on the other hand, do place a premium on out-of-vehicle travel time, suggesting that they have difficulty with access to the stations and/or reaching their final destinations. This is not surprising given the small number of rail stations and their spatial distribution relative to the patterns of population and employment in Atlanta.

The results for the land-use variables also reveal important differences between bus and rail riders as well as insights into the importance of transit-oriented development (TOD). Bus riders in Atlanta are not influenced by the presence of a transit-oriented development at either the origin or destination. The CBD does not emerge as a statistically significant destination for bus riders; indeed, lower density employment clusters emerge as important destinations for these riders. For rail riders, on the other hand, the CBD does emerge as an important travel destination, and two of Atlanta's TODs (Midtown and North Avenue) emerge as important contributors to rail patronage, in excess of what would otherwise be predicted by the employment levels or densities of these zones.

POLICY IMPLICATIONS

Transit commuters who consider themselves bus riders seem to want a grid of routes connecting the region's employment centers with faster, more direct, and more frequent service. Shelters, good pedestrian connections and other amenities at transfer points are also implied as being important to these largely transit-dependent riders. With such amenities, many more transit-dependent riders will use transit, presumably relying less on friends and relatives for chauffeured auto rides. Many of these riders appear to use trains to speedily move from one part of the region to the other, relying on buses at one or both ends of the trip, so good transfer connections between buses and trains will also increase ridership of transit-dependent riders.

Transit commuters who consider themselves rail riders, who primarily access transit by automobile, want trains to take them to major employment destinations, including the CBD and some TODs. Serving more of these riders, who are more likely to be choice riders than their bus rider counterparts, will require extending lines into job-rich corridors and developing stations and station environments in those corridors with those qualities typical of the TODs like North Avenue and Midtown. The more that can be done with a network of several regional rapid transit lines, the greater the number of choice riders using transit in the Atlanta region. If a transfer to a bus is required to complete the trip, the service will attract lower status workers who none-the-less will live in auto-oriented environments and will make use of autos to access the system. Are these choice riders, as well? The model results suggest that many of them are choice riders. Their numbers would increase in a more expansive regional network of regional rapid transit lines that had excellent bus transfers to jobs within one to two miles of stations.

A grid of local buses tied into such a regional rapid transit system would greatly increase the number of transit-dependent riders, as well, because it would enable them to reach additional employment opportunities that are presently difficult or impossible for them to reach by transit. These results derive from a study of Atlanta, Georgia, but given their consistency with lessons derived from other locales, they provide important policy guidance to transit agencies seeking to increase ridership by both rider groups.

I. INTRODUCTION

This report examines how multi-destination, integrated bus-rail transit systems can better serve choice riders while continuing to expand the travel opportunities of the transit-dependent. The background is a growing body of evidence, including earlier Mineta Transportation Institute-sponsored research, showing that multi-destination transit systems are far more effective in attracting passengers and more efficient in use of resources to carry each passenger than central business district (CBD)-focused systems. At the same time, however, evidence is beginning to show that multi-destination transit systems appeal largely to transit-dependent riders (also called captive riders), whose demand for transit service appears to be highly elastic with respect to the shortening of transit travel time between origin and destination. Given the interest in using transit investments to lure people from their automobiles in order to reduce greenhouse gas emissions and reduce congestion, it is imperative that the appeal of such systems to choice riders (also called discretionary riders) also be understood. However, this issue remains as yet relatively unexplored.

The purpose of this study is to analyze the structure of transit demand in different segments of a multi-destination, multimodal rail and bus transit network to understand which elements of the network appeal to transit-dependent riders and which elements appeal to choice riders and why the possible differential in appeal exists. The researchers sought to learn how to improve the attractiveness of such networks for choice riders without losing the networks' appeal to transit-dependent riders. We estimate models of transit demand between pairs of traffic analysis zones within a metropolitan area served by a multi-destination, multimodal transit system, following the method we used in an earlier study that analyzed transit demand in Broward County, Florida. In that case the transit system was a county-wide, all-bus grid network, and we estimated a model explaining transit work trips between all pairs of origins and destinations, which we defined as traffic analysis zones (TAZs). This study builds directly on that earlier work.

In this study, we examine the multi-destination, integrated bus and rail transit network for Atlanta, Georgia. Atlanta provides an opportunity to explore the consequences of a multi-destination transit network for bus patrons (largely transit-dependent riders) and rail patrons (who disproportionately illustrate choice rider characteristics). Using data obtained from the 2000 Census, coupled with data obtained from local and regional organizations in the Atlanta metropolitan area, we estimate several statistical models that explain the pattern of transit trips across the Atlanta metropolitan area. In other words, we develop statistical equations that allow us to explain the influence of different types of variables on transit ridership. We segment the statistical analysis based on a distinction between bus (transit dependent) and rail (choice rider) patrons and the type of travel destination (including the CBD, auto-oriented regional centers, and transit-oriented developments). The models explore the relationship between the number of trips from one TAZ to another as a function of a combination of land use, transit service quality, and socioeconomic characteristics of TAZ residents.

The results of the statistical models show that bus riders and rail riders are different, with bus riders exhibiting more transit-dependent characteristics and rail riders more choice rider characteristics. However, both groups of riders value many of the same attributes of transit service quality (including shorter access and egress times and more direct trips) and their use of transit is influenced by many of the same variables (including population and employment). At the same time, the factors that influence transit demand vary depending on the type of travel destination the rider wishes to reach, including whether it is the CBD or a more auto-oriented, suburban destination. The results of the study offer new insights into the nature of transit demand in a multi-destination transit system and provide lessons for agencies seeking to increase ridership among different ridership groups.

The results suggest that more direct transit connections to dispersed employment centers, and easier transfers to access such destinations, will lead to higher levels of transit use for both transit-dependent and choice riders. The results also show that the CBD remains an important transit destination for self-described rail riders, but not for their bus rider counterparts. Certain types of transit-oriented development also serve as significant producers and attractors of rail transit trips bound for certain kinds of travel destinations.

II. LITERATURE REVIEW

This research project is informed by a body of scholarship that examines the relationship between transit ridership and transit network design. The roots of this literature lie in studies that relate transit ridership trends to changing urban structure. Meyer, Kain, and Wohl's 1965 study highlighting the historic relationship between urban decentralization, the decline of the classic central business district, and declining transit patronage across the Unites States was an early landmark in this literature.[1] Subsequent work by Hendrickson,[2] Jones,[3] Mierzejewski and Ball,[4] Meyer and Gomez-Ibanez,[5] Pisarski,[6] and Taylor[7] has largely echoed these earlier findings, which emphasize the importance of a strong central business district and more centralized development patterns for transit ridership success. Paired with the findings of Pushkarev and Zupan's[8] classic study of the relationship between the strength of the central business district, residential density, and transit ridership in the New York metropolitan area, these studies suggest that the most appropriate transit systems planning strategy is for agencies to focus their systems on the traditional central business district (or its closest equivalent) and to support land use planning initiatives that intensify residential and employment development densities to be more transit supportive. Policies that promote CBD-focused express bus routes, and/or CBD-focused rail transit systems and policies that promote transit-oriented development (TOD) around rail transit stations are two important outgrowths of this body of scholarship.

The key problem that transit agencies face is that the central business district is no longer the primary center of economic activity in most metropolitan areas in the United States. Atlanta's CBD, for example accounted for only 6.4% of the 5-county region's 1,819,500 jobs in 2000[9] A transit system focused on the central business district might do a good job serving CBD-bound commuters, but it does so at the expense of providing poor or no service to other important travel destinations. The left panel in **Figure 1** illustrates this problem. Here, our hypothetical transit agency seeks to connect outlying neighborhoods to jobs in the central business district, as much of the traditional transit literature suggests it should do. Perhaps the transit agency provides express bus or even rail transit as premium, higher-speed services in some of these neighborhood-to-CBD travel corridors. But the schematic shows that such a transit system structure misses a large number of possible travel destinations, represented here as major employment clusters.

This is not to say that the transit agency will fail in its efforts to serve the neighborhood-to-CBD commuter travel market. The transit agency might provide high enough quality service to capture a large share of the CBD commuter travel market, perhaps as high, for example, as Pittsburgh's Port Authority of Allegheny County Transit (PAT) did when the authors studied that system in earlier research for the Mineta Transportation Institute.[10] PAT captured about 50 percent of the CBD-bound commute travel market. Nearly 75 percent of its routes served the Pittsburgh CBD. It was perhaps one of the closest real-world examples to the schematic shown in the left panel of **Figure 1**. Unfortunately, the Pittsburgh CBD had continued to decline in its relative importance as a regional employment center in the midst of continued regional employment decentralization. PAT staked its future to a declining travel market, a problem shown in its worsening riding habit and service productivity trends in recent years.

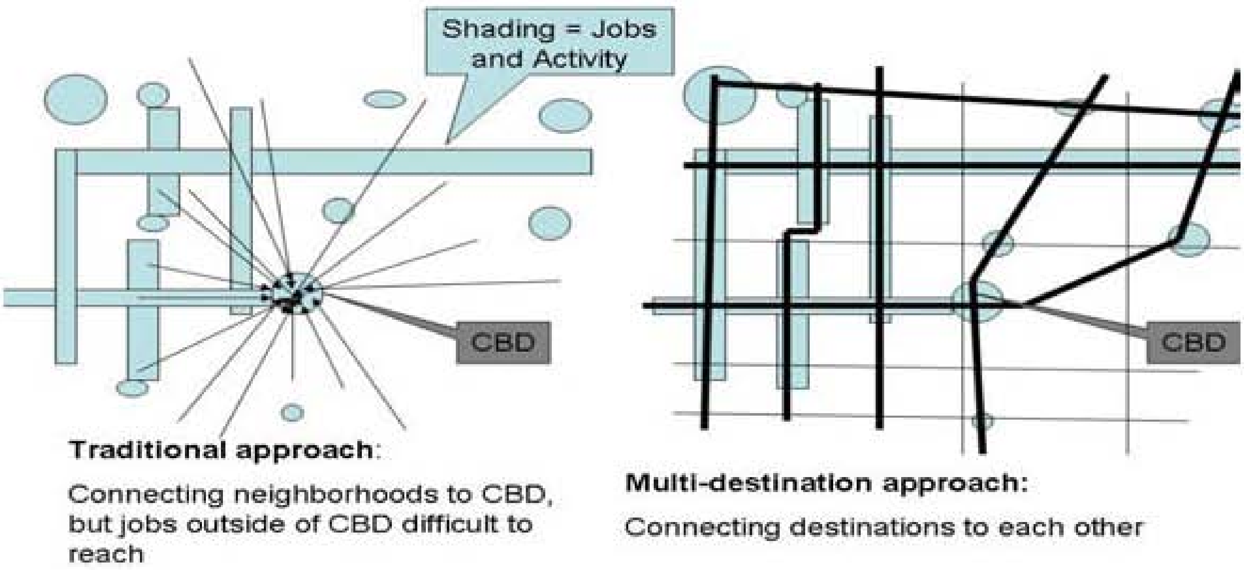

Figure 1. Traditional (Radial) Versus Multi-destination Transit Systems

The alternative to the traditional CBD-focused, radial transit systems structure is shown in the right panel of **Figure 1**. This panel shows what the literature terms a multi-destination system structure because it is designed to focus on a diverse array of possible travel destinations.[11] The multi-destination approach decentralizes the transit network to better fit the decentralized pattern of regional travel destinations. In the figure, the system is structured as a modified grid that connects the various employment clusters, one of which is the CBD. The strength of the multi-destination approach is that it does fit the dispersed pattern of activities. Its weakness is that it must rely on passenger transfers to facilitate the various connections, a key difference from the traditional radial structure that emphasizes one-seat rides whenever possible.

The transfer is the key to making the multi-destination system work, because it makes the linkages across the array of travel destinations possible for the rider and financially feasible for the transit agency. The transfer is also a potential stumbling block if it is not well-coordinated, given the extensive literature testifying to the negative view transit passengers have of transfers. Transit riders tend to weigh their time spent waiting for a bus and/or transferring as being much more onerous than the time spent traveling on a vehicle.[12] Because of this, many transit agencies have tried to avoid instituting transfers as much as possible. Other transit agencies, however, have recognized the opportunity for cross-regional connections that transfers provide and have planned their networks accordingly.

A recent body of literature has begun to examine the potential for multi-destination transit systems to increase transit ridership, although there is still a relative paucity of scholarship that directly compares radial with multi-destination systems or subjects multi-destination systems to rigorous statistical analysis. Mees's recent work employed case study analysis to demonstrate the effectiveness of multi-destination transit networks in North America, Europe, and Australasia, although he did not subject his case study investigations to rigorous comparative or statistical analyses.[13] The Center for Transit-Oriented Development's recent report on *Transit Oriented Development (TOD) and Employment* makes a descriptive and statistical argument that rail transit systems attract greater ridership, the more that they directly serve dispersed employment centers in addition to CBDs.[14]

The authors of this report have conducted a series of quantitative analyses of multi-destination transit systems in the United States, including direct comparisons of metropolitan areas with radial versus multi-destination transit networks. One report examined transit performance in all U.S. metropolitan statistical areas (MSAs) with between 1 million and 5 million persons in 2000.[15] The study stratified the metropolitan areas into four groups based on the structure of the transit network (radial or multi-destination) and network modal composition (bus-and-rail or bus-only). **Table 1** shows that the median multi-destination MSA outperformed its radial counterpart in terms of growth in riding habit (passenger miles per capita), while **Table 2** shows they also enjoyed better service productivity (load factor, the ratio of passenger miles to vehicle miles) than their radial counterparts. Across all U.S. transit systems, transit patronage (on a per capita basis) declined across the United States and service productivity (load factor) worsened between 1984 and 2004, but the deterioration in both performance measures was much less severe in metropolitan areas with multi-destination systems, as the two tables indicate. In both years, the metropolitan area with the median multi-destination system had higher riding habit and better service productivity than its radial counterpart. Higher riding habit and better service productivity did not come at the expense of deteriorating cost effectiveness (operating expense per passenger mile), as **Table 3** indicates. In this table, a higher cost number indicates less effective (more expensive) service. The table indicates that, as a group, multi-destination metropolitan areas were able to carry passengers at lower cost than their radial counterparts. A statistical examination of multi-destination transit system productivity in the same MSAs confirmed that the more decentralized a transit network was, the higher its service productivity.[16]

Table 1. System Orientation and Riding Habit (Passenger Miles per Capita)[17]

Multidestination Bus-and-Rail MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Atlanta	173.06	149.07	-13.86%
Dallas	63.33	66.12	4.40%
Denver	131.74	149.01	13.11%
Miami	125.14	163.80	30.90%
New Orleans	161.51	94.92	-41.23%
Portland	161.89	223.71	38.19%
Sacramento	74.41	67.66	-9.07%
Saint Louis	71.66	91.72	28.00%
San Diego	117.19	148.87	27.03%
Seattle	203.13	198.06	-2.49%
Median	*128.44*	*148.94*	*8.76%*

Radial Bus-and-Rail MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Buffalo	82.21	56.53	-31.23%
Cleveland	144.50	94.57	-34.56%
Hartford	68.50	59.43	-13.24%
Houston	97.41	99.28	1.92%
Jacksonville	55.01	48.28	-12.23%
Memphis	40.87	55.85	36.66%
Minneapolis-Saint Paul	105.62	86.36	-18.24%
Pittsburgh	130.46	116.43	-10.75%
Salt Lake City	70.66	80.66	14.15%
Median	*82.21*	*80.66*	*-12.23%*

Multidestination Bus-Only MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Las Vegas	22.67	107.05	372.17%
Milwaukee	143.49	101.99	-28.93%
Norfolk	53.06	51.32	-3.26%
Phoenix	40.16	53.49	33.20%
Rochester	53.67	39.13	-27.10%
San Antonio	101.14	82.84	-18.09%
Median	*53.36*	*68.16*	*-10.68%*

Radial Bus-Only MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Albany	53.40	45.90	-14.05%
Austin	60.16	80.02	33.02%
Birmingham	21.32	17.13	-19.64%
Charlotte	22.23	36.68	65.02%
Cincinnati	81.42	72.40	-11.08%
Columbus	82.39	25.15	-69.48%
Dayton	85.99	41.61	-51.61%
Grand Rapids	16.37	17.03	4.04%
Greensboro	11.67	9.50	-18.65%
Greenville	4.46	4.94	10.69%
Indianapolis	44.54	22.82	-48.76%
Kansas City	33.83	25.74	-23.92%
Louisville	86.59	40.42	-53.32%
Nashville	34.97	20.15	-42.39%
Oklahoma City	12.52	16.75	33.80%
Orlando	27.24	68.62	151.96%
Providence	55.51	55.07	-0.78%
Raleigh	15.96	27.64	73.13%
Richmond	69.86	29.39	-57.93%
Tampa	38.64	38.82	0.48%
Median	*36.80*	*28.51*	*-12.56%*

Table 2. System Orientation and Productivity (Passenger Miles per Vehicle Mile)[18]

Multidestination Bus-and-Rail MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Atlanta	13.88	13.79	-0.72%
Dallas	11.86	8.60	-27.50%
Denver	9.17	7.47	-18.51%
Miami	11.38	10.34	-9.13%
New Orleans	14.64	8.68	-40.72%
Portland	8.41	12.25	45.53%
Sacramento	11.35	9.14	-19.52%
Saint Louis	7.77	9.16	17.92%
San Diego	10.95	11.15	1.77%
Seattle	11.21	9.38	-16.29%
Median	*11.28*	*9.27*	*-12.71%*

Radial Bus-and-Rail MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Buffalo	10.23	6.49	-36.61%
Cleveland	14.21	7.97	-43.95%
Hartford	10.24	6.77	-33.93%
Houston	9.81	9.56	-2.62%
Jacksonville	7.56	5.64	-25.44%
Memphis	6.67	8.18	22.61%
Minneapolis-Saint Paul	9.70	8.19	-15.63%
Pittsburgh	10.05	7.18	-28.59%
Salt Lake City	6.05	5.56	-8.11%
Median	*9.81*	*7.18*	*-25.44%*

Multidestination Bus-Only MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Las Vegas	10.90	11.23	3.05%
Milwaukee	9.29	7.19	-22.64%
Norfolk	8.31	7.65	-7.96%
Phoenix	8.88	6.29	-29.18%
Rochester	8.97	6.59	-26.45%
San Antonio	8.59	8.01	-6.74%
Median	*8.92*	*7.42*	*-15.30%*

Radial Bus-Only MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Albany	9.15	6.97	-23.83%
Austin	7.24	6.98	-3.55%
Birmingham	6.83	5.98	-12.50%
Charlotte	9.46	6.90	-27.02%
Cincinnati	9.95	9.11	-8.45%
Columbus	12.75	4.81	-62.27%
Dayton	12.96	5.56	-57.12%
Grand Rapids	5.63	5.73	1.79%
Greensboro	8.57	4.92	-42.63%
Greenville	5.24	7.00	33.73%
Indianapolis	10.66	6.31	-40.76%
Kansas City	6.59	4.74	-28.03%
Louisville	11.96	6.47	-45.89%
Nashville	8.53	5.28	-38.13%
Oklahoma City	4.80	5.11	6.46%
Orlando	7.22	9.37	29.93%
Providence	8.72	7.19	-17.55%
Raleigh	6.18	4.55	-26.29%
Richmond	11.57	5.96	-48.50%
Tampa	8.26	5.99	-27.52%
Median	*8.55*	*5.98*	*-26.65%*

Table 3. System Orientation and Cost Effectiveness (Operating Expense per Passenger Mile, 2006)[19]

Multidestination Bus-and-Rail MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Atlanta	$0.41	$0.57	40.08%
Dallas	$0.70	$0.71	1.60%
Denver	$0.70	$0.67	-4.61%
Miami	$0.62	$0.66	7.03%
New Orleans	$0.49	$0.98	97.42%
Portland	$0.72	$0.60	-16.08%
Sacramento	$0.52	$0.87	66.07%
Saint Louis	$0.87	$0.65	-25.92%
San Diego	$0.45	$0.52	15.96%
Seattle	$0.54	$0.82	51.67%
Median	*$0.58*	*$0.66*	*11.49%*

Radial Bus-and-Rail MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Buffalo	$0.66	$1.27	91.93%
Cleveland	$0.54	$0.88	62.75%
Hartford	$0.56	$0.92	63.71%
Houston	$0.60	$0.55	-8.57%
Jacksonville	$0.60	$0.87	45.16%
Memphis	$0.78	$0.65	-15.70%
Minneapolis-Saint Paul	$0.66	$0.83	25.59%
Pittsburgh	$0.76	$0.97	27.88%
Salt Lake City	$0.60	$0.91	51.56%
Median	*$0.60*	*$0.88*	*45.16%*

Multidestination Bus-Only MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Las Vegas	$0.49	$0.46	-5.40%
Milwaukee	$0.60	$0.87	43.97%
Norfolk	$0.62	$0.59	-5.46%
Phoenix	$0.64	$0.94	46.67%
Rochester	$0.70	$1.05	49.73%
San Antonio	$0.49	$0.57	16.61%
Median	*$0.61*	*$0.73*	*30.29%*

Radial Bus-Only MSAs	*1984*	*2004*	*Percent Change (1984-2004)*
Albany	$0.52	$0.84	60.93%
Austin	$0.99	$0.84	-15.12%
Birmingham	$0.76	$0.69	-8.33%
Charlotte	$0.52	$0.77	46.67%
Cincinnati	$0.64	$0.59	-8.33%
Columbus	$0.45	$1.45	225.23%
Dayton	$0.41	$1.05	156.68%
Grand Rapids	$0.83	$0.92	10.01%
Greensboro	$0.47	$1.18	154.39%
Greenville	$0.60	$0.59	-2.41%
Indianapolis	$0.50	$0.75	48.08%
Kansas City	$1.09	$1.16	7.06%
Louisville	$0.43	$0.84	97.51%
Nashville	$0.50	$0.95	88.28%
Oklahoma City	$0.97	$0.77	-20.80%
Orlando	$0.45	$0.50	12.40%
Providence	$0.62	$0.91	46.10%
Raleigh	$0.74	$0.89	20.14%
Richmond	$0.47	$0.90	92.51%
Tampa	$0.45	$0.82	83.94%
Median	*$0.52*	*$0.84*	*46.39%*

Earlier work by the same authors in a time-series analysis of transit ridership in Atlanta, Georgia found a positive relationship between employment decentralization within the transit agency service area and transit ridership, indicating that the decentralized transit network structure successfully connected the decentralized pattern of employment destinations within the transit agency service area.[20] By contrast, there was no statistical relationship between the amount of employment in the Atlanta CBD and transit patronage over the time series data.

In general, these recent studies by Brown and Thompson found that multi-destination route structures, in which rail lines serve as the backbone connecting major regional destinations and bus lines serve as ribs connecting to many other destinations and residential areas, outperform radial systems on three performance criteria. The multi-destination systems have higher regional transit ridership per capita, greater passenger occupancy per vehicle mile, and lower real operating expense per passenger or passenger mile. Multi-destination bus-rail systems greatly outperform express bus/local bus systems on these criteria.

These findings suggest that transit service planning and marketing strategies based on market segmentation, such as identifying peak period work trips to the CBD as the primary market to serve,[21] lead to less effective transit systems with perhaps less political support compared to systems oriented to a wide range of ridership, which is the case for multi-destination systems. The results also suggest that policy can have a significant impact on increasing or decreasing transit patronage,[22] in contrast to earlier studies that found external factors were the primary determinants of transit demand.[23] A recent study examining just the patronage of rail transit lines also found that performance was related to the multi-destination design of the rail systems. Those rail systems with higher ridership served major employment concentrations in the suburbs in addition to the CBD, while lower ridership systems served only CBD employment.[24]

While these studies suggest higher ridership and productivity associated with multi-destination transit systems, they do not address how different ridership markets are affected by different network structures. The focus on the CBD, a hallmark of radial network structures, reflects a desire to tap the commuter market, in particular riders who have a choice between using public transit or driving a car for their trip to and from work. The focus on commuter travel, and particularly travel by choice riders (sometimes also called discretionary riders), also relates to long-running interest in using transit to reduce traffic congestion and more recent interest in using transit to reduce vehicle miles traveled (VMT) as part of an overall greenhouse gas reduction strategy.

