SMARTRAQ

INTEGRATING TRAVEL BEHAVIOR AND URBAN FORM DATA TO ADDRESS TRANSPORTATION AND AIR QUALITY PROBLEMS IN ATLANTA

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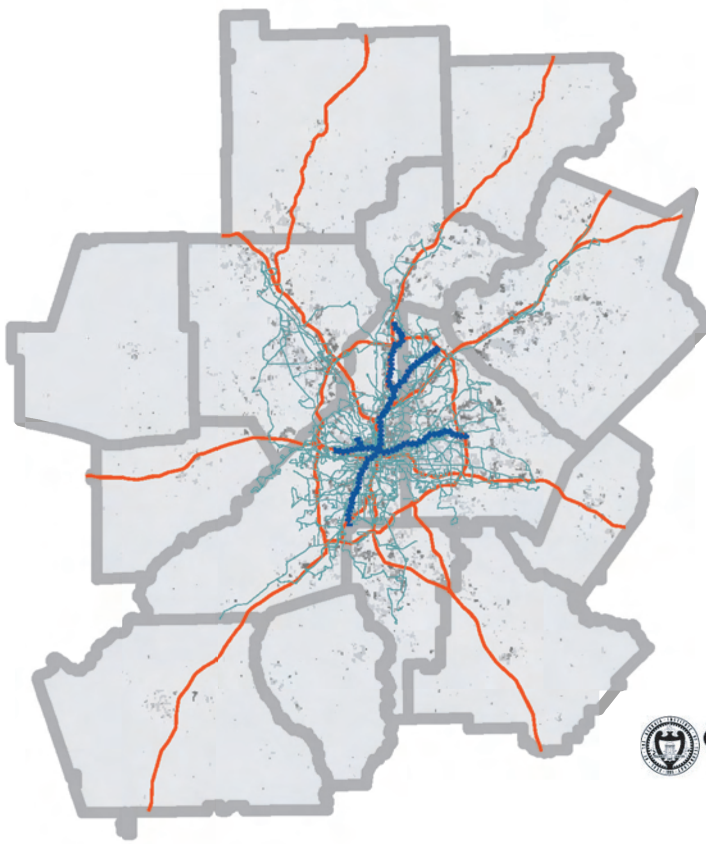

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SMARTRAQ BACKGROUND

SMARTRAQ's ("Strategies for Metropolitan Atlanta's Transportation and Air Quality") stated goal is to "develop a framework for assessing land use and transportation policies having the greatest potential for reducing the level of auto dependence and vehicle emissions in the Atlanta metropolitan area while sustaining the economic vitality and environmental health of the region." SMARTRAQ (www.smartraq.net) was initiated by the Georgia Department of Transportation (GDOT) and has received additional and significant financial support from the Georgia Regional Transportation Authority (GRTA) and the U.S. Centers for Disease Control and Prevention (CDC), among other organizations. The research program's central goal has been to develop and implement an activity-based household travel survey for the Atlanta region that generates a better understanding of the relationships between land use patterns, travel behavior, and vehicle emissions.

ABSTRACT

During 2001 and 2002, the SMARTRAQ research program collected data on travel behavior, physical activity and attitudes from the members of 8,069 households in the 13 county ozone non-attainment Atlanta region. Additionally, at the same time the SMARTRAQ program also developed a regional parcel-level land use database. Together, these components allowed program investigators to study systematically the effects of land use on travel behavior, vehicle emissions and physical activity.

Statistically significant inverse relationships were found for the effect of urban form (net-residential and intersection densities, mixed use) on vehicle emissions, miles and hours traveled, and obesity. The likelihood of walking and using transit was positively correlated with overall physical activity patterns. Moreover, nearly a third of the people in the Atlanta region indicated that they wanted to reside in walkable and transit-oriented communities with a mix of nearby land uses. However, people in this group often had to suffice with auto-oriented communities, indicating a gap between a large market segment's development preferences and the supply of such development in the region.

The data analysis shows that achieving regional goals of clean air, reduced current and future demand on the transportation network, and a high quality of life will be fostered by policies and plans which focus growth into existing and emerging urban centers, thereby creating higher levels of density, land use mix, connectivity, and which provide the infrastructure necessary for a quality pedestrian, bicycling, and transit environment.

Keywords: travel survey, travel behavior, air quality, emissions, physical activity, land use, urban form.

EXECUTIVE SUMMARY

I. INTRODUCTION

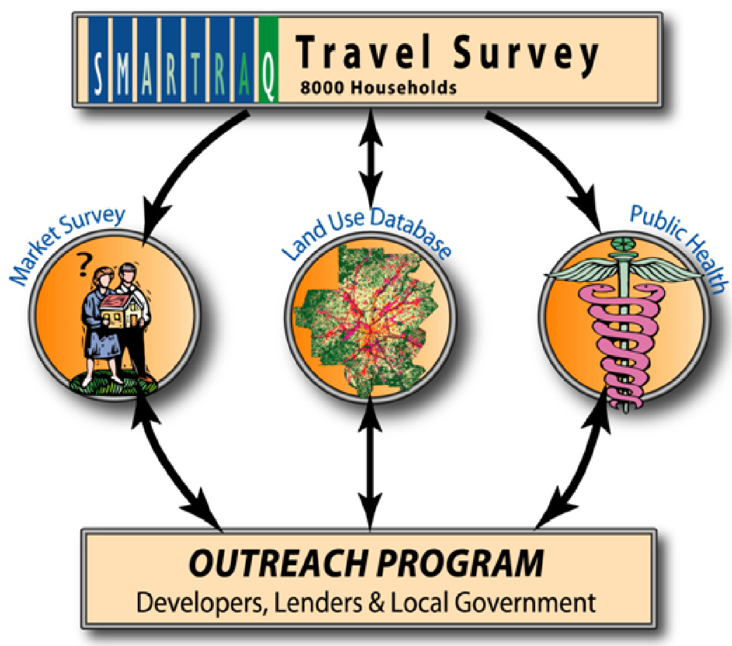
In September 1998, the Georgia Department of Transportation (GDOT) initiated an important new research program designed to examine and document the relationships between land use, travel behavior and vehicle emissions in the 13-county portion of the Atlanta region designated as an air quality non-attainment area. The project was contracted to researchers at the Georgia Institute of Technology (Georgia Tech), who assumed responsibility for its design, coordination, and implementation. Known as SMARTRAQ ("Strategies for Metropolitan Atlanta's Transportation and Air Quality"), the project was later expanded to include additional research elements, and it received substantial funding and support from the Federal Highway Administration (FHWA), the Centers for Disease Control and Prevention (CDC) and the Georgia Regional Transportation Authority (GRTA). This document constitutes the final report to GDOT under this research program.

The research design proposed by Georgia Tech and agreed to by the four principal agencies participating in the project (GDOT, GRTA, CDC, and the Atlanta Regional Commission [ARC]), consisted of several major elements described below and shown in Figure 1:

- Designing a regional activity-based household travel survey instrument and sampling plan for use by the ARC in collecting household and trip information from 8,000 households in the region.
- Developing a 13-county parcel-level geographic information system (GIS) land use database to enable precise stratification of the household survey and permit detailed analyses of the relationships between urban form (land use) factors, travel behavior, vehicle emissions, and physical activity patterns.

- Designing and implementing a state-of-the-art physical activity survey that included global positioning system (GPS) instrumentation in order to examine the relationships between urban form, physical activity, and public health.
- Developing a regional market survey of households to collect data on latent demands for alternative forms of residential development, including so called "smart growth" development.
- Conducting before and after studies of, three Livable Centers Initiative (LCI) plans by applying findings from the project.
- Conducting a series of open workshops and forums with developers, lenders, and local governments to examine obstacles to and opportunities for "smart growth" development.
- Performing descriptive and inferential analyses using the collected data to identify and examine relationships between significant variables, to evaluate the performance of LCI plans, and to quantify latent market preferences.

Figure 1: SMARTRAQ research design



From its beginning, the SMARTRAQ program emphasized the interdisciplinary nature and purpose of the research, reaching out to many diverse agencies and organizations to obtain expertise and insights from people in different fields, including land development, transportation, environment, and public health. At the level of pure research, the goal was to perform analyses of collected data to explain the relationships between land development patterns and travel behavior and measures of air quality and public health. The program was also designed to assist the ARC in developing and evaluating travel models for use in preparing the Regional Transportation Plan. And it was intended to create a dialogue between developers, lenders, and local government officials on the barriers to and best practices for developing mixed-use, walkable and transit-oriented communities.

This report presents an analysis of the household travel and physical activity surveys, an analysis of the 13-county parcel-level land use database, and results of descriptive and inferential analyses of the survey data that explain the relationships between land use, travel demand, and vehicle emissions.

II. SIGNIFICANT FINDINGS AND RESULTS

A. Atlanta Household Travel Survey

A key element of the 2001/2002 SMARTRAQ Atlanta Household Travel Survey (AHTS) sampling plan provided for over-sampling in dense neighborhoods within the region. The purpose was to ensure an adequate representation of households from such neighborhoods in order to study the relationship between land use variables and other demographic and behavioral variables listed above. The sample was stratified by net residential density (NRD), wherein the goal was to have 20% of the sample fall within each of five identified NRD levels. More than twenty percent of the total sample was at an NRD of six dwelling units per acre or greater, while less than forty percent was at an NRD of less than two units.

Table 1: Distribution of households in SMARTRAQ General Purpose Survey by Net Residential Density (NRD)

NRD	*Frequency*	*Percent*	*Cumulative Percent*
0 – 2	3099	38.4	38.4
2 – 4	2036	25.2	63.6
4 – 6	1200	14.9	78.5
6 – 8	10.3	10.3	88.8
8+	901	11.2	100.0
Total	8069	100.0	100.0

Data collected in the regional travel survey included demographic information such as household size, income, and ethnicity; information about the household's travel-relevant attributes or assets, such as its number of vehicles and the attributes of those vehicles (e.g., engine size, type of fuel used, make and model of the vehicle); and, critically, given the objectives of this survey, spatial information about the household generated by the parcel-level database, such as the attributes of the area around each of the households in the database (the household's "buffer"). Additionally, descriptive information was gathered about each person in the survey and data was gathered about the travel patterns of every person above five years of age.

The 2001/2002 survey included many more households, therefore resulting in more people and trips being included in the final trip tables, than was the case for the 1991 Atlanta regional survey conducted by ARC, which was the last such travel survey. In 2001/2002, the research parameters of the SMARTRAQ program required that a larger survey was needed in order to provide sufficient data across a wide range of land uses. Selected results from the two surveys are compared below, followed by a bulleted summary of findings in the following categories—emissions, weekend travel behavior, travel patterns, attitudinal responses, physical activity patterns, and land use database.

B. Comparing 1991 & 2001/2002 Travel Survey Results

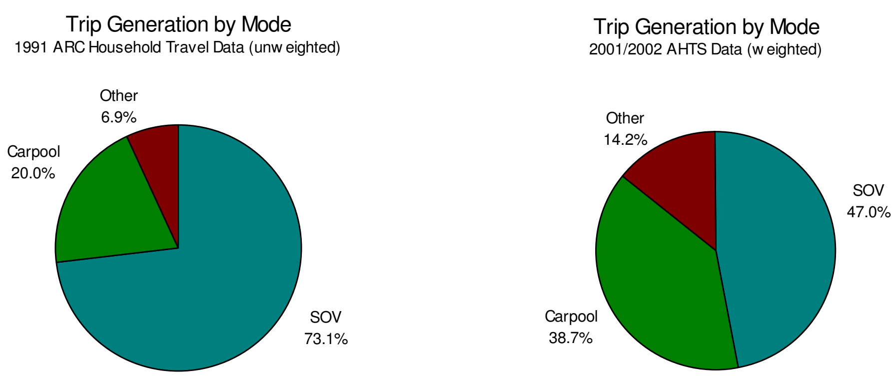
Two car households represent similar percentages in the 1991 and 2001/2002 surveys, at 48.1 and 43.4% respectively. However, the more recent survey had a higher percentage of zero and one car households and fewer households with three or more, as compared to the 1991 survey population.

In 1991, the average survey participant was 38 years old, household income was between $40,000 and $50,000, and there were approximately 2.77 persons and 2.18 vehicles per household. ***In 2001/2002, the average participant was younger (34 years old), household income was approximately the same, there were slightly fewer vehicles per household (1.78), and slightly fewer people (2.64 persons) per household.***

On an average weekday in 1991, the average household made 9.26 vehicle trips, traveled 82 miles, and spent more than three hours behind the wheel. ***On an average weekday in 2001/2002, the average household made fewer trips (7.90), traveled fewer miles (79.2), and spent less time (about 2.6 hours) driving.***

Single occupant and carpool trips made in private vehicles accounted for 93 percent of the travel data in 1991 Household Survey and 86 percent of the travel data in the 2001/2002 AHTS.

Figure 2: Trips per mode in the 1991 and 2001/2002 surveys



Other consists of school bus trips, transit, and walking. SOV = single occupant vehicle

In the area of work versus non-work travel, more than 75 percent of the trips taken were for non-work purposes in 1991. This percentage rose to 81 percent in 2001/2002. Work trips in the survey were 68.6% longer in distance than non-work trips in 1991 and 58.8% longer in 2001/2002.

The average travel time to work was 24.62 minutes in 1991 and rose to 26.15 minutes in 2001/2002. The average travel time for non-work trips was 19.81 minutes in 1991 and remained stable at 19.08 minutes in 2001/2002.

The average household spent 3.2 hours per day traveling in a private vehicle in 1991 versus only 2.6 hours in 2001/2002. This is due to a reduction in the number of trips per household, as the overall mean trip time has only decreased slightly, from 20.80 minutes in 1991 to 19.88 minutes in 2001/2002.

In 1991, a significant proportion of the trips taken were short in time with nearly 2,800 or 13 percent of the trips less than seven minutes in duration. In 2001/2002, this percentage rose to 18 percent (16,591) of all trips. More than a third of the vehicle trips taken in the Atlanta region were less than 15 minutes in duration in 1991 and 40 percent were less than 15 minutes in 2001. In 1991, 84 percent of all trips were less than 30 minutes long and in 2001/2002, 74 percent were less than 30 minutes.

The average travel distance for all trips taken in the survey was nearly nine miles in 1991 and about ten miles in 2001/2002. In 2001/2002, about 18 percent of trips, as compared to over 25 percent in 1991, were less than three miles in distance. Nearly half of the trips in the survey were less than five miles in distance in 1991 and about 30 percent of trips were less than five miles in 2001/2002.

Table 2: 1991 and 2001 household weekday travel descriptive results

	1991 (unweighted)			2001/2002 (weighted)			
Variable	**Mean**	**Std. Dev.**	**Range**	**Mean**	**Std. Dev.**	**Range**	**Units**
Number of Trips	9.26	6.08	1 - 41	7.90	5.76	1 - 52	Trips per Household
Trip Distance	8.88	9.16	0.2 - 73.4	10.02	13.21	1 - 245	Miles
Trip Time	20.80	13.82	2.26 - 130.62	19.88	15.15	1 - 85	Minutes
Number of Work Trips	2.04	1.13	1 - 8	1.47	1.45	0 - 16	Trips per Household
Work Trip Distance	12.02	10.46	0.34 – 60.76	14.32	17.44	1 - 340	Miles
Work Trip Time	24.62	15.56	2.26 - 116.34	26.15	18.20	1 - 115	Minutes
Number of Non-Work Trips	7.22	5.37	1 - 43	6.43	5.39	0 - 48	Trips per Household
Non-Work Trip Distance	7.13	7.96	0.2 - 73.4	9.02	12.10	1 - 202	Miles
Non-Work Trip Time	19.81	13.16	3.02 - 130.62	19.08	15.50	1 - 96	Minutes
Vehicle Miles Traveled	82.2	66.36	0 - 602.04	79.2	56.62	0 - 831	Miles per Household
Vehicle Hours Traveled	3.2	2.25	0 - 16.82	2.6	1.58	0 - 16.13	Hours per Household

C. Vehicle Emissions

This and the following sections present person-level descriptive and inferential results for just the 2001/2002 AHTS survey data.

Mean daily vehicle emissions decrease with increasing NRD. Per person per weekday emissions estimates for the 2001/2002 AHTS survey were calculated for four pollutants—oxides of nitrogen (NO_x), hydro-carbons (HC), carbon monoxide (CO) and carbon dioxide (CO_2).

The mean daily emission generation levels for people in the $50,000 - $74,999 income range is over 18% greater for NO_x, HC, and CO than for people in the lowest income (less than $30,00) category. This percentage difference is less than is seen between the two groups for miles traveled—24%. A possible explanation for this may include the greater presence of newer vehicles in higher income households; the mean vehicle age is 3 to 4 years older in the lowest income bracket than in the highest income bracket households.

In contrast with the other pollutants, CO_2 mirrors VMT generation rates in two ways. ***The highest income category has the highest per person CO_2 emissions rate, and the increase across income categories (lowest to highest) is similarly large, 33% for VMT and 37% for CO_2.***

Modeled estimates of vehicle emissions show that per person emissions of nitrogen oxide (NOx), hydrocarbons (HC) and carbon monoxide (CO) vary by NRD. Emissions for these pollutants are lower by 16 to 22 percent as residential density exceeds four housing units per acre compared with density levels below four units. For carbon dioxide (CO2), comparable emissions are 25 to 31 percent lower.

D. Travel Patterns

The mean number of trips taken per person per day is 3.9 (excluding those individuals that did not report travel at all). The number of trips taken by survey respondents varies. Males and central county residents made 3.7 trips/day versus 3.9 trips/day for individuals living in outlying counties; females took 4.0 trips per day for females.