VMT reduction is considered an important policy goal necessary for reducing greenhouse gas emissions and reducing dependence on fossil fuel energy sources.[25] These authors argue that if policy can encourage densification of most new development, single occupant vehicle (SOV) use could be reduced, at least marginally, partly because transit would be made a more viable competitor to the auto. The Brown and Thompson findings suggest that policy makers could make a head start on reducing VMT of SOV users right now by taking transit to where development is going (for example, by implementing multi-destination transit systems); if over time, regions do in fact densify, particularly with Transit Oriented Development (TODs) around transfer nodes of a multi-destination, multimodal transit network, the modal diversion to transit would only increase.

This reasoning is valid if multi-destination transit systems grow their patronage by diverting trips from single occupant vehicle (SOV) users. Brown and Thompson assumed this to be the case until recently, but their Mineta-funded study of the evolution of eleven multimodal rail-bus systems in mid-sized metropolitan areas (metropolitan areas with populations from 1 million to 5 million) over a 25 year period suggests otherwise for at least some of the growth in patronage.[26] On-board surveys of transit passengers who use multi-destination, multimodal systems typically categorize passengers into three types: bus-only riders, bus-rail riders, and rail-only riders. Results are quite consistent between surveys in different parts of the country. They show that transit riders using buses exclusively and riders using combinations of buses and trains to get to where they are going exhibit similar characteristics, which are those of transit-dependent riders (sometimes also called captive riders). It is only passengers who use trains exclusively who exhibit characteristics of choice riders. Such survey findings suggest that multi-destination transit systems have achieved growing ridership largely from transit-dependent persons, whose demand for transit seems highly elastic with respect to more direct service. The rail lines are the only parts of the systems that seem to attract choice riders, but we do not know whether choice riders are destined only to the CBD, to the CBD plus other major employment concentrations served by the rail lines, or to employment concentrations near suburban rail stations and reachable by a short bus ride after passengers disembark from trains.

To further explore the extent to which multi-destination transit systems attract transit-dependent and choice riders, the authors of this report compared supply and demand of two all-bus systems, one offering multi-destination service and the other CBD-oriented service.[27] We compared the evolution and performance of the two systems over time. We also conducted a cross-sectional, statistical analysis of rider demand for the multi-destination bus system, which is in Broward County, Florida. Our results yield insights into the structure of contemporary transit demand.

Broward County in the greater Miami metropolitan area and Tarrant County in the greater Dallas-Ft. Worth metropolitan area both are home to about 1.8 million people and both have grown at similar rates. Both counties contain the second largest transit systems in their respective metropolitan areas. The counties differ primarily in that Broward County lacks a major central business district, whereas Tarrant County contains the Ft. Worth central business district. Transit network structure in the two counties differs, as well. Broward County Transit serves the highly dispersed employment and population in the built up parts of the county with a grid of bus routes on major arterial roads. The T, serving Tarrant County, connects many but not all residential areas in the county to employment in the Ft. Worth central business district while not serving well or at all most employment in the remainder of the county. The T operates a local radial bus system focused on the CBD. Superimposed on this, it operates a peak hour radial express bus system to attract choice riders to the CBD.

The transit system in Broward County carries almost 400 percent more ridership per capita than does the transit system in Tarrant County, while each bus mile operated in Broward County carries about 35 percent more passengers.[28] The express bus system in Ft. Worth contributes fewer than three percent of The T’s transit riders. The comparison between transit in Broward and Tarrant counties reinforces our conclusion that multi-destination transit systems are more effective and productive than radial systems for dispersed regions.

The statistical analysis, however, shows that the demand for transit in Broward County is mostly from transit-dependent persons.[29] The results are consistent with Pucher and Renne’s earlier national analysis.[30] In the analysis, we specified a model predicting transit work trips between all pairs of 921 traffic analysis zones (TAZs) in Broward County as an exponential function of variables measuring characteristics of the origin zone population, destination zone employment, and quality of transit service linking origins and destinations. We estimated the model with negative binomial regression. The results show that variables associated with a transit-dependent population are highly important for explaining transit ridership, thus indicating an overwhelmingly transit-dependent ridership profile. For every percent that the proportion of households with children increases in an originating zone, transit use increases by 1.4%. For every percent that an originating zone's auto ownership rises, transit use declines by 2.45%. For every percent that an originating zone's median income increases, transit use declines by 0.73%. Variables describing origin zone TOD qualities, based upon definitions found in the literature[31] and walkability have no influence on transit ridership.

The results associated with the destination zone variables also support the profile of a transit-dependent ridership. For every percent that employment in a destination TAZ is raised above the mean, ridership attracted to that zone is predicted to increase by .54%, but for every percent that employment density increases, transit ridership to the zone declines by .06%. The fact that employment density at the destination zone has no statistical impact on ridership (sharply in contrast to the authors' expectations) can be interpreted as a consequence of a largely transit-dependent population. We found that higher density employment, such as that in the Ft. Lauderdale center, attracted relatively few transit work trips in Broward County. Far more workers used transit to travel to low density work sites dispersed throughout the county. The negative coefficient for employment density in the model estimation reflects the greater attractiveness of low density suburban employment for the transit-dependent workers in Broward County.

We also found, contrary to expectations, that TOD qualities, the presence of parking fees, and more walkable zones had marginal or no statistical effect on increasing transit ridership. The small parking and TOD effects are particularly surprising to us, given the strong emphasis placed on these attributes in the literature for increasing transit ridership. In Broward County, however, far more transit riders are destined to work sites without parking fees than to work sites with parking fees.

The variable that had the greatest effect in determining transit ridership was the transit travel time between the origin zone and the destination zone. For every percent that transit travel time is reduced from the mean, the model predicts that transit ridership will increase by 2.77%. This variable shows that transit-dependent ridership, rather than being a fixed amount regardless of service quality, increases tremendously if the transit travel time between origin and destination is reduced.

These results are for a bus-only multi-destination network, and they are based on an analysis of work trips between most pairs of traffic analysis zones in the county. We suspect that if we ran a similar analysis on a service area with an integrated bus-rail system instead, and moreover, we estimated different models for bus and rail riders traveling to different sets of destinations within the transit service area, we would obtain a range of demand functions for transit, giving greater insight into the nature of transit demand in a multi-destination transit network. We suspect that such a segmented analysis would reveal sub-markets where there are choice riders and other sub-markets where there are none. What we are seeking is an understanding of policies that would boost choice transit ridership beyond the traditional suburb-to-CBD market, while preserving what appears to be a major benefit in multi-destination systems for transit-dependent riders. That is the purpose of this study.

III. CASE STUDY SELECTION

Our study examines transit ridership demand in a U.S. metropolitan area with a multi-modal, multi-destination transit system in the year 2000. In order to conduct the research, we required data for our dependent variable, the number of transit work trips traveling between an origin and a destination, and explanatory variables that measured the quality of transit service (transit travel time between the origin and destination), the socioeconomic characteristics of the origin and/or destination (population, employment, income, vehicle accessibility, and so on), and the nature of the built environment (transit-oriented development). Most of these variables are obtained from the U.S. Census Bureau or local Metropolitan Planning Organizations (MPOs). However, two variables are obtainable only from very specialized data sources, and their availability played a major role in determining the location of our case study.

The dependent variable reporting the number of transit work trips traveling from an origin to a destination, geocoded into traffic analysis zones (TAZs), is available from the Year 2000 Census Transportation Planning Package (CTPP), a specialized transportation database derived from responses to the 2000 Census Long Form Questionnaire. This variable reports the travel mode for commute trips. Respondents select from a number of travel modes, including automobile, walk, bicycle, and several transit modes. Of interest to this study are the transit modes labeled “bus or trolley bus” and “subway or elevated.” We assumed, incorrectly as it turned out, that these data would be available for all potential study areas in the United States.

The transit travel time between traffic analysis zones represents our key measure of transit service quality. These data are typically obtained in the form of skim files of inter-zonal travel times produced by travel demand models in use by metropolitan planning organizations. Their transit skims measure components of travel time, including both in-vehicle and out-of-vehicle portions of the trip. We assumed that these data would be more difficult to obtain because they are produced by models whose components and outputs are not part of public databases, as the CTPP data are.

Our study area had to have data available for both these critical variables for roughly the same year. We began the research intending to study Miami, Florida. Our earlier work had examined transit demand in adjoining Broward County and past research for Mineta had given us both insight into the structure and function of the regional transit system and a number of local informants who might be useful contacts for local data or any system-related questions. We discovered quickly, however, that CTPP data are not available for Miami. The region has excellent transit skims, as we knew from our earlier Broward County study, but lacks the dependent variable necessary for our research.

San Diego, California was the second choice for our study area. San Diego was one case study in our earlier Mineta research, and one of the authors has extensive familiarity with the local transit system reaching back into the 1970s. We also have a number of local informants in San Diego. We soon discovered that while San Diego has CTPP data available for our dependent variable, its transit skims are organized at a more disaggregate level of geography than traffic analysis zones that made the analysis we proposed to conduct nearly impossible to execute within the timeframe and budget proposed to Mineta.

Portland, Oregon was the third choice for our study area. We had informants in the study area and familiarity stemming from prior research and from one author's professional contacts and experience. Unfortunately, while Portland possessed excellent transit skims, it did not have the required CTPP data for the study.

We finally turned to Atlanta, Georgia as our fourth option. We had previously conducted research in Atlanta, including for Mineta, and we had some familiarity with the regional transit system and a number of MPO and transit agency contacts. The Atlanta Regional Commission uses regional transportation demand models that produce tables of transit travel times between all pairs of traffic analysis zones that are linked by transit service, and it has such tables depicting transit travel times for 2002. We were able to obtain the required CTPP data for the year 2000 for our dependent variable and the local MPO staff at the Atlanta Regional Commission (ARC) was willing to share their 2002 transit travel times with us. Due to the availability of the required variables, Atlanta emerged as the study location.

In addition to data availability, Atlanta met all the other key criteria for our study location. It has a combined bus-and-rail transit system whose primary operator, the Metropolitan Atlanta Rapid Transit Authority (MARTA), restructured its bus network into a multi-destination system following the introduction of rail transit to the region. It also has a small number of transit-oriented developments at rail transit stations, the most famous of which is Lindbergh Center. Atlanta emerged as a logical and ideal study area for this research.

OVERVIEW OF THE ATLANTA METROPOLITAN AREA

For our study, we examine transit ridership in the five counties at the heart of the 28-county Atlanta Metropolitan Statistical Area: Clayton, Cobb, DeKalb, Fulton, and Gwinnett. In 2000, these counties had a combined 2.9 million people[32] and 1.8 million jobs.[33] Hereafter, we refer to these five counties as the Atlanta Metropolitan Area. The five counties are shown in **Figure 2**, along with the present-day metropolitan expressway and rail transit system. Atlanta's Central Business District (CBD) is located where the east-west and north-south rail lines cross. The east-west expressway (Interstate 20) also intersects with the north-south expressway (the combined Interstates 75 and 85) in the CBD.

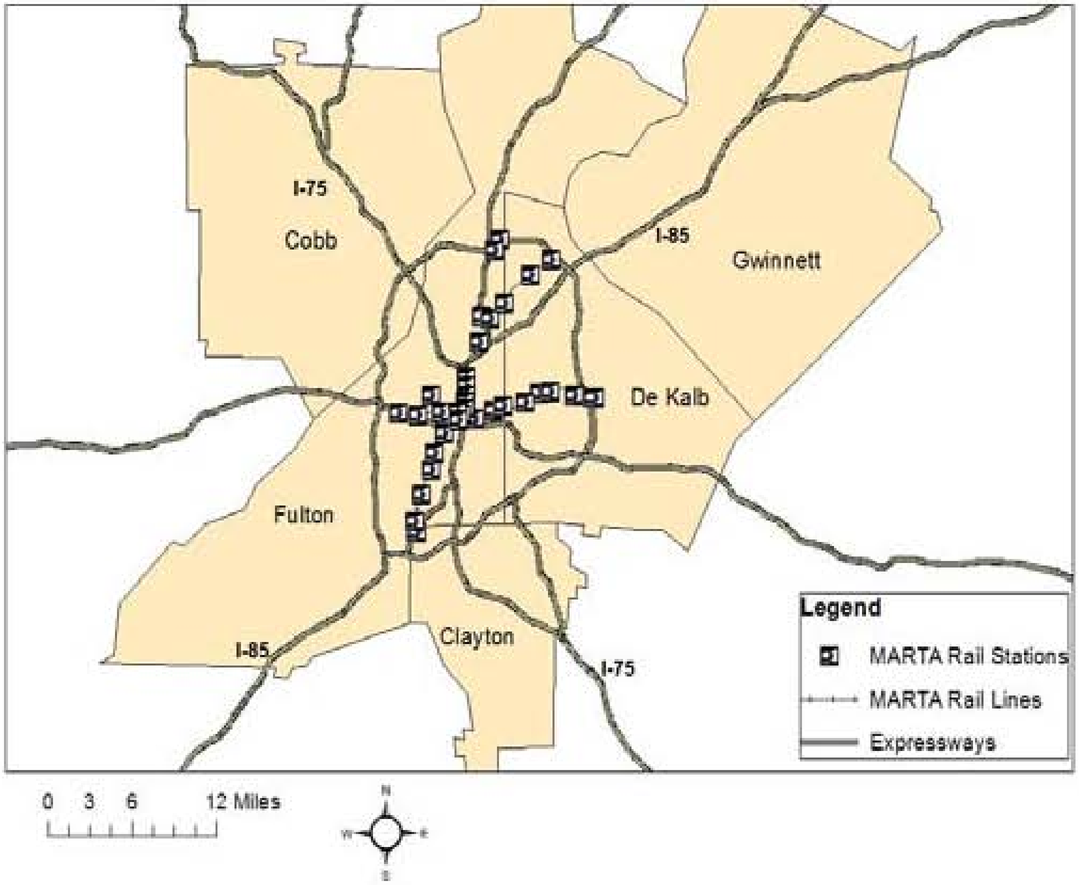

Figure 2. Atlanta Metropolitan Area[34]

Our investigation of transit ridership in Atlanta focuses on the year 2000. In 2000, transit service in Atlanta centered on three counties: Cobb, DeKalb, and Fulton. Transit service in Clayton and Gwinnett Counties was then limited to a small number of traffic analysis zones served by a handful of Metropolitan Atlanta Rapid Transit Authority (MARTA) bus routes, and/or a single MARTA rail line, that crossed or touched their county boundaries.

POPULATION AND EMPLOYMENT IN THE ATLANTA METROPOLITAN AREA

As noted earlier, in 2000 the Atlanta Metropolitan Area contained 2.8 million persons spread over five counties.[35] **Figure 3** maps the distribution of this population across all TAZs within the five-county metropolitan area.[36] The map shows scattered patterns of high and low population TAZs, but these patterns are influenced by the widely varying sizes of the TAZs.

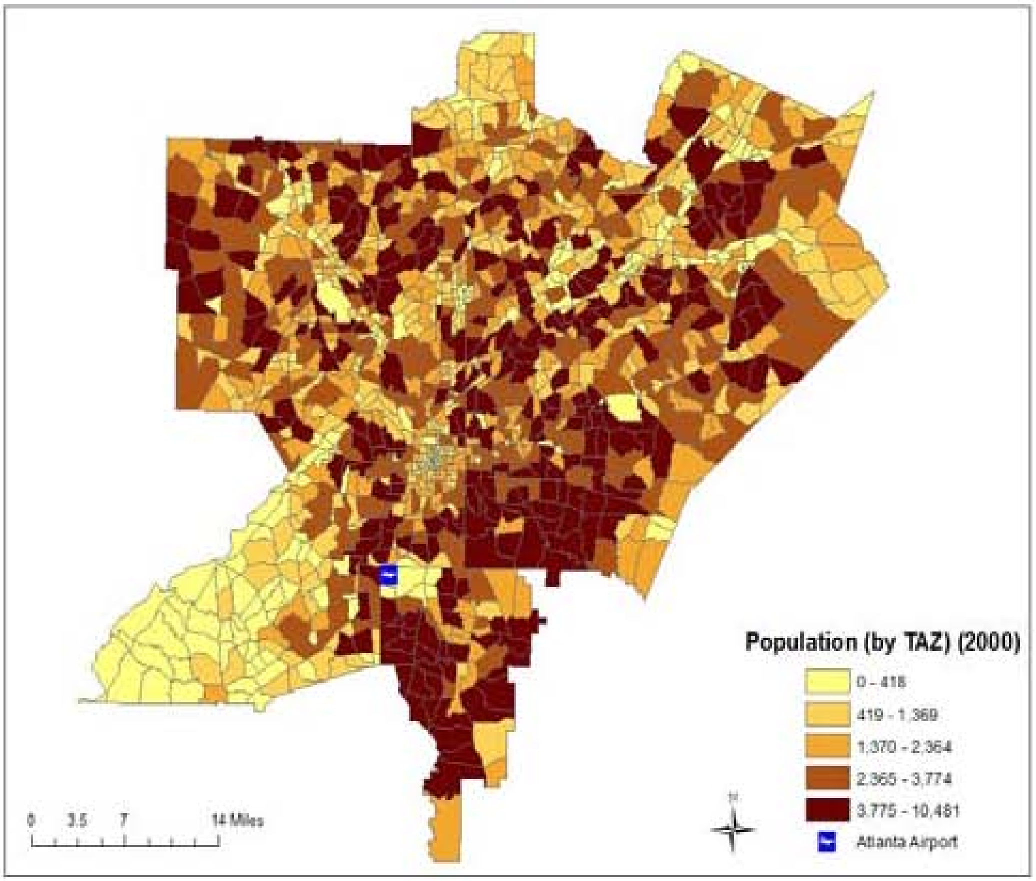

Figure 3. Atlanta Metropolitan Area Population (by TAZ): 2000[37]

Figure 4 accounts for varying TAZ size and reports population density by TAZ (persons per acre) in 2000. Most of the Atlanta metropolitan area is characterized by low to very moderate population densities. This map shows clusters of medium and higher population densities located at the core of the region in central Fulton and DeKalb Counties and along major expressway and arterial corridors in the outer, suburban areas in Cobb and Gwinnett Counties. Combined, these two maps give a sense of where the major population concentrations are located within the Atlanta region.

These clusters represent potential origin zones for transit trips in the region. We hypothesize that TAZs that contain large absolute numbers of residents and/or have higher popular densities should be associated with large numbers of transit trip origins. We explore this hypothesis later in the report.

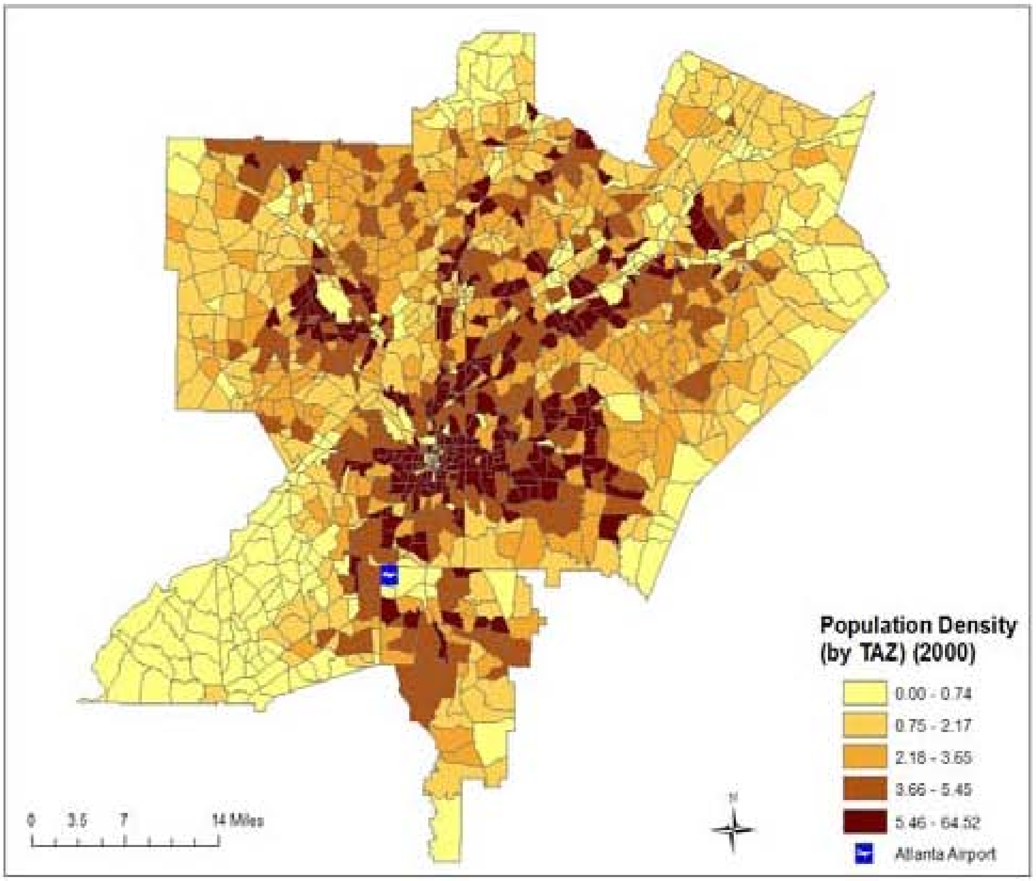

Figure 4. Atlanta Metropolitan Area Population Density (by TAZ): 2000[38]

In 2000, the five counties also accounted for 1.8 million jobs.[39] These jobs represent potential destinations for transit trips. **Figure 5** maps the distribution of employment by TAZ across the five counties. Employment is much more concentrated than population. Most employment is located north of the Atlanta CBD in north central Fulton and Northwestern DeKalb Counties, and in expressway corridors in Cobb and Gwinnett Counties. There is some additional employment clustering south of the Atlanta CBD in the Hartsfield-Jackson International (Atlanta) Airport area. As was true of the earlier population map, the clustering is at least partially a function of the varying sizes of the TAZs.

Figure 6 reports employment density (jobs per acre) in 2000 for the five counties. Most of the Atlanta metropolitan area is characterized by very low employment densities. Higher density employment clusters can be seen in the core of the region, along major expressway corridors, particularly to the northwest and northeast of the regional center into Cobb and Gwinnett Counties, around the airport, and in some rail transit corridors in northern Fulton and DeKalb Counties.

We hypothesize that TAZs with large numbers of jobs will tend to be destination zones for large numbers of transit trips. This hypothesis is a logical one as the particular type of transit trips analyzed in this study are the journey-to-work trips reported in the 2000

Census. The research literature suggests that areas with large total employment and areas with high employment density should be very attractive transit travel destinations, and therefore the relationship should be a positive one between the employment variables and transit trip destinations.

However, we conducted a study in Broward County, Florida, that is similar to this one for Atlanta, which found the expected positive relationship between total employment and transit work trip destinations, but found a negative relationship between employment density and transit trip destinations.[40] We suspect this somewhat surprising finding was due to the overwhelmingly transit-dependent nature of the Broward County system's ridership. Riders on that system were largely headed toward low-density, dispersed, auto-oriented employment centers. Some riders were also headed to the higher density employment centers in places like downtown Fort Lauderdale and downtown Hollywood, but not nearly to the extent predicted by the amount of employment in these locations. We are unsure of the reason for the lower trip attractions to the two Broward County city centers, but assume that many of the jobs in the city centers are held by white-collar workers who would not ride buses. The transit users in much greater numbers sought to reach large clusters of employment scattered about the county, but not to reach the areas with higher density employment. Given this finding in the earlier study, we were not sure what to expect in terms of the relationship between employment density and transit trip destinations, although we did expect to find a positive relationship between total employment and transit trip destinations.

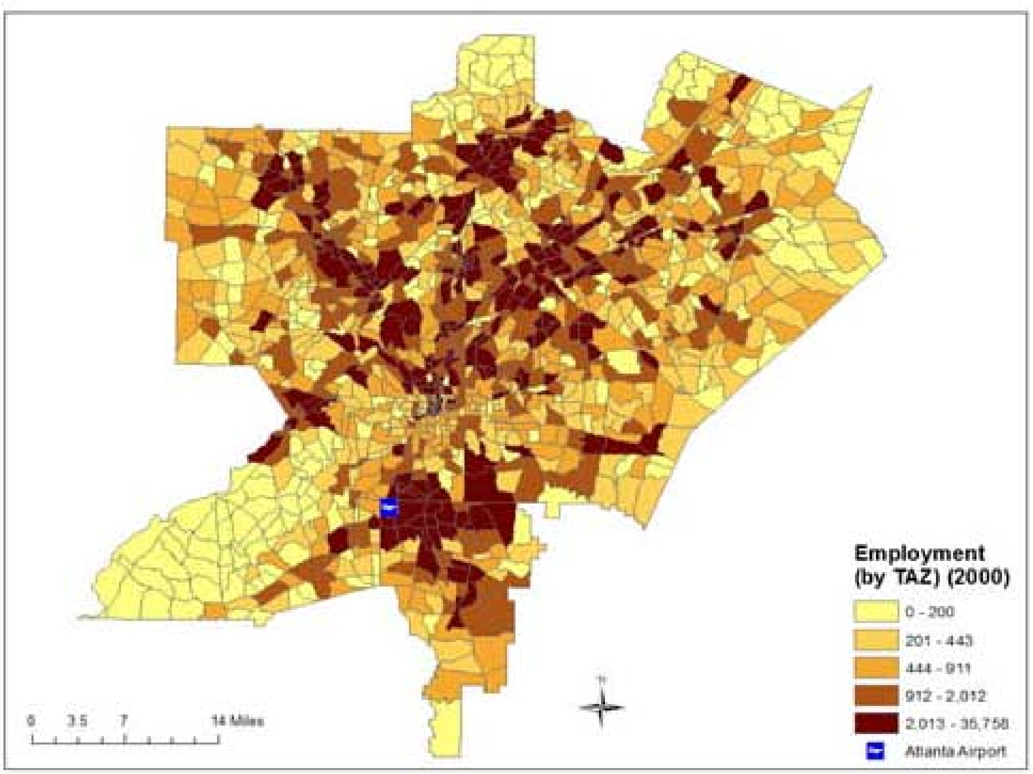

Figure 5. Atlanta Metropolitan Area Employment (by TAZ): 2000[41]

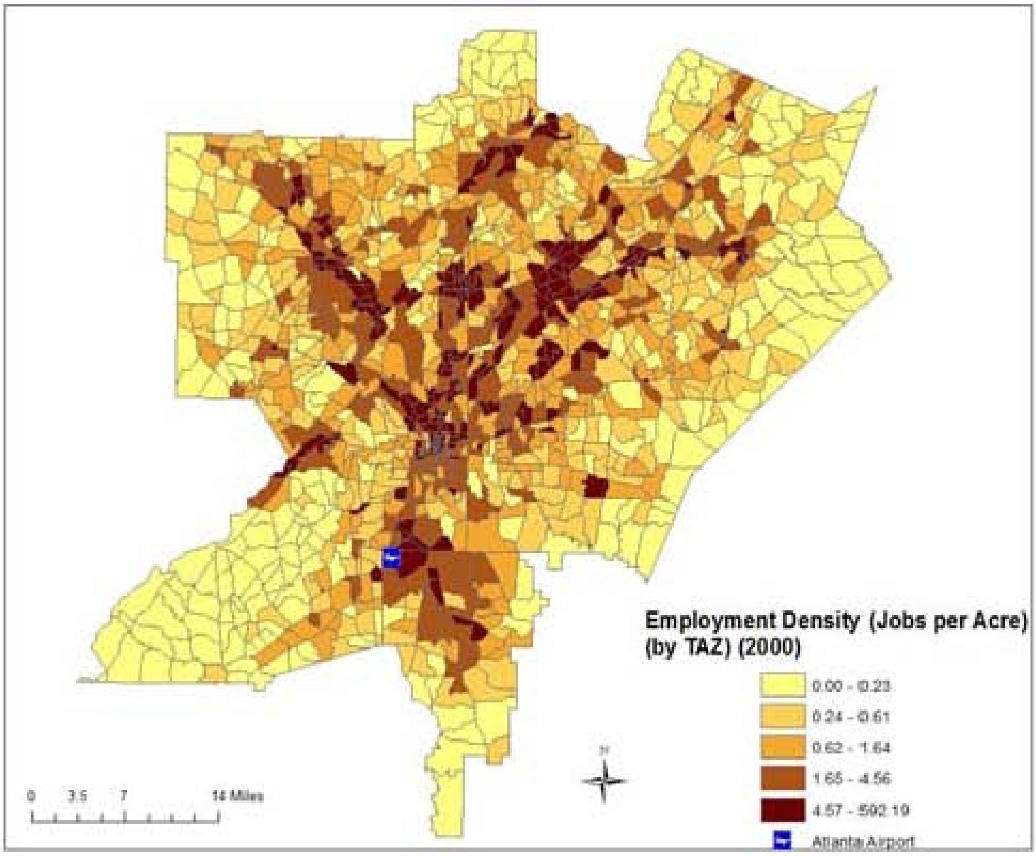

Figure 6. Atlanta Metropolitan Area Employment Density (by TAZ): 2000[42]

Socioeconomics of the Atlanta Metropolitan Area

Socioeconomic factors are among the most frequently cited explanations for transit use, particularly among the transit-dependent population, and these variables are important components of the statistical analysis presented later in the report. Based on a review of the literature and prior work on the determinants of transit ridership in Broward County, Florida, we identified six socioeconomic variables that we believe might explain differences in transit use across TAZs. These six variables are: percent white population, median household income, number of vehicles per capita, percent of households without children, unemployment rate, and vacancy rate. We explore the spatial distribution of each variable across Atlanta's TAZs over the next several pages.

Historically, the Atlanta metropolitan area has been very racially segregated, characterized by largely black neighborhoods in the southern and central portions of Fulton and DeKalb Counties extending into northern Clayton County and largely white neighborhoods in northern Fulton and DeKalb Counties and the suburban counties of Cobb and Gwinnett. This racial divide is one important explanation for MARTA's restriction of service largely to Fulton and DeKalb Counties. The suburban counties were originally supposed to be included in the MARTA transit sales tax district, but their largely white voters rejected the proposal in the late 1960s.

Figure 7 shows that the Atlanta metropolitan area is still marked by a high degree of racial separation, with large concentrations of non-white resident TAZs in southern and central Fulton and DeKalb Counties, as well as the older communities in the suburban counties, and concentrations of white resident TAZs in the northern portions of Fulton County and in the outer suburban counties. Most of the TAZs that are well-served by MARTA (the systems map is shown later in **Figure 15**) are heavily minority in their residential composition. MARTA's bus transit system in particular has long been associated with the area's minority community, and we therefore hypothesize a negative relationship between a TAZ's percent white population and the number of transit trip origins in the TAZ.

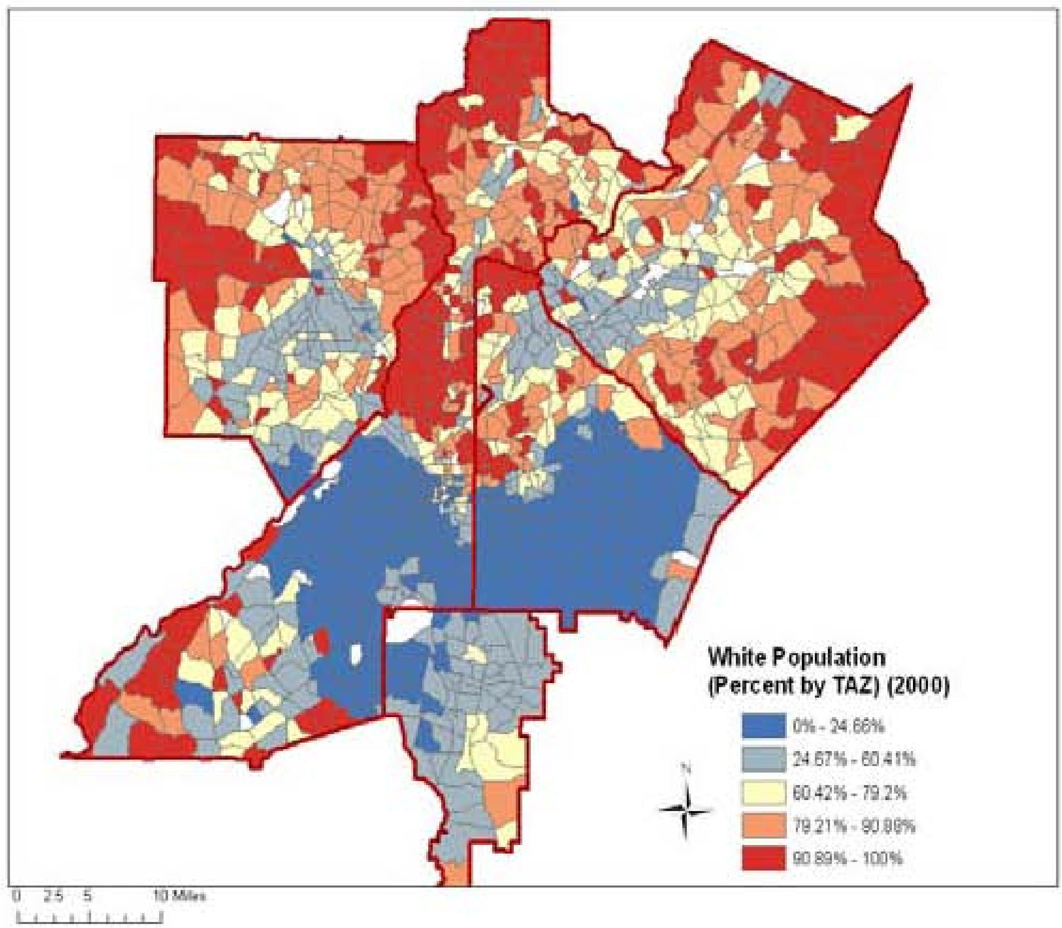

Figure 7. Percent White Population in Atlanta (by TAZ): 2000[43]

Figure 8 shows that the Atlanta metropolitan area is also characterized by a high degree of residential segregation by income. The figure shows median household incomes in 2000 (in unadjusted dollars) by TAZ. The spatial pattern of median household income is quite similar to the racial map, showing a clear north-south divide within the core of Fulton and DeKalb Counties, high income northern and outer suburban concentrations, and low to moderate income clusters in the older suburban communities in Cobb and Gwinnett Counties. Research suggests that most bus riders come from lower income groups, while rail riders tend to have slightly higher incomes. We hypothesize that the number of bus trip origins in a zone will fall as the zone's income rises, because we suspect that most Atlanta bus riders exhibit transit-dependent characteristics. We are unsure how the median household income variable will affect the number of rail trip origins in a given TAZ.

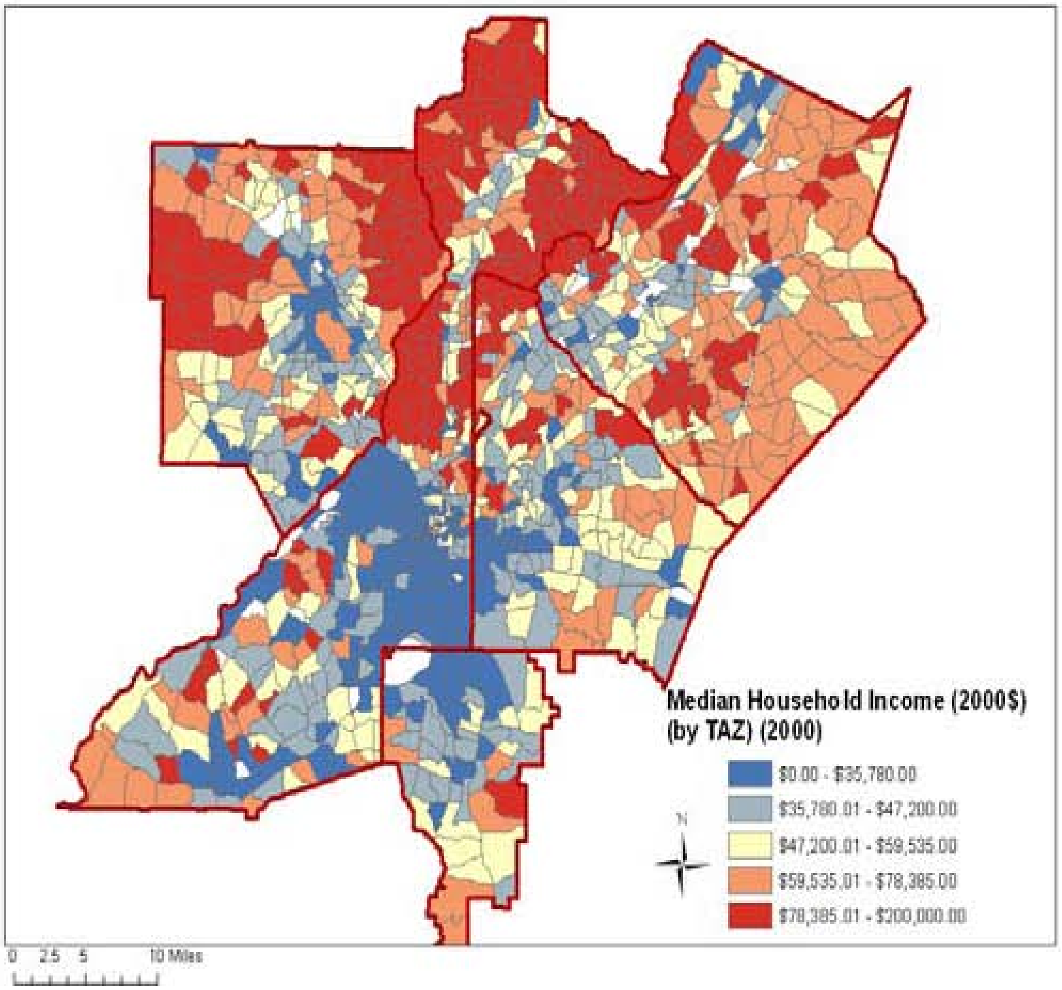

Figure 8. Median Household Income in Atlanta (by TAZ): 2000[44]

Many transit scholars see vehicle access as among the most important determinants of transit usage, particularly for transit-dependent individuals, and we include this variable in our statistical analysis. **Figure 9** maps the spatial distribution of vehicle access by TAZ by looking at the ratio of the number of vehicles to number of persons in each TAZ. Lower ratios thus denote low overall levels of vehicle accessibility.

The figure clearly indicates a large cluster of low vehicle accessibility in the center of the metropolitan area extending from the boundary of Fulton County eastward through the center city and into western DeKalb County. Clusters of low vehicle access can also be found on the outer edges of DeKalb and Gwinnett Counties and in central Cobb County. By contrast, the north central part of the metropolitan area, made up of TAZs that were predominantly white and predominantly higher income as shown in the preceding two figures, enjoy high levels of vehicle accessibility.

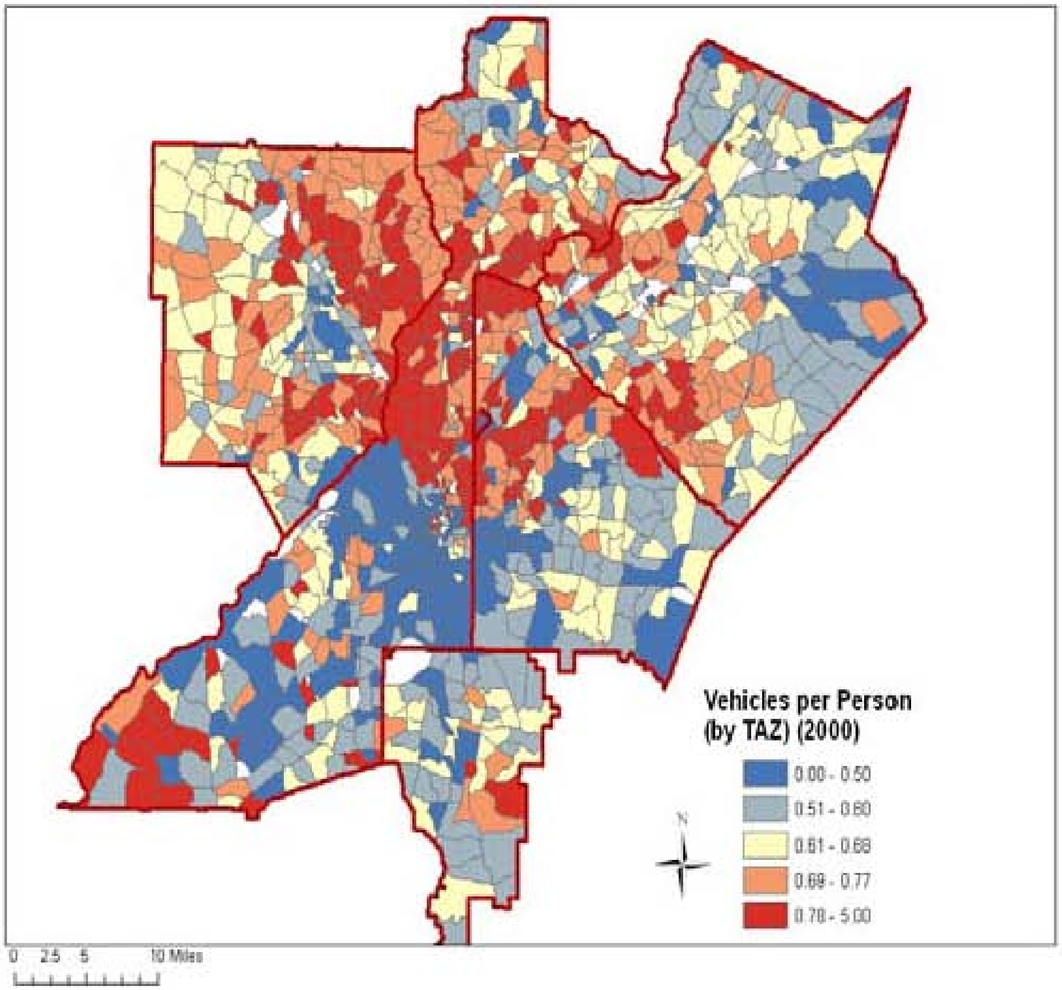

Figure 9. Vehicle Accessibility in Atlanta (by TAZ): 2000[45]

Based on our hypothesis that most Atlanta bus riders exhibit transit-dependent characteristics, we hypothesize that the number of bus transit trip origins will be higher in TAZs with lower ratios of vehicles to persons. Because we suspect that rail riders exhibit choice rider characteristics, we hypothesize either a positive or neutral relationship between the number of rail transit trip origins in a TAZ and the ratio of vehicles to persons.

In our earlier study of the determinants of transit ridership in Broward County, Florida, we found that the percent of households without children in a TAZ proved to be a statistically significant predictor of the number of transit trip origins in a TAZ. Broward County Transit riders were overwhelmingly low-income, transit–dependent individuals with limited vehicle accessibility. Larger households were more likely to use transit than smaller families, including those without children. For Atlanta, we employ the same variable and expect to find the same statistical results. **Figure 10** provides a map of the spatial distribution of this variable, which shows a cluster of TAZs with overwhelmingly childless households in the center of the metropolitan area, but otherwise a very spatially dispersed pattern.

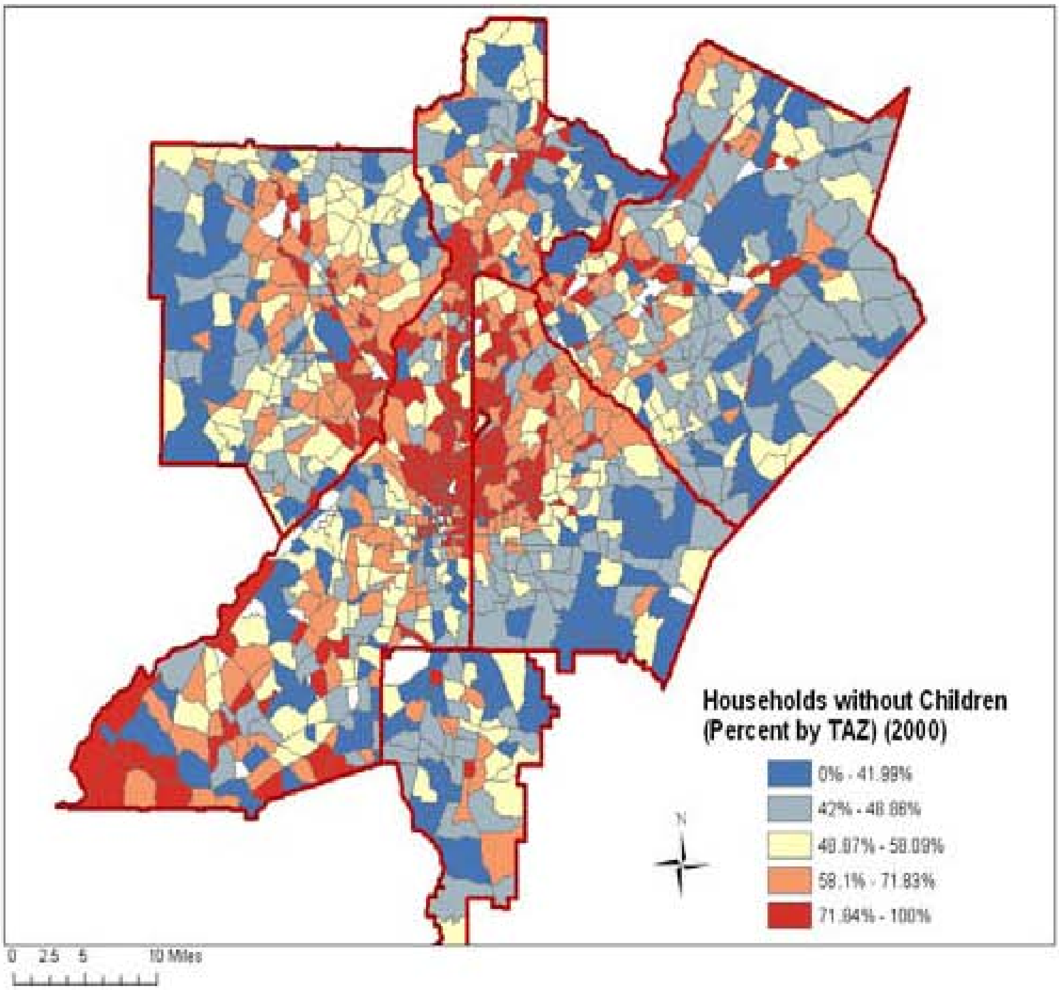

Figure 10. Percent Households without Children in Atlanta (by TAZ): 2000[46]

During preliminary statistical testing of our models, we discovered a significant spatial bias in the difference between observed transit trips (reported in the CTPP) and predicted transit trips (produced by our statistical model) that appeared to be clustered in economically distressed areas in the Atlanta metropolitan area. Our model tended to over-predict the number of transit trips originating in these TAZs. We therefore sought to include Census variables that would help to capture the economically distressed nature of these TAZs. We identified two variables: unemployment rate and the vacancy rate for residential dwelling units.