Whites made 40% more trips than Latino/Hispanics, and 17% more than African-Americans. Those in the highest income bracket (more than $75,000 annually) made

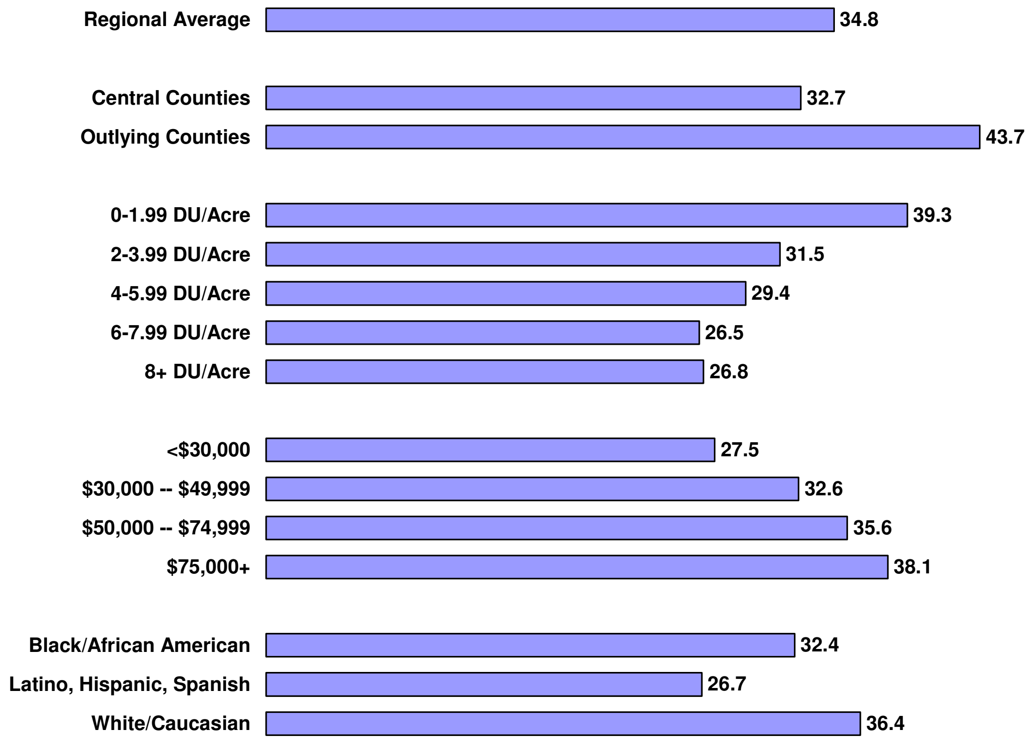
24% more trips than those in the lowest income bracket (less than $30,000 annually). More education (here defined as having an undergraduate degree or not) is associated with more trip making, with holders of Bachelor's degrees making 28% more trips per day on average compared with those without a degree.

Based on estimated trip distances, Atlantans 5 years and older who made trips on a weekday traveled an average of about 35 miles and slightly over an hour in private vehicles (includes driving or riding in automobiles, trucks and vans). (Figure 3)

The average number of person trips per day varies little over the entire range of residential densities (3.8 to 3.9 trips per person per day). Yet vehicle miles of travel (VMT) is from 25 to 33 percent lower for households in densities above four housing units per acre as compared with those in the lowest density range (0-2 housing units per acre). For daily person minutes of travel, the comparable results are from 25 to 31 percent less person minutes of travel. (Figure 3)

Figure 3: Average Weekday Daily Vehicle Miles of Travel per Person

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)



Average commute to work time by county, across all modes, varies from a low of almost 27 minutes in Fulton County to a high of about 36 to 38 minutes for the less urbanized, edge counties of Douglas, Fayette, Forsyth, Paulding, and Cherokee.

Very few bicycle trips were reported. Eighty-three people made 220 bicycle trips, 0.2% of the weighted total of trips.

Walking was the third most common travel mode used by survey respondents. According to the weighted results of the 2001/2002 AHTS, 4.8% (6,109) of trips were on foot, as compared to 5.3% by school bus and 86.8% either as a driver of passenger of a private vehicle.

The average daily trip rate of walkers increased with increasing net residential density, ranging from 1.8 to 2.3 trips per day per person reporting one or more walk trips (Table 3).

Table 3: Mean Daily Walk Trips per Person by NRD

(Individuals over four years of age and less than 19.9 trips, or three standard deviations above the mean, over the two-day period)

Net Residential Density (du/net res. acre)	Percent of Total Walk Trips	Mean Daily Trip Rate per Walker
0 – 1.999	24.0%	1.8
2 – 3.999	30.0%	2.0
4 – 5.999	17.8%	2.0
6 – 7.999	6.7%	2.3
8+	21.4%	2.3

Of the walkers participating in the survey, 54% were female and 46% were male (2,113 respondents, weighted). The weighted sample of bicyclists consists of 18% female and 82% male (83 respondents, weighted). This compares to 52.5% female and 47.2% male for the entire weighted survey population.

Of people who walked, the most prevalent age group is 10-14 years old, with 300 respondents or 14% of the sub-sample. The age group 35-39 (219 people or 10%) is the peak of a normal curve. The left tail of the curve is the 20-24 (5%) age group and the right tail is the 70-74 (1%) age group.

More commonly than the surveyed population, bicyclists and walkers have no household vehicles, and fewer multiple vehicles. Walkers more often own a single vehicle.

The highest average daily walk trips per person are attributed to the less than $30,000 income bracket (2.1) and the lowest is attributed to the $75,000 or more income bracket (1.9).

Transit was the fourth most common travel mode used by survey respondents. The weighted results of the 2001/2002 travel survey show that 2.1% (3,066) of trips were by transit, as compared to 4.8% (6,109) by walking, 5.3% by school bus and 86.8% by private vehicle.

Transit users are over twice as often African American, 2.5 times as likely to have household annual incomes under $20,000, live in the two highest NRD levels, and six times as often live in a household with no vehicles.

The majority of transit trips were taken by those with incomes of less than $30,000, indicating lower income brackets are more likely to ride transit, although not much more frequently than other transit riders of higher incomes.

The lowest average transit trip rate occurred for households located in the least dense level. People living in the two highest density levels and, unexpectedly, the 2-3.999 du/net res. acre level had the highest average trip rates (Table 4).

Table 4: Mean Daily Transit Trips per Person by NRD

Net Residential Density (du/net res. acre)	Percent of Total Transit Trips (weighted)	Mean Daily Trip Rate per Rider (weighted)
0 – 1.999	13.9%	1.9
2 – 3.999	37.9%	2.3
4 – 5.999	19.8%	2.1
6 – 7.999	7.9%	2.3
8+	20.4%	2.3

The number of average daily transit trips per person increase from 11 to 21 percent as residential density exceeds four units per acre when compared with those living in the lowest density level.

Most survey respondents indicated that a personal vehicle was the usual mode for commuting to work. When viewed at the county level, self-reported commute modes yield some unexpected results:

- ***Unusually high percentages of transit/paratransit use for two counties without a transit system,*** Douglas (6.23%) and Fayette (5.22%), as compared to Cobb (1.12%), which has a transit system; and
- ***Forsyth, a less-urbanized county on the region's edge, has the fourth highest walk percentage, 4.99%.***

E. Weekend Travel behavior

While the 1991 Household Travel Survey was restricted to behavior for one weekday, the 2001/2002 AHTS also included weekend travel. Each participant provided data over a two-day period, with at least one day always falling on a weekday. Of the entire set of 126,304 trips (weighted) in the survey, about 13% occurred on a weekend, a relatively low proportion of total trips due to the collection of travel data from fewer households on the weekends.

Private vehicles are used by more people on Saturdays (88%) than any other day, and Sunday the least (71%). Sunday transit users are a quarter of the weekday level.

People travel in a private vehicle on the weekends almost as far as they drive during the week. In fact, the average VMT on a typical Saturday or Sunday is only 6% lower than the average VMT on a typical weekday (32.5 miles on the weekend and 34.8 miles on a weekday). On both weekdays and weekends, those people living in the central counties[1] drive the least while those in the outer counties[2] drive the furthest.

During the week, people who live in one of the eight outlying counties travel 34% more miles than central county residents, but on the weekend the difference decreases to 23% more. While residents in both regional locations drive less on the weekend, the rate

[1] Clayton, Cobb, DeKalb, Fulton, Gwinnett
[2] Cherokee, Coweta, Douglas, Fayette, Forsyth, Henry, Paulding, Rockdale

of reduction is greater for those living in the outer counties than central counties, for mileage the difference is 14% vs. 5%.

People in the lowest density range travel 37% more miles on average than people in the highest density, but their NO_x generation is only 8% more, HC 4% more, and CO 7% more.

People living in the middle density range (4-5.999 du/net res. acre) are estimated to produce the fewest emissions, with the lowest followed by the highest density range producing the most.

F. Attitudinal responses

A unique aspect of the 2001/2002 Atlanta regional household travel survey is the inclusion of a series of questions concerning respondent attitudes toward urban form, transit use, and other issues. These questions assess how respondents felt about their neighborhoods, public transportation, and alternative transportation programs in the workplace. Selected results are presented below.

1. Access to Public Transit

About 38% of survey respondents indicated that they would not use public transportation under any circumstance. ***But, over 60% of the respondents indicated that at least one type of destination located near public transportation would encourage them to use public transportation.***

Over 30% of people indicated a grocery or retail store, bank/credit union, doctor/health clinic, or sports facility would be important to have near transit. Schools and parks were not seen as important to have near transit (Table 5).

Table 5: Percent of respondents indicating which types of places would be important to have near transit (multiple responses allowed)

Place type	% indicating important to them (weighted)
Grocery store	34.9%
Retail store	32.5%
Day care	12.3%
Bank / credit union	31.7%
Doctor / health clinic	32.2%
Restaurant	31.6%
School	0.0%
Sports facility	30.1%
Park	0.0%
None	37.9%

Most respondents from the entire surveyed population indicated that it was very difficult to access various destinations using public transit; in contrast, less than 20% indicated that it was "very easy" to get to most of the listed destinations by transit.

In contrast to the large entire survey sample population, 30% and more of transits users (people who reported at least one transit trip during the survey period) found it very easy to get to the various destinations, with a much smaller percentage (around 20%) indicating access being very difficult.

2. Employer Provided Transportation Options

The survey included questions about employer-provided transportation programs and services, such as subsidized parking or transit passes, telecommuting, and bicycle storage. An initial question asked respondents to indicate whether their employer offered any programs and services from a list of such items.

Respondents reported that flexible work schedules were the most common form of employer-provided program or service (51.4% of all respondents answering this question). Only 17.3% of people indicated that their employer subsidized their parking.

However, in comparison, parking was reported to be free for 93% of the 14,073 (weighted) trips to work made during the two day reporting period.

Of those who indicated that the employer offered the program or service, subsidized parking was used most frequently, followed closely by flexible work schedules, and subsidized transit.

Of those who answered that their employer did not provide a program or service, respondents indicated that they would be most likely to use a flexible work schedule if offered the choice (46.1%), followed by telecommuting (35.6%), a guaranteed ride home (26.6%), subsidized parking (24.6%), and free or subsidized transit costs (22.5%). The least likely option was bicycle storage. About the same percentage of respondents (almost 50% in both cases) indicated that they would "not likely" use subsidized parking or free/subsidized transit (Table 6).

Table 6: Likelihood of using employer-provided programs and services if offered

	Subsidized parking	Free / subsidized transit costs	Flexible work schedule	Tele-commuting	Carpool / vanpool assistance	Guaranteed ride home	Bicycle storage
likely	24.6%	22.5%	46.1%	35.6%	19.9%	26.6%	7.1%
somewhat likely	13.5%	16.5%	15.6%	12.9%	22.9%	19.0%	8.0%
not likely	48.7%	49.1%	21.7%	38.0%	47.6%	43.6%	75.2%
Don't know	11.2%	10.3%	13.5%	11.0%	8.0%	9.3%	8.1%
Refused	1.9%	1.6%	3.1%	2.6%	1.5%	1.5%	1.7%
Total	100%	100%	100%	100%	100%	100%	100%

3. Neighborhood Quality

A series of questions asked one randomly selected adult per household, 2,240 individuals (weighted) in all, to evaluate their neighborhood in terms of a variety of qualitative indicators and to assess the walkability of their neighborhood as a consequence.

For all respondents, nearly 40% rate their neighborhood as "excellent" with respect to being near major roads and interstates. About 37% indicate that their neighborhood is easy to walk in, followed by "near shops and services" (33%), "school quality" (32.6%), and "low crime" (31.5%).

At the other end of the spectrum, over 40% of the sample respondents say that their neighborhood rates a "poor" for being near public transit, while "closeness to job" receives a poor rating for 23.5% of respondents. Only small percentages of respondents gave the other factors a poor rating.

Transit users (people who reported at least one transit trip during the survey period) rate the proximity of transit to their neighborhood as excellent at a much higher rate, compared with the entire surveyed population. Similarly, far fewer, on a percentage basis, rate it poor compared with the entire surveyed population.

For respondents living in the least dense neighborhoods, satisfaction was substantially higher for neighborhood affordability, school quality, and crime than for those respondents living in higher density neighborhoods. Additionally, for the categories "near shops and services" and "near outdoor recreation," satisfaction was unexpectedly marginally higher for people living in the lowest density areas than in the highest density ones.

Conversely, respondents living in the highest density neighborhoods were more satisfied with ease of walking and proximity to employment, public transit, and major roads/interstates. Finally, while respondents in higher density areas did indicate a higher degree of satisfaction with walking conditions in their neighborhood, the difference in scores between the lowest and highest density areas (2.6 to 2.4 respectively) is not as great as might be expected.

The percent of respondents in the lowest net residential density category (2+ dwelling units per residential acre) responding that there are no destinations within a short walk is much higher (46.2%) than all other categories. Conversely, those in the highest density category (8+ dwelling units per residential acre) often responded that a destination was within a short walk at a rate twice that of those living in the lowest density category – this is true for grocery and retail stores, banks, doctors' offices, and restaurants.

G. Physical Activity Survey

The health and physical activity data from 816 people was collected through a sub-survey of the larger Atlanta 2001 and 2002 AHTS. Participants in the sub-survey received a paper questionnaire and one of two personal equipment packages—an activity monitor or an electronic travel diary (ETD).

The physical activity questionnaire consists of three primary sections—walking, bicycling, and social interaction. The unweighted findings include:

1. Walking

- ***Walking frequency varied positively with increased neighborhood net residential density.*** The NRD of the 81.5% of respondents who walk at least once per week is 4.9 housing units/net-residential acre, compared to a density of 10.2 for the 7.3% of the sample who are daily walkers.
- ***Residents of high density neighborhoods walk more in their own community,*** while residents of low density neighborhoods walk more frequently elsewhere.
- ***Respondents living in neighborhoods with a high mix of residential, commercial and office land uses (and also high density) tended to strongly agree there were destinations such as services and shops within walking distance of their home.*** Respondents living in areas with a lower mix of uses (and less density) strongly disagreed with this statement.
- ***The largest proportion of obese individuals (body mass index >=30) is in the category of respondents that do not walk at all in a given week,*** and unexpectedly the second highest proportion is associated with daily walkers**.** The

group of people who walk three to six times per week had the lowest obesity percentage.

- ***People who live in neighborhoods with a mix of shops and businesses within easy walking distance are 7 percent less likely to be obese, thus lowering their relative risk of obesity by 35 percent.*** And the average white male living in a compact community with nearby shops and services is expected to weigh ten pounds less than his counterpart living in a low density, cul-de-sac subdivision.
- ***Results from the SMARTRAQ physical activity and health survey show strong links between time spent driving and obesity, as well as between neighborhood characteristics and obesity.*** For example, every additional 30 minutes spent in a car each day is associated with a 3 percent greater chance of being obese.

2. Bicycling

- ***The frequency of bicycling and the presence of bicyclists in a neighborhood both increase with residential density***. While most respondents (74.9%) do not ride a bicycle at all, 24.8% (N=202) ride a bicycle at least once per week but not every day.
- ***While relatively few people surveyed actually ride a bicycle on a regular basis, 86.5% reported seeing bicyclists present in their neighborhood at least once per week,*** indicating that most neighborhoods are able to support at least some bicycling.
- ***Although people that bicycle at least once per week tend to live in higher density, more mixed neighborhoods, the conditions for bicycling are not necessarily better there***. People in high density neighborhoods tended to disagree with the statement "there are good road conditions for bicycling in my neighborhood." Those that agreed with the statement generally live in lower density neighborhoods.

3. Social Interaction

- ***Slightly over half of respondents reported knowing seven or more neighbors.*** All but 5.7% know at least one neighbor.
- ***Despite denser living conditions, the number of neighbors known tended to be inversely related to mean net residential density.*** The lowest NRD was actually calculated for the set of respondents that know seven or more neighbors. The highest NRD was found for those that know only one or two neighbors.
- ***Similarly, use mix tended to be highest for those that strongly disagreed or disagreed with the statement "living in my neighborhood gives me a sense of community."*** Mix tended to be lowest for those that agreed with the statement. A blend of commercial, office and residential uses also does not appear to necessarily ensure a sense of community. NRD was highest for those that strongly disagreed or disagreed and highest for those that agreed. Despite the more compact living conditions of a higher NRD neighborhood, the close proximity of neighbors does not necessarily instill a sense of community.

H. Parcel-Level Land Use Data

A major component of the SMARTRAQ research program was the construction of a parcel-level land use database for the thirteen counties in the study area. The data was assembled by the Georgia Tech Center for Geographic Information Systems (CGIS) using local and regional information sources.

There are 1,140,284 parcels in the thirteen-county study area. As shown in Table 72, the most parcels are contained in Fulton (20.1% of regional total), Cobb (16.9%), DeKalb (16.4%), and Gwinnett (14.9%) Counties. The least are in Rockdale (2.5% of regional total) and Paulding (2.7%) Counties.

Table 7: Parcel count by county

	Number	% of total
Cherokee	52,955	4.6%
Clayton	64,926	5.7%
Cobb	192,584	16.9%
Coweta	32,565	2.9%
DeKalb	187,153	16.4%
Douglas	33,319	2.9%
Fayette	32,903	2.9%
Forsyth	39,554	3.5%
Fulton	229,458	20.1%
Gwinnett	170,023	14.9%
Henry	45,373	4.0%
Paulding	31,074	2.7%
Rockdale	28,397	2.5%
Regional total	1,140,284	100%

Single-family residential parcels are the most common, by far, in the region, accounting for 82.1% of all parcels. Vacant parcels are the second most common, at 7.7% of the total. In order, the next most common are multi-family residential (3.0%), commercial (2.8%), and industrial (1.0%) parcels. Parcels with unknown use types constitute 1.2% of the total. Therefore, residential parcels (single- and multi-family housing plus mobile homes) constitute 85.6% of all parcels in the region.

The largest average parcel sizes tend to be in outlying counties, while the smallest tend to be closer to the region's core. In order of ranking, Henry, Coweta, Fayette, and Cherokee counties have the largest average parcel sizes, while Fulton and Gwinnett have the smallest.

Single-family residential parcels account for over half (52.7%) of the acreage in the region, followed by vacant parcels (19.5%), agricultural parcels (9.3%), and commercial parcels (6.6%). The four largest counties in terms of actual acres are Fulton, Coweta, Cherokee and Gwinnett. The smallest are Clayton, Cobb, and DeKalb counties.

In the Atlanta region, the extremely high growth rates of the 1980s and 1990s are reflected in the parcel data. Only a quarter of the region's parcels were built before 1964 and only 50% before 1980. In contrast, fully a quarter of the region's parcels have been built since 1989.