Figure 11 maps the spatial distribution of unemployment rates by TAZ and **Figure 12** maps the spatial distribution of vacant dwelling units. The patterns in these two maps are similar, but far from identical, to the patterns seen in the earlier maps showing median household income, the number of vehicles per person, and the percent white population. The patterns are similar, but the variables are not correlated with one another. We include these two variables in our statistical model to account for economic distress. We expect both variables to have a negative effect on the number of transit trip origins in a TAZ.

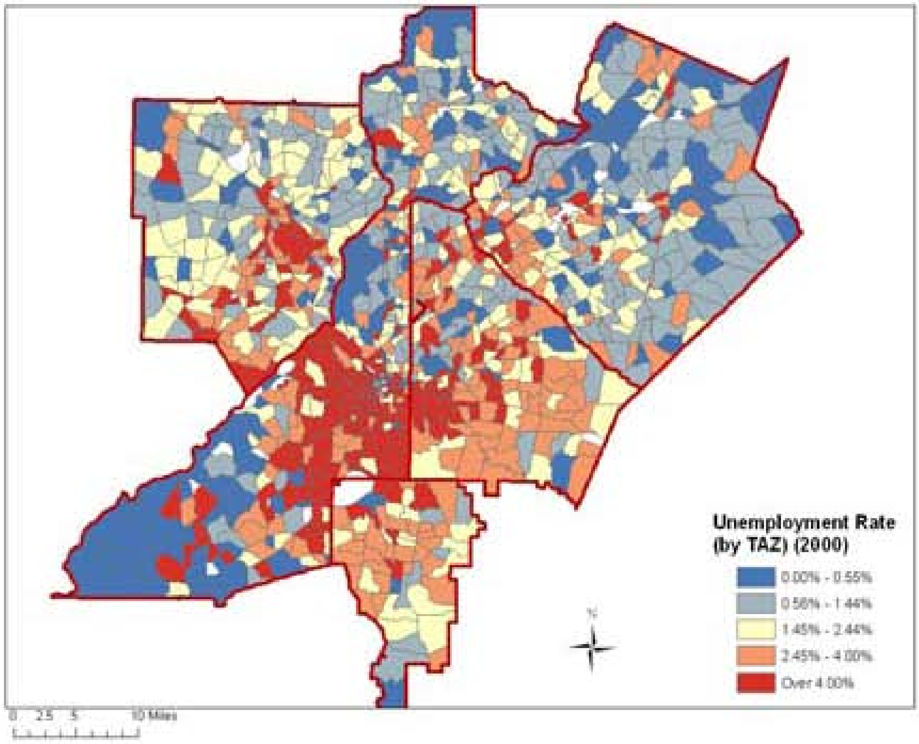

Figure 11. Unemployment Rate in Atlanta (by TAZ): 2000[47]

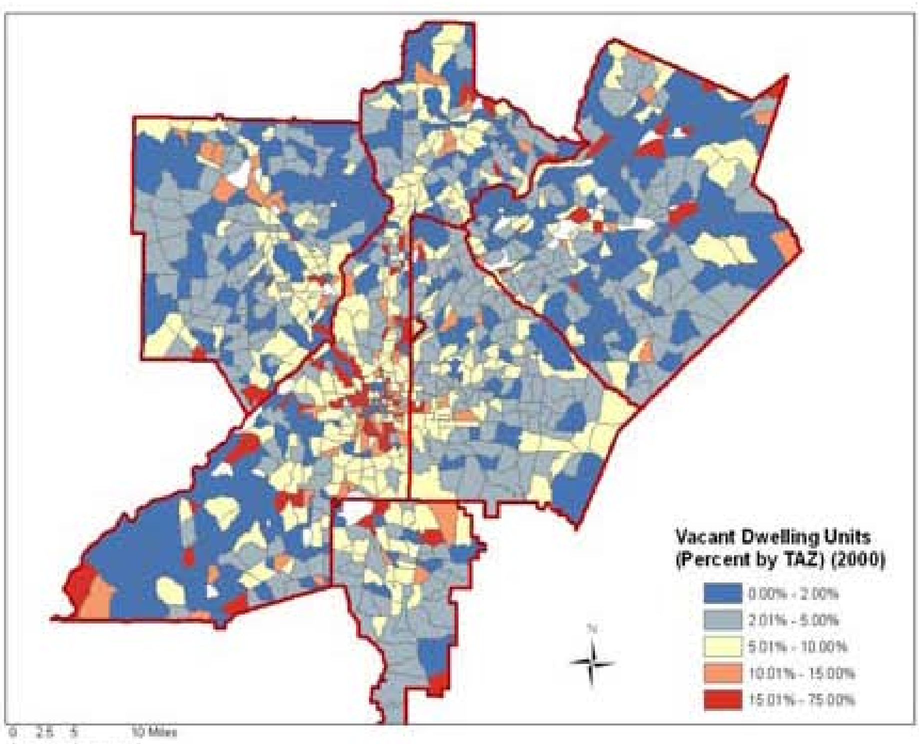

Figure 12. Vacancy Rate for Residential Dwellings in Atlanta (by TAZ): 2000[48]

IMPORTANT REGIONAL TRANSIT DESTINATIONS IN ATLANTA

The Atlanta Regional Commission (ARC), the metropolitan planning organization (MPO) for the Atlanta metropolitan area, defines a number of geographic areas that are of special interest in the study because of their potential role as destinations for transit trips. These key geographic areas are: the Atlanta Central Business District (CBD), Atlanta city center, transit-oriented developments, and regional centers. We include each of these geographies in our statistical analysis presented later in the report.

The Atlanta CBD and city center are located in Central Atlanta. The CBD is Atlanta's original commercial district and is largely an office district. The city center encompasses portions of the historic CBD, as well as the adjacent Midtown area. The Midtown area (included in the city center) contains offices as well as cultural institutions and residential development. Combined, these two areas contain 10 MARTA rail stations and sit at the heart of the regional rail transit network (see **Figure 13**).

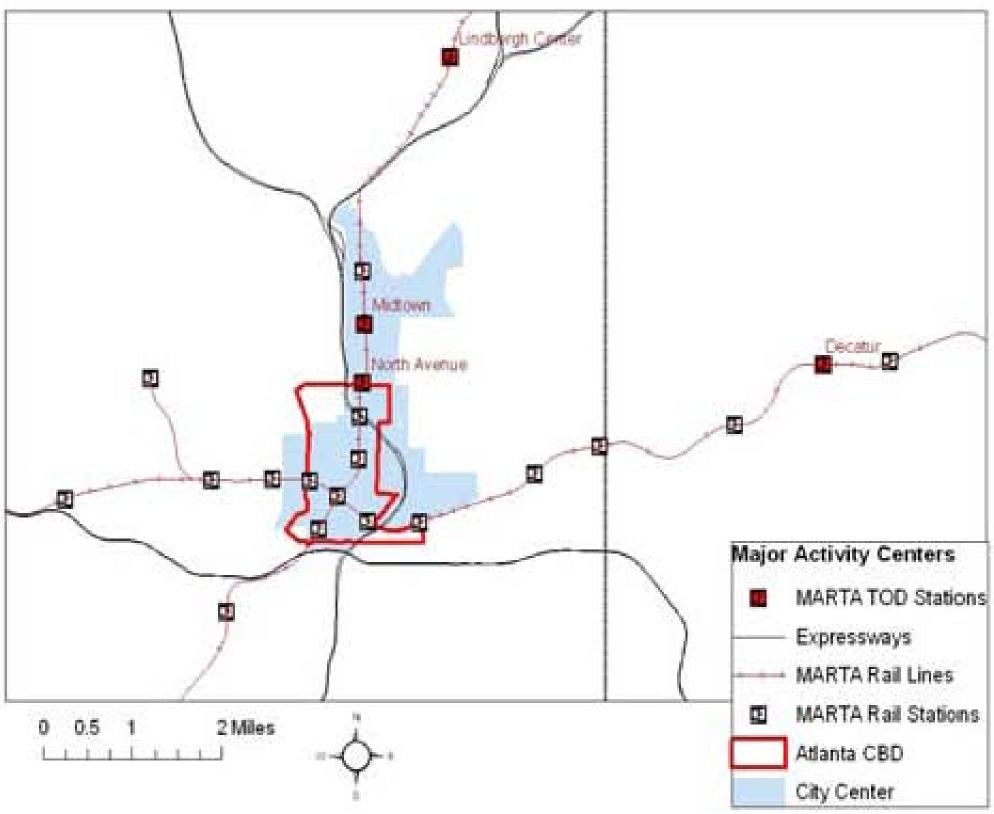

Figure 13. Central Atlanta[49]

Another set of important potential transit destinations are the regional centers. ARC defines regional centers as geographic areas that contain 10,000 or more jobs within approximately four square miles. **Figure 14** shows the location of regional centers in relation to the Atlanta CBD and the metropolitan expressway system. Most of the regional centers are oriented toward expressways or major arterial roads and represent automobile-oriented development, although there are a few exceptions.

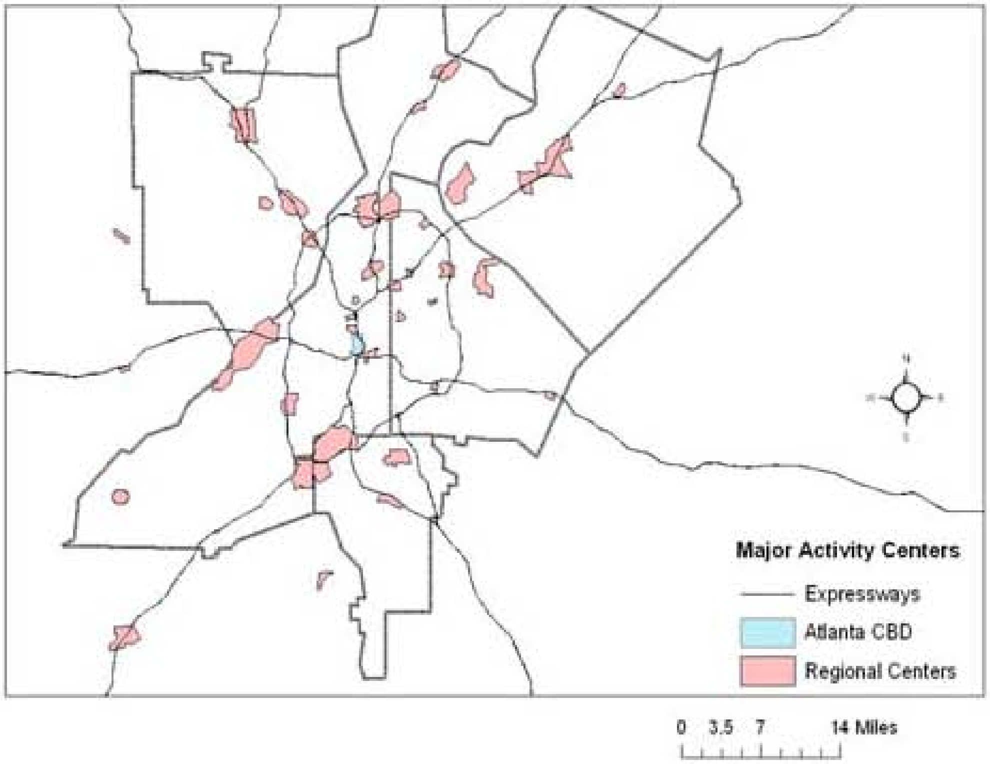

Figure 14. Regional Centers in the Atlanta Metropolitan Area[50]

A final set of potential important transit destinations are the area's transit-oriented developments (TOD). Transit-Oriented Developments are higher density, more mixed use developments centered on rail stations characterized by more walkable, more pedestrian-friendly, and less auto-oriented urban designs. In 2000, the Atlanta metropolitan area contained four transit-oriented developments centered on MARTA rail stations, as recognized by ARC, the Transit Cooperative Research (TCRP) program, and the Urban Land Institute's (ULI) Atlanta Chapter.[51] Two of the Atlanta metropolitan area's four rail TODs lie within the city center: Midtown and North Avenue; the two other TODs lie outside the city center: Decatur and Lindbergh Center. All four TODs can be seen on the map in **Figure 13**.

ATLANTA METROPOLITAN AREA TRANSIT SERVICE IN 2000

In 2000, two transit agencies operated fixed-route services in the Atlanta metropolitan area: the Metropolitan Atlanta Rapid Transit Authority (MARTA), which began bus operations in 1972, and Cobb Community Transit (CCT), which began bus operations in 1990 (see **Figure 15**). Three other transit agencies, Clayton County Transit (C-TRAN, in 2001), Georgia Regional Transportation Authority X-Press (GRTA, in 2004), and Gwinnett County Transit (GCT, in 2001), subsequently established bus service, although C-TRAN discontinued its service in March 2010 due to county budget difficulties.[52] These three agencies are not considered further in this report because they were not operational at the time of the 2000 Census.

Much of the job growth in the Atlanta region in the years prior to 2000 (and since then, as well) occurred in Gwinnett and Cobb Counties where transit service prior to 2000 was either non-existent or very sparsely developed. In 2000 these two counties accounted for 41 percent of the five-county region's 1,819,500 jobs.[53] These large employment concentrations without adequate transit service undoubtedly account for the overall low ranking of the Atlanta Metropolitan area in the Brookings Institution's recent ratings of the degree to which transit service connects to jobs in America's metropolitan areas.[54]

In 2000, transit agencies in Atlanta (dominated by MARTA, which accounted for 97 percent of all metropolitan area passenger miles) carried 3.7 percent of all journey to work trips, down from 7.0 percent in 1980 and 4.4 percent in 1990.[55] The declines occurred as more and more employment clusters opened outside of MARTA's service area, particularly in Gwinnett, Cobb, and Clayton Counties. These transit travelers in 2000 represent the universe of observations from which the sample data were drawn for our statistical analysis presented later in this report.

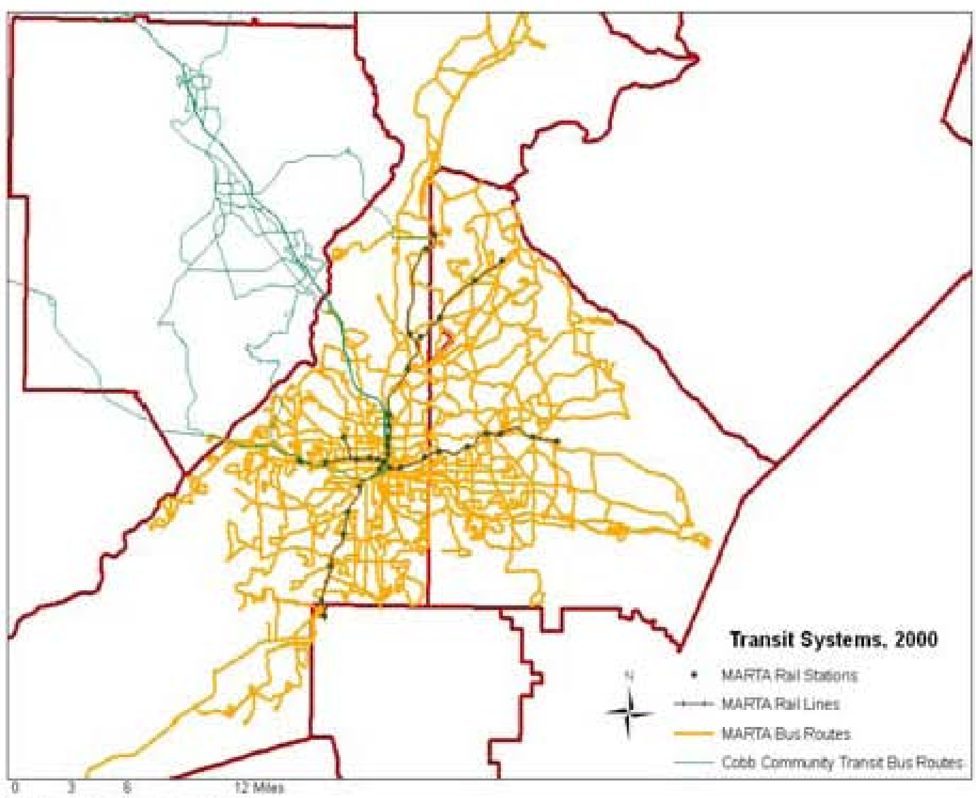

Figure 15. Atlanta Metropolitan Area Transit System in 2000[56]

METROPOLITAN ATLANTA RAPID TRANSIT AUTHORITY

The primary transit agency in the Atlanta metropolitan area was and remains the Metropolitan Atlanta Rapid Transit Authority (MARTA). At the time of the study, MARTA operated a combined bus and rail transit system largely confined to Fulton and De Kalb Counties, whose residents pay sales taxes to support MARTA's transit service. MARTA operated 154 bus routes in early 2000, and its rail system included 36 stations.[57] Two rail stations, North Springs and Sandy Springs, opened in December 2000 (see **Table 4**). MARTA's base fare in 2000 was $1.50 per trip, with free system-wide transfers.[58] MARTA also offered pre-paid, discounted token fares and a number of special pass programs for seniors, the disabled, students, and area visitors.

In 2000, MARTA carried 83.8 million rail unlinked passenger trips and 83.1 million bus unlinked passenger trips, or approximately 240,000 trips per day by each mode.[59] Rail riders traveled an average of 6.0 miles per trip and bus riders traveled an average of 3.3 miles per trip.[60] According to ARC's 2001-2002 On-Board Survey, 68% of MARTA bus trips and 78% of MARTA rail trips were commute trips.[61]

Table 4. MARTA Rail Stations and Their Opening Dates[62]

Station	Opening Date	Station	Opening Date
Avondale	June 30, 1979	Lindbergh Center	December 15, 1984
Edgewood/Candler Park	June 30, 1979	Lakewood/Fort McPherson	December 15, 1984
East Lake	June 30, 1979	Lenox	December 15, 1984
Inman Park/Reynoldstown	June 30, 1979	Oakland City	December 15, 1984
Georgia State	June 30, 1979	Brookhaven	December 15, 1984
King Memorial	June 30, 1979	East Point	August 16, 1986
Decatur	June 30, 1979	Chamblee	December 19, 1987
Five Points	December 22, 1979	College Park	June 18, 1988
Vine City	December 22, 1979	Airport	June 18, 1988
Omni/Dome/GWCC	December 22, 1979	Bankhead	December 12, 1992
West Lake	December 22, 1979	Doraville	December 29, 1992
Hamilton E. Holmes	December 22, 1979	Kensington	June 26, 1993
Ashby	December 22, 1979	Indian Creek	June 26, 1993
Garnett	December 4, 1981	Buckhead	June 8, 1996
North Avenue	December 4, 1981	Dunwoody	June 8, 1996
Civic Center	December 4, 1981	Medical Center	June 8, 1996
Arts Center	September 11, 1982	*North Springs**	*December 16, 2000*
Peachtree Center	September 11, 1982	*Sandy Springs**	*December 16, 2000*
West End	September 11, 1982		
Midtown	September 11, 1982	** These stations opened after the time of the study.*	

In 2000, MARTA provided 27 million bus revenue miles of service and served 273 million bus passenger miles.[63] That same year, MARTA provided 21.6 million rail revenue miles of service and served 503 million rail passenger miles. **Figure 16** shows that MARTA bus and rail patronage increased in the late 1990s, as new rail extensions opened leading up to the 1996 Olympic Games, represented by the highest peak on the rail passenger mile trend line.

Figure 17 shows that MARTA offered approximately the same level of bus service from 1984 to 2000, while it substantially increased rail service as new rail stations opened (see **Table 4**). Comparing ridership and service we can determine one measure of service productivity: load factor (passenger miles per revenue mile). Bus and rail service productivity increased during the middle and late 1990s. Bus load factor increased from 8.4 passenger miles per revenue mile (1994) to 10.0 passenger miles per revenue mile (2000). Rail load factor increased from 18.1 passenger miles per revenue mile (1994) to 23.4 passenger miles per revenue mile (2000).

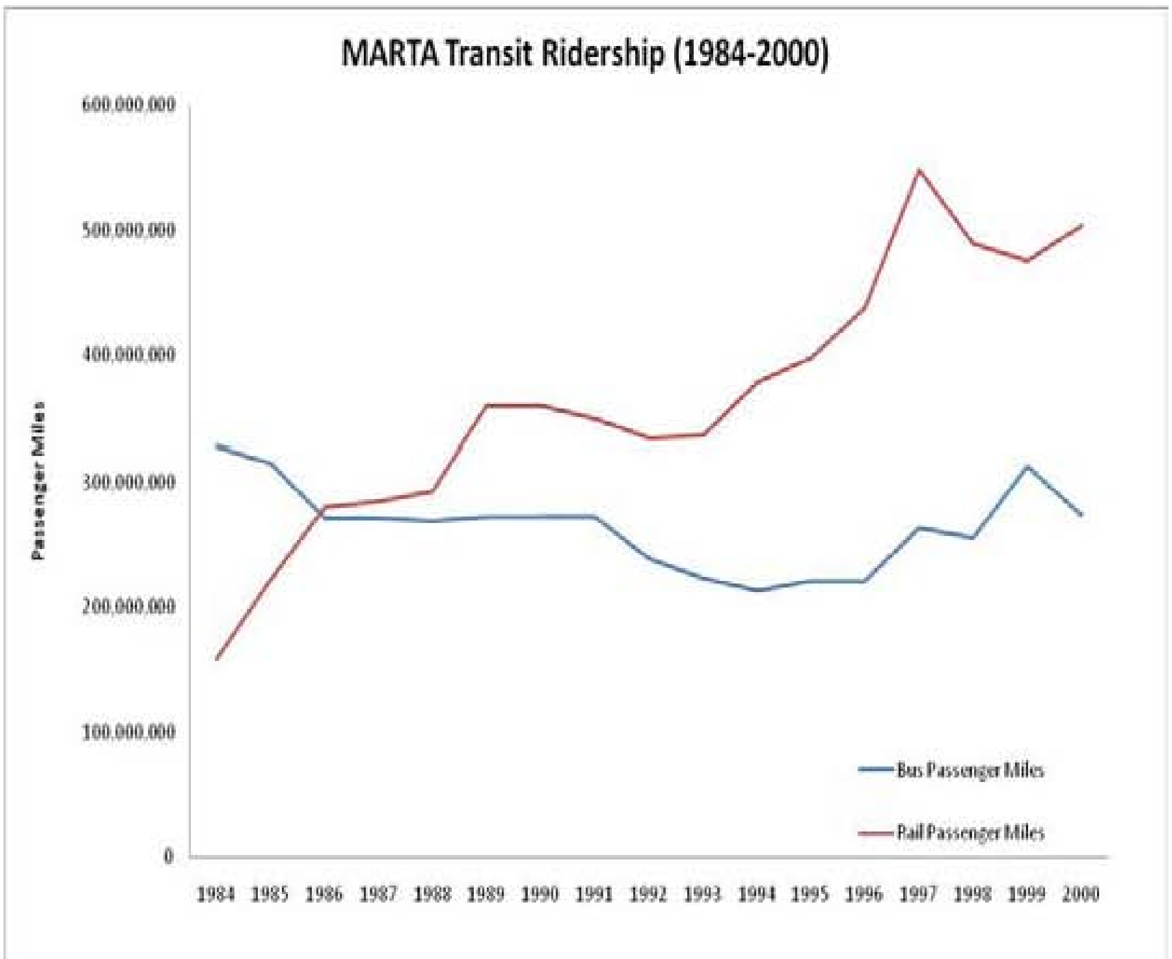

Figure 16. MARTA Transit Ridership (Passenger Miles) (1984-2000)[64]

COBB COMMUNITY TRANSIT

The other transit agency included in this study is Cobb Community Transit (CCT), which accounted for about 3 percent of all metropolitan transit passenger miles in 2000. In 2000, CCT operated 13 local bus routes, largely within Cobb County, and two express bus routes that served downtown Atlanta.[65] Three CCT local bus routes provided service to MARTA rail transit stations outside the Atlanta CBD. In 2000, local bus fares were $1.25 and express bus fares were $3.00 for a one-way trip or $4.00 per round trip.[66] Reciprocal fare agreements allowed CCT patrons to transfer to MARTA bus and rail services without paying an additional fare.

In 2000, CCT provided 1.8 million bus revenue miles of service and served just less than 23 million bus passenger miles.[67] CCT ridership and service increased significantly between 1990 and 2000. **Figure 18** shows that ridership increased from 13.7 million to 22.9 million passenger miles. **Figure 19** shows that service increased from 1.3 million to 1.7 million revenue miles. Service productivity increased from 10.3 to 13.3 passenger miles per revenue mile.

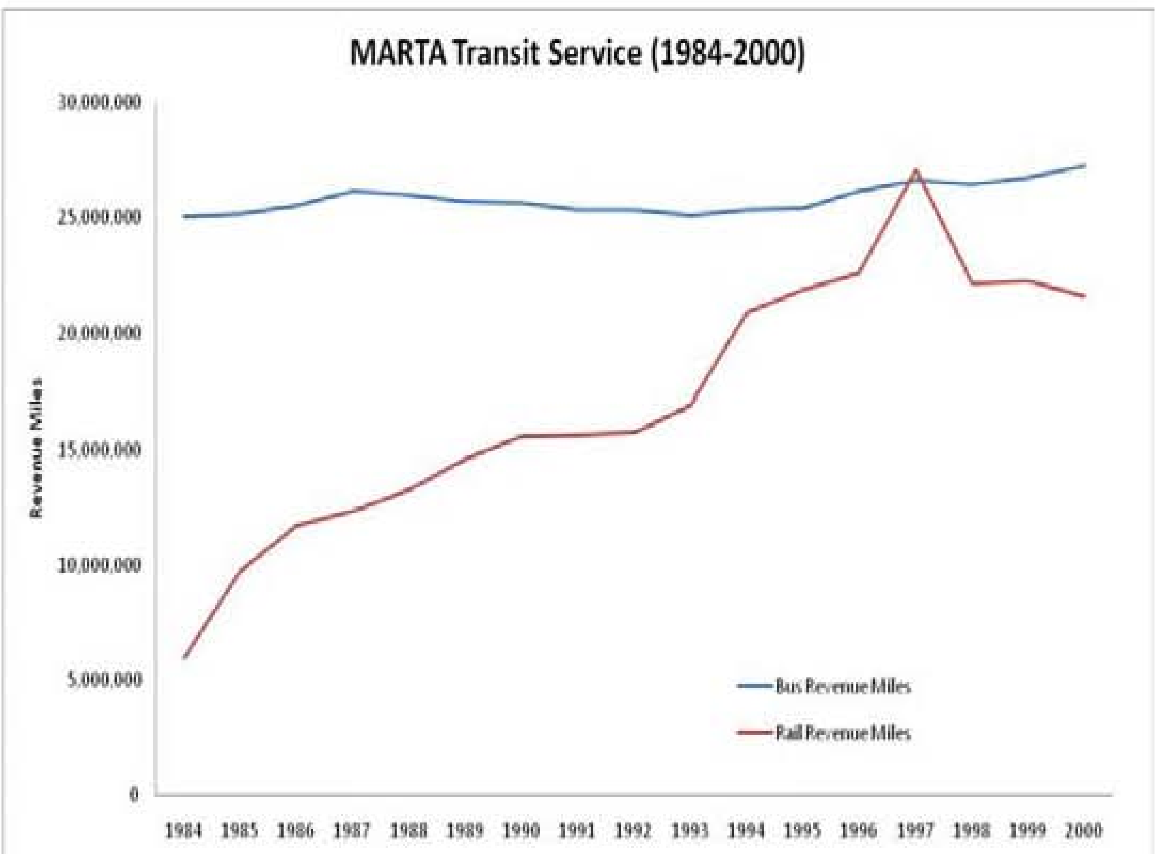

Figure 17. MARTA Transit Service (Revenue Miles) (1984-2000)[68]

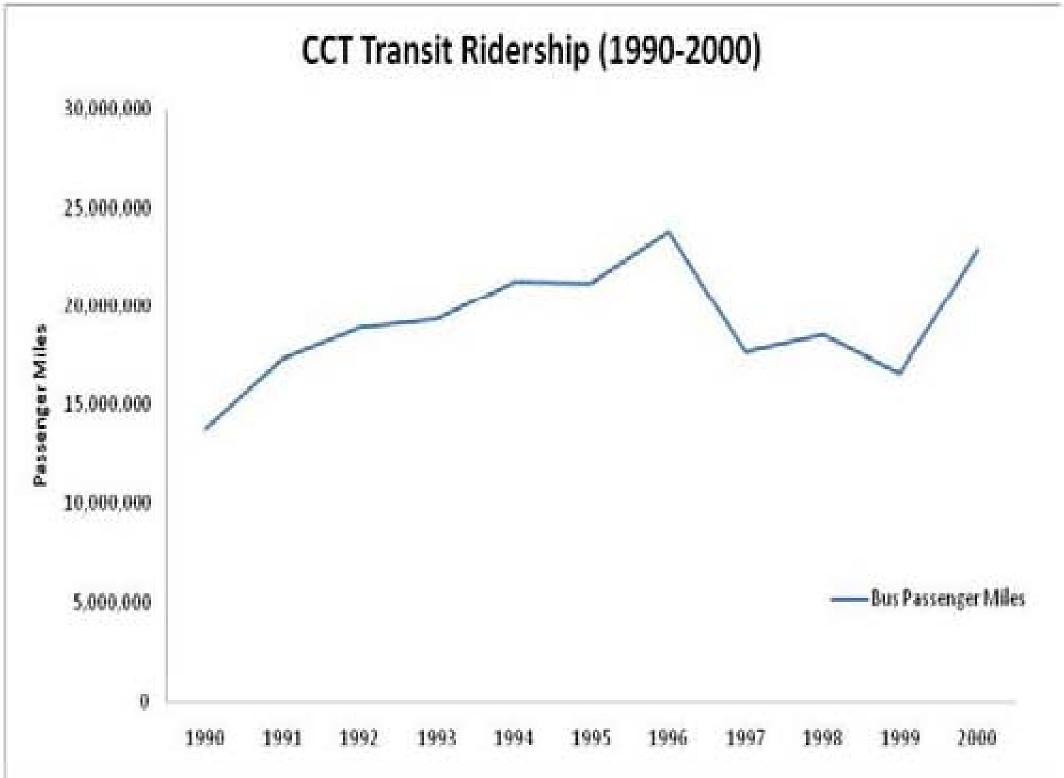

Figure 18. CCT Transit Ridership (Passenger Miles) (1990-2000)[69]

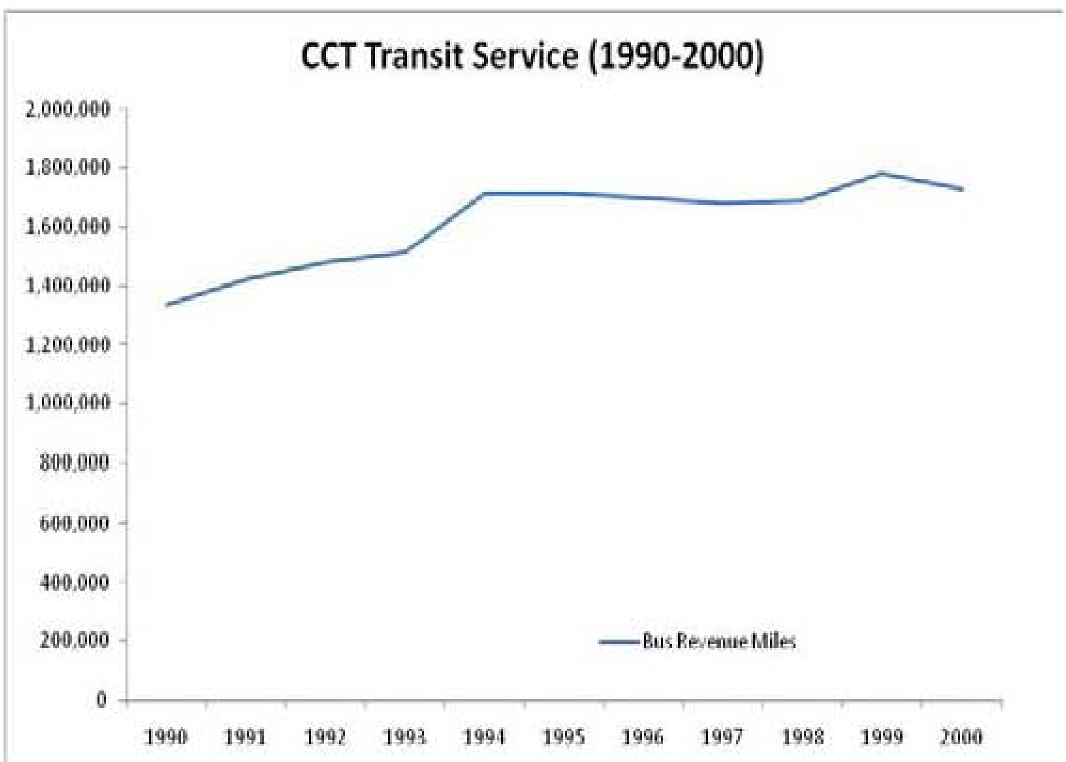

Figure 19. CCT Transit Service (Revenue Miles) (1990-2000)[70]

2000 CENSUS JOURNEY TO WORK TRANSIT TRIPS

Our measure of transit ridership in this study derives from the Census Transportation Planning Package (CTPP) compiled from the results of the 2000 Census. We are specifically interested in understanding the socioeconomic, transit service quality, and land use variables that influence the number of journey to work (commute) transit trips traveling from one zone (the origin zone) to another (the destination zone). The relevant dependent variables are available in Part 3 of the CTPP, which examines travel flows between pairs of TAZs for all reported commute trips. Travelers are assigned to one mode of transportation based on their responses to Census long form questions. Two transit modes are of interest for the Atlanta study: “bus or trolley bus” transit and “subway or elevated” rail transit, as these are the two modes in operation in Atlanta at the time of the 2000 Census.

The CTPP allows a transit rider to only choose one mode for their trip. For Atlanta, this mode is bus or rail. Many real-world transit trips involve the use of multiple modes, such as walk to bus, transfer to rail, transfer to bus and walk to rail, and transfer to bus. Many survey respondents undoubtedly make these and other multimodal trips, and it is unclear how they would categorize themselves. Would they refer to themselves as bus riders or rail riders? It is unclear. This is a limitation of the original CTPP data.

As we describe below, many individuals who identified themselves as bus riders in the CTPP data in reality transferred from bus to train and perhaps back again in making their trips to work. We therefore make adjustments, where appropriate, to their travel times as we discuss in the methodology section of the report to reflect instances of shorter travel times by combinations of buses and trains in comparison to bus-only trips. In terms of individuals who identified themselves as rail riders, and who may have accessed rail by automobile or bus, we also use the ARC On-Board survey to apportion rail riders across these potential access modes.[71] For many rail riders, we calculate the access time to transit as a weighted proportion of the access times of the potential access modes, as we discuss later in the report.

Table 5 shows the destinations of transit riders using bus or train to get to work. The table shows that the types of destinations characteristic of the two groups of riders are very different and reflect the objectives of the bus route restructurings that accompanied the progressive introductions of rail transit segments. Before the route restructurings, long bus routes connected most neighborhoods in the Atlanta region to the Atlanta CBD. Rail lines substituted for much of the bus mileage running along trunk roads entering the CBD, and many of the shortened bus routes were terminated at rail stations, essentially forcing a transfer for those bus riders who wanted to reach the CBD. At the same time, however, different bus routes congregating at suburban rail stations made it possible for bus users to reach many suburban destinations.

Table 5. Destinations of Transit Riders Using Bus or Rail (2000)

Destination	Access Mode to Transit	CTPP Riders
All Transit-Accessible Destinations	Walk to Bus	12,371
Atlanta Central Business District	Walk to Bus	2,327
Regional Centers	Walk to Bus	4,609
City Center Excluding CBD	Walk to Bus	1,129
All Transit-Accessible Destinations Outside City Center	Walk to Bus	8,915
All Transit-Accessible Destinations	Weighted Access to Rail	6,121
Atlanta Central Business District	Weighted Access to Rail	3,427
Regional Centers	Weighted Access to Rail	935
City Center Excluding CBD	Weighted Access to Rail	1,759
All Transit-Accessible Destinations Outside City Center	Weighted Access to Rail	1429

Table 5 shows that in 2000 most bus riders (8,915 out of 12,371 riders surveyed) were in fact taking advantage of the suburban transfer capability, destined to suburban rather than CBD jobs. Many of the suburban jobs were located in job clusters, but a substantial number were scattered as well. Of the 8,915 bus riders traveling to suburban jobs, more than half of them (4,609) were traveling to what ARC defines as regional centers. About a quarter of the daily bus riders traveled to jobs in the CBD and the adjoining city center areas.

In contrast to bus riders, most rail riders (3,427 out of 6,121 riders surveyed) were headed to jobs in the CBD, and another 935 riders were destined to city center stations just north of the CBD. Still, there was a substantial number of rail riders headed to jobs in the rest of the metropolitan area (1,759 riders or 29 percent of rail riders surveyed), and most of these were headed to jobs in what ARC calls regional centers.

Figures 20 and **21** give greater meaning to these numbers. **Figure 20** shows the destinations of bus riders going to work in the year 2000. The densest clusters of jobs accessed by bus riders were in the Buckhead area (in some cases close to rail stations), around Emory University and Decatur, around Georgia Tech, and along the south rail corridor toward the airport. Regional centers that had no or few jobs accessed by bus riders typically had no bus service going to them (Gwinnett and Clayton Counties) or poor bus service (Cobb County).

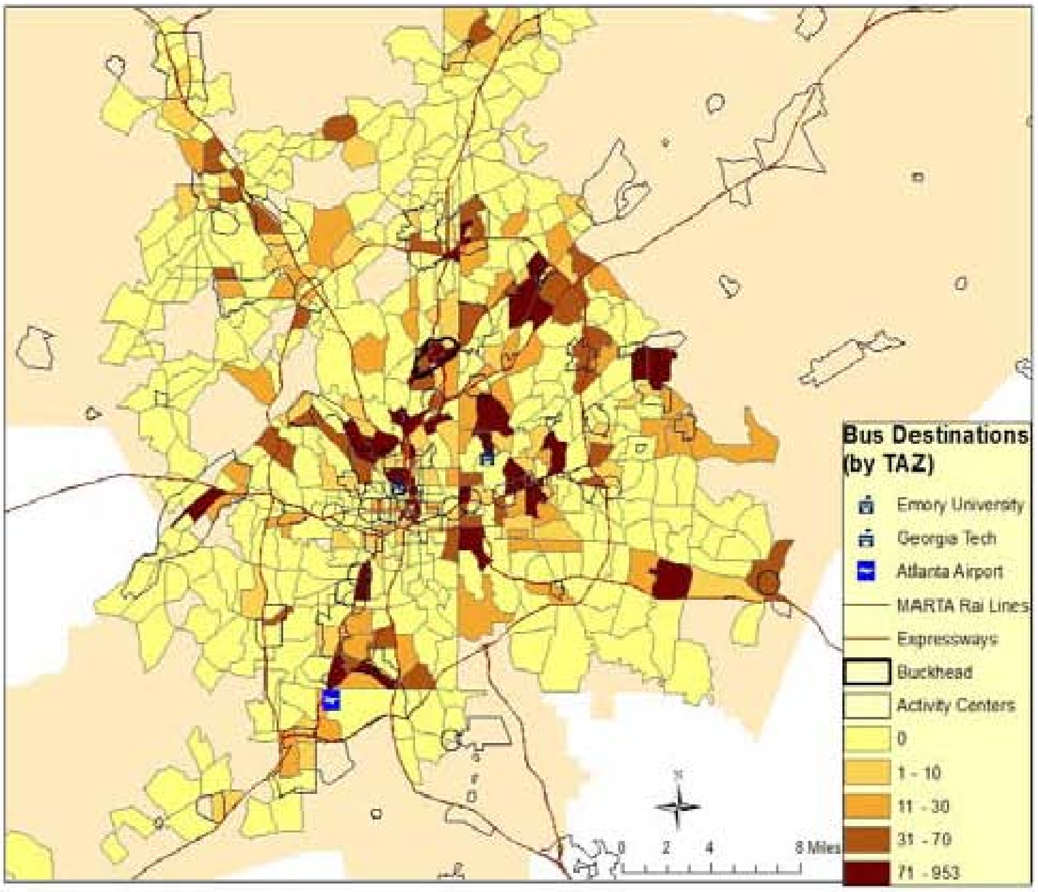

Figure 20. Destinations of Atlanta Bus Riders Going to Work, 2000[72]

Note: Zones colored using yellow-brown colors have transit service.

Figure 21 shows destinations of rail riders going to work in the year 2000. It shows that most rail riders were traveling to jobs immediately adjacent to rail stations, not only in the CBD and Midtown areas, but elsewhere. In some cases, such as stations in the CBD, stations serving Midtown, Lindbergh, and the Airport, many riders could walk to destinations. Other destinations of rail riders, such as Georgia Tech, a zone just north of Emory University, a freeway-oriented commercial area north of the city center adjacent to the split of I-75 and I-85, required riders to transfer to buses for the final leg of their trips. So, while most rail riders who were going to work outside of the CBD and city center were going to regional centers, it was only to a small subset of regional centers directly adjacent to rail stations or reached by a short bus ride. Rail riders tended to avoid traveling to regional centers located farther away, and there were a couple of regional centers located along the south rail line that they avoided, as well.

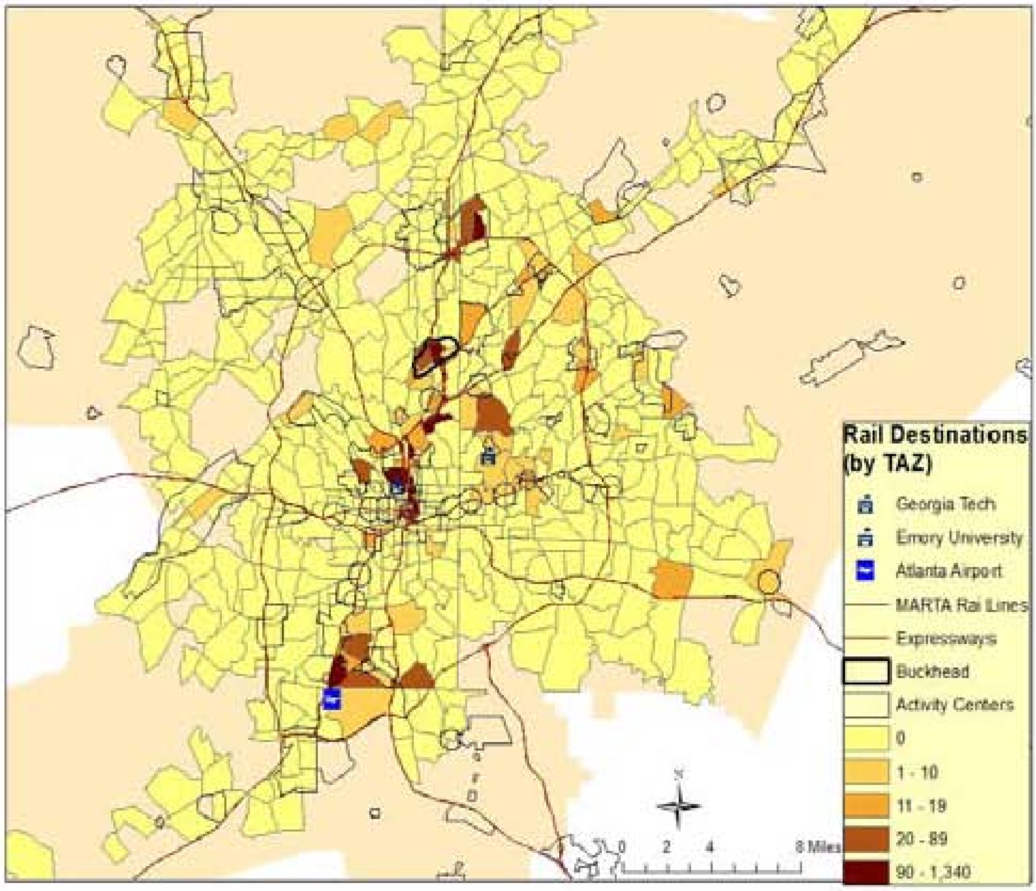

Figure 21. Destinations of Atlanta Rail Riders Going to Work, 2000[73]

Note: Zones colored using yellow-brown colors have transit service.

Figure 22 shows the zones where work-bound bus riders lived in the year 2000. The great majority of riders originated in the southern and western districts of the metropolitan area, generally characterized by lower median household incomes, lower levels of vehicle accessibility, higher unemployment rates, and higher vacancy rates. Fewer bus riders came from more affluent zones. Some bus riders lived in zones along I-85 in the northeastern sector of the area as well as in central Cobb County, but these zones were also characterized by lower incomes. (See **Figure 8**, discussed earlier.)

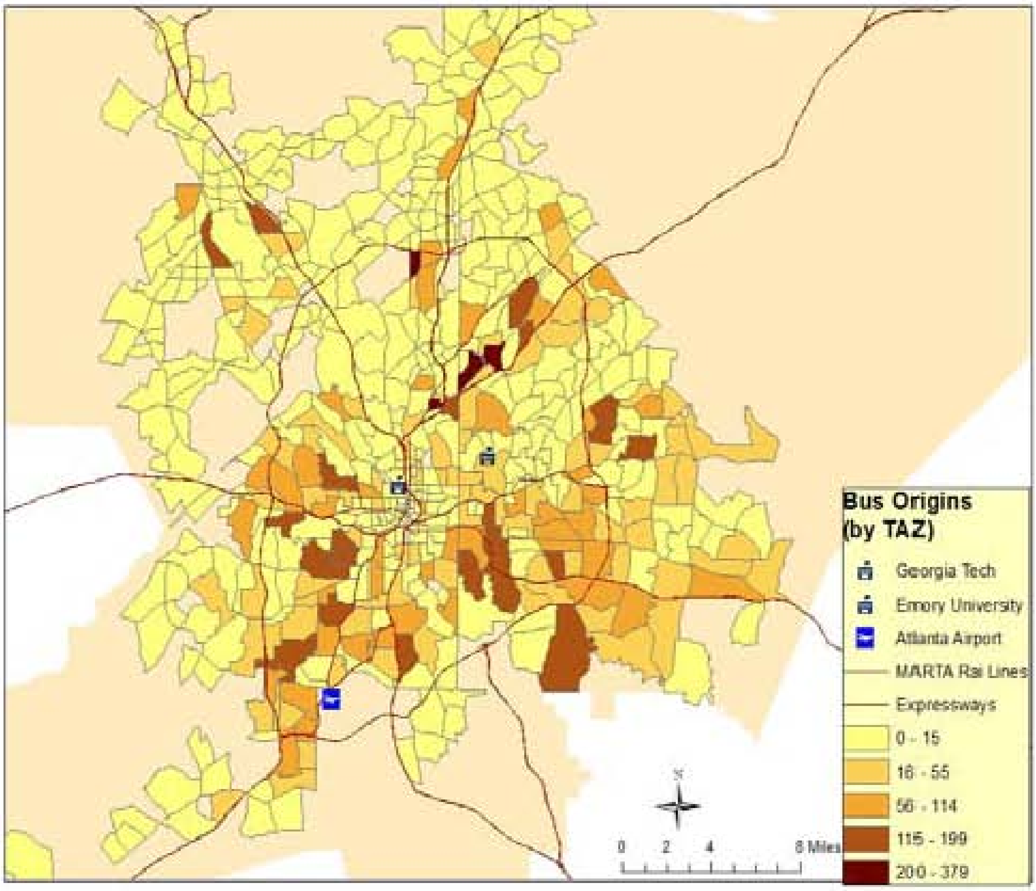

Figure 22. Origins of Atlanta Bus Riders Going to Work, 2000[74]

Note: Zones colored using yellow-brown colors have transit service.