The newest parcels (on average) fall into the categories of mobile homes, office, industrial, and single-family residences, all of which have a mean age of 1975 or later.

In only Fulton and DeKalb counties are the mean ages of parcels greater than the mean for the region (1975). For six counties – Forsyth, Gwinnett, Henry, Fayette, Paulding, and Cherokee – the mean age is after 1980.

III. CONCLUSIONS & RECOMMENDATIONS

Research presented in this report demonstrates the importance of land use in affecting vehicle miles and time traveled, as well as vehicular production of oxides of nitrogen and hydrocarbon emissions. Findings at the personal travel level demonstrate that travel patterns and emissions are sensitive to residential density, land use mix and the level of street connectivity (intersection density). Increases in each of these land use measures are positively associated with decreases in vehicular travel and emissions, when controlling for socio-demographic factors.

Although living in denser, mixed use and more walkable neighborhoods apparently does not produce stronger feelings of "community" among residents, based on survey responses, there are clear positive associations with travel, air quality and health factors.

Over two million more people are projected for the Atlanta region over the next 25 years. With the results of the SMARTRAQ project providing a better understanding of the relationships between land use, travel behavior and vehicle emissions, future growth can be positively influenced in important ways. If planned carefully, new development could help reduce per capita travel and vehicle emissions produced by these newcomers. By strategically locating new development and transit services in close proximity, it could help reduce the demands for vehicle travel for the region's current population. Achieving this objective could be enhanced by integrating new residential and employment development with existing development in ways that increase residential density, mix of land uses and connectivity (intersection densities) of existing developed areas.

Based on survey data analysis results, the land use data base and emissions modeling, five major policy-level recommendations emerge:

1. ***Matching Growth and Regional Transportation*** – Focusing a portion of new growth into existing and emerging urban centers in order to achieve higher levels of density, land use mix and connectivity and providing adequate infrastructure for pedestrian, bicycling and transit travel could be an effective strategy to complement other regional efforts to improve traffic congestion and air quality. Supportive land use policies in combination with regional transportation investments targeted at increasing the desirability and accessibility of carpooling, transit, and non-motorized travel could have a positive effect on altering travel patterns and reducing mobile source emissions.

2. ***Land Use is Local*** -- Land use strategies are required to address the unique social and physical characteristics of central, suburban, and ex-urban areas of the region. Strategies are required that speak to the unique sets of issues associated with retrofitting existing communities, such as providing quality pedestrian and bicycle linkages between existing residential, office, and commercial uses already located in proximity to one another. In emerging communities, it is critical to provide travel options to the car for both local and regional needs. This can be achieved by situating residential, commercial, office, and recreational/open space land uses within close proximity to developing transit corridors and park and ride facilities.

3. ***Mixed Use, Density, and Connectivity are Synergistic*** -- Land use policies that have potential for reducing auto dependence will need to encourage <u>both</u> proximity (density and mixed use) and connectivity. Consolidation and intermixing of land use in conjunction with increased street connectivity offer important solutions when combined with increased connectivity for local access on foot and by bike, and with regional transit that is competitive, in terms of time and out of pocket cost, with the private vehicle.

4. ***Market Preferences*** **–** Results of the SMARTRAQ market survey suggest a significant latent demand (30 percent) for more walkable environments. These results are further supported from observations of higher appreciation rates for in-

town development and through expressed demands for projects recently opened in the region's core. These choices could be further enhanced if buyers were provided prices that are competitive with other options. Changes to lending policies and to development regulations could enable this underlying demand to be realized in the form of increased supply of residential developments that afford alternative travel choices for work and non-work purposes.

5. ***Education and Public awareness*** – The general public as well as the professional development and transportation communities could benefit by being made more aware of the improvements to quality of life that can be achieved through increased pedestrian and transit investments, more carpooling, ridesharing and employer incentives and more permissive development regulations. Lending institutions and builders, if better apprised of the market for smart growth and the success of such new developments could be less averse to risk such developments.

In an increasingly complex world, better informed policy and investment decisions that link goal-based performance measures with program development will be critical to future success. The SMARTRAQ research effort provides a solid foundation for considering future transportation and land development alternatives.

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CHAPTER I – INTRODUCTION

I. REPORT DESCRIPTION

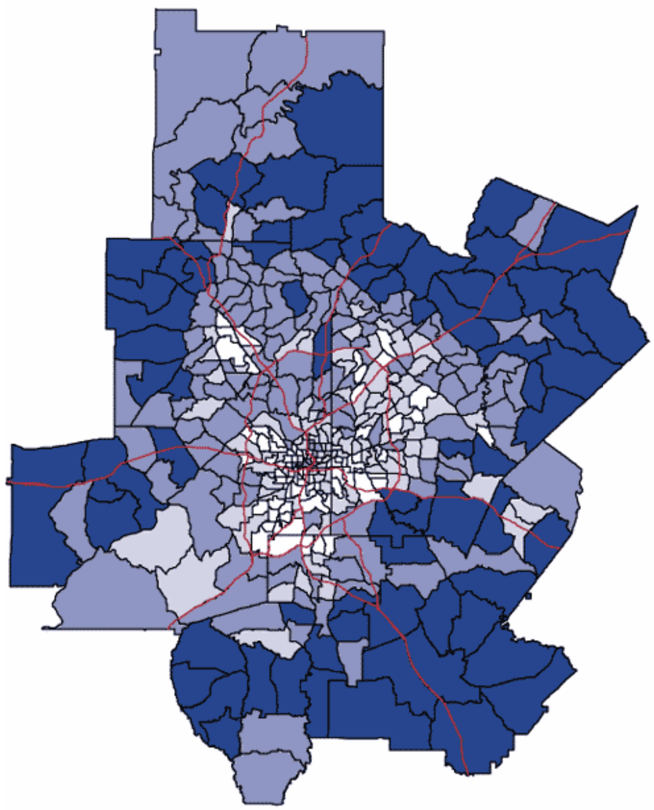
This report constitutes the final report under the research program sponsored by the Georgia Department of Transportation (GDOT) known as SMARTRAQ ("Strategies for Metropolitan Atlanta's Transportation and Air Quality"). In 1998, GDOT initiated this research program and provided the Georgia Institute of Technology (Georgia Tech) with the responsibility for the program's design, coordination, and completion. While SMARTRAQ was initiated by GDOT and has received a significant share of funding from this transportation agency, substantial financial and technical support has also been provided by the Georgia Regional Transportation Authority (GRTA) and the U.S. Centers for Disease Control and Prevention (CDC).

This report provides analyses of data collected under the guidance of the SMARTRAQ research program, in particular inferential analyses of quantitative data from a regional household travel survey, a parcel-level regional land use database, and other sources of data. This six year effort has produced dozens of technical reports, each with a focus on one element of the overall research program. Several of these reports are referenced and/or summarized here, however the primary focus of this report is on the analysis of the effect of urban form and land use on travel behavior and vehicle emissions.

II. SMARTRAQ BACKGROUND: GROWTH AND DEVELOPMENT PROBLEMS IN ATLANTA

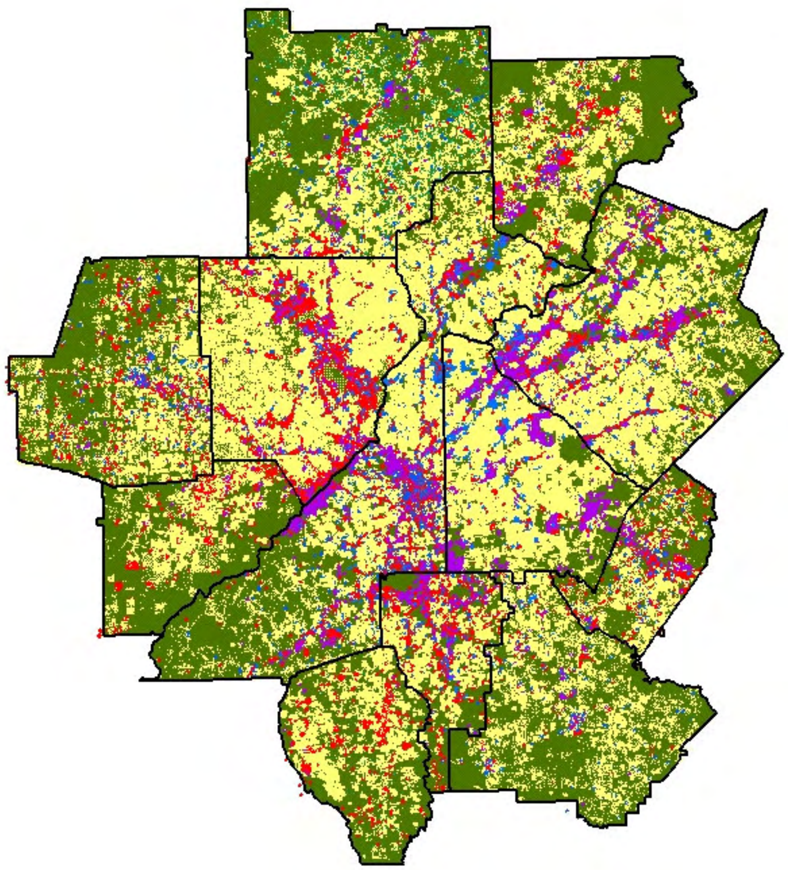
The Atlanta region's development trajectory has been marked by periods of rapid growth, particularly during the economic boom decades of the 1980s and 1990s. During this period, development was characterized by rapid in-migration to the region, low residential development densities, the rigid separation of different types of land uses, and low levels of investment in transit service throughout most of the region. The result was a strong increase in private vehicle travel, for instance in terms of vehicle miles of travel (VMT). The largest private vehicle increases were found in the region's outlying counties, which had experienced the most rapid residential growth during the 1990s and, as a result, had come to a point where they contained most of the region's residents (Figure 4).

Figure 4: Population Change in the Atlanta metropolitan region, 1990-1999, by Census Tract
[darker shades of blue represent higher population growth rates]



These trends reflected underlying land use patterns. As shown in Figure 5, the rapid urban and suburban development of the 1980s and 1990s resulted in such development covering the majority of the region. The most intensive growth has followed the contours of the region's vast Interstate road network, which served as mechanisms for spreading commercial and residential development throughout the region (the most intensive commercial development is shown in red and violet in the figure, while residential development is represented by yellow and light green colors). Most of the region's counties are now characterized by development rather than by their traditional rural landscapes; for the four "core" counties (Fulton, DeKalb, Cobb, and Gwinnett), there is almost no rural component left save for the southwest corner of Fulton County. For the remainder of the region, only the farthest corners of the most outlying counties have retained large swaths of heavily farmed and forested land (shown in dark green).

Figure 5: Land development patterns in the Atlanta region



By the late 1990s, these development and travel behavior trends had deteriorated the region's air quality to the point where the region ran afoul of Clean Air Act Amendment (CAAA) regulations. Since the 1970s the Atlanta region has not met (attained) National Ambient Air Quality Standards (NAAQS) for ground level ozone. In the early 1990s the CAAA and the federal transportation act established a linkage between regional air quality and transportation funding that requires mobile source emissions to conform to, or be below, a cap set by the state of Georgia, as part of its overall strategy for attaining NAAQS.

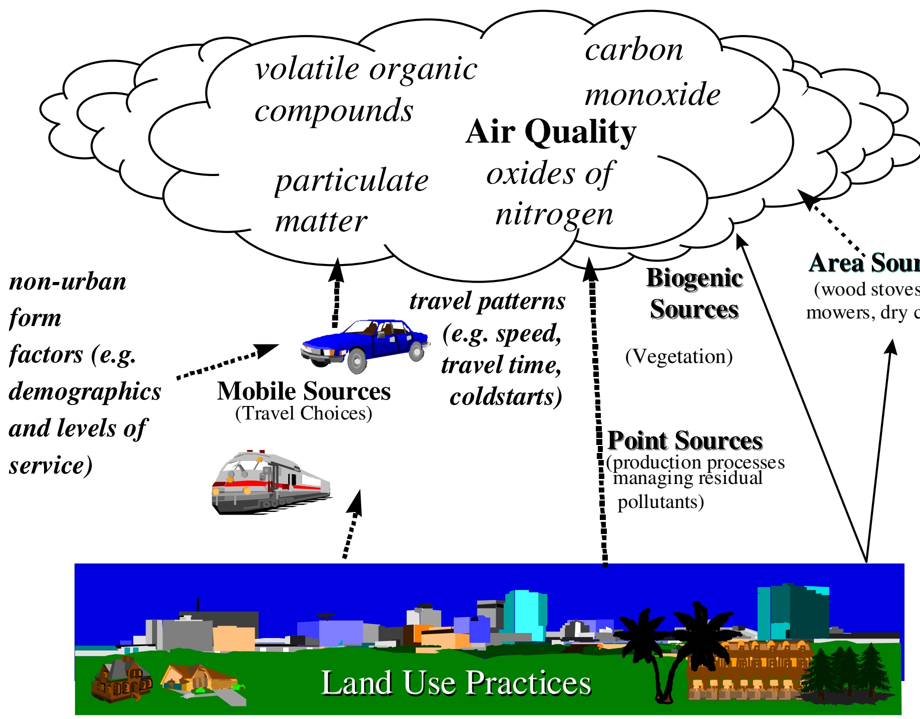
In the late 1990s federal transportation funds for road construction were withheld from the region until it could produce and adopt a conforming regional transportation plan. This development prompted calls for a reappraisal of how to approach transportation policy in the region. Such calls recognized that land development patterns were linked closely to travel behavior, which in turn were linked to public policy issues such as land development policies, transportation investment policies, and public health outcomes.

Academic and applied research in Atlanta and around the country had come to show that land development patterns had an influence on household and individual VMT (as well as other travel behaviors such as numbers of trips, numbers of vehicle trips, and so on). The land development variables that were shown to have some influence included residential and employment density levels and the extent of mixture or separation of different land uses. While these variables influenced the "proximity" or crow-fly distance between travel destinations, other variables also were shown to play a role in influencing how easy or difficult it is to get from one destination to another. These variables, which determine how well "connected" transportation systems are, impact route directness.

Urban form variables that influenced proximity and connectivity were recognized as important elements of a highly complex air quality equation. This complexity is shown in Figure 6, which illustrates how land use patterns have indirect but nonetheless important influences on air quality. According to this model, for example, land use patterns determine where point sources are located, and therefore the degree to which pollutants emitted by these sources play a role in metropolitan air quality. Land use patterns also influence how people travel. They determine how close or far apart destinations are, how streets systems are connected, and in other ways. The model does not assume that other, non-urban-form factors, play no role in air quality—it acknowledges the importance of such factors as demographics in shaping travel and, therefore, emissions. Yet the argument contained in the model articulated the complexity of the air quality problem that the Atlanta region was facing by the turn of the new century.

Figure 6: A conceptual model of air quality / land development relationships

(Source: Frank, Journal of Urban Planning and Development,1998)



III. SMARTRAQ: CREATION OF AN INTERDISCIPLINARY RESEARCH AGENDA

During the last half of the 1990s a growing recognition that air quality was a function of multiple variables and conditions, including the indirect influences of land development patterns on travel choice, which led many community leaders in the Atlanta region to call for different ways of approaching transportation planning and research.

SMARTRAQ was created in the midst of this shift in perspective. This research program was built upon the idea that solving the region's transportation and air quality problems required an approach that recognized the linkages across seemingly different policy areas. During the initial stages of the research program, representatives from GDOT, GRTA, CDC, and Georgia Tech formulated an overarching mission statement for the

SMARTRAQ program, emphasizing the interdisciplinary nature and purpose of the program. This statement asserts that the purpose of SMARTRAQ is:

> "To develop a framework for assessing land use and transportation policies having the greatest potential for reducing the level of auto dependence and vehicle emissions in the Atlanta metropolitan area while sustaining the economic vitality and environmental health of the region."

From its inception, SMARTRAQ has been an interdisciplinary program that is designed to capture the complex nature of the phenomena under study. Transportation investment and transportation policy should be assessed within the context of their influences upon land use decisions, resulting travel patterns; and the collective influence of these factors on the environment and human health. By demonstrating the linkages between transportation, land use, environment, and health it is hoped that transportation and land use decision making will be brought into a larger public policy context.,

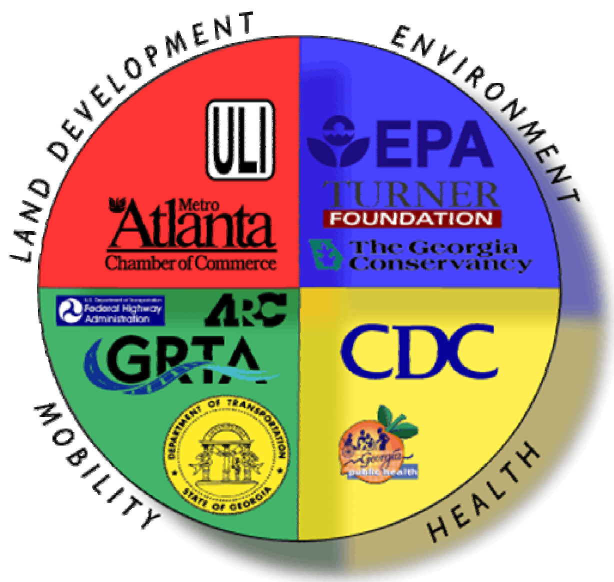
In Figure 7, transportation, environmental, and public health policies both influence and are influenced by one another (here, the "environmental" sphere encompasses both the natural environment, e.g., the atmosphere, and the built environment). Causality flows back and forth between these policy areas: the built environment influences travel behavior, while travel behavior pollutes the natural environment; public health outcomes such as asthma result from both direct environmental factors (poor air quality) and indirect ones (high VMT, for instance). The dollar sign at the center of the figure is meant to suggest how investment in any one of these spheres is most productive when the effects of such investment on the other two spheres is incorporated into public decision-making.

Figure 7: Interdependence of policy spheres

Critically, public health in this model is not viewed solely through an air quality lens (meaning respiratory illnesses). In addition to the air quality linkages between public health, transportation, and the environment, there is also an important physical activity dimension. As is well known, physical activity is an important component of healthy lifestyles, contributing to long-term health and well being. Sedentary lifestyles are contributors to a host of chronic diseases and ailments, including obesity, diabetes, premature aging, skeletal and muscular decay, and even poor mental health. The model illustrated by Figure 7, and incorporated into the SMARTRAQ research program, recognizes the importance of physical activity in public health and, further, the relationships between physical activity, the built environment, and transportation investment and policy. Simply stated, public health is enhanced when people have access to environments in which they can engage in physical activity and is worsened when people have a difficult time finding such environments. For instance neighborhoods that have certain features such as sidewalks and safe crossing intersections may encourage walking; walking and bicycling may be easier to engage in when destinations are close enough together to make travel by these modes practical; certain types of transportation systems, for instance hiking/biking trails and public transit, may encourage physical activity, especially walking and bicycling, while others may discourage it, such as busy thoroughfares that make journeys by these modes dangerous and unpleasant.