Work-bound rail riders, on the other hand, lived in more dispersed locations in the year 2000, as shown in **Figure 23**. One reason that rail riders were more dispersed than bus riders is that about 52% of them accessed rail stations by auto, according to an onboard MARTA survey of riders.[75] While conducted in 2002, the access patterns revealed by the survey were unlikely much different two years earlier. The census-based data in **Figure 23** show that some work-bound rail riders live in a corridor along the south line, depressed by most economic measures, but others live in more affluent minority areas in the southeast and east of DeKalb County and others in moderate income areas of north-central Fulton County (see **Figures 8**, **11**, and **12** shown earlier). In addition there is a scattering of riders living in more affluent areas throughout the region at great distances from the rail lines, a pattern indicating access by auto.

What can we make of these patterns? First, what emerges from the bus data is a group of riders from less affluent areas traveling to work in centers located largely in more affluent areas. Given that many of the destinations of these bus riders were adjacent to rail stations and that the transit route structure made it difficult to get to such areas except by transferring to MARTA trains, we suspect that many of the bus riders were in fact using a combination of bus and rail modes to complete their trips. One may infer that the bus and bus/rail service was a help economically to the population using it, and that the dispersed nature of the bus system was a great help for this group in reaching the very dispersed distribution of jobs in Fulton and DeKalb Counties. Unfortunately, there remained many jobs without transit access outside of Fulton and DeKalb Counties.

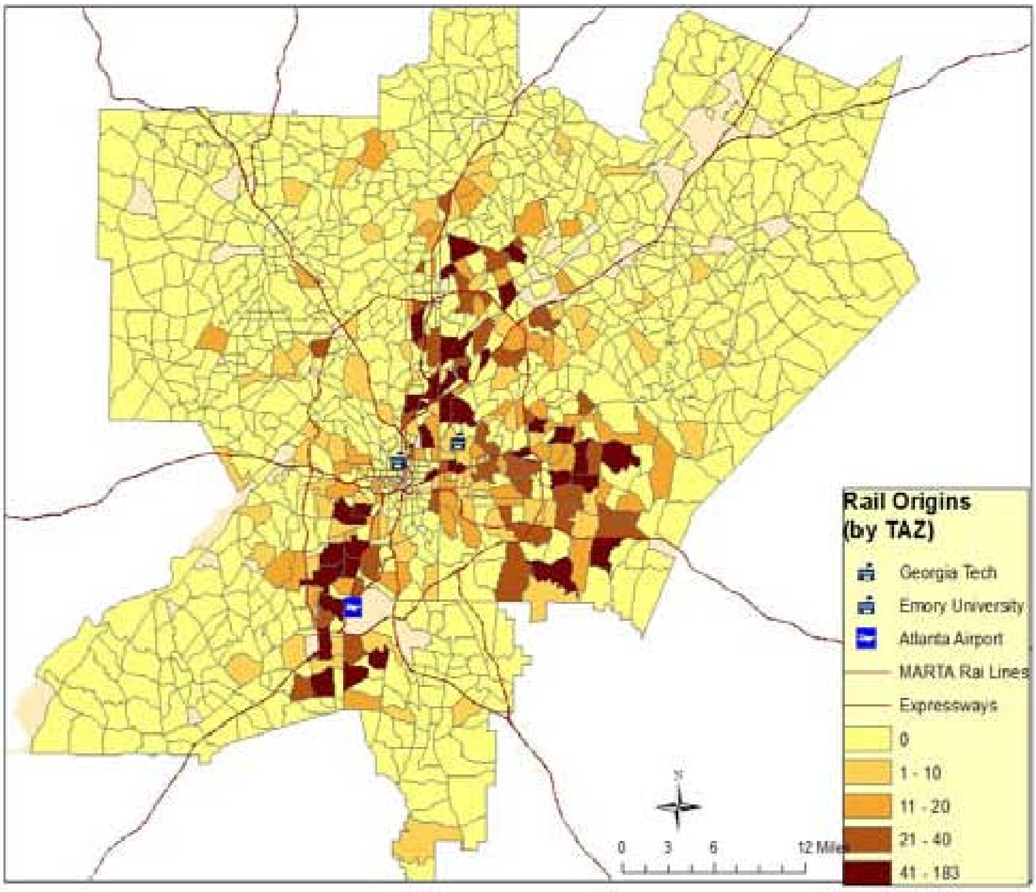

Figure 23. Origins of Atlanta Rail Riders Going to Work, 2000[76]

Note: Zones colored using yellow-brown colors have transit service.

The rail riders represent more of a mix of different types of riders. The figures indicate that some are similar in characteristics to bus riders, but there are clearly important differences as well. There appear to be significant numbers of more middle class rail riders with higher incomes and greater access to cars. A large part of this group may live in minority areas. There are also some rail riders who appear to come from more affluent areas. In general, these riders appear willing to use trains to stations, from which they can walk to jobs directly; a minority of riders appear willing to transfer to buses to reach jobs located near stations.

To gain more insight about characteristics of transit riders and policies that might induce more of them to use transit, we now turn to specification and estimation of demand models.

IV. METHODOLOGY

The methodology in this study is to specify and estimate models that predict bus and rail transit work trips (the dependent variable) from one part of a metropolitan area (traffic analysis zone or TAZ) to another. In other words, we develop statistical equations that allow us to explain the influence of different types of variables on transit ridership. The approach is similar to that used by the authors in their statistical analysis of bus passenger demand in Broward County, Florida.[77] In this case study, however, we employ two sets of models. For one set of models, the dependent variable consists of transit users who identified themselves as "bus or trolley bus" riders in the 2000 CTPP. For the other set of models, the dependent variable consists of transit users who identified themselves as "subway or elevated" riders in the 2000 CTPP. We treat the former group as (self-identified) bus riders and the latter group as (self-identified) rail riders, although many riders in either category undoubtedly use multiple modes for their trips. The explanatory variables used in the models include socioeconomic variables from the 2000 CTPP, land use variables defined by the local MPO, and variables that measure transit service quality (broken into three components: in-vehicle, out-of-vehicle, and transfer time) obtained from the travel time skims of the regional travel demand model.

MODEL SPECIFICATION

Our dependent variable is a count variable whose minimum value is 0. Many of our observations, which represent travel between an origin zone and a destination zone, have a value of 0, indicating no transit trips between that particular origin-destination pair. This type of dependent variable is best analyzed using an exponential functional form that can be estimated using negative binomial regression.[78] We estimated this model using the STATA statistical package. The first cut for a general model specification is shown below:

Equation 1

where,

T_{ijk} = the number of transit work trips originating in zone i and terminating in zone j using primarily mode k (either rail or bus as self-described by survey respondent)
POP_i = population in originating zone i
$PERCENT\_WHITE_i$ = percent of zone i's population that is white
$MEDHHINC_i$ = median household income in originating zone i
$\%HHWCHILD_i$ = percentage of households without children in originating zone i
$VEHPOP_i$ = Ratio of vehicles to population in originating zone i
$TODO_i$ = TOD dummy variable (1 = TOD; 0 otherwise) for originating zone i
EMP_j = employment in destination zone j
$TODD_j$ = TOD dummy variable for destination zone j (1 = TOD destination zone; 0 otherwise);
CBD_j = CBD dummy variable for destination zone j (1 = CBD destination zone; 0 otherwise);
REG_CENTER_j = regional center dummy variable for destination zone j (1 = regional center destination zone; 0 otherwise);

IVT_{ij} = in-vehicle transit travel time (time riding inside transit vehicle or vehicles) between zone i and zone j
OVT_{ij} = time walking and/or driving from origin to transit stop plus time waiting for first transit vehicle plus time walking from last transit vehicle to final destination
$XWAIT_{ij}$ = time waiting to transfer between transit vehicles
b = parameters to be estimated

In words, equation 1 tells us that work transit trips originating in zone i and destined to zone j are influenced by variables characterizing the beginning of the trip, other variables characterizing the destination of the trip, and still other variables characterizing the trip itself. Variables characterizing the originating zone i include population, the percentage of population that is white, median household income, the percentage of households without children, the number of personal vehicles available per capita, and whether it is a TOD. Variables characterizing the destination zone j include the magnitude of employment, whether it is a TOD, whether it is in the CBD, and whether it is in a regional center. Variables describing the transit trip between origin and destination include out-of-vehicle time (not including transfer time), in-vehicle time, and transfer time. We eliminated any TAZs for which no transit connections exist from the data set.

We estimated equation 1 for both bus and rail models to all transit-accessible destinations. We then investigated the results for evidence of spatial autocorrelation by aggregating all transit flows originating in a TAZ that were predicted by the model and all transit flows ending in a TAZ that were predicted by the model and comparing these predicted totals to the numbers of observations reported for the aggregated origins and destinations in part 3 of the CTPP. Spatial autocorrelation refers to the correlation of the values of a variable based on spatial location. In this case, there is concern that the numbers of transit trip origins or destinations in a zone for our transit travel flows might be spatially correlated to the number of transit trip origins or destinations in adjacent zones. Researchers can test for spatial autocorrelation by examining residuals (the difference between the value predicted by the model and the observed value of a variable) and calculating statistics such as Moran's I; both procedures can be conducted in ESRI's ARCGIS software.

We began our analysis by mapping the pattern of residuals for origins and for destinations for our bus and rail models to identify the presence of any obvious spatial patterns. We also calculated Moran's I for the patterns of residuals. The Moran's I statistic indicated the presence of spatial bias in the distribution of residuals at the origin end of the trip for both the bus and rail models. Casual observation of the residuals suggested that the model was over-predicting trip origins in poorer TAZs where we expected to find high levels of transit use. We speculated that additional explanatory variables might be needed to account for this spatial bias.

We hypothesized that many of the areas with over-predictions were economically depressed. We obtained two additional variables from the CTPP to account for the over-prediction: the vacancy rate for residential dwelling units in the origin TAZ and the unemployment rate in the origin TAZ. Both variables can be used to indicate the economic conditions in a zone. Statistical tests indicate that the variables were not correlated, and thus potentially captured different dimensions of economic distress. Including these two additional variables in our models increased the explanatory power of the models and reduced the incidence of spatial autocorrelation. Further investigation suggested that the addition of density variables for population (in the origin TAZ) and employment (in the destination TAZ) would further improve model performance, as indeed occurred.

Our attempts to eliminate spatial bias from the work trip predictions of our bus and rail models led us to add the following explanatory variables:

$UNEMP\_RATE_i$ = percentage of workforce living in originating zone i who are unemployed
$VACANCY\_RATE_i$ = percent of dwelling units in originating zone i that are vacant
POP_DEN_i = population density of originating zone i
EMP_DEN_j = employment density of destination zone j

The four additional variables result in the following general specification of the model:

Equation 2

Equation 2 is the general model used in this study. As does the model represented by equation 1, equation 2 results in no spatial bias of estimates on the destination end of the trips for either the bus or rail models. It eliminates spatial bias seen in equation 1 on the origin end of rail trips, and it greatly reduces but does not entirely eliminate spatial bias on the originating end of bus trips. Moran's I test statistics for spatial autocorrelation are 0 for the two sets of destinations and .01 for rail origins and .05 for bus origins.

We estimated a total of 10 different statistical models for this study, with five different sets of travel destinations defined for bus and for rail. We expected to find differences in the models for bus versus those for rail, because of differences in the rider groups between

$$T_{ijk} = \exp(b_0 + b_1 * POP_i + b_2 * POP\_DEN_i + b_3 * PERCENT\_WHITE_i + b_4 * MEDHHINC_i +$$
$$b_5 * \%HHWCHILD_i + b_6 * VEHPOP_i + b_7 * UNEMP\_RATE_i + b_8 * VACANCY\_RATE_i +$$
$$b_9 * EMP_j + b_{10} * EMP\_DEN_j + b_{11} * TODD_j + b_{12} * CBD_j + b_{13} * REG\_CENTER_j$$
$$+ b_{14} * IVT_j + b_{14} * OVT_j + b_{15} * XWAIT_j)$$

choice and transit-dependent riders. The five bus models are listed below:

1. Bus passengers to all transit-accessible destinations
2. Bus passengers to Atlanta CBD
3. Bus passengers to city center outside of Atlanta CBD
4. Bus passengers to all destinations except CBD and city center outside of CBD
5. Bus passengers to regional centers

We hypothesized that the bus models would largely reflect the presence of a transit-dependent population, although we also hypothesized that we might find more evidence of choice riders in two models: bus passengers to Atlanta CBD and bus passengers to city center outside of Atlanta CBD. Our model results support these hypotheses.

We estimated rail models for the same sets of destinations, as listed below:

6. Rail passengers to all transit-accessible destinations
7. Rail passengers to Atlanta CBD
8. Rail passengers to city center outside of Atlanta CBD
9. Rail passengers to all destinations except CBD and city center outside of CBD
10. Rail passengers to regional centers

We hypothesized that we would find more evidence of choice riders in the rail transit models. We hypothesized that we would find the highest concentration of choice riders in the CBD model, followed by the city center outside of CBD model. We expected rail riders to most closely resemble transit-dependent riders in the rail to regional centers model, because these passengers must use a bus transfer to reach most of the regional center destinations. Our model results by and large support these hypotheses.

TRANSIT TRAVEL TIME VARIABLES

Most of the explanatory variables used in our models are straightforward in their construction and will be familiar to transit scholars. These variables are also discussed and mapped earlier in the report. However, the travel time variables require further elaboration. As noted earlier, transit travel time is our key indicator of transit service quality. We break transit travel time into three components, based on the travel model skims: in-vehicle travel time, out-of-vehicle travel time (not including transfer time), and transfer time. We selected this construction of the travel time variable because interpretation of the variable parameters will lend themselves to different types of policy recommendations for improving transit service quality. Our hypothesis is that out-of-vehicle and transfer time will be weighted twice as heavily as in-vehicle travel time, based on previous studies cited in the literature.

As noted earlier, our bus models include passengers who self-identified as bus riders, although many of them may use multiple modes to complete their trips. In order to calculate zone-to-zone travel times for these trips, we first calculated travel time entirely by bus and then travel time by a combination of bus and rail, where a rail link was present, for all origin-destination pairs. We then compared the two travel times. If the bus-only travel time was shorter, we used it as the travel time for that origin-destination pair. However, if the bus and rail travel time was shorter, we used this travel time as long as the time savings was at least 10%. We employed the 10% rule to account for the inconvenience of having to make the transfer, in excess of the transfer time itself.

Our rail models include passengers who self-identified as rail passengers although many of these passengers might also use multiple modes either on the access mode (bus or auto) or the destination end (bus or walk) of the trip. The determination of mode selection and travel time for the destination end of the trip is built into the skim files. For the access end of the trip, it is unclear how an individual traveler accesses the rail system. We used the results of the 2001-2002 On-Board Transit Survey to apportion the flows across the potential access modes and weighted the travel times accordingly.

V. STATISTICAL ANALYSIS OF TRANSIT RIDERSHIP IN ATLANTA

We estimated a series of models for bus and rail, as noted above, beginning with models for both modes examining ridership to all transit-accessible destinations in the Atlanta study area. We refer to these models as regional models. We specified two variations to the regional bus model, one assuming that all passengers who identified themselves as bus passengers used only walking and the bus to travel from their home to place of employment. For the other specification, we assumed that passengers who identified themselves as bus passengers took either the bus or a combination of bus and rail to reach their place of work, depending upon whether the all-bus path or the bus-rail path (plus 10 percent additional travel time to account for the inconvenience of transferring between modes) was the shorter of the two paths. The latter assumption resulted in about 6,000 of the 12,000 passengers who identified themselves as bus passengers being assigned to all-bus paths between origin and destination, and the other passengers being assigned to bus-rail paths. Estimation of both regional models yielded parameters that tell the same story of what variables are important and not important in explaining bus passenger demand.

We report the results for the regional and sub-regional bus models that assumed a mix of all-bus and bus-rail paths because it is consistent with the observation that a large

$$T_{ijk} = \exp(b_0 + b_1 * POP_i + b_2 * PERCENT\_WHITE_i + b_3 * MEDHHINC_i +$$
$$b_4 * \%HHWCHILD_i + b_5 * VEHPOP_i + b_6 * TODO_i + b_7 * EMP_j + b_8 * TODD_j + b_9 * CBD_j +$$
$$b_{10} * REG\_CENTER_j + b_{11} * IVT_j + b_{12} * OVT_j + b_{13} * XWAIT_j)$$

number of bus users were traveling to zones in the north adjacent to rail stations, and a combination of bus and rail routes would provide the shortest travel time to reach such destinations, particularly when traveling from the southern part of the study area (where many bus users began their trips, as shown in **Figure 22** presented earlier).

We also specified two variations for the regional rail model, one assuming that all passengers who identified themselves as rail passengers used automobiles to access trains, and the other assuming that roughly half used autos and half used buses to reach trains. For the latter assumption, we modeled the access path as the auto access path if no transit was available, but park and ride was available; the walk/bus access path if there was no park and ride available, but bus access was available; and a weighted average of the two if both modes of access were available. The specific weighting scheme was based on the *2001-2002 On-Board Survey*.[79] As with the bus models, the estimation of the two variations of the regional rail model resulted in parameters that tell the same general story of what is important in creating rail passenger demand. We report on the model with weighted access because it reflects better the multimodal characteristics of many rail users.

BUS RESULTS

Table 6 presents estimation results for the regional bus model. The pseudo r square of .057 is low, but typical of this type of model. The pseudo r square tells us the proportion of variability in ridership from one zone to another explained by the collection of explanatory variables. The hypothesis that the model explains nothing about bus rider demand has a probability of 0 at three decimal places, and we reject it. Thus, the model explains some variation in regional bus rider demand. The statistical significance of the estimated parameters and their elasticity at means (or their multiplier effect if they are a dummy variable) are what most interests us. What we see by looking at the collection of parameters is a model that very strongly depicts transit-dependent riders who, none-the-less, are highly sensitive to the quality of transit service that they receive.

Bus ridership is generated in proportion to the population of an origin zone (origin TAZ), and higher population density boosts ridership generation even more, but as auto access, median household income, and the percentage of the population that is white goes up, the propensity of the zone to produce bus transit trips goes down. All of these effects are strong. As population goes up by one percent, the propensity of the zone to produce bus transit trips goes up by 1.01 percent, all else being equal, and as population density goes up by one percent, the propensity of the zone to produce bus transit trips goes up by 0.47 percent. Working in the opposite direction, as the percentage of the zone that is white goes up by one percent, bus ridership drops by nearly one percent, as median household income increases by one percent, bus transit trip generation drops by 0.91 percent, as vehicles per capita increase by one percent, bus transit trip generation drops by 2.23 percent. Economic stress in the zone also depresses bus transit trip generation. As the percent of the workers living in the zone who are unemployed goes up by one percent, bus transit trip generation declines by 0.67 percent.

Variables that are important in attracting bus transit work trips at the destination (destination TAZ) include employment (number of jobs), employment density, and whether or not the destination zone is in the CBD. For every percent that employment in the destination zone increases, bus transit trips attracted to the zone increase by 1.14 percent. This is expected, but what follows is not. For every percent that employment density increases by one percent, bus transit trips attracted to the destination go down by 0.20 percent, a small but statistically significant relationship in the opposite direct from what one would expect. Moreover, if the destination zone is in the CBD, the highly statistically significant results indicate that bus transit trips attracted to the zone would be 57 percent lower than if the zone were located somewhere else.

Upon reflection, these astonishing results are not surprising. If one refers to **Figure 20** presented earlier, one can see very clearly that most bus transit trips are destined to zones scattered throughout the region. Over three quarters of the bus transit trips are going to non-CBD zones, most of which have lower employment densities than zones found in the center of the region. The types of jobs that highly transit-dependent workers seek may have a lower probability of being located in the CBD than in more peripheral locations. These results are very similar to those found by the authors in a study of bus transit demand in Broward County, Florida.[80]

Table 6. Regional Bus Model for Atlanta

Model Summary					
Number of Observations		40,269			
Pseudo R squared		0.057			
LR chi squared		933.900			
Prob chi squared		0.000			
Log likelihood		-7,721.782			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-2.1985	0.000	0.452	-0.993	
Population	0.0003	0.000	3,675.036	1.008	
Population density	0.0796	0.000	5.907	0.470	
Median household income	-0.0000	0.000	50,535.130	-0.910	
Percent households w/o children	1.0232	0.153	0.609		
Vehicles per person	-3.5830	0.000	0.621	-2.225	
Vacancy rate for residential units	-2.1953	0.082	0.061		
Unemployment rate	-15.0868	0.000	0.044	-0.662	
Transit oriented development	-0.1863	0.669			
Destination Zone Variables					
Employment	0.0003	0.000	4,150.849	1.141	
Employment density	-0.0198	0.001	9.850	-0.195	
Transit oriented development	0.0939	0.675			
Regional center	0.0998	0.442			
CBD	-0.5620	0.004			0.570
Transit Travel Time Variables					
Out of vehicle travel time	0.0001	0.327	1,705.421		
In vehicle travel time	-0.0005	0.000	3,765.486	-1.750	
Transfer time	-0.0005	0.000	1,118.775	-0.593	
Constant	1.2519	0.010			

It is also noteworthy that the transit-oriented development (TOD) variables contribute nothing that is statistically significant for either generating or attracting bus transit work trips. This finding also is consistent with what we found in the Broward County study, but it is a major difference from what we found in the regional rail model (where one TOD variable is highly significant), as we explain later. The difference between the bus and rail models may be explained by the fact that TOD zones may not be places where highly transit-dependent populations are likely to live or work. TOD zones, however, may be attractive to transit riders who are choice riders, a quality more typical of rail riders.

There are three variables describing the ease for using transit to travel from origin to destination: in-vehicle travel time (IVT), transfer time, and out-of-vehicle travel time (OVT), all explained earlier. In-vehicle travel time is highly significant. For every percent that it decreases, bus transit ridership increases by 1.75 percent. Given that employment is a major attractor of transit trips, particularly in more peripheral areas, the sensitivity of demand to IVT suggests that a major policy objective should be to connect residential areas to work areas as directly as possible by bus routes. This consideration implies a more expansive grid of routes connecting suburban employment centers now poorly served by transit, because transit cannot directly serve many origin-destination pairs without transfers. That the wait time for transfers is also highly significant (with ridership increasing by 0.59 percent for every percent that the transfer wait time is reduced), suggests that transfers should be well designed, and that connecting routes should have short headways.

The surprising variable here is out-of-vehicle travel time, which has a parameter close to 0, which is statistically insignificant. This variable is comprised of walking time at the beginning and end of a transit trip as well as the wait for the first transit vehicle. We know from the transfer time variable that headways matter; so, what we conclude from the unimportance of this variable is that bus transit stops are so ubiquitous throughout the study area that walking to and from them is not an issue. This is another major difference with the regional rail model, where rail stations are few in number, often far removed from important origins and destinations, and where walking distances are a major factor affecting ridership.

SUB-REGIONAL BUS MODELS

We then examined four models that examined bus ridership to different types of travel destinations: Atlanta CBD, city center outside the CBD, regional centers, and all destinations outside the city center and CBD. We refer to these as sub-regional models to differentiate them from the overall regional model that includes all travel destinations. The sub-regional models largely echo the results of the regional bus model, although there are two important differences between the pair of models that represent destinations in central Atlanta and the pair of models that represent more dispersed destinations. The models for bus trips to the CBD and the city center outside the CBD show the vehicles per person variable as being statistically insignificant and the median household income variable also becoming insignificant as it changes from negative to positive. These results likely reflect the inclusion of some higher income, choice riders among the bus riders bound to these destinations. We now discuss the results of each of the sub-regional bus models in turn.