The interdisciplinary nature of the SMARTRAQ research program required the principals involved in the project to reach out to multiple organizations in order to obtain expertise and insights possessed by people in disparate fields. Georgia Tech and the program's sponsoring agencies partnered with a large number of organizations to assist in initiating and completing the many different program components. As shown in Figure 8, these organizations span all the program's focal areas (land development, mobility, environment, and public health) and range from public planning agencies (Atlanta Regional Commission) to private research firms (Urban Land Institute) to philanthropic organizations (Turner Foundation).

Figure 8: SMARTRAQ partners

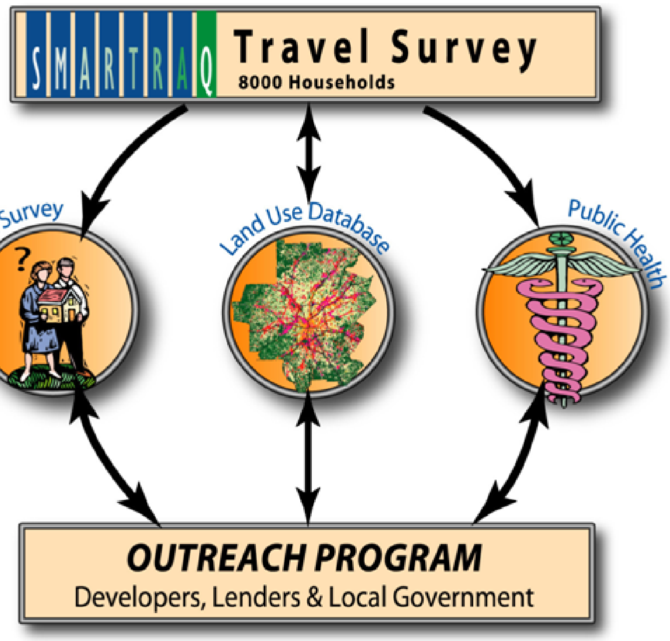


IV. SMARTRAQ RESEARCH DESIGN

From its beginning, the SMARTRAQ research program purpose of research has been threefold. First, at the level of pure research, the goal is to perform analyses of collected data that explain the relationships between land development patterns, travel behavior, environmental, and public health outcomes. In terms of workload and funding levels, this represents the larger part of the research program, involving the program's many data collection and analysis components. Second, the SMARTRAQ program was intended to assist the Atlanta region in the evaluation of the travel, environmental, and health implications of alternative approaches to development under consideration; that is to apply the research to practice. Thirdly, the program was to help create a dialogue on the barriers and best practices to building more environmentally sustainable communities. Here, the idea was to identify stumbling blocks and obstacles to developers, lenders, and local government officials in the delivery of less automobile dependent forms of development. The SMARTRAQ program benefited from this four part outreach series by gaining from the ideas and interests of different stakeholders within the region, and through the application of lessons learned to the program's research agenda.

Both the pure research and the community involvement agendas found their way into the formal SMARTRAQ research design, illustrated by Figure 9. In the figure, there are two "anchors" at the top and the bottom. These represent the pure research and the practical application sides of the program—pure research represented by the 8,000-household travel survey in the top box and practical application by the outreach program shown in the bottom box. In the middle are three separate but linked components: a "stated preference" or market-based survey of households, a parcel-level land use database, and a physical activity and public health survey. These three middle components are true research components, designed with the express purpose of collecting scientifically valid data, yet also benefit from practical application, all being the products of different types of community outreach. Each of the SMARTRAQ components is summarized below.

Figure 9: SMARTRAQ research design



A. *Regional household travel survey*

The box at the top of Figure 9 references the core product of the SMARTRAQ research program, a survey of 8,069 households in the 13-county Atlanta region.[3] As the program's focus is on the effects of land use on travel behavior and vehicle emissions in the Atlanta region, it was important to design the data collection plan to allow for stratification by land use type, i.e., by net residential density levels within the region, in order to be able to distinguish between land use variables and the influence of demographic and other non-urban-form factors on travel behavior. The general purpose survey is the joint product of work conducted at Georgia Tech, its sponsoring partners, the ARC, and an independent survey research firm, NuStats. The survey updates the region's household-level travel database, data which had not been collected since 1991. Besides the incorporation of a land

[3] Ground-level ozone non-attainment area under the federal Clean Air Act for Cherokee, Clayton, Cobb, Coweta, DeKalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Henry, Paulding, and Rockdale

use-based stratification plan, the SMARTRAQ general purpose survey improved upon previous regional travel surveys by: collecting data on a wider array of household demographic variables (e.g., more precise income and ethnicity data) and on individual characteristics (e.g., selected health attributes of respondents); dramatically extending the sample size to enable more sophisticated sub-regional analyses; and formally incorporating methods for increasing representation in the sample of "traditionally underserved households" (i.e., poor and minority households that have been shown to be harder to reach through standard surveying approaches).

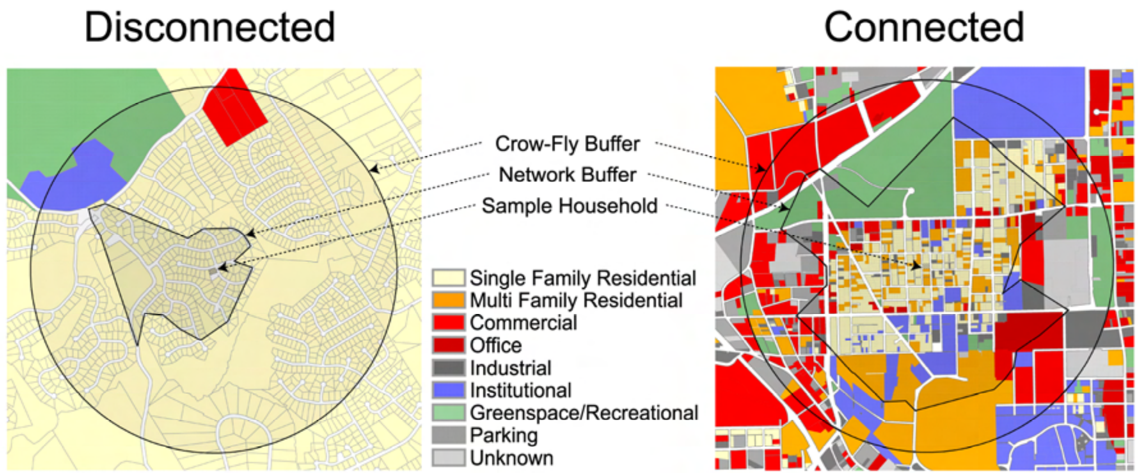
B. *Land use database*

A second major component of the research program is was the assemblage of a thirteen county parcel-level land use database. The SMARTRAQ land use database, created by the Center for Geographic Information Systems (CGIS) at Georgia Tech, is the Atlanta region's first regional parcel-level land use information system. Before this database was created, planning agencies had had no access to region-wide data at the parcel level. Parcel-level databases provide a higher level of detail than traditional land cover databases and support the ability to assess how land use patterns influence travel behavior and other relevant characteristics of regional growth. CGIS compiled data from local, county, and regional information sources. The database contains information about 1.2 million parcels in the thirteen-county region.

Along with the regional household travel survey data, the regional land use database provides the bedrock information for understanding the land use / travel behavior connection. The regional land use database provides powerful tools for this purpose, including not only standard macro-scale measures of land development patterns (e.g., residential and employment density, measures of land use mix), but also permits a variety of micro-scale measures such as street connectivity, average block size for a given area, parking distribution, and building setback distances.

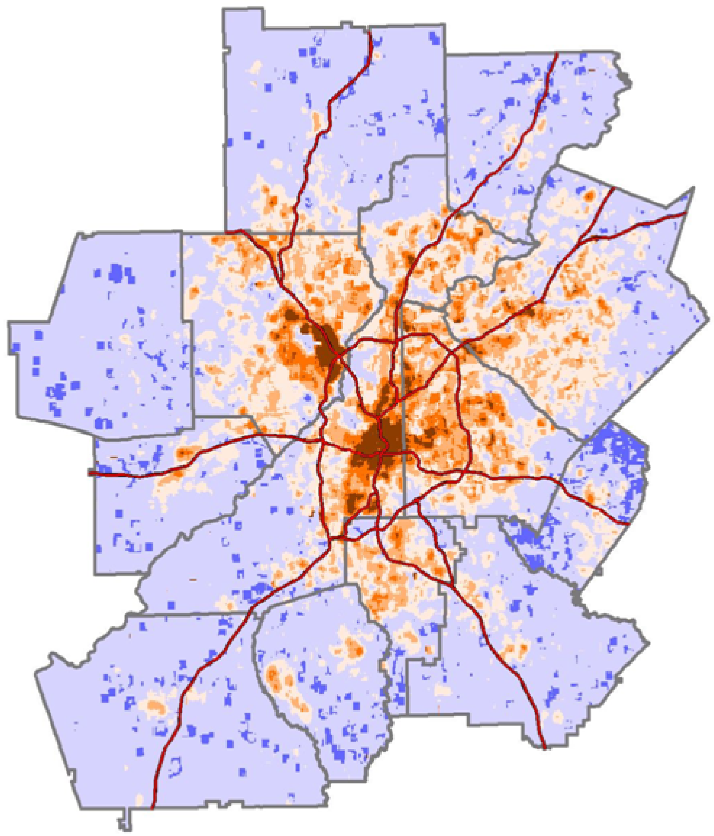
A parcel-level database permits the creation of an extensive variety of tools to assist SMARTRAQ researchers and planners in state and regional agencies in understanding how the Atlanta region has developed. These insights, in turn, can be either information for answering other research questions, as has been the case often in the SMARTRAQ program, or can be used as valuable stand-alone information. For instance, Figure 10 provides an example of one of the most valuable uses of a parcel-level land use database, the ability to identify the land use characteristics of an area around a specific parcel. In the example shown in the figure, parcels from two sample households in the database are compared. For each household, two "buffers" are drawn around the parcels, one a perfect circle and the other an irregular polygon. The perfect circle is the same size for each parcel and represents the straight-line or "crow-fly" distance from the parcel center to a specific distance from that center. The irregular polygons are also buffers, are also centered on the household parcel, and yet are different sizes and shapes. They represent the area that one could travel over the street system (the network) up to a specific distance from the parcel center (say, one kilometer). The larger the network buffer relative to the crow-fly buffer, the more connected the street system. The image on the left in Figure 10 is an example of a household in a disconnected street system; here, the network buffer is small relative to the crow-fly buffer. The image on the right is an example of a household in a more highly connected street system; here, the network buffer is much larger, occupying a larger fraction of the crow-fly buffer.

Figure 10: SMARTRAQ land use database: household-based street network buffers



In comparison, Figure 11 provides an example of how aggregated parcel-level data can generate important information for the entire region. The figure is a "surface map" showing variations in "walkability" across the region, where "walkability" is defined in terms of connectivity. The map shows variation in buffer connectivity, where darker shades of red and orange signify higher levels of walkability, while gray and blue signify lower levels.

Figure 11: Walkability map of Atlanta region, using SMARTRAQ parcel-level data



C. *Community Preference Market survey*

The "market survey" circle in Figure 9 refers to a component of the SMARTRAQ program that sought to reveal the "stated preferences" of people in the region for different types of community designs – ranging from pedestrian and transit to more auto oriented. An underlying premise of this component of the study was that revealed preferences, or the choices for housing and community types made in the marketplace, do not necessarily equate with the underlying preferences held by area residents. Home buyers and renters will optimize amongst available options. However, the more constrained or limited the choice set, the less likely that revealed demand or choices made will equal underlying preferences. This survey serves to identify the degree of match or mismatch between what is provided and what is desired, in terms of community design, by Atlanta area residents. It also provides an understanding of the degree to which specific elements of community design, such as sidewalks, and nearby shops and services, are desired, and the willingness to make trade-offs in other aspects of community design, such as lot size, for these amenities.

Respondents to this survey were asked to rate the desirability of different neighborhood attributes. These included residential location choice, the importance of open space, the need for having easy accessibility to mass transit or highways, desired lot and house size, preferred neighborhood street characteristics, desired architectural and design cues, and the availability of services and amenities within walking distance from one's home. The stated preference survey was designed to influence land-use modeling at the regional level, inform the regional political process by highlighting opportunities for policy changes, and provide an alternative source of information about the real estate market to development professionals. For more details please see the separate SMARTRAQ report II.A.3 provided to GRTA.

D. *Public health*

The public health circle in Figure 9 represents three separate surveys, a physical activity paper questionnaire including questions on self reported physical activity and social interaction and two instrumented sub surveys to gain objective data. The two instrument packages were:

- a personal digital assistant with global positioning system to objectively measure spatial and temporal aspects of travel; and
- an accelerometer survey to objectively measure physical activity.

As discussed above, public health issues were an important initial focus of the SMARTRAQ program. Again, the public health component of SMARTRAQ has emphasized air quality outcomes, physical activity patterns, and other aspects of health including weight. These components were added to the research program to derive a more complete picture of the physical activity and health patterns of respondents. The regional household travel survey also includes a set of questions focusing on physical activity, health, and the quality of the built environment for walking and biking.

A number of questions that are contained in the CDC's Behavioral Risk Factor Surveillance System (BRFSS) survey were utilized, including general health questions and questions about a person's height, weight, and frame size. Additionally, a sub-sample of households participated in a health-focused survey, which utilized both traditional (paper) and electronic data collection instruments. For more details please see the separate SMARTRAQ reports VII.30, and supporting reports III.11 through III.16, provided to GDOT.

E. *Outreach program*

The bottom box in Figure 9 represents a coordinated outreach program that had as a goal the collection of information about growth and development issues in the Atlanta region. SMARTRAQ program researchers convened four outreach sessions to achieve this goal, involving three distinct groups of stakeholders in the land development process. These groups were developers, financial lenders, and local government officials. Each one-day session was aimed at answering the central question of why growth and development proceeds along its current lines in the Atlanta region. The lessons learned from these sessions were summarized, along with independent research, into a document titled *Trends, Implications & Strategies for Balanced Growth in the Atlanta Region*, released in 2001. A fourth conference was held to release these findings and to discuss the lessons learned from the outreach program. This report and others were provided to GDOT by SMARTRAQ as reports #VII.23 through VII.26.

V. SMARTRAQ PRODUCTS

The size and scope of the SMARTRAQ research program has resulted in the production of a large number of reports, documents, and databases, many of which have been submitted to GDOT and/or GRTA in the form of contract reports. Throughout this report, other completed reports are referenced as sources of additional detail, but they will not be extensively discussed here. The entire import and contribution of the SMARTRAQ research effort can really only be fully understood by considering the collective body of work completed over the nearly six year period of work for the Georgia DOT and GRTA. Listed here are a few of the largest and most critical work products that the program has produced:

- Regional household travel survey data from 8,069 households, stratified by household size, income, and net residential density;
- A 1.2 million parcel land use database;
- Physical activity and health survey data from over 900 households;
- Stated preference survey data from over 1,400 households;
- Descriptive and inferential statistical summaries of the regional household travel survey data, plus quantitative estimates of the air quality effects of regional household travel;
- Quantitative analysis of the traditionally underserved households component data in the regional household travel survey, and assessment of that component's effectiveness;
- Quantitative analysis of the physical activity and health survey data, from both the traditional (paper) and the electronic (hand-held devices) instruments used to collect data;
- Quantitative analysis of the stated preference survey data;
- Assessment of selected ARC Livable Centers Initiative (LCI) project sites;
- Outreach program results, as summarized in the document *Trends, Implications & Strategies for Balanced Growth in the Atlanta Region.*

For a complete list of report titles under both contracts please see Table 8 and Table 9.

Table 8: SMARTRAQ Deliverable for GDOT

Deliverable Number	Name/Description
Task Area I	**DESIGN TRAVEL SURVEY INSTRUMENT**
1	Literature review of TMIP and activity based regional modeling
2	Draft sampling strategy and survey instrument[1]
3	Summary of expert panel and stakeholder responses to draft of survey instrument and sampling strategy [2]
4	Review and comment of pretest results
5	Summary of expert panel feedback on results of pretest, based on distribution of pretest results to expert panel for review and comment
6	Finalized survey instrument[2]
Task Area II	**REGIONAL LAND USE DATABASE AND DESCRIPTIVE ANALYSIS**
7	Integrated land use data into GIS environment
8	Descriptive Analysis of Existing Regional Land Use Datasets (including ARC Data, ES-202 Data, Census Data, and Digital Aerial Data)
9	Land use database. Conduct database clean-up and deliver database.
10	Land use measures. Deliverable consists of disaggregate methods for the calculation of measures of density, mix, and connectivity for the households in the household travel survey.
Task Area III	**ELECTRONIC INSTRUMENTATION**
11	Sampling strategy for household survey for spring data collection[1]
12	Refined sampling strategy and survey for fall data collection[1]
13	Summary report containing: (1) a draft test plan for field testing of personal instrumentation packages; (2) field and usability test results of the personal instrumentation packages; (3) and plans for modifications to personal instrumentation packages
14	Summary report containing: (1) a draft test plan for pre-testing of personal instrumentation packages; (2) a review and summary of pretest results; (3) finalized deployment plans and training packet of personal instrumentation packages; (4) and plans for final personal instrumentation package modifications, based on participant feedback
15	Summary report containing an overview of the personal instrumentation packages data collection process; (2) summary statistics on data collected; (3) detailed statistics on trips captured by electronic travel diaries
16	Interim and final data sets for personal instrumentation packages
17	Report containing summary of data collection results: compare HH travel survey with vehicle instrumentation results
Task Area IV	**CONDUCT HOUSEHOLD TRAVEL SURVEY** [No deliverables under this task area]
Task Area V	**DATA INTEGRATION AND ANALYSIS**
18	Integrated land use, travel survey, and vehicle emissions data for 8000 household survey sample[3]

Deliverable Number	Name/Description
19	Descriptive analyses of travel, land use, and vehicle emissions data for 8000 household survey sample
20	Cross-sectional analyses of land use, travel, physical activity, and vehicle emissions relationships for 8000 household survey sample [1]
21	Summary report containing recommendations and applications to regional travel demand modeling for 8000 household survey sample [3]
Task Area VI 22	**BUILDING A LAND USE – TRANSPORTATION – AIR QUALITY DIALOGUE** Detailed statement of work for outreach program
23	Write-ups from the first three outreach events [1]
24	Guidebook that communicates the results of the SMARTRAQ outreach and best practices research and analysis [1]
25	Three, four-page newsletters
26	Report that evaluates the success of the outreach events and a work plan for outreach that is supported in part by additional data from the project
27	SMARTRAQ website
Task Area VII 28	**DEVELOP, PRETEST, AND IMPLEMENT PUBLIC HEALTH RESEARCH AGENDA** Questions for inclusion in the ARC household travel survey
29	Questionnaire to be administered concurrently with the household travel survey [5]
30	Report to GDOT and CDC communicating the result of analyses of the relationships between urban form characteristics, physical activity, and non-motorized transportation patterns

Table 9: SMARTRAQ Deliverables for GRTA

Section #	Deliverable #	Deliverable Title
Section I: Expanding the Land Use Information System & Regional Travel Survey		
A. Land Use Information System		
Plan Development	1.2.1	Agency Interview Report
	1.2.2	Database Standards Document
	1.2.3	Data Collection Plan—Livable Center Initiative (LCI)
	1.2.3	Data Collection Plan--Region
Database Design	2.1	Database Design
	2.2	Data Translation Tables
Database Construction	3	Expanded Land Use Database: Database Construction—LCI
	3	Expanded Land Use Database: Database Construction—Region
Application Development	4	Application Development

	Analysis & Variable Formation	5	Database Analysis: Performance Indicators
B.	Travel Data Requirements		
	Expand Travel Survey Sampling Plan	1	Sampling Plan Procedure
		2	Stratification Procedure
		7	Achieve More Physical Activity Questionnaires (PAQ)
		9	Achieve More PAQs
		10	Achieve More Act. Monit. Surveys
	Develop Performance Indicators & Models for Conducting Sub-Regional Analyses	3	Performance Indicators
		4	Data Analysis of Regional Survey & Baseline of Indicators Established
		5	Modeling Travel Behavior Using Network Buffer Analysis at the Parcel Level
		6	Facility Performance-- Self-Reported vs. Modeled Trip Time and Distance
		8	Trip Linking and Matching GPS Detail and Summary Files
Section II: Policy Based Sub-Surveys			
A.	Stated Preference for Residential Location		
	Design Survey Instrument & Sampling Plan	1	Design of Stated Preference (SP) Survey
		2	Pretesting of SP
		2.5	SP sub-survey enhancement
	Analyze Survey Data & Report Findings	3	Data Analysis of SP Survey Results
B.	(EJ) Defining Mobility Needs of Traditionally Under-Served Populations		
	Develop Methods & Sampling Plan	4	Review of Legislative Requirement of Traditionally Underserved
		5	Sampling Plan, Traditionally Underserved Populations
	Analyze Survey Data & Report Findings	6	Analysis of Travel Patterns of Traditionally Underserved Populations
Section III. Models for Implementation			
	Evaluate Three (3) LCI Proposals		
	Conduct Before Study	1	Livable Center Initiative (LCI)--before study
	Conduct After Study (A)	2	LCI-build out
	Conduct Schematic Design Study (B)	3	LCI--proposed design
	LCI Analysis Tool	4	LCI Proposal and Investment Assessment Model

VI. SUBSEQUENT SECTIONS OF THIS REPORT

The remainder of this report provides findings from quantitative assessments of the regional household travel survey data, including a review of descriptive statistics produced from the data, an inferential statistical analysis, and a set of estimates from the survey data regarding household travel-related emissions. Chapter two reviews the methodologies used to perform these tasks, including: a detailed review of the travel survey process; a discussion of which urban form variables were used to measure land development patterns; and a summary of how emissions estimates were modeled using the household travel survey data. Chapter three offers a review of the descriptive statistical findings from the travel survey data, comparing findings from the 1991 and 2001/2002 regional household travel surveys as well as person-level findings from the 2001/2002 version. Chapter four consists of an inferential statistical assessment of the travel survey data, focusing upon four key travel and travel-related variables: mode split, vehicle hours of travel, VMT, and emissions estimates. Chapter five summarizes the report and offers policy recommendations for the Atlanta region.

CHAPTER II – DEVELOPMENT OF THE URBAN FORM AND TRAVEL BEHAVIOR DATABASE FOR THE ATLANTA METROPOLITAN REGION

I. INTRODUCTION

Three primary databases were developed as part of the SMARTRAQ research project. These contain data regarding travel behavior, parcel-level regional land use patterns, and vehicle emissions, and are referred to respectively as:

- 2001/2002 Atlanta Household Travel Survey (AHTS)
- Land Use Database, version 1.5, and
- Trip-level emissions.

These databases are designed to support the testing of hypothetical relationships between land use, travel choice, and vehicle emissions developed through air quality, transportation, and growth management related policy directives. The databases designed for this study enable:

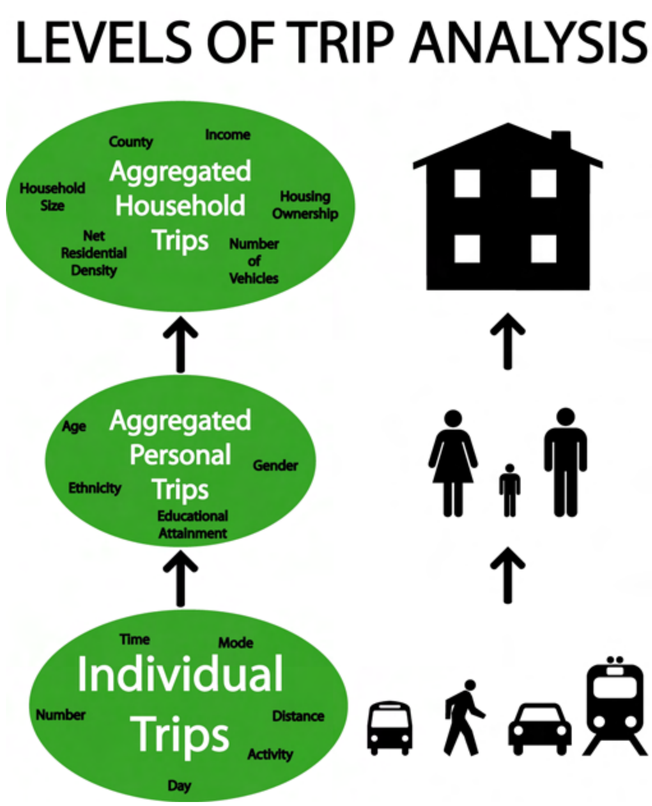
- Descriptive assessments of basic travel (e.g. VMT), demographic (e.g. age, income) characteristics and community-scale measures of residential density, mix of uses and street connectivity;
- Testing of relationships between urban form, travel behavior, and vehicle emissions; and
- Testing of relationships between urban form, travel behavior, and physical activity.

II. DATABASE STRUCTURE

The most basic building block of data (or unit of analysis) is the trip. Data reported at the trip level refers to data collected from the trip diary completed by each participant in the household (or calculated from data that was originally collected through this instrument). Trip-level data includes purpose, mode of travel, travel time, speed, and distance. Land use characteristics are estimated for buffered areas at each trip's origin and destination.

Data reported at the person level refers to either (a) data that was collected from the respondent by way of the telephone interview process or (b) to trip-level data that has been aggregated to the person level. The aggregation process means that data from every trip taken by, for instance, person X in household Y are reported as person X's travel behavior. (The term "aggregation" does not always mean that the mathematical sum of all trip characteristics is taken for a person; sometimes the mean, median, or other statistic is more useful or sensible). Similarly, data reported at the household level refers to either (a) data that was collected from respondents about the household's collective attributes (for instance, household income) or (b) to trip-level data that has been aggregated to the household level. For travel behavior by households, all trips made by all residents of the household are aggregated (in this case, summed) and reported. Figure 12 provides a visual framework for the organization of the data used for this study and the aggregation process.

Figure 12: Data Aggregation



SMARTRAQ

The principle variables constructed during this study are presented below in Table 10. Data derived from this process allowed for the determination of the relationships between urban form and travel behavior.

Table 10: Variables Studied

Urban Form	Net Residential Density Mixed Use Connectivity
Travel Behavior	Vehicle Hours of Travel Vehicle Miles Traveled
Vehicle Emissions	Cold-start Activity Oxides of Nitrogen, Volatile Organic Compounds, and Carbon Monoxide
Demographic Factors	Age, Income, Household Size, and Vehicle Ownership

The sets of trips made by each household were then summed at the person level enabling the attributes of household travel to be characteristics of the household.

Presented results are based on weighted data (unless otherwise indicated) because the purpose is to extend the findings from the sample to the larger region. The data reported in this section has been weighted by six variables (weights provided to Georgia Tech by NuStats, the survey firm that implemented the survey): net residential density (NRD), county, household income, household size, race/ethnicity, and household vehicle ownership. According to NuStats, the weighting process was "based on the ratio between the proportion which exists in the population and the proportion in the sample." After taking population estimates from various sources (e.g., Census data, ARC data), "composite weights were generated based on the products of the underlying weights . . . This composite weight was then normalized to ensure the number of weighted cases equaled the number of unweighted cases."

III. SURVEY PROCESS SUMMARY

The purpose of this section is to summarize the household recruitment and data retrieval processes used by NuStats during the course of the survey effort. NuStats has submitted to the Georgia Department of Transportation, Georgia Regional Transportation Authority and the Atlanta Regional Commission an exhaustive account of these processes (contained in a volume titled "2001 Atlanta Household Travel Survey: Working Papers #1-6" and "2001 Atlanta Household Travel Survey, Final Report," April 2003);[4] this section includes a synthesis of the main points of these reports.

A. Stratification of General Purpose Survey by Land Use Category

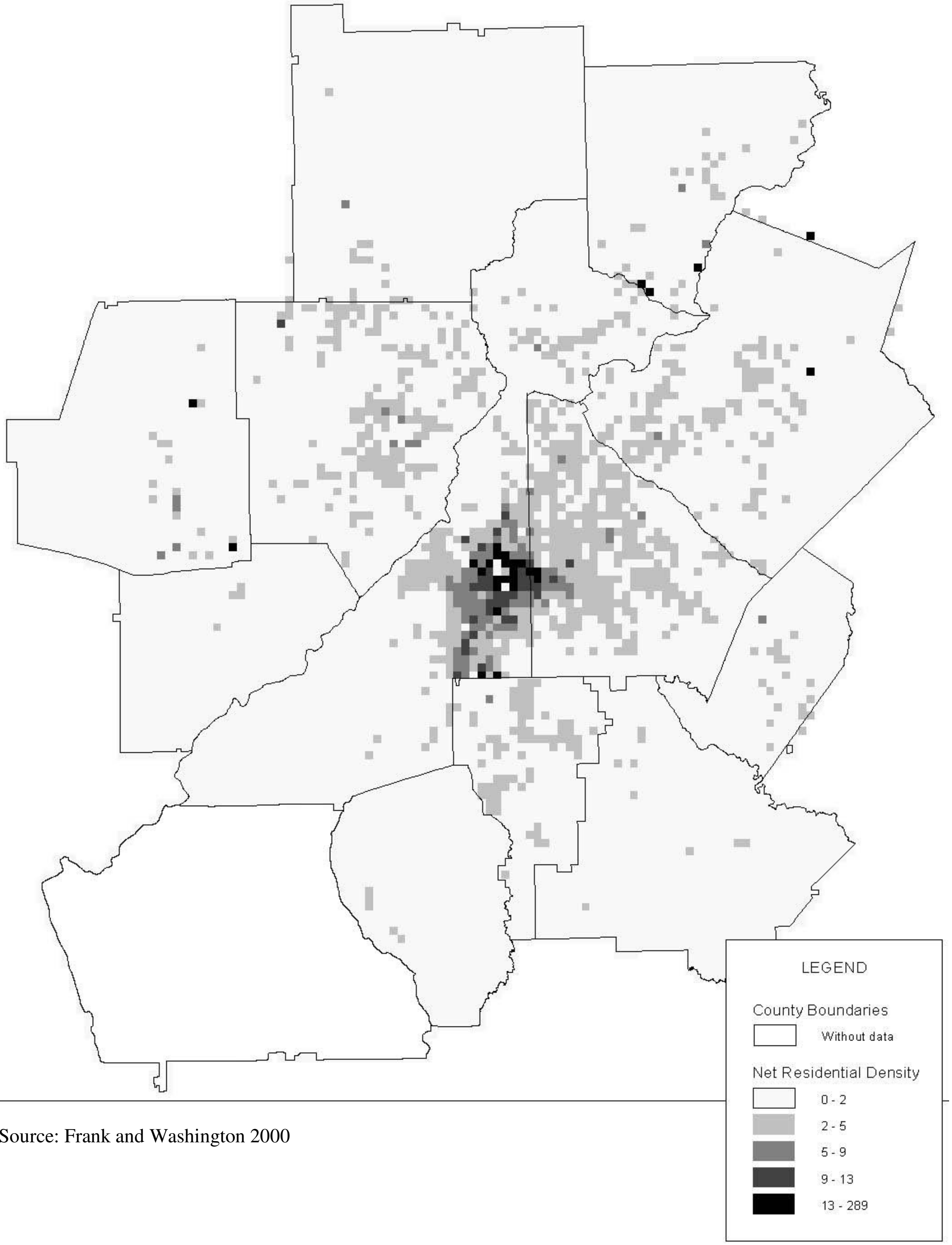
The first step in attempting to understand, on a regional level, how land use patterns and travel are related is to gather data of the correct type, quantity, and quality. To do so requires a survey sampling plan that stratifies by land use; this is necessary because a simple random sample will fail to generate enough households across the entire land use spectrum. Regional travel surveys typically stratify by demographic and socioeconomic variables such as income, household size, and/or household type for the same reasons. Household income and size have long been acknowledged as being important determinants of travel and are frequently incorporated into research designs that attempt to understand the impact of land use patterns on travel behavior (Cervero and Gorham 1995; Dunphy and Fisher 1994; Kitamura, Mokhtarian, and Laidet 1994).

This logic extends to land use variables as well. Because contemporary development tends to be very similar (in terms of density and mixture of uses as well as in terms of street networks), the majority of households in a region tend to exist in neighborhoods

[4] The NuStats report also contains a number of summary tables reporting basic findings from the sample. A number of tables reported in this section can be found in the NuStats report. However, NuStats reported findings using the data-weights supplied to ARC, rather than the weights supplied to Georgia Tech., meaning that the data reported here may differ slightly from that reported by NuStats. The data was re-weighted to make use of a more disaggregate method of determining the net-residential density for each household (Census block group versus 1km grid cell).

that contain very similar land use patterns. Without a stratification strategy it would be impossible to get enough variation to allow for sophisticated and rigorous statistical analysis of the effect of land use patterns on travel behavior. Figure 13 provides an illustration of why stratification is necessary in the Atlanta region, showing that the great majority of the region is low in net residential density (NRD–the land use variable by which the SMARTRAQ research program has stratified).

Figure 13: Net Residential Density for the 13-County Atlanta Metro Area



Source: Frank and Washington 2000

Only a small percentage of the region exists at NRD levels higher than two dwelling units per acre. Unfortunately, in the Atlanta region as in many other regions around the country, stratification by land use patterns had never been attempted at the regional level before. Inevitably, the result was that it has been impossible to assess the influence of land use patterns on travel because there is very little data at higher NRD levels. The last regional household travel survey, the 1991 Atlanta Regional Commission (ARC) household travel survey, did not stratify by land use. It captured almost no variation in residential density within the region – more than 90 percent of the ARC's data was obtained from households located in areas with less than 4.5 units per acre while more than 75 percent of its households were located in areas at density levels less than 1.6 units per acre.

For the 2001/2002 AHTS the sample was stratified by NRD, wherein the goal was to have 20% of the sample fall within each of the five NRD levels. Household income and size were not used as stratification variables, according to NuStats, because "current income data was unknown at the time of the study and the relationship between NRD and household size was unknown." Additionally, NuStats over-sampled the region along two other, unrelated variables: by county and by low-income and minority status.[5]

The SMARTRAQ sampling plan thus over-sampled dense neighborhoods in order to ensure an adequate representation of households from such neighborhoods. The sampling plan utilized NRD levels for stratification purposes, with density measured at the scale of one square kilometer grid cells (areas not in residential use were subtracted, or netted out, of the land area calculation for each cell).[6] The data that is shown in Figure

[5] The focus on county-level data was the result of needing enough households in each county so ARC could perform its county-level planning and modeling functions; over-sampling was required because "it was apparent that the county level coverage was adversely impacted by the NRD stratification". Finally, the over-sampling of low-income and minority households formed part of an equity-based outreach strategy (titled the "traditionally underserved" component of SMARTRAQ) to recruit sufficient numbers of historically difficult-to-recruit households.

[6] Gross residential density is defined as the total number of households per unit of area, while net residential density subtracts those parcels dedicated to non-residential purposes. Population density measures the number of residents per unit area (Holtzclaw 1994).

13 (showing NRD levels within the region) is at a one square kilometer grid level. The region's area was divided into some 10,000 squares of one kilometer on each side. Five NRD groupings were utilized (0 to 2, 2 to 4, 4 to 6, 6 to 8, and 8 or more households per acre).

The goal of dividing the total sample into equal parts across the five density ranges was not met: the number of households in each of the higher density cells (four households per acre and over) represents less than twenty percent of the sample (Table 11). In order to have a statistically significant number of households in each grouping, these results might require that the number of NRD categories be collapsed, from the current five to perhaps three. However, despite these results, when compared with the 1991 results the stratification strategy clearly resulted in many more households represented in higher NRD categories than would have been the case had a simple random sampling technique been utilized. As is shown in Table 12, more than twenty percent of the total sample was at an NRD of six dwelling units per acre or greater, while less than forty percent was at an NRD of less than two units. These figures contrast sharply with the regional land use data in the same table, demonstrating that a simple random sampling technique likely would have reversed these results.

Table 11: Distribution of households in SMARTRAQ General Purpose Survey by Net Residential Density (NRD)

NRD	*Frequency*	*Percent*	*Cumulative Percent*
0 – 2	3099	38.4	38.4
2 – 4	2036	25.2	63.6
4 – 6	1200	14.9	78.5
6 – 8	10.3	10.3	88.8
8+	901	11.2	100.0
Total	8069	100.0	100.0

Table 12: Land use patterns in the thirteen-county Atlanta region compared with household recruitment patterns

NRD	*I KM Square Grids**	*Surveyed HHs***
0 - <2	88.7%	38.4%
2 - <4	8.5%	25.2%
4 - <6	1.8%	14.9%
6 - <8	0.6%	10.3%
8+	0.4%	11.2%

* Percent of smart squares in the region at each level of NRD;

** Percent of households in the General Purpose survey from each level of NRD

B. Household recruitment and data collection process

The household recruitment and data collection process contained seven steps, which in turn constituted half of all the steps in the surveying process designed by NuStats (Table 13). The process began with an advance mailing, followed by a recruitment call and interview, geo-coding of important addresses attached to the household's indicated travel patterns, mailing travel diaries to the household, placing a reminder call, then, finally, a data retrieval interview designed to capture two days' worth of travel by all members of the household older than four years. This design utilized a random digit dialing method of recruitment, wherein households with listed and unlisted numbers were selected at random from a database of telephone numbers, for all households with telephones in the region.