The results for the CBD model are shown in **Table 7**. Bus ridership to the CBD is influenced by three variables that describe the origin zone, all of which are also significant in the regional model: percent of white population, total population, and population density. The larger the percent of white population in a zone, the fewer bus transit trips to the CBD are generated in the zone. If the percent of white population increases one percent, bus trips to the CBD decline 1.5 percent. Higher population and higher population density both lead to more bus trips to the CBD. If the population in an origin zone increases one percent, bus trips to the CBD increase 0.94 percent; if population density increases one percent, bus trips to the CBD increase 0.68 percent. However, the other three origin zone variables that were significant in the regional model (median household income, vehicles per person, and unemployment rate) are not significant in this model, likely because the CBD riders include a mix of transit-dependent riders and choice riders, some of the latter perhaps using express bus service or traveling from nearby destinations.

Ridership to the CBD is affected by two variables in the destination zone—employment and employment density. Both variables were also significant in the regional model, although their elasticities are larger in this model. Even in the CBD, higher employment density depresses transit ridership to some extent, indicating that the bus riders tend to travel to lower density parts of the CBD. Finally, bus trips to the CBD are also influenced by both in-vehicle travel time and transfer time, as was also true for the regional model. A one percent reduction of in-vehicle travel time would increase bus trips to the CBD 1.24 percent; a one-percent reduction in transfer time would increase bus trips to the CBD 0.61 percent.

Table 7. Sub-Regional Model: Bus Trips to the Atlanta CBD

Model Summary					
Number of Observations		4,376			
Pseudo R squared		0.060			
LR chi squared		176.480			
Prob chi squared		0.000			
Log likelihood		-1,386.478			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-3.4422	0.000	0.438	-1.507	
Population	0.0003	0.001	3,547.874	0.939	
Population density	0.1129	0.026	5.998	0.677	
Median household income	0.0000	0.888	50,256.670		
Percent households w/o children	2.4240	0.179	0.615		
Vehicles per person	-2.8748	0.110	0.618		
Vacancy rate for residential units	-2.4393	0.504	0.064		
Unemployment rate	-7.3509	0.189	0.046		
Transit oriented development	-0.3380	0.726			
Destination Zone Variables					
Employment	0.0003	0.000	6,296.643	1.745	
Employment density	-0.0259	0.010	14.683	-0.380	
Transit oriented development					
Regional center					
CBD					
Transit Travel Time Variables					
Out of vehicle travel time	0.0003	0.367	1,402.373		
In vehicle travel time	-0.0004	0.004	2,801.226	-1.239	
Transfer time	-0.0014	0.014	445.709	-0.612	
Constant	-1.5035	0.233			

The results for the city center outside the CBD model are shown in **Table 8**. In this model, we likely capture a mix of transit-dependent and some choice riders, as the variables that highlight transit-dependency in the regional model are not significant in this model. In the origin zone, only total population is a significant predictor of transit trips to the city center outside the CBD, while among the destination zone variables only total employment is statistically significant. Higher population zones generate more bus transit trips to the city center outside the CBD, while zones with higher total employment attract more of these trips. Bus riders bound for these destinations are sensitive to out-of-vehicle travel time, perhaps reflecting difficulties either accessing transit or reaching their final travel destination, as well as in-vehicle travel time.

Table 8. Sub-Regional Model: Bus Trips to City Center Outside Atlanta CBD

Model Summary					
Number of Observations		2,861			
Pseudo R squared		0.051			
LR chi squared		80.210			
Prob chi squared		0.000			
Log likelihood		-748.315			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-0.8808	0.480	0.473		
Population	0.0005	0.002	3,482.167	1.666	
Population density	-0.0442	0.641	6.037		
Median household income	0.0000	0.832	51,152.050		
Percent households w/o children	0.7237	0.789	0.632		
Vehicles per person	-3.5317	0.140	0.630		
Vacancy rate for residential units	2.8206	0.634	0.065		
Unemployment rate	-0.5717	0.959	0.043		
Transit oriented development	0.8108	0.516			
Destination Zone Variables					
Employment	0.0003	0.000	5,604.058	1.629	
Employment density	-0.0254	0.224	15.305		
Transit oriented development					
Regional center					
CBD					
Transit Travel Time Variables					
Out of vehicle travel time	-0.0010	0.040	1,456.590	-1.520	
In vehicle travel time	-0.0006	0.009	2,864.807	-1.652	
Transfer time	-0.0011	0.065	645.296		
Constant	0.6902	0.757			

The final two bus models have results that more closely resemble the regional model results. They paint a picture of a more transit-dependent ridership than do the CBD or city center outside the CBD models. **Table 9** reports the results for the model examining bus trips to regional centers, which are more dispersed employment clusters defined by ARC. Among the origin zone variables, total population, median household income, and unemployment rate are significant variables. Higher population zones produce more of these bus trips, while zones with higher unemployment rates produce fewer trips. Zones with lower median household incomes tend to produce more trips to regional centers, reflecting a lower-income ridership profile. Among the destination zone variables, only total employment is a significant attractor of bus trips. Bus patrons destined to regional centers are very sensitive to in-vehicle travel time and transfer time; these riders are more sensitive to these two variables than any other bus rider group we examined. A one percent reduction in in-vehicle travel time would increase ridership to regional centers 2.41 percent. A one percent reduction in transfer time would increase ridership to regional centers 0.96 percent.

Table 9. Sub-Regional Model: Bus Trips to Regional Centers

Model Summary					
Number of Observations		14,015			
Pseudo R squared		0.060			
LR chi squared		364.780			
Prob chi squared		0.000			
Log likelihood		-2,872.999			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-1.0991	0.084	0.475		
Population	0.0004	0.000	3,617.206	1.367	
Population density	0.0682	0.069	5.866		
Median household income	0.0000	0.000	51,934.000	-1.553	
Percent households w/o children	-1.8905	0.178	0.617		
Vehicles per person	-2.4575	0.053	0.632		
Vacancy rate for residential units	0.4185	0.829	0.061		
Unemployment rate	-10.3167	0.022	0.042	-0.437	
Transit oriented development	0.1646	0.815			
Destination Zone Variables					
Employment	0.0002	0.000	5,391.906	1.152	
Employment density	-0.0117	0.134	13.170		
Transit oriented development					
Regional center					
CBD					
Transit Travel Time Variables					
Out of vehicle travel time	0.0002	0.175	1,755.637		
In vehicle travel time	-0.0006	0.000	4,148.780	-2.409	
Transfer time	-0.0009	0.000	1,118.241	-0.964	
Constant	2.6059	0.005			

The final bus model examines bus ridership to all destinations outside the city center and CBD. The results are reported in **Table 10**. The origin zone variables describe a more minority, lower-income population residing in zones with lower levels of automobile access. They are a clearly transit-dependent ridership. These riders are destined for zones with larger total employment, but not high employment densities. They are largely destined to sprawling, suburban employment centers. These riders are sensitive to both in-vehicle travel time and transfer time, and they would increase their ridership if bus trips were more direct and transfers better coordinated. A one percent reduction of in-vehicle travel time would increase ridership 1.85 percent. A one percent reduction in transfer time would increase ridership 0.66 percent.

Table 10. Sub-Regional Model: Bus Trips to All Other Destinations

Model Summary					
Number of Observations		33,032			
Pseudo R squared		0.057			
LR chi squared		674.840			
Prob chi squared		0.000			
Log likelihood		-5,546.897			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-2.2711	0.000	0.451	-1.025	
Population	0.0003	0.000	3,708.587	0.997	
Population density	0.0749	0.004	5.883	0.441	
Median household income	0.0000	0.000	50,518.580	-1.197	
Percent households w/o children	1.0027	0.240	0.607		
Vehicles per person	-3.5246	0.000	0.621	-2.188	
Vacancy rate for residential units	-2.2342	0.123	0.060		
Unemployment rate	-17.6461	0.000	0.044	-0.770	
Transit oriented development	-0.1823	0.746			
Destination Zone Variables					
Employment	0.0003	0.000	3,740.712	1.102	
Employment density	-0.0204	0.010	8.737	-0.178	
Transit oriented development	0.2590	0.520			
Regional center	0.0408	0.787			
CBD					
Transit Travel Time Variables					
Out of vehicle travel time	0.0001	0.358	1,767.120		
In vehicle travel time	-0.0005	0.000	3,971.239	-1.850	
Transfer time	-0.0005	0.000	1,248.951	-0.656	
Constant	1.6477	0.005			

SUMMARIZATION OF BUS RESULTS

Taken as a group, the results of the bus models paint a picture of an overwhelmingly transit-dependent ridership profile (characterized by lower incomes and lower levels of vehicle access), particularly among bus riders bound to destinations outside the CBD and city center. Bus riders seek to reach destination zones with large numbers of jobs, but they are not necessarily destined to the highest density employment centers. They are highly sensitive to transit travel time, including both in-vehicle travel time and transfer time. These results have important implications for transit policy, as we discuss later. We now turn to an examination of rail riders.

RAIL RESULTS

Table 11 presents estimation results for the weighted access regional rail model. The pseudo r square of .104 is low, but typical of this type of model. As noted earlier, the pseudo r square tells us the proportion of variability in ridership from one zone to another explained by the collection of explanatory variables. The hypothesis that the model explains nothing about rail passenger demand has a probability of 0 at three decimal places, and we reject it. Thus, the model explains some variation in rail passenger demand. What the model explains about rail patronage is conveyed by the statistical significance of the estimated parameters, and for those that are statistically significant, the model reports their impact on rail patronage. As with the bus model, practical impact is measured by elasticity for continuous explanatory variables and by the multiplying effect on estimated patronage for dummy variables when they take on the value of 1. (When they have a value of 0, dummy variables have no impact on predicted patronage.)

What we see by looking at the parameters is a model that depicts more affluent, auto-owning riders using transit than does the bus model. The rail riders are willing to use rail transit to get to jobs throughout the region (not just jobs in the CBD), so long as they can walk to jobs once they get off the trains or can easily transfer to frequent buses that do not take long to reach jobs in the vicinity. CBD and TOD at the rail destination (though not at the rail origin) are highly important to potential rail riders.

Turning to the effect of individual variables on rail ridership, we begin by examining variables describing the origin (origin TAZs). We see that ridership is generated in proportion to the total population of a zone, and that for every one percent increase in the zone's population, rail ridership will increase by 1.3 percent. Population density of the originating zone is also important, although the elasticity of ridership with increasing density is less than half of what it is for increasing population. As was true for the regional bus model, the regional rail model shows that the higher the percentage of white population in the originating zone, the lower the transit ridership, although the elasticity is less than half of that for the bus model.

Table 11. Regional Rail Model for Atlanta

Model Summary					
Number of Observations		70,409			
Pseudo R squared		0.104			
LR chi squared		1,064.090			
Prob chi squared		0.000			
Log likelihood		-4,566.384			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-1.3569	0.002	0.550	-0.746	
Population	0.0004	0.000	3,637.274	1.284	
Population density	0.1013	0.000	4.938	0.500	
Median household income	-0.0001	0.147	58,382.860		
Percent households w/o children	-1.2230	0.213	0.557		
Vehicles per person	2.7891	0.010	0.653	1.821	
Vacancy rate for residential units	-4.2040	0.040	0.050	-0.209	
Unemployment rate	1.5851	0.675	0.036		
Transit oriented development	0.8900	0.123			
Destination Zone Variables					
Employment	0.0003	0.000	4,184.467	1.231	
Employment density	-0.0095	0.026	8.123	-0.077	
Transit oriented development	1.6338	0.000			5.123
Regional center	0.1383	0.420			
CBD	1.5173	0.000			4.560
Transit Travel Time Variables					
Out of vehicle travel time	-0.0012	0.000	2,871.520	-3.330	
In vehicle travel time	-0.0002	0.000	3,220.258	-0.772	
Transfer time	-0.0008	0.000	1,075.413	-0.884	
Constant	-3.6163	0.000			

Unlike the case of the regional bus model, median household income of the originating zone has no statistical impact on rail transit ridership, while higher automobile access greatly increases rail ridership. For every percent that vehicles per capita increase in a zone, rail ridership in the zone increases by 1.8 percent. We interpret this strong relationship to mean that if a zone has a surfeit of autos, it is easier for some of the autos to be parked all day at rail stations. This interpretation is consistent with the observation derived from the on-board survey discussed earlier—that a large proportion of rail riders use autos to access trains. Also consistent with this interpretation is the unimportance that the model places on origin zone TODs for generating rail transit patronage. Origin zone TODs have no statistically important effect on increasing rail transit usage beyond what is predicted by the other explanatory variables.

The model also shows that the two variables portraying economic distress in originating zones, unemployment rates and vacancy rates, have little impact on depressing rail ridership. The vacancy rate does have a statistically significant effect on depressing rail transit patronage, but the elasticity is low, and the unemployment rate among job-age workers living in the zone has no statistically significant impact on generating rail transit ridership in the zone. Taken together, these origin zone variables describe more of a choice rider profile for rail patrons in Atlanta, a clear contrast with the regional bus model whose origin zone characteristics denote a more transit-dependent rider profile.

We now turn to the destination zone variables. The most important variable for attracting rail commuters to a destination zone is, not surprisingly, total employment. Every one percent increase in employment increases rail patronage by 1.23 percent. Employment density is also important, but negatively, though its practical effect is almost nothing. For every percent that employment density of a destination zone goes up, rail transit patronage is depressed by .08 percent. This variable reflects the fact, discussed earlier in the context of **Figure 21,** that half of the rail passengers in the survey were destined to zones outside of the CBD, which had lower employment densities. On the other hand, if a destination zone is located in the CBD, the number of rail trips attracted to it as otherwise predicted by the model is multiplied by 4.6. If a destination zone is a TOD, the number of rail trips attracted to it as otherwise predicted by the model is multiplied by 5.12. The high multiplicative values of these two dummy variables indicate that attractive mixed-use developments within short, attractive walks of rail transit stations play a large role in attracting rail transit patrons. The dummy variables likely also reflect the effect of higher parking rates on shifting passengers from autos to auto-access rapid transit.

Variables that measure how easy it is to use trains to travel from an origin to a destination are highly important in affecting rail ridership. In-vehicle travel time, comprised of both time spent riding trains and buses, is moderately important, with an elasticity of -0.772. Time waiting for connecting buses and trains is also moderately important, with an elasticity of -0.884.

What stands out, however, as the travel time variable most affecting rail passenger usage is out-of-vehicle travel time (OVT). OVT is comprised of time to walk or drive from home to transit (or the weighted average of walking and driving where both options are available, as described earlier) at the beginning of the trip, and the time spent walking from transit to work at the destination end of the trip. It also includes waiting for the first transit vehicle to arrive. For every one percent OVT increases, rail transit commute trips decline by 3.3 percent. The model shows that work trip rail passengers weigh every minute spent in OVT 4.84 times as much as they spend time riding in the train cars.

What the findings for out-of-vehicle travel time demonstrate is the difficulty that a rail system of limited scope has in connecting origins and destinations. This quality of the rail system was shown earlier in **Figure 21,** which shows the destinations of workers who identify themselves as rail riders. Most rail riders travel to jobs very close to rail stations; a much smaller number transfer to buses to reach jobs located farther away. The figure suggests that job holders who identify themselves as rail riders have difficulties reaching their final destinations from the destination rail stations; if they did not, one would see a map showing destinations scattered more widely from rail stations. The importance of the out-of-vehicle travel time variable in affecting rail ridership reinforces this conclusion, as does to a lesser extent the transfer time variable. In-vehicle travel time is relatively less important than out-of-vehicle travel time because trains are relatively fast, and their travel time is not an issue to passengers, in contrast to the depressing effect of slow buses, as shown earlier in the bus models. What really matters, however, are lengthy waits when transferring between trains and buses, as shown in the transfer time variable, and the final walk to destination, as indicated in the out-of-vehicle travel time variable. This conclusion is reinforced when we look at the tremendous impact that destination TODs have on multiplying rail ridership in comparison to the insignificant impact that origin TODs have on ridership. Where destination TODs exist, walking to the final destination is relatively short and attractive, and rail ridership to the TOD increases by 500% over what the model otherwise would predict for that zone. This finding is very similar to the findings of Cervero that workers will use rail transit to reach suburban office buildings, so long as the suburban office buildings are no more than a short walk from rail stations.[81]

The prominence of the out-of-vehicle travel time variable in the rail model suggests that if rail transit stations could be brought into close proximity of most employment concentrations in the Atlanta region, rail ridership would grow tremendously. The prominence of the destination TOD variable suggests that if the walk environments were attractive, patronage would grow another five-fold. There we have the essence of a set of policies for greatly increasing choice rider transit use.

SUB-REGIONAL RAIL MODELS

We also estimated four sub-regional rail transit models for Atlanta based on the rider's travel destination: Atlanta CBD, city center outside the CBD, regional centers, and all other destinations outside the city center and CBD. As with the bus models, we refer to these as sub-regional models to differentiate them from the regional model that includes all destinations. The sub-regional models all indicate the importance of total population in origin zones and total employment in destination zones in generating rail transit patronage between zones. The sub-regional models also highlight the importance of out-of-vehicle travel time as an important explanatory variable influencing rail transit demand between two zones. However, there are also important differences in the model results, as we discuss in the following pages. These model differences provide some insights into the characteristics of the travelers who use rail transit to reach different types of destinations, as well as possible policy interventions that might help transit agencies attract more of these travelers.

The first sub-regional model examines rail patronage for travelers destined to the Atlanta CBD. The model results are shown in **Table 12**. The results show that origin zones with larger total populations and lower residential dwelling unit vacancy rates generate larger numbers of transit trips. Both results echo the results of our regional rail model. A key difference between the CBD model and the regional model (as well as the other sub-regional models) is the importance of transit-oriented development on the origin end of the trip. If an origin zone for rail trips to the CBD is a TOD, the number of rail trips produced by it as otherwise predicted by the model is multiplied by 13.3. This result is in marked contrast to our other rail models where TOD in the origin zone is statistically insignificant. In the destination zone, total employment is an important attractor of rail transit patronage, as is true of our regional and other sub-regional rail models. Employment density is statistically unimportant.

Two origin-zone variables present surprising results. They are the auto access variable and the population density variables, both of which are insignificant in this model. A possible explanation for these unexpected results is the existence of two categories of riders using trains to access the CBD. One is by lower-income workers destined to service jobs, who come from higher density zones adjacent to rail stations in the south and access trains by walking. (See **Figure 23** earlier.) The other is by higher-income workers destined to white-collar jobs who live in very low density zones and access trains by autos. The auto access and density characteristics of both categories of rider are opposite to each other and taken together they statistically wash out the importance of these two variables.

Table 12. Sub-Regional Model: Rail Trips to the Atlanta CBD

Model Summary					
Number of Observations		6,834			
Pseudo R squared		0.054			
LR chi squared		234.180			
Prob chi squared		0.000			
Log likelihood		-2,040.124			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-1.0507	0.096	0.512		
Population	0.0005	0.000	3,652.575	1.689	
Population density	0.0925	0.062	5.205		
Median household income	0.0000	0.860	56,776.100		
Percent households w/o children	0.2671	0.842	0.571		
Vehicles per person	2.1868	0.119	0.645		
Vacancy rate for residential units	-8.1565	0.003	0.055	-0.450	
Unemployment rate	-9.6106	0.066	0.039		
Transit oriented development	2.5873	0.009			13.294
Destination Zone Variables					
Employment	0.0003	0.000	6,515.249	1.707	
Employment density	-0.0142	0.113	14.603		
Transit Travel Time Variables					
Out of vehicle travel time	-0.0010	0.000	2,143.584	-2.052	
In vehicle travel time	-0.0004	0.012	2,073.903	-0.851	
Transfer time	0.0013	0.269	356.731		
Constant	-3.7048	0.002			

The results for the three travel time variables provide important insights into the value rail riders destined to the CBD place on the quality of the transit trip itself. The statistical insignificance of transfer time is unsurprising for these riders because they don't need to transfer from one rail line to another to reach the CBD. All rail lines serve the CBD. They are also unlikely to need to transfer to a bus to reach their final travel destination. The statistical insignificance of the transfer time variable suggests many rail riders destined for the Atlanta CBD access rail by automobile at park and ride lots, while the statistical significance of the TOD variable at the origin end suggests many other riders walk to access rail. Few CBD-bound rail riders appear to use bus transit to access the rail system. The statistical insignificance of transfer time for these CBD-bound riders stands in dramatic contrast to the statistical significance of transfer time for rail riders destined to regional centers and to destinations outside the city center and CBD, as discussed later.

Rail riders destined to the Atlanta CBD are sensitive to both in-vehicle and out-of-vehicle travel time. They are nearly 2.5 times as sensitive to out-of-vehicle travel time as they are to in-vehicle travel time. The model suggests that a 1% reduction in out-of-vehicle travel time would result in a 2.1% increase in rail transit patronage; a 1% reduction in in-vehicle travel time would increase patronage by about 0.9%. Rail transit speed seems to matter to this category of rail rider.

The second sub-regional model examines rail transit riders destined to the city center outside the Atlanta CBD. The model results are shown in **Table 13**. As was true for CBD bound riders, the total population in the origin zone is an important predictor for trips to the city center. Also, total employment in the destination zone remains an important attractor of rail trips. The model indicates that these travelers also have relatively high levels of automobile access in their origin zone, suggesting that they are more likely to be choice riders.

Unlike the CBD model, TOD at the origin zone is unimportant in explaining rail ridership. To understand the implications of this finding, one has to keep in mind that two of the four TODs that we identified for Atlanta are located within the destination zone of this sub-regional model. These are the Midtown and North Avenue TODs. Thus, they do not figure as originators to transit trips. The remaining two TODs are located outside of the central area of Atlanta (Lindbergh Center and Decatur), and zones located within them are identified as origin TOD zones. The insignificance of TOD at the origin in this model, as opposed to its significance in the CBD model, suggests that the TODs located outside the city center (Decatur, Lindbergh Center) do not contribute meaningfully to rail transit use over and above what their populations would suggest.

On the other hand, the significance of the origin TOD variable for the CBD model (which identifies zones in all four TODs as TOD zones on the origin end of the trip), suggest that only two of the four TODs contribute meaningfully to transit patronage on the origin end of the trip. These are the two TODs inside the city center (Midtown, North Avenue). Subsequent statistical analysis confirmed that only the two city center TODs contribute meaningfully to transit patronage as either trip origins or destinations, beyond what would be predicted by other explanatory variables in the model.

These results suggest that there is a qualitative difference in the character of the Midtown and North Avenue TODs that separate them from the Lindbergh Center and Decatur TODs. That qualitative difference is important to the origination of transit trips, but as of this writing we have not identified what the qualitative difference is. The Transit Cooperative Research Program report on transit oriented developments in the U.S. is silent on this point; it merely identifies the four TODs in Atlanta, but it describes in a general way the characteristics of only one of those TODs (Lindbergh Center).[82]

Among the travel time variables, only out-of-vehicle travel time is statistically significant for rail riders traveling to the city center outside the CBD. A 1% reduction in out-of-vehicle travel time would result in a 2.8% increase in rail trips. Out-of-vehicle travel time for these riders seems to largely encompass automobile driving time to rail stations and walking time at the destination end of the trip. We suspect that sensitivity of transit patronage to this variable reflects passengers' unwillingness to walk far to reach destinations within the central area; they will use transit more if the destination that they seek is easily walkable from the station. Passengers also seem reluctant to transfer to buses to reach their final destination. We infer this reluctance from the statistical insignificance of the transfer time variable. The statistical insignificance of the in-vehicle travel time variable suggests that few riders are dissatisfied with the speed of the trains. This variable becomes significant only in models where passengers ride a significant distance on buses.