Table 13: NuStats recruitment, data retrieval, & data inspection processes (from NuStats Final Report, June 2002)

Stage	Stage Description	Progression Criteria
1	**Sample Generation**	None
2	**Geocode Home Addresses**	• Geocoded addresses go to Stage 3 • Ungeocoded listed addresses and unlisted addresses go to Stage 4
3	**Advance Mailing** – Introductory letter is mailed to sampled households electing this option	• All sample progresses to Stage 4.
4	**Recruitment Interview** – Sampled households are contacted to secure participation in the study. Those who agree to participate provide demographic data and are assigned travel days	• If the interview is completed, goes to Stage 5 • If the interview is not completed, exception report is generated • If interview is not attempted, sample status is updated and sample is scheduled for callback.

		sample is scheduled for callback.
5	**Geocode Habitual Addresses** – work and school addresses are geocoded	• If address geocodes, goes to Stage 6 • If address does not geocode, exception report generated and also proceeds to Stage 6 but flagged.
6	**Diary Placement** – A personalized diary packet is prepared and mailed to each recruited household	• If packet is mailed, goes to Stage 7 • If packet is not mailed, exception report generated to indicate reason
7	**Reminder Call** – Recruited households are contacted to confirm receipt of diary packet and remind about upcoming travel days	• If household is ready, goes to Stage 10 • If household needs new packet, goes to Stage 6 • If household is rescheduled, can go to Stage 6 or 10 • If household refuses, exception report is generated and assigned to interviewer specializing in refusals
8/9	**Travel Days** – Household members record travel on assigned days	
10	**Retrieval Interview** – The first retrieval call is placed the day following travel or at a respondent-designated time	• If household provides data according to definition of "complete", goes to Stage 11 • If household did not record travel data and is rescheduled, can go to Stage 7 or 9 • If household refuses, exception report is generated and assigned to interviewer specializing in refusals
11	**Field Edits** – the night the retrieval interview is completed, work is checked for completeness	• If work meets standards, goes to Stage 12 • If work does not meet standards household is assigned for callback/verification
12	**Data Processing** – at the conclusion of each data collection shift, all data are processed and prepared for edit check and geocoding	• If processed data meets completeness standards, goes to Stage 13 • If processed data does not meet completeness standards, exception report is generated and household is assigned for correction / callback
13	**Geocoding of Trip Ends** – all new address information (new or updates to previously collected information) is geocoded through both batch and interactive processes	• If geocoded, goes to Stage 14 • If not geocoded, exception report is generated and household assigned for correction/callback • Daily reports monitoring hit rates
14	**Data Quality Checks** – all data is subjected to visual inspection and edit check program to ensure quality standards and data specifications are met	• If passes, goes to Stage 15 • If fails, exception report is generated and household assigned for correction/callback • Daily reports monitoring pass rates
	Process complete – data ready for delivery	• If process complete, data flagged for delivery and process ends • If process not complete and time thresholds crossed, exception report is produced and data specialist addresses household to ensure data movement

The database structure utilized by NuStats follows the three levels of data generated by the regional travel surveys – the household, the individual, and the trip. The data list includes demographic information such as household size, income, and ethnicity; information about the household's travel-relevant attributes or assets, such as its number of vehicles and the attributes of those vehicles (e.g., engine size, type of fuel used, make and model of the vehicle); and, critically, given the objectives of this survey, spatial information about the household generated by the parcel-level database, such as the attributes of the area around each of the households in the database (the household's "buffer").

Additionally, descriptive information was gathered about each person in the survey and data was gathered about the travel patterns of every person above five years of age. Finally, of course, trip-level data was gathered for every trip taken by each person in every participating household. This three-layered data collection strategy allows for a wide range of questions to be asked over a wide range of topics.

A final note should be made with respect to the weighting process employed by NuStats. The weighting of survey data is necessary when there is reason to believe that the characteristics of the sample vary along some important dimension(s) from the population. For instance, the over-sampling process described above produced a sample containing many more households (proportionally) at higher density ranges than exist within the region; therefore, weighting the data to account for this discrepancy is required to adjust the sample to reflect actual land use and demographic conditions in the region. NuStats utilized six variables in the weighting process: NRD, household county, household income, household size, race/ethnicity, and household vehicle ownership.

IV. TRAVEL BEHAVIOR DATA METHODS

A. VMT/VHT means and aggregations

The initial data set used to create the inferential models includes the 14,527 (unweighted) people 16 years or older from the 8,069 household survey. The models use both demographic and household-based urban form variables. The demographic variables were self-reported by the participants. The trip time, distance and emissions values were calculated using participant-reported trip origin and destination locations, time of day of travel, mode used, and vehicle age. Please see below for details on the estimation processes.

The vehicle miles traveled (VMT), vehicle hours traveled (VHT) and emissions model datasets include only those people for whom distance and time values were present for all trips made (all modes, even though these models are only for vehicular travel) across the weekdays of the two day period in which they recorded their travel behavior. The emissions models datasets also required that people use a single vehicle for all their vehicle trips in order to be included in the selection criteria. This requirement was necessary in order to allow vehicle age to be considered in the daily emissions model. These final data sets range from 7,261 to 8,670 people, depending on the model.

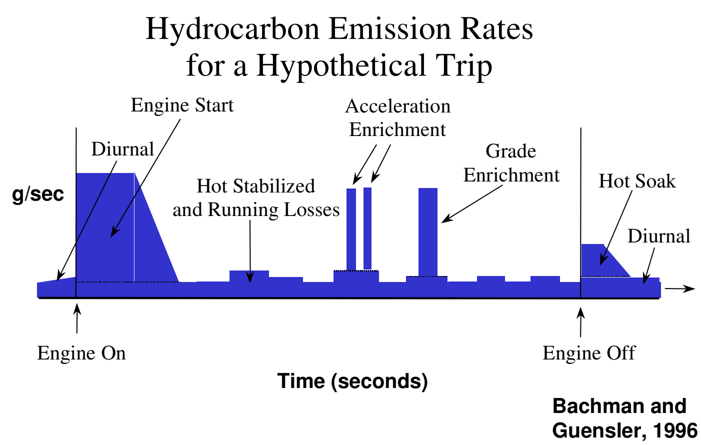
Before summing daily total VMT, VHT, and emissions for each person in the dataset, the trip level values were adjusted in two ways. The first adjustment was to create a daily average value of those variables for each trip. This average was created by dividing each trip's VMT, VHT, and emissions value by the number of weekdays (either one or two) in that person’s two day travel reporting period. The second adjustment was to divide those values by the number of people traveling together. For bus travel, occupancy was assumed to be 20 for off-peak travel and 50 for peak travel. For personal motor vehicle travel, occupancy was the driver plus all passengers. After making these two adjustments a weekday total was summed for each variable for each person. These final values were used as the dependent variables in each of the inferential models described in Chapter IV.

B. Trip-Level Emissions Estimation

Trip-level emissions estimates allow analysts to relate travel behavior to air quality, thereby developing further understanding of the relationships between land use, travel choices, and air quality. Planners in the Atlanta region can use this data to make better decisions regarding future development patterns and transportation strategies.

Trip emissions and the underlying emission rates vary by a wide range of vehicle operating and environmental conditions. Mean grams/sec or grams/mile emission rates vary by vehicle type, condition, and power demand. To accurately estimate the emissions for a trip, analysts must have as much information as possible about the vehicle, the operating conditions, and trip travel time. While average travel speed per trip is an adopted industry standard and a good estimate of transportation system performance, it is a poor predictor of emissions. This is partially due to the fact that average travel speed per trip fails to capture the speed profile of the trip, which entails acceleration rates and speeds per trip segment (Guensler, 1997). Figure 14 characterizes the rate of emissions of hydrocarbons generated in grams/second per trip.

Figure 14: Hydrocarbon Emission Profile



The AHTS provides enough information to develop emission estimates at accuracy levels suitable for drawing broad conclusions related to land use and travel behavior impacts.

There is not enough information, however, to accurately estimate the exact quantity of pollutant generated by a specific trip.

The methodology and assumptions for generating SMARTRAQ trip level emission estimates are described below. Emissions of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x) and carbon dioxide (CO_2) are estimated. The travel variable for each pollutant is defined in the database as the total number of grams of NO_x, VOC, or CO per vehicle trip. Emitted directly from the combustion process, each of these pollutants is a hazard to human health; high concentrations of NO_x and CO in particular have been linked to an increased susceptibility to respiratory disease in humans (Boubel, 1994). Once in the atmosphere, the various forms of these gases play a central role in the formation of the secondary pollutant, tropospheric ozone, for which the Atlanta region does not meet National Ambient Air Quality Standards.

The emission estimation process uses two primary databases, relies on three major assumptions and consists of four basic steps:

Databases

- 2001/2002 Household Travel Survey Trip Data
- 2000 ARC Loaded TRANPLAN Network

Assumptions

- Drivers accurately reported trip information (no missing trip chain elements, correct trip end locations, etc).
- Actual trip travel times and speeds can be represented by the shortest network time path estimated from the 2000 ARC travel demand forecasting model.
- The base emission rates generated by MOBILE 6.2 are accurate.

Steps

1. Estimate the vehicle resting time between trips (soak time)
2. Estimate trip activity parameters (travel times and speeds)
3. Estimate base emission rates using MOBILE 6.2
4. Estimate total trip emissions

The next section provides more detailed information on the inputs and the process itself.

Databases

- 2001/2002 Household Travel Survey Trip Data

The fields from the 2001/2002 Household Travel Survey that are necessary for estimating emissions are the origin and destination coordinates, the trip mode, the trip sequence, the trip starting and ending times, vehicle model year, and the number of people traveling together (trip party). Initial data assessments showed that approximately 18% of the reported trips have origin or destination coordinates that are missing or assigned to the nearest zip-code or city centroid. These "unmatched" trip ends are the result of the respondent providing incomplete information regarding one or both trip end locations.

Distance, time, and emission values are imputed for trips with one or more unmatched trip end by identifying trips with matched endpoints most similar to each trip with missing endpoints and averaging their estimated values. In general, trips are deemed similar if they are made by the same mode, for the same purpose and had similar reported travel times, land use around the participant's residence and regional location. Please see Section IV.C of Chapter II for a more detailed explanation of this process.

The calculation of the soak time requires identifying the vehicle rest time before each trip. The first reported trip for a vehicle is assumed to have a soak time of 8 hours. After that initial trip, soak times are assumed to be reported accurately (trip start time minus previous arrival time).

1. 2000 ARC Loaded TRANPLAN Network

The 2000 Atlanta Regional Commission's (ARC) loaded TRANPLAN network for morning (AM), evening (PM) and off-peak time periods is used as the basis for determining shortest time paths. The advantage of this network is that it has estimated link travel times for congested and uncongested periods. This allows potential trip routes to vary by travel time at different times during the day. The disadvantage of this network is that it does not include all roads in the network, just the major roads. It was decided the ability to estimate congested travel times was more important than an accurate representation of local road travel. Local road travel is estimated using other techniques, described below.

2. 2001/2002 Emissions Estimation

The method for estimating vehicle trip emissions is divided into five primary components:

- Emission rates,
- Engine start activity,
- Trip paths,
- Trip emissions, and
- Modal adjustments.

a) Emission Rates

Emission rates are calculated using the U.S. Environmental Protection Agency's MOBILE 6.2 model. With assistance from the Georgia Department of Natural Resources, default parameters were identified for Atlanta in 1999 (climatic data, inspection/maintenance programs, fuel type, etc.). Trip specific conditions are also identified and included in the estimation. MOBILE 6.2 using 68 different soak time intervals generates a full range of engine start emission rates. Similarly, unique emission rates for each possible facility class[7], speed[8], vehicle type[9], and model year[10] are generated. These values become "lookup" tables of base emission rates (grams per start or grams per mile) for certain trip-specific operating conditions.

b) Engine Start Activity

Engine start activity refers to the soak time, or the time a vehicle spends with the 'engine off' between trips. The soak time matches to a time interval in the base emission rate lookup table.

c) Trip Paths

Trip paths are estimated using a Dykstra's algorithm to identify the shortest time path from the reported origin to the reported trip destination over the appropriate TRANPLAN network. Every road segment in the shortest time path solution is recorded in a database. Each of these segment IDs links back to a database containing the segment travel time and speed.

Since the TRANPLAN networks do not contain local roads, a different strategy is used to identify the total local road travel time. Euclidean distances are calculated from the trip end to the closest point on the road network. This distance is assumed to be traveled at a speed of 15 mph. This travel time is below most standards for average speed on local roads. The difference in speeds accounts for road curvatures and turns that are not represented in the Euclidean calculation.

At the end of the process the amount of time and average speeds for every segment of the estimated trip path are identified.

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[7] Road facility classes: freeway, ramp, arterial, and local.
[8] Speed range: 0-70 mph in 5 mph increments. Speeds greater than 70 mph a 70 mph emission factor.
[9] Vehicle types: light duty vehicles, buses, motorcycles.
[10] Model year: Vehicles less than or equal to 25 years old had unique emission rates. Vehicles older than 25 years used the 25 year old emission rate. Vehicles with an unknown age were assumed to be the mean model year—1999.

d) Trip Emissions

The emissions estimation process assigned base emission rates to the trip segments and calculated total trip emissions. Engine start emissions were assigned as 'grams per start' emissions directly from the base emission rate lookup table. Running exhaust emissions were estimated for each road segment of each trip. The base emission rate for each segment was identified from the emissions lookup table using the vehicle model year, vehicle type, facility type, and average speed. The base grams/mile rate was multiplied by the length of the road segment. All the segment emission estimates for the trip were aggregated together to generate a single trip running exhaust emissions value.

Engine start emissions and running exhaust emissions for each trip were summed to identify total estimated trip emissions. In addition, emissions for the reported trip travel time were also calculated using the ratio of estimated travel time to reported travel time.

e) Modal Adjustments

Modal adjustments to the trip emissions were applied to adjust emissions for vehicle occupancy and for specific mode characteristics. Trip emissions were divided among all of the individuals that were reported to be in or assumed to be in the vehicle. School buses and off-peak transit buses were assumed to have an occupancy of 20. Peak hour buses were assigned an occupancy of 50. Para-transit trips were assumed to have occupancy of three. Trips without an occupancy reported were assigned an occupancy of one. Engine start emissions were not estimated for some modes (school buses, transit buses, and taxis) because there were not trip-specific engine start episodes.

C. Methodology to Group Similar Trips to Impute Travel Time, Distance and Emissions

1. Overview

Of the over 116,000 trips in the 2001/2002 AHTS, participants provided enough trip end location information for 80% (93,224) to be address geo-coded, thereby providing their x/y coordinates. See Table 14 below. Of the remaining trips, slightly more than 2% (2,655) have one or more endpoint(s) outside the region, and approximately 18% have "inaccurate" information about one or more trip ends. Inaccurate information includes those locations not address geo-coded or were only geo-coded to a city or zip-code centroid depending on the extent of information provided by the participants.

Table 14: Geo-coding status of Trip Origins and Destinations

		Destination Endpoints					
		Accurate	**Inaccurate**			**Not in region**	
Origin Endpoints		matched	unmatched	city centroid matched	zip code centroid matched	out of area	Total
Accurate Coordinates	matched	93,224	4,357	1,537	3,693	998	103,809
Inaccurate coordinates	unmatched	4,266	566	56	137	80	5,105
	city centroid matched	1,520	55	102	84	15	1,776
	zip code centroid matched	3,677	137	85	390	33	4,322
Not in region	out of area	938	85	18	33	455	1,529
Total		103,625	5,200	1,798	4,337	1,581	116,541

Of the 18% of trips within the region but with inaccurate origin or destination information, 19,455 trips or about 94% of that group are motor vehicle trips. In order to increase the number of motor vehicle trips with estimated travel time, distance, and emissions, program researchers developed a methodology to determine which of the 93,224 trips with accurate coordinates (TAC) are most similar to each of the trips with inaccurate coordinates (TIC).

Of the TICs, 18,368 or 89% were made by the personal motor vehicle, with the survey participant either the driver or a passenger. It was felt the other motor vehicle (public bus, paratransit and school bus) modes had too few trips to use to impute values. Motorcycle trips were also few in number, but this was not an issue since all had address geo-coded trip ends.

The methodology described below, derived from an evolutionary approach to selecting variables upon which to match TACs to TICs. The quality of the matches resulting from different combinations of match-variables was compared primarily on the basis of the number of TICs trips for which similar TACs were found and the standard deviation within the group of similar trips for time, distance and emissions. A combination of match-variables was considered better if it provided groups of similar TACs for more TICs, and if the standard deviation within similar groups was less, i.e., they had more homogeneity of trip attributes.

2. Define "Similar"

Six variables are used to define similar sets of trips:

- Mode (must match exactly)
- Duration (Tolerance of + / - 5 minutes)
- Period of the day with majority of travel time (must match exactly)
- Destination activity (must match exactly)
- Urban form surrounding person's households (20 ranges—must be in same range)
- Distance of household to center of the region (3 ranges—must be in same range)

Trips are considered similar if they match, within the tolerances stated below, for all six variables. As stated above, the mode for which this methodology is applied is the personal motor vehicle (driver and passenger) only. Duration and the period of day within which the majority of each trip occurs are derived from participant reported departure and arrival times. A day is divided into four categories used by the Atlanta Regional Commission in their regional travel demand modeling efforts. In twenty-four-hour time they are: 06:00-10:00, 10:00-15:00, 15:00-19:00 and 19:00-06:00. The destination activity is self-reported using one of the following 31categories, as shown in Table 15.

Table 15: Self-reported destination activities

0= No other activities	16= ATM, banking, post office, bill payment
1= Eating/preparing meals at home	17= Waiting for transportation
2= Entertainment	18= Drop off/Pick someone up
3= Visit friends/relatives	19= Sleep
4= Working	[no "20"]
5= Work related business (sales call, conference, errand)	21= Rest/Relax
6= School (attending classes)	22= Pick up something/Drop something off
7= Incidental shopping (groceries, gas, meds)	23= Personal (bath, shower, get dressed)
8= Major shopping (furniture, clothes, auto, etc)	24= Personal Business
9= Watching children	25= Volunteer work
10= Household work/Outdoors work	26= Getting Ready
11= Fitness/Exercising	27= Other at home activities (homework, reading, playing)
12= Outdoor recreation (vacation, camping, sightseeing, etc.)	28= Work related from home/doing work from home
13= Medical/Dental (appointment, treatment, procedure)	97= Other
14= Community meetings, political/civic events, public hearing	99= DK/RF
15= Worship/religious meeting	

Land use mix around each participant's household and the distance of that household from the center of the region are objectively derived. These values, used for each trip, regardless of whether they have an endpoint at the home or not, are described below.

a. Urban Form

The urban form around each home consists of net-residential density[11], intersection density[12] and land use mix[13]. The z-score for each of these variable was determined for

[11] Derived from 2000 Census block group level number of housing units, and the ARC 2000 land cover data, which supplies acreage by residential land use. The number of residential acres per block group is determined. Housing units divided by net-residential acres provides the density value.

[12] Number non-access controlled intersections with three or more road approaches intersecting within the one kilometer road-network based buffer around each home.

[13] The land use database (v.1.5) was used to aggregate the estimated number of square feet by use category to the level of the 1 km road-network based buffer around each survey participant's home. Land use mix used the square feet of four categories—residential, commercial, office and institution. The formula is the sum of the proportion of inhabited space land use (estimated square footage of developed land divided by the total square footage of area) multiplied by the natural log of the proportion of inhabited space for each land use, divided by the natural log of the number of land uses, multiplied by negative one.

each household. The sum of these three scores was grouped into 20 equal categories. Trips with a category match are considered similar.

b. Household Distance from Region's Center

The unique traffic analysis zone (TAZ) from ARC's 1990 network was identified for each participants' home. The traffic analysis zone for the approximate center of the region (intersection of Marietta and Peachtree Streets in downtown Atlanta) was also identified. Using an ARC provided file containing TAZ to TAZ distances, the distance from each home to the center of the region was identified. These distances were grouped into three equal categories: 0-11.7, 11.7-23.4, and more than 23.4 miles, and each household was assigned to one of these ranges. Trips with a category match are considered similar.

3. Results & Imputation Process

The above methodology resulted in identifying similar trips for slightly more than 89% of the trips (16,385 of the 18,368) with incomplete endpoint information (TICs). The 11% for which no similar trips were found either had incomplete information for one or more of the match variables or had no other similar trip.

For each trip with incomplete location information, imputed travel time, distance and emissions values were calculated by taking the average of the values estimated for its group of trips found to be similar. Please see Chapter II, Section IV.C for a detailed description of the process to estimate these values.

Ten or more matches were established as the threshold for imputing values based on a comparison of means for three groups of trips. Of the 16,385 trips with similar trips identified nearly 40% (6,419) of them each had less than nine other trips to which it was similar. The mean travel distance was determined for all those trips with fewer than 10 matches (group 1), those with 10 or more (group 2), and those trips which initially had complete trip end information (group 3). The mean distance is higher for those trips with fewer than ten matches (12.7 miles), as compared to group 3 (9.6 miles). The group 2 mean (9.3 miles) more closely approximates the data of the trips for which geo-coded information was available (group 3). Using ten or more matches as a threshold results in an additional 6,419 trips without imputed values.

V. WALK / BIKE TRIP DISTANCE ESTIMATION METHODOLOGY

The walk / bike trips require a different methodology from the vehicle trips because they have different resolution (shorter distances) and are not impacted by peak period congestion. While the travel demand forecasting network is suitable for estimating vehicle trip paths, the absence of local roads prohibits accurate assessment of short trips. Since walk and bike trip time and distance estimates are not tied to the impacts of congestion on travel time (estimated in the travel demand forecasting network), a more detailed and spatially accurate road database could be used. Detailed road databases are widely available. A road database from Geographic Data Technologies (GDT) was used for this analysis. The procedures and reasoning were as follows:

1. The GDT road database for individual counties was combined into a composite road database for the 13-county region. By joining the databases, cross-county travel could be calculated.
2. Freeways and freeway ramps were flagged to prevent any path estimation from traversing their features. Non-motorized trips are unlikely to occur on these features and their presence could only cause estimation errors.
3. The GDT road lines were segmented into 200 foot sections. A limitation of the ESRI ArcInfo software is that it won't allow shortest path routines to partially cross road lines. By segmenting the data, the resolution of the stopping and ending point of the trip is limited to 200' from each origin and destination.
4. An ArcInfo AML was written and used to cycle through each trip, estimate the distance, and write the results to a file. By having all of the process in a macro program, it is repeatable and could be used to experiment with other road databases or path finding parameters.

There are two significant assumptions in this methodology that should be noted:

1. *Actual walk / bike distances are similar to the shortest-distance path along local roads*. This assumption will hold for many trips, but does not consider pedestrian networks (school campuses, office park, etc.). Further research needs to be conducted to identify potential trip types or locations that do not logically fit the theory.
2. *The origin and destination locations are accurate*. If the starting and ending points are incorrectly identified or have significant positional errors, then the estimated paths will also have significant errors.

A. GPS Trips

While not reported here, program researchers developed methodologies to align raw GPS trip data with self-reported trip data. Please see SMARTRAQ's report VII.30, which was provided to the GDOT.

VI. ACTIVITY MONITOR

While not reported here, methodologies to select valid hours and days for activity monitor data analysis are described in detail in SMARTRAQ's report VII.30, which was provided to the GDOT.

VII. BUILT ENVIRONMENT

It is well known that land use patterns play an important role in shaping travel behavior and, as a result, impact traffic congestion and air pollution. The SMARTRAQ research program is a major effort designed to improve our understanding of how land use shapes travel behavior. Land use patterns influence travel through the way in which they shape the proximity between destinations, through how well or poorly connected destinations are, and through how the built environment is designed.

Proximity refers to the straight-line or crow-fly distance between two points in space. Higher densities and a mixture of uses increase proximity by bringing destinations closer together. Connectivity refers to how easily it is to travel along transportation systems – usually streets – between any two destinations. Some types of street networks, for instance grid street networks, make travel between destinations easier by shortening trip distances, while other types of systems, for instance the kind of curvilinear and hierarchical systems found in most suburban areas of the Atlanta region, lengthen the distance. Design refers to how the elements within the built environment – buildings, streets, and so forth – shape behavior through both their form and functionality. Theoretically, both proximity and connectivity shape travel behavior through influencing mode choice as well as the length of the trip. Design shapes behavior through influencing safety and aesthetics for motorists as well as non-motorists (Frank and Engelke 2001).

Understanding how land use patterns (residential, commercial, and employment patterns within the metro area) influence travel is a critical objective of the SMARTRAQ research program, specifically to better understand the interactions between:

- land use patterns at the place of residence, demographics, transportation investment, and *trip level mode choice;*
- land use patterns at the place of residence, demographics, transportation investment, and *person level vehicle miles and hours traveled, emissions produced; and*
- land use patterns at the place of residence and employment, demographics, transportation investment, and *person level physical activity patterns*.

To accomplish this objective, SMARTRAQ depended on two basic strategies, one having to do with how household travel survey data was collected (stratification by land use category) and the other having to do with how land use data was measured and used. The former is described in above, the latter is described in detail below.

A. Creation of the Land use database

As part of SMARTRAQ, the Georgia Tech Center for Geographic Information Systems developed a parcel-level land use database for the 13 non-attainment counties in the Atlanta region. In addition to providing a basis to understand SMARTRAQ's travel survey results, the land use database is a significant information resource for a wide range of activities related to understanding the impacts of the built environment on transportation systems performance, air quality, water quality, and public health.

The advent of geographic information systems (GIS) has greatly extended the ability to manage detailed information about urban areas (Chapin, Kaiser and Godschalk, 1995). GIS can handle the vast amounts of data required to characterize land uses at the metropolitan scale (see Moudon and Huber, 2000). More importantly, GIS provides a framework for analyzing the spatial relationships among land uses. Parcel-level databases are the preferred way to represent land use. They provide the detail required to investigate complex patterns of land use and to address questions of proximity, agglomeration and the mixture of uses. Parcels are the units at which land is traded. Thus, the assemblage of land use information at the parcel level enables a direct linkage to be made between our understanding of complex land use patterns, which is a descriptive endeavor, and the underlying economic development forces that shape our urban form. The next sections provide a basic description of the process used to develop parcel-based regional land use database as a part of the SMARTRAQ project.

1. Existing Land Use Data

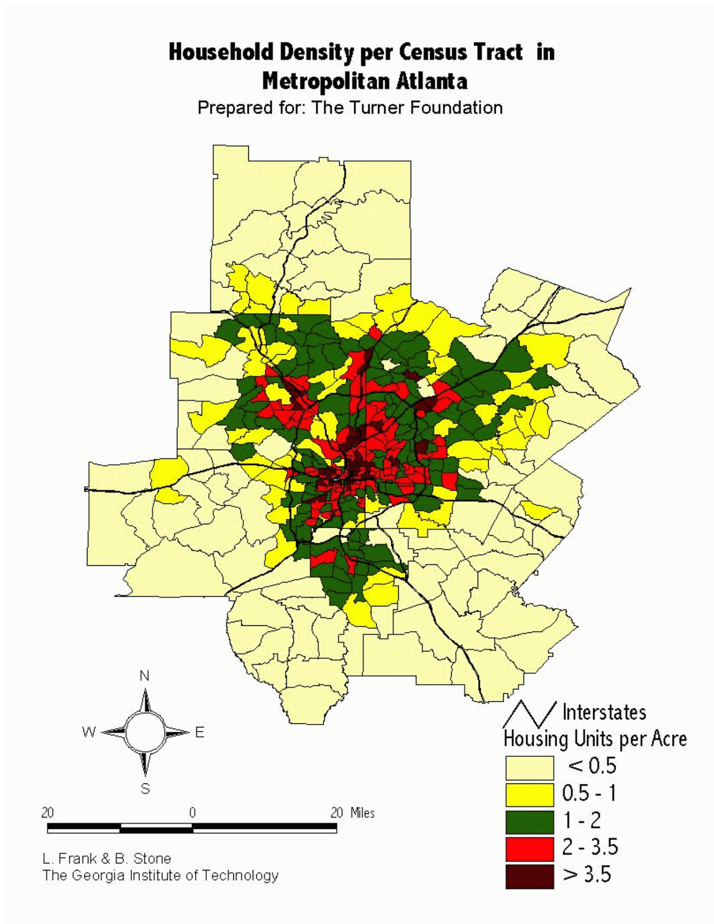
The only land use database, existing prior to the SMARTRAQ effort, for the entire Atlanta region was "land cover data" developed by the Atlanta Regional Commission (ARC). The ARC land use database was primarily developed to support its population and employment forecasting model (DRAM-EMPAL, for disaggregate residential allocation model / employment allocation model). This database is based on aerial photography, not on cadastral information. Land use is represented by polygons that are

5 acres or more that are classified into one of 14 land use categories. These polygons represent contiguous areas of a single use that can be identified from aerial photos. At the time of the SMARTRAQ work, the current land use data was based on 1994 photography. This database covers the 10-county ARC region.

In addition to the land cover data developed by the Atlanta Regional Commission, population and employment data is required to support ARC's land use forecasting model known as DRAM/EMPAL. For population or household data, the census provides the number of housing units for various levels of geography. The block is the smallest unit for which housing units are tabulated. More detailed information is available at the block group level. While it does not address land use specifically, census data on population can also provide useful information on related topics such as population density. This can be used to cross reference information on residential land uses provided in the parcel data. The census does not, however, provide any information on non-residential land uses.

Figure 15 provides a geographical representation of gross residential density at the Census tract scale for the Atlanta Region in 1995.

Figure 15: Gross Residential Density



Most places in the Region, shown in the lightest color, have extremely low levels of residential density (less one unit per half acre). While largely consistent with maps shown later in this report based on the newly developed parcel database, there are significant inaccuracies inherent with this method of calculating residential density. Therefore, "gross" residential density levels shown in Figure 15 are misleading. Parcel data is required to estimate the non-residential land area and enables an accurate estimate to be made of the degree of concentration of residential use based on the numbers of residences divided by the amount of residential land area.

Several private firms, most notably Dorey's Publishing and Information Guide and CoStar (formerly Jamison Research) maintain extensive proprietary databases on office, commercial and industrial uses. These firms conduct quarterly surveys on space utilization and absorption for the real estate industry. While these databases cover only the most urbanized part of the region and do not include small owner-occupied offices, they provide very accurate and up-to-date information on the office and commercial markets. These databases can be used to improve the accuracy of the major office and commercial concentrations within our land use database. These areas are particularly important as trip attractors.

Aerial or satellite-based imagery also provide land use / land cover information for the 13 county area. Multi-spectral satellite imagery (SPOT or LANDSAT) can be used to assess land cover and land cover change. It is not yet possible to automatically detect land use at the detail needed for transportation planning (office, commercial, multi-family, etc.). The state has provided one-meter digital orthophotography for the metro area. Black and white photography was taken in 1994 and color infrared photography was taken in 1999. Manual review of this photography can provide insight into more general patterns of land uses. Large clusters of particular land uses can be identified using this photography. While aerial photography cannot resolve individual land uses, it can support and reinforce land use classifications derived from other sources.

2. Constructing the Regional Land Use Database version 1.5

While each of the databases described above are well suited for their intended applications, they do not provide sufficient detail to support analysis of the SMARTRAQ travel survey.

A major part of the SMARTRAQ research effort was the development of a parcel-level land use database for the 13-county Atlanta region. Each county is required to maintain a database of the taxable property in its jurisdiction. The county databases are the most comprehensive listing of land parcels available in most jurisdictions. Annually, each county must prepare and submit a copy of its property tax digest to the Georgia

Department of Revenue. The Department provides guidelines as to the basic fields that must be included in this database. However, the general format, content and naming conventions vary widely between jurisdictions. Even considering this variation, the county tax assessors' parcel files are the best foundation for constructing a detailed land use database for the Atlanta region.

To avoid negotiating with 13 individual tax assessors and then reformatting the database records into a common format, we purchased a set of parcel-level, tax assessor records from Property Data Systems, Inc, a private data vendor serving the real estate industry. This company annually acquires parcel level tax records for most of the counties in the metro Atlanta area and converts them into a standard database structure, which it sells on CD with a proprietary software system. The SMARTRAQ project purchased a copy of the 1999 tax assessor data for 12 metro area counties covered by PDS (data for Coweta County was not available). By special arrangement, this data was supplied in its raw format without the accompanying front-end software.

To make the PDS data useful for the project, they had to be geo-referenced. Given the size of the database, we decided to represent the parcels by their centroids rather than carrying boundary polygons for all 1.2 million parcels. This decision was reinforced by the fact that a majority of the counties did not have digital parcel maps and the scope of the project did not include digitizing hundreds of thousands of parcels. PDS had digitized the centroids of each parcel relative to a scanned image of a tax map. Each database record included pixel coordinates relative to its scanned image, however these images were not registered to any real-world coordinates. While this scheme allowed the PDS software to associate the parcel attributes with a scanned tax map, it would not allow us to analyze the spatial relationship among parcels on different maps nor would it allow the integration of the parcel data with other GIS layers (e.g., the street network).

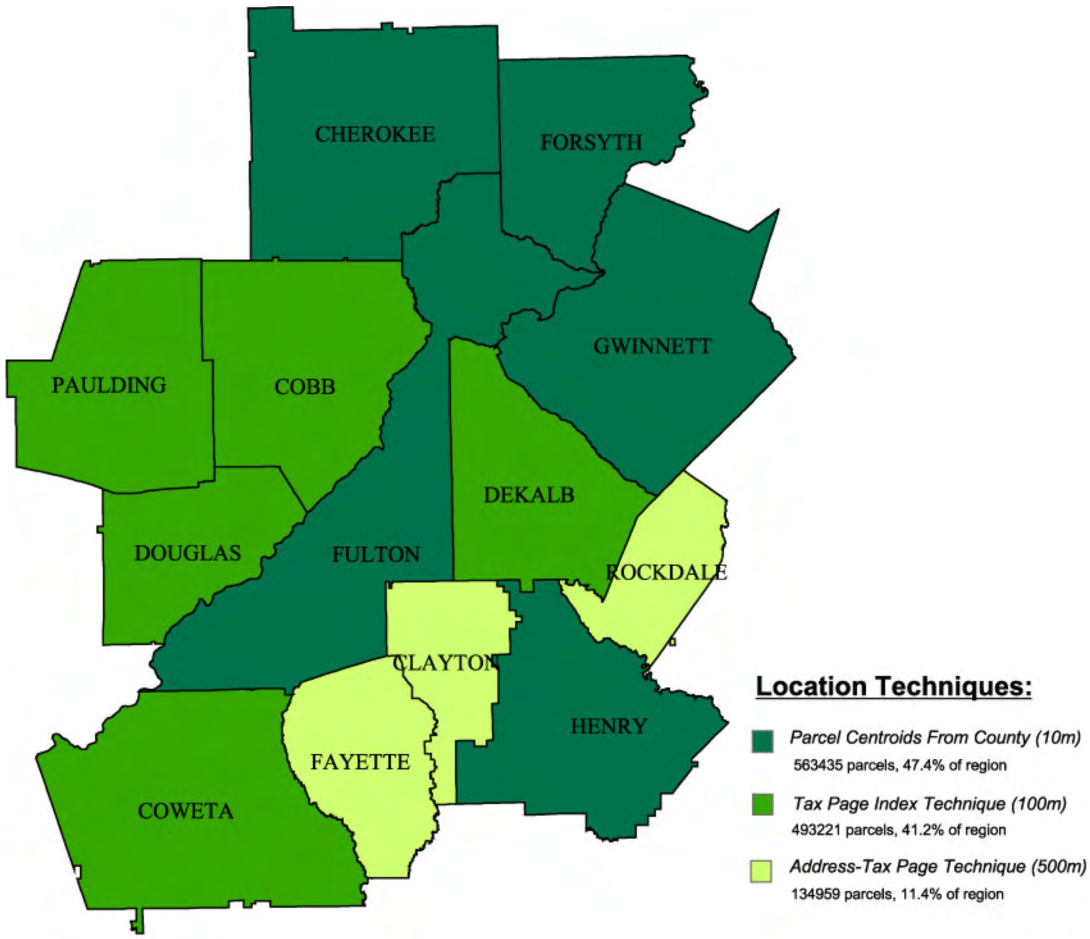
A combination of methods was used to solve this problem. For those counties where a parcel map was available, attribute records were simply linked to the parcels. It was then a simple matter to generate the centroids from the parcels. Our analysis suggests that these parcel locations are accurate within 10 meters. For those counties that had digital index maps of their map pages, we used the indices to locate the tax map and used the PDS pixel coordinates to locate the centroids within the page boundary. Our analysis suggests that parcel centroids located in this manner are accurate within 100 meters. For those counties that had neither parcel boundaries nor digital index maps, we resorted to address matching. Table 16 shows the proportion of parcels located by each method.