Table 13. Sub-Regional Model: Rail Trips to City Center Outside Atlanta CBD

Model Summary					
Number of Observations		4,474			
Pseudo R squared		0.053			
LR chi squared		78.530			
Prob chi squared		0.000			
Log likelihood		-704.650			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-1.3936	0.288	0.540		
Population	0.0006	0.000	3,517.138	2.272	
Population density	-0.0202	0.859	5.285		
Median household income	0.0000	0.283	57,319.360		
Percent households w/o children	1.0264	0.699	0.582		
Vehicles per person	5.8821	0.046	0.653	3.838	
Vacancy rate for residential units	10.5443	0.115	0.056		
Unemployment rate	-1.9390	0.854	0.037		
Transit oriented development	1.7033	0.252			
Destination Zone Variables					
Employment	0.0003	0.000	5,821.359	1.674	
Employment density	-0.0110	0.351	13.257		
Transit Travel Time Variables					
Out of vehicle travel time	-0.0012	0.000	2,239.025	-2.782	
In vehicle travel time	-0.0001	0.747	2,208.179		
Transfer time	0.0001	0.932	553.096		
Constant	-9.0892	0.000			

The final two sub-regional rail transit models focus on more decentralized, auto-oriented travel destinations. The first model looks specifically at rail riders destined to regional centers, which are ARC-defined employment concentrations typically associated with expressway or arterial road development. As noted earlier in the report, few of these centers are located near rail transit stations; many rail riders destined for these locations by and large transfer to bus to complete their trip. Thus, these are true multimodal transit riders. The models indicate that these riders share many more characteristics with bus riders than with rail riders bound for the Atlanta CBD or the city center outside the CBD.

Table 14 reports the results for rail trips to regional centers. As was true of the preceding models, total population in the origin zone and total employment in the destination zone remain important predictors of transit ridership. Unlike the preceding models, rail riders destined to regional centers tend to have lower incomes. On the other hand, they enjoyed relatively high access to automobiles, as was true also for riders destined to the city center outside the CBD.

Table 14. Sub-Regional Model: Rail Trips to Regional Centers

Model Summary					
Number of Observations		25,269			
Pseudo R squared		0.103			
LR chi squared		281.340			
Prob chi squared		0.000			
Log likelihood		-1,220.135			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-1.4723	0.113	0.572		
Population	0.0005	0.000	3,591.150	1.724	
Population density	0.2227	0.000	4.854	1.081	
Median household income	-0.0001	0.001	59,911.500	-3.355	
Percent households w/o children	-2.5324	0.263	0.559		
Vehicles per person	7.9503	0.002	0.662	5.261	
Vacancy rate for residential units	-7.2823	0.069	0.049		
Unemployment rate	8.0034	0.399	0.034		
Transit oriented development	2.0690	0.118			
Destination Zone Variables					
Employment	0.0003	0.000	5,304.589	1.706	
Employment density	-0.0170	0.059	10.175		
Transit Travel Time Variables					
Out of vehicle travel time	-0.0015	0.000	2,950.743	-4.283	
In vehicle travel time	-0.0003	0.046	3,450.162	-0.867	
Transfer time	-0.0017	0.000	1,037.530	-1.717	
Constant	-3.7452	0.034			

Rail riders destined to regional centers are very sensitive to travel time. All three travel time variables are statistically significant and have relatively high elasticities. These riders are most sensitive to out-of-vehicle time (elasticity = -4.3) and transfer time (elasticity = -1.7). High sensitivity to out-of-vehicle travel time reflects both the initial access time to transit and a walk to their final destination, either from a rail station or from a bus, to which they transfer. The riders' relatively high sensitivity to transfer time is not surprising. Most of these riders must transfer from rail to bus to reach their final destination. Many do so, but they clearly view this time as a burden. The model indicates that a 1% reduction in transfer time would increase ridership to regional centers by 1.7%.

Rail riders bound to these destinations are also sensitive to in-vehicle travel time; a 1% reduction of in-vehicle travel time would result in a 0.9% increase in ridership. Such a reduction might be accomplished by more direct routing of the bus routes used by travelers to reach their final destinations.

The final sub-regional model examines rail ridership to all destinations outside both the CBD and the city center. We include this model based on the hypothesis that riders bound for non-

CBD and non-city center travel destinations would have somewhat different characteristics and sensitivities than would their counterparts traveling to those destinations. The model results appear to confirm that hypothesis. The model results are shown in **Table 15**.

The model results indicate that origin zones characterized by more minority populations, larger total populations, higher population densities, higher levels of vehicle access, and lower residential vacancy rates generate more rail transit trips. Destination zones with larger total employment, but not higher employment densities attract more rail transit trips. Combined, these results suggest a more minority, choice rider, but lower median household income rider profile. They present a profile for riders destined to jobs that are located in major employment clusters, but not developed at the highest employment densities. They appear to seek jobs in more suburban employment centers, although not necessarily the regional centers officially designated by ARC.

Unlike for the regional rail model, destination zones that are categorized as TODs have no influence on attracting transit passengers over what their employment magnitude would suggest. We were surprised with this difference, but then realized that, as discussed earlier, the difference likely reflects important qualitative differences in the characteristics of the Midtown and North Avenue TODs on one hand from the Lindbergh Center and Decatur TODs on the other hand. The regional model, which designates destinations lying within all four of the TODs as TOD destination zones, reveals that the TOD designation is highly important for attracting transit trips. On the other hand, this sub-regional model, which designates only destination zones lying within the Lindbergh Center and Decatur TODs as TOD zones, shows that TOD designations have no effect on attracting transit trips. We conclude that the latter two TODs are ineffective, but the former TODs are effective for attracting transit trips in greater magnitudes than what their employment levels suggest, but as noted earlier, we do not know what the most important qualitative differences are between these two sets of TODs.

Rail riders bound for these destinations are sensitive to all three dimensions of travel time. Given their pattern of destinations, it is likely that they must transfer to a bus to complete their rail trips. A 1% reduction in transfer time, achieved by better coordination of bus and rail connections or by more frequent bus service, would increase ridership 0.8 percent. These riders are even more sensitive to the other components of travel time. A 1% reduction in out-of-vehicle travel time would increase ridership 4.1%, while a 1% reduction in in-vehicle travel time would increase ridership 1.4%. These elasticities suggest that making transit trips more direct, which would be accompanied by a reduction in travel time, would lead to sizeable ridership increases by this group of rail riders.

Table 15. Sub-Regional Model: Rail Trips to All Other Destinations

Model Summary					
Number of Observations		59,101			
Pseudo R squared		0.097			
LR chi squared		358.380			
Prob chi squared		0.000			
Log likelihood		-1,663.119			
Variable	**Coefficient**	**P value (sig.)**	**mean**	**elasticity**	**dummy multiplier if dummy = 1**
Origin Zone Variables					
Percent white population	-1.8356	0.020	0.555	-1.019	
Population	0.0003	0.000	3,655.005	1.219	
Population density	0.1646	0.001	4.880	0.803	
Median household income	-0.0000	0.045	58,649.160	-1.434	
Percent households w/o children	-2.6345	0.156	0.554		
Vehicles per person	4.3735	0.037	0.654	2.860	
Vacancy rate for residential units	-7.8822	0.027	0.049	-0.384	
Unemployment rate	4.5138	0.493	0.035		
Transit oriented development	0.5211	0.638			
Destination Zone Variables					
Employment	0.0003	0.000	3,791.039	1.200	
Employment density	-0.0090	0.284	6.986		
Transit oriented development	0.0635	0.932			
Regional center	0.3668	0.222			
Transit Travel Time Variables					
Out of vehicle travel time	-0.0014	0.000	3,003.573	-4.105	
In vehicle travel time	-0.0004	0.000	3,429.430	-1.355	
Transfer time	-0.0007	0.017	1,198.056	-0.828	
Constant	-2.6552	0.037			

SUMMARIZATION OF RAIL RESULTS

These results reveal that survey respondents who identify themselves as rail riders on the whole behave differently than survey respondents who identify themselves as bus riders. They have higher incomes, they have more access to autos, they are less sensitive to signs of economic distress at origin ends of trips (most likely because such distress does not exist in zones where they live), and they are more sensitive to long walking distances from stations to their place of work. As in the bus model, rail riders come largely from minority areas, but not nearly to the same extent. They also tend to travel to the CBD to a greater extent and to destination TODs (North Avenue and Midtown in particular), as well. Nonetheless, about a quarter of them transfer to buses to complete trips to work sites located away from rail stations.

Looking at passengers destined to only zones in the CBD, we see lower-income riders who primarily access rail by automobile and who walk to their final destination. Transferring is not important to them, because there is no need to transfer to buses to reach destinations in the CBD, and while they potentially could use buses to access rail, we conclude from the unimportance of the transfer time variable and the importance of the auto access variable that they do not. They drive from their homes to rail stations, instead. The propensity of these riders to originate their trips in TODs is high, so long as the TODs are those in the midtown area and not those in the Decatur or Lindbergh Center areas. Looking to workers who identify themselves as rail riders who are destined to the city center outside of the CBD, we see riders with substantially the same characteristics as those destined to the CBD.

Looking at transit commuters who identify themselves as rail passengers, but who are destined to destinations beyond the CBD or city center areas, we see that higher income people are less likely to travel to such destinations than they are to travel to city center or CBD zones. A substantial number or commuters in this category have access to automobiles. The transfer variable is very important, however, and some members of this category may access trains by transferring from buses. Others may transfer from trains to buses to reach their final destination. Most regional centers are located at some distance from train stations, so most passengers destined to regional centers must complete their trips on buses. The results of the regional model, combined with those of the various sub-regional models, suggest that destination zones with characteristics of TODs like the Lindbergh Center or Decatur TODs have no particular attraction for this category of commuter other than what the magnitude of employment in the zone would suggest, but TODs with characteristics of those like Midtown and North Avenue attract substantially more riders than predicted by employment alone. Subsequent statistical investigation confirmed this suggestion. Only the two city center TODs contribute meaningfully to rail transit patronage. Future research is needed to determine the characteristics of the Midtown and North Avenue TODs that are important attractors of transit ridership.

SIMILARITIES AND DIFFERENCES BETWEEN BUS AND RAIL RIDERS

By and large, the model results confirmed our hypothesis that bus riders were overwhelmingly transit-dependent riders, and rail riders included a disproportionate number of choice riders. By and large, rail riders tend to come from zones with high levels of vehicle access and bus riders from zones with low levels of vehicle access. The models highlight important similarities as well as differences between the two rider groups. In terms of similarities, both bus and rail trips are produced in larger numbers in zones with higher populations and higher population densities. They are also both attracted to destinations with larger numbers of jobs, but generally not areas with the highest densities of employment. Both bus and rail riders are also generally quite sensitive to in-vehicle travel time and transfer time. These similarities suggest that both bus and rail riders would benefit from transit service policies that seek to connect major employment concentrations by relatively direct service involving relatively seamless, coordinated transfers. Transit agencies in Atlanta, and likely elsewhere as well given the consistency of these results with those of our earlier study in Broward County, would enjoy higher patronage as a result.[83]

In terms of differences between bus and rail riders, bus riders tend to come from zones with lower income, lower vehicle access (as noted above), and higher minority populations. While rail riders also come disproportionately from heavily minority zones, they come from zones with high levels of vehicle access and the income variable is not significant, except in the cases of rail riders destined to more dispersed destinations who tend to come from zones with lower incomes, but also relatively high levels of vehicle access. Bus riders do not place the same importance on out-of-vehicle travel time to transit as do rail riders, suggesting that bus stops are distributed in such a way that most patrons can easily access the stops to board a bus and then exit the vehicle to reach their final destination. Rail riders, on the other hand, do place a premium on out-of-vehicle travel time, suggesting that they have difficulty with access to the stations and/or reaching their final destinations. This is not surprising given the small number of rail stations and their spatial distribution relative to the patterns of population and employment in Atlanta.

The results for the land use variables also reveal important differences between bus and rail riders as well as insights into the importance of transit-oriented development. Bus riders in Atlanta are not influenced by transit-oriented development characteristics at either the origin or destination end of a trip. The CBD does not emerge as a statistically significant destination for bus riders; indeed, lower density employment clusters emerge as important destinations for these riders. For rail riders, on the other hand, the CBD does emerge as an important travel destination, and two of Atlanta's TODs (Midtown and North Avenue) emerge as important contributors to rail patronage, in excess of what would otherwise be predicted by the employment levels or densities of these zones. We are unsure exactly what it is about these two TODs that make them so different from their counterparts in Decatur and Lindbergh Center, although an analysis of aerial photography of these areas suggests that differences in the mixture of land uses, the walkability of the zones, and perhaps the treatment and price of parking might all play roles.

VI. POLICY IMPLICATIONS

We began this study by asking what types of policies would expand the use of transit by choice riders while at the least not hurting transit-dependent riders. We answer the question by first reiterating the quality of the transit system that is useful to both categories of work trip riders. Transit commuters who identify themselves as bus riders seem to want a network of routes connecting the region's employment centers with faster, more direct, and more frequent service. Shelters, good pedestrian connections and other amenities at transfer points are also implied as being important to these largely transit-dependent riders. With such amenities, many more transit-dependent riders will use transit, presumably relying less on friends and relatives for chauffeured auto rides. Many of these riders appear to use trains to speedily move from one part of the region to the other, relying on buses at one or both ends of the trip, so good transfer connections between buses and trains will also increase ridership of transit-dependent riders.

Transit commuters who consider themselves rail riders, who primarily access transit by automobile, want trains to take them to major employment destinations, including the CBD and some TODs. Serving more choice riders will require extending lines into job-rich corridors and developing stations and station environments in those corridors with those qualities typical of the TODs like North Avenue and Midtown. The more that can be done with a network of several regional rapid transit lines, the greater the increase of choice riders using transit in the Atlanta region.

If a transfer to a bus is required to complete the trip, the service will attract lower status workers who nonetheless will live in auto-oriented environments and will make use of autos to access the system. Are these choice riders, as well? The model results suggest that many of them are choice riders. Their numbers would increase in a more expansive regional network of regional rapid transit lines that have excellent bus transfers to jobs within one to two miles of stations.

It goes without saying that the grid of local buses tied into such a regional rapid transit system would greatly increase the number of transit dependent ridership, as well, because it would enable them to reach additional employment opportunities that are presently difficult or impossible for them to reach by transit. These results derive from a study of Atlanta, Georgia, but given their consistency with lessons derived from other locales, they provide important policy guidance to transit agencies seeking to increase ridership by both rider groups. Certainly, more money would be needed first to develop such a system and then to operate it, but the characteristics of transit demand from Atlanta reported here and the performance of multi-destination transit systems elsewhere suggest that an expanded multi-destination transit network in Atlanta would have beneficial results. Regional riding habits would increase substantially without sacrificing productivity, while operating cost per passenger would decline. Both transit-dependent and choice riders would use this expanded network in larger numbers than they use the present one.

APPENDIX A: VARIABLE DEFINITIONS AND DATA SOURCES

Many of the variables used in this study are from the 2000 U.S. Census. The 2000 census included a 100% survey (using the short form questionnaire) and a sample survey of one of every six households (using the long form questionnaire). The population and race variables come from the 100% survey, while the other census variables are obtained from the sample survey. The census data are also subject to data suppression to protect the identity of individual respondents. Data suppression has the largest possible effects at smaller levels of geographic aggregation, such as transportation analysis zones.

Acres: The physical size of the origin transportation analysis zone.

Source: Atlanta Regional Commission, "Transportation Analysis Zone" GIS shape file, available at: http://www.atlantaregional.com/info-center/gis-data-maps/gis-data/gis-data (accessed January 1, 2011).

Bus Transit Commuters: The number of commuters traveling to work primarily by bus or trolley bus from transportation analysis zone i to transportation analysis zone j for all origin and destination pairs. These census data derive from the long form questionnaire, which sampled approximately one of every six households.

Source: 2000 Census Transportation Planning Package, Part 3 Worker Flows: All Workers, Table 06X8 Means of Transportation to Work. Available online at: http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1348&DB_Short_Name=CTPP%202000 (accessed January 1, 2011).

Central Business District (CBD): The historic commercial core of Atlanta, defined by the Atlanta Regional Commission. All transportation analysis zones lying within this core are designated part of the CBD.

Source: Atlanta Regional Commission, "Superdistricts" GIS shape file, available at: http://www.atlantaregional.com/info-center/gis-data-maps/gis-data/gis-data (accessed January 1, 2011).

City Center: The expanded commercial core of Atlanta including the CBD and Midtown areas of Atlanta, defined by the Atlanta Regional Commission. All transportation analysis zones lying within this area are designated part of the City Center.

Source: Atlanta Regional Commission, "Activity Centers" GIS shape file, available at: http://www.atlantaregional.com/info-center/gis-data-maps/gis-data/gis-data (accessed January 1, 2011).

Employment: The total number of jobs in the destination transportation analysis zone. These census data derive from the long form questionnaire, which sampled approximately one of every six households.

Source: 2000 Census Transportation Planning Package, Part 2 At Workplace: All Workers, Table 15X1, Occupation by Industry. Available online at: http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1344&DB_Short_Name=CTPP 2000 (accessed January 1, 2011).

Households without Children: The percent of households in the origin transportation analysis zone without children. These census data derive from the long form questionnaire, which sampled approximately one of every six households.
Source: 2000 Census Transportation Planning Package, Part 1 At Residences: Workers in Households, Table 38X1 Age Group of Youngest Child in the Household by Means of Transportation to Work. Available online at: http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1340&DB_Short_Name=CTPP 2000 (*accessed January 1, 2011).*

In Vehicle Travel Time: Travel time while onboard a transit bus or train traveling

from transportation analysis zone i to transportation analysis zone j, obtained from the transit travel time skims in the 2002 Travel Forecasting Model Set For the 20 County Atlanta Region.

Source: Atlanta Regional Commission 2010. Files provided by Mr. Steve Lewandowski of the Atlanta Regional Commission on November 8, 2010.

Median Household Income: The median household income in the origin transportation analysis zone. These census data derive from the long form questionnaire, which sampled approximately one of every six households.

Source: 2000 Census Transportation Planning Package, Part 1 At Residence: All Households, Table 88X1, Median Household Income by Number of Workers in Household. Available online at: http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1343&DB_Short_Name=CTPP 2000 (accessed January 1, 2011).

Out of Vehicle Travel Time: Travel time accessing the initial transit vehicle, waiting to board the vehicle, and then exiting the final transit vehicle to reach the final destination from transportation analysis zone i to transportation analysis zone j, obtained from the transit travel time skims in the 2002 Travel Forecasting Model Set For the 20 County Atlanta Region. For the bus commute trips, this access time includes walk access only. For the rail commute trips, this variable is a weighted combination of auto access and walk access time using data reported in the *2001-2002 Regional On-Board Transit Survey*, Table 11.

Source: Atlanta Regional Commission 2010. Files provided by Mr. Steve Lewandowski of the Atlanta Regional Commission on November 8, 2010.

Percent White Population: The percent of the total population in the origin transportation analysis zone that is white. These census data derive from the short form questionnaire, which is designed to survey all households.

Source: 2000 Census Transportation Planning Package, Part 1At Residence: All Persons, Table 50X2 Hispanic Origin by All 3 Categories of Hispanic Origin where Race of Person is White. Available online at: http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1341&DB_Short_Name=CTPP 2000 (accessed January 1, 2011).

Population: The total number of persons residing in the origin transportation analysis zone. These census data derive from the short form questionnaire, which is designed to survey all households.

Source: U.S. Census Bureau, 2000 Census Transportation Planning Package, Part 1 At Residence: All Persons, Table 047X1, Total Number of Persons. Available online at: http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1341&DB_Short_Name=CTPP 2000 (*accessed January 1, 2011).*

Rail Transit Commuters: The number of commuters primarily traveling to work by subway or elevated train from transportation analysis zone i to transportation analysis zone j for all origin and destination pairs. These census data derive from the long form questionnaire, which sampled approximately one of every six households.

Source: 2000 Census Transportation Planning Package, Part 3 Worker Flows: All Workers, Table 06X10 Means of Transportation to Work. Available online at: http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1348&DB_Short_Name=CTPP%202000 (accessed January 1, 2011).

Regional Centers: The Atlanta Regional Commission defines regional centers as places that have 10,000 or more jobs within four square miles serving as employment, shopping, and entertainment destinations for people traveling from around the Atlanta region. There are 38 designated regional centers. All destination end transportation analysis zones lying within one of these areas was designated as part of a regional center.

*Definition source: Atlanta Regional Commission, http://www.atlantaregional.com/transportation/plan-2040/glossary-terms (*accessed June 30, 2011*).*

GIS shape file source: Atlanta Regional Commission, "Activity Centers" shape file available at http://www.atlantaregional.com/info-center/gis-data-maps/gis-data/gis-data (accessed June 30, 2011).

Transfer Time: Travel time spent waiting to transfer from one transit vehicle to another during a trip from transportation analysis zone i to transportation analysis zone j, with times estimated as half the headway of the next transit vehicle, for all transfers. The data are obtained from the transit travel time skims in the 2002 Travel Forecasting Model Set For the 20 County Atlanta Region.

Source: Atlanta Regional Commission 2010. Files provided by Mr. Steve Lewandowski of the Atlanta Regional Commission on November 8, 2010.

Transit-Oriented Development: These transportation analysis zones are located within ¼ mile of all MARTA rail transit stations, located outside the Atlanta CBD, that are identified as transit-oriented developments (circa 2000) according to the Transit Cooperative Research Program's Report 102, the Urban Land Institute's Atlanta Chapter, and the Atlanta Regional Commission's Station Typology report. The resulting four station areas have a minimum of 55 jobs per acre and 14 residents per residential acre within ¼ mile of the station, according to the 2000 Census.

Unemployment Rate: The percent of persons aged 16 and over that are unemployed in the origin transportation analysis zone. These census data derive from the long form questionnaire, which sampled approximately one of every six households.

Source: U.S. Census Bureau, 2000 Census Transportation Planning Package, Part 1 At Residences: All Persons, Table 54X4, Persons Age 16 And Over; For All 3 Categories Of Sex; Employment Status Is Unemployed*. Available online at:* http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1341&DB_Short_Name=CTPP 2000 (a*ccessed January 1, 2011).*

Vacancy Rate: The percent of dwelling units in the origin transportation analysis zone that were classified as vacant. These census data derive from the long form questionnaire, which sampled approximately one of every six households.

Source: U.S. Census Bureau, 2000 Census Transportation Planning Package, Part 1 At Residence: Housing Units, Table 86X 1, All Housing Units; For All 3 Categories Of Occupancy Status; For All 7 Categories Of Number Of Units In Structure. *Available online at:* http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1342&DB_Short_Name=CTPP 2000 (a*ccessed January 1, 2011).*

Vehicles per Capita: The ratio of vehicles to population in the origin transportation analysis zone. These census data derive from the long form questionnaire, which sampled approximately one of every six households.

Source: U.S. Census Bureau, 2000 Census Transportation Planning Package, Part 1 At Residence: Housing Units, Table 109X1, Aggregate Number of Vehicles in Households. *Available online at:* http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=1343&DB_Short_Name=CTPP 2000 (a*ccessed January 1, 2011).*

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ACRONYMS AND ABBREVIATIONS

ARC	Atlanta Regional Commission
CBD	Central Business District
CCT	Cobb Community Transit
C-TRAN	Clayton County Transit
CTPP	Census Transportation Planning Package
ESRI	Environmental Systems Research Institute
GCT	Gwinnett County Transit
GRTA	Georgia Regional Transportation Authority
IVT	In-Vehicle Travel Time
MARTA	Metropolitan Atlanta Rapid Transit Authority
MPO	Metropolitan Planning Organization
MSA	Metropolitan Statistical Area
OVT	Out-of-Vehicle Travel Time
PAT	Port Authority of Allegheny County Transit
SOV	Single-Occupant Vehicle
TAZ	Traffic Analysis Zone
TOD	Transit Oriented Development
ULI	Urban Land Institute
VMT	Vehicle Miles Traveled

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