Table 16: Parcel Location Methods

Location Method	Spatial Accuracy	Percent Matched	Proportion of Database
Parcel Boundaries	+/- 10 meters	99%	42%
Index Map	+/- 100 meters	99%	39%
Address Matching	+/- 500 meters	85%	19%

Figure 16 shows which methods were used for each county. Fortunately, the larger counties tended to have parcel maps, so nearly half of the records in our database could be located using the most accurate method – linking to a parcel map.

Figure 16: Parcel Location Techniques by County



Fulton, Gwinnett, Cherokee and Henry Counties provided parcel boundaries or centroid coordinates to Georgia Tech directly. The data came as either CAD files or ArcView shapefiles. For the CAD files (Cherokee and Henry), parcel identification label points were converted to ESRI shapefile points. For the parcel boundary files, centroid points were generated for the geometric center of each parcel. The parcel location was referenced by a parcel identification that was a combination of tax map district, block, landlot, and parcel numbers. These fields were used to create a unique parcel ID that could link the geo-referenced points with the assessor data. Forsyth County has also promised to provide a copy of its parcel boundaries in the future.

Paulding, Cobb, DeKalb, and Douglas Counties did not have parcel boundary files available. These counties did provide digital or paper maps of the individual tax pages. The PDS assessor data was originally scanned from county tax maps and coded with pixel coordinates identifying parcel locations relative to their page location. By linking the geo-referenced tax map page locations with the individual PDS records, geo-referenced parcel locations could be estimated using these page coordinates. Some errors in position do occur as a result of variable map scales and orientation. Parcels that were located using this technique are generally within 150 meters of their true location.

Coweta County was not included in the PDS database and was combined with the 12 county spatially integrated dataset. Since reliable address matching was not available for most of Coweta County, Georgia Tech GIS Center staff digitized 35,000 parcel centroids using the method above.

Fayette, Clayton, Rockdale and Forsyth Counties did not have geo-referenced location nor tax page index maps. Using an approach similar to the procedure described above, the tax page locations were estimated using address-geocoding.

1) All the parcels in these counties were address-geocoded using the ARC's ARCMAP product resulting in a 50-70% match rate (Forsyth used TIGER98).

2) Parcels were grouped by tax map page (ID provided by PDS). If more than 5 properties were successfully geocoded, their locations were used to estimate the real world locations of the tax map pages. The correctly matched parcel real-world locations were averaged to calculate the center of mass for their real world coordinates and the page coordinates. These properties were also used to define the scale of the map (page to world ratio).

3) With the estimated tax map page real-world location and map scale, the remaining un-geocoded parcels were located using their relative paper positions to the estimated center of mass.

Figure 17 shows the steps in this process. We were able to locate 95% of parcels in these counties using this technique. The remaining 5% fell beneath the accuracy thresholds for identifying a tax map page. Of the 95%, all are within one kilometer of their true locations, and most are within 400 meters.

Figure 17: Index Page Geocoding Steps

Tax Map Page

Address-Geocoded (60%)

Relative-to-Page (100%)

This effort produced the first parcel level land use database for the 13-county Atlanta region. While it is less than perfect in several respects, it provides a solid foundation to begin to analyze the land use patterns in one of the fastest growing metropolitan regions in the country.

3. Cleaning the Database

After conducting several preliminary analyses on the SMARTRAQ Land Use Database, we identified some problems that required cleaning before finalization of the data.

The location methods provide reasonable spatial accuracy. Matching data records to existing parcel boundaries is the preferable and most accurate method. Fulton County is the best example of this method. Address matching provides adequate locations where we have both a good site address and a good street network to match against (i.e. the 10 counties covered by ARC Map). The pixel location/ index method developed for Cobb and DeKalb Counties provides better spatial accuracy than simple address matching and was extended to locations and needs to be extended to Douglas County.

The quality and accuracy of the attribute data is more problematic. Assessed value is consistently present, however, different assessing practices and appraisal schedules lead to some differences in relative valuations across counties.

Accurate land use classification and building size are especially critical as we begin to use this dataset in conjunction with the activity survey. Unfortunately, there is little standardization among the way individual county assessors classify land use. The PDS file provided four fields that describe land use in one way or another. We have used a combination of these fields to create our own 12-category land use classification variable To resolve the classification of records that are currently unknown and to improve the overall accuracy of the land use classification, we are performing a parcel-by-parcel review of all non-residential parcels in combination with a visual inspection of the associated 1-meter digital orthophotography. While this is extremely labor intensive, the importance of these types of parcels in trip generation warrants the effort.

The building square footage of office and commercial structures is again quite variable by county (even non-existent in some). We have been using two methods to create square footage where none currently exists. We have been matching our records to the Dorey Publishing real estate guide for office space in the major activity centers. This data is not as useful for the Class B market or the outlying counties. For these areas we have also developed square footage estimates based on a series of county-specific regression models. These models use the assessed value, which is almost always present, to estimate the square footage of improvements. Separate regression models have been estimated for office, commercial and industrial uses by county.

Developing a regional land use information system is a major endeavor. While a good start, this first phase of data development is only the beginning of the establishment of a regional land use information system that will be useful for a wide array of purposes. Land use is a highly dynamic process. Therefore, it will be critical that common data formats for collection and reporting be established across county boundaries and that the database be updated on a regular basis. The Georgia Regional Transportation Authority (GRTA) invested in a second phase of database development as part of SMARTRAQ. The second phase utilized parcel boundary geometries for each parcel in the 13 county region. Polygon shapes, versus point shapes, provide additional benefits for spatial analysis in GIS.

Parcel boundaries are included for those counties that had either GIS or CAD boundaries available. For the five counties (Clayton, Cobb, Douglas, Fayette and Paulding), where parcel boundaries were not available and could not be constructed, each land parcel is represented by its centroid. For consistency, parcel centroids were provided for all 13 counties in the region. Table 17 shows the type of boundary data provided for each county in the land use database.

Table 17: Parcel Boundaries by County

COUNTY	MAPPING SOFTWARE	PARCEL FILES
Cherokee	AutoCAD	Parcel Boundaries
Clayton	None	No Parcel Geometry Exists. Land Use 1.5 is used
Cobb	ESRI	Centroid format with updated attribute database is used
Coweta	None	Parcel Boundaries
DeKalb	Microstation	Parcel Boundaries
Douglas	ESRI	Parcel geometry will be available by the end of July 2003. Meanwhile, Land Use 1.5 will be used.
Fayette	AutoCAD	The county does not plan to share the data. Land Use 1.5 is used
Forsyth	ESRI	Parcel Boundaries
Fulton	ESRI	Parcel Boundaries
Gwinnett	ESRI	Parcel Boundaries
Henry	Microstation	Parcel Boundaries
Paulding	ESRI	Parcel geometry will be available by the end of July 2003. Meanwhile, Land Use 1.5 will be used.
Rockdale	Microstation	Parcel Boundaries

The SMARTRAQ Land Use Database Version 2.0 is published in two formats: Geodatabase for users running ArcGIS 8.1 or higher and as ESRI Shapefiles for users running ArcView 3.2 or compatible software.

The DeKalb County parcel boundaries were constructed by the Center for GIS from 1,000 CAD files (Intergraph DGN format) provided by the county representing individual tax maps. Since these files were originally created as stand alone map pages, they have never been edge matched. As a result, significant gaps and overlaps will be found at the edges of adjacent map sheets. While every effort was made to eliminate the sliver polygons that result, a significant number remain and the user must exercise caution when using this file. These sliver polygons have not been linked to attribute records.

B. Land Use Measures – Basic Approaches

Historically, land use measures have been aggregate measures – consisting of average values measured over a (usually) large geographic area. Perhaps the main reason as to why this is the case has to do with the availability of land use data at such scales. Researchers can access data provided by the Census Bureau or a regional planning body. Census tracts and traffic analysis zones (TAZs) have been used many times to provide, for example, population or employment density figures (Frank, Stone, and Bachman 1999). Such data has the enormous advantages of being readily available, easy to use, and accepted as legitimate within the planning profession.

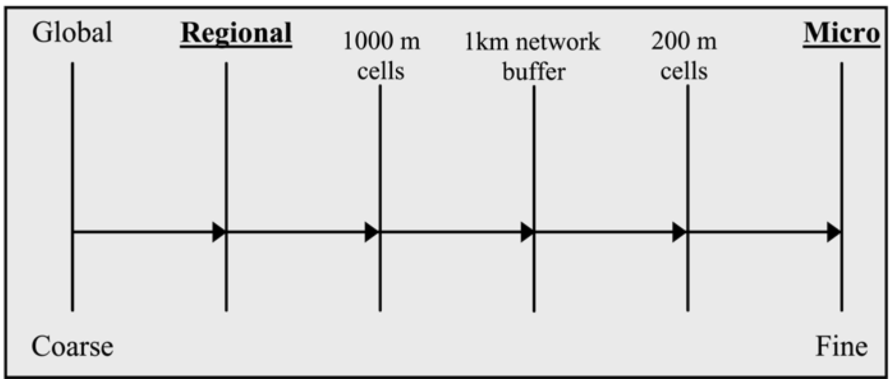
However, land use data at such large spatial scales suffers from some serious drawbacks. First, all measures based on Census tracts or TAZs or, indeed, any geographic polygon are averages. They represent the average level of density, the mixture of uses, or any other land use-related phenomenon within the boundaries of the polygon. As a result, by definition they cannot provide a representation of the variation that might be occurring internally, within different parts of the polygon. Obviously, the larger the polygon the worse this is likely to be. A closely related problem has to do with what occurs at the edges of the polygons. Recall that, theoretically speaking, land use variables such as density and mixture of uses influence how people travel. Therefore, one's surrounding environment is believed to have a strong influence on travel behavior.

When a researcher relies on a Census tract or other large polygon for land use information, there exists the real possibility that people whose households are located at or near the edges of the polygon may be influenced as much by what is happening (speaking in terms of land use patterns) in the adjacent polygon as in their own. For example, if a researcher relies on Census tract data to provide information about density, each tract will provide an average density level for the entire tract. This is problematic for heterogeneous tracts that, for example, include suburban residential communities and an historic town center with a greater mix of uses, more compact development, and a higher population density. If these conditions were true, people living at this edge of the tract would, in all likelihood, be influenced by the conditions in the adjacent town center – shopping, entertainment, services, and perhaps even employment destinations might be located there, for example. Again, the larger the polygon that is used, the worse this problem is likely to be.

A final problem has to do with the nature of aggregated measures. The boundaries of the polygons that are used by government agencies are rarely, if ever, drawn with any sense of pre-existing land use patterns in mind. This is hardly surprising, as the data is usually collected for some other analytic purpose, usually having to do with the need to have reliable data about economic, demographic, or social phenomena. (Many of these polygons tend to overlap roughly with broad settlement patterns, however; Census tracts, for example, are based on population, meaning that the density of population in an area determines their shape and size. Nonetheless, other attributes of the real, on-the-ground environment tend not to be factored into the drawing of these boundaries.)

One of the ways to solve these myriad problems is to decrease the size of the polygons that are the basis of the aggregate measures. Essentially, by decreasing the polygon, the researcher is attempting to allow the natural variation that exists in the real world, on the ground within cities and suburbs, to be reflected in the measure. As shown in Figure 18, aggregate data can be arrayed across a continuum, from the global level down to very small, micro levels.

Figure 18: Aggregate data – Largest to smallest resolution



In Figure 18, this is represented as a continuum with the coarsest data (a planetary or global level of aggregation) on the left and extending to ever-finer levels, eventually reaching the micro level. Of course, land use data can be, and is, collected at national and global levels, but for purposes of understanding travel patterns in the Atlanta region, it is necessary to confine the discussion of aggregate data to regional and sub-regional levels. The sub-regional level includes Census tracts, TAZs, and other ways of dividing the region. At the regional level, aggregate data does have some utility. Cross-regional comparisons utilize data at this scale. For example, over a decade ago two transportation planners conducted a seminal study that compared the gasoline consumption patterns across North American, Asian, and European cities (Newman and Kenworthy 1989). Their study, which concluded that lower density levels were correlated with higher gasoline consumption, was based on an assessment of data at the regional level.

However, as has been made clear above, to assess the influence of land use patterns within a region, data at this level of aggregation has limited utility. Even data at smaller scales than the region suffers from the problems outlined in the above paragraphs – Census tract and TAZ data fall into this category.

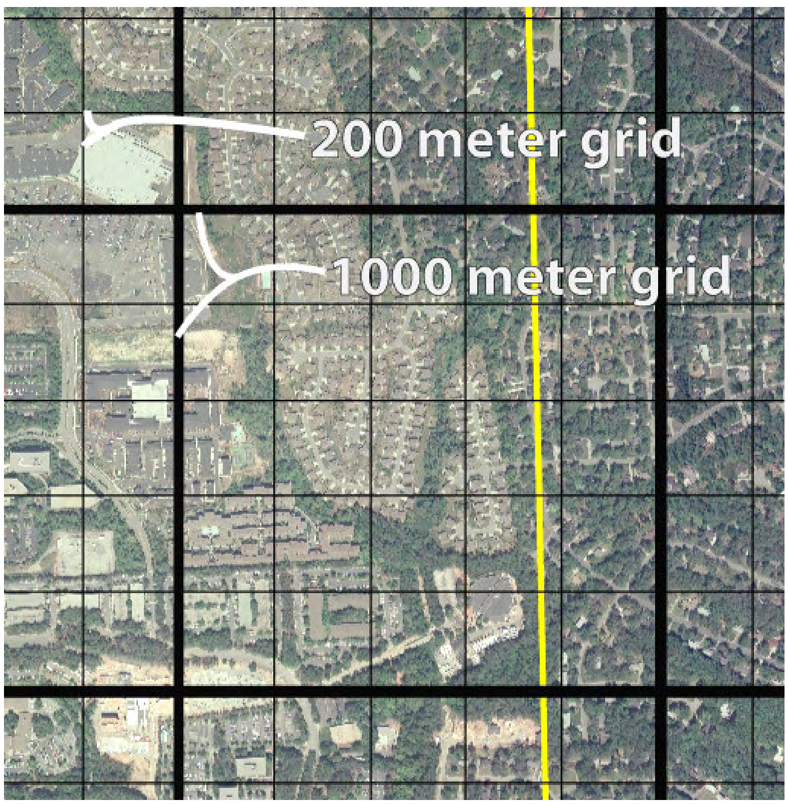
Only at finer scales can these problems be resolved. The data shown previously in Figure 15 (showing net residential density levels within the region) is at a one square kilometer grid level is, the region's area was divided into some 10,000 squares that are one kilometer on a side. Data from an initial version of the SMARTRAQ land use database was then used to calculate the average net residential density for each square, and was used to stratify the survey sample. This type of data is known as raster data. Raster data "quantizes space into a series of uniformly shaped cells" (DeMers 2000) such as a square or other uniform geometric space. These cells are then "filled" with data, so that each cell is associated with a data point for each variable that is measured – density, mixture of uses, and so forth. Raster data can be contrasted with vector data.

Vectors are also polygons but are based on a concept of space being continuous instead of being discrete, as is the case with raster cells. A vector is a polygon consisting of lines in space that connect to form a polygon. These polygons can be any shape and a collection of vector polygons are usually of multiple shapes and sizes. Census tracts and TAZs can be thought of as vector polygons.

For the purposes of stratifying the survey, the one-kilometer grid cell data was sufficient. However, like Census tracts and TAZs, this level of resolution cannot be relied upon to provide accurate data about the variation that exists in the built environment. To employ a finer and more accurate level of analysis, the SMARTRAQ research program is employing raster measures at an even finer level of resolution, a grid system created and supplied by ARC. The cells in this system are 200meters / 4953 feet long north to south, and approximately 166m / 3807' wide east to west, and cover the 13 county region

The expectation is that such a grid will allow the real, on-the-ground variability that exists in the built environment to be more accurately reflected in the measure. As the size of each raster cell is reduced, less urban space needs to be reflected in the measures contained in the cell. Figure 19 shows the scale contrast between the one-kilometer cell and the 200-meter cell.

Figure 19: Example of 200 meter grid cell (light line) versus one-kilometer grid cell (heavy line) level of resolution

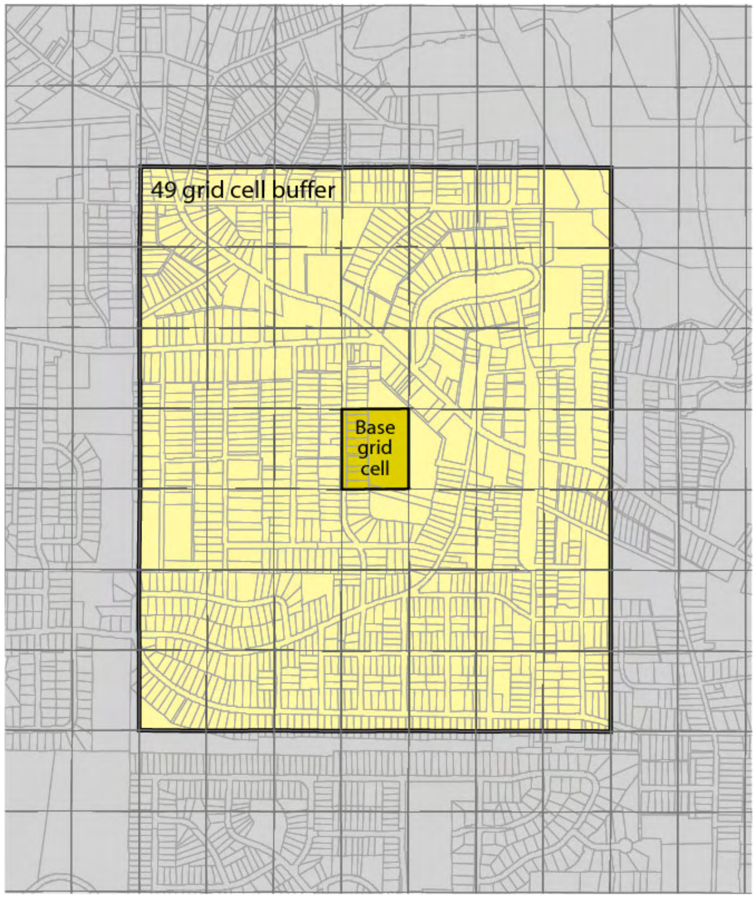


One might note that even the 200-meter resolution level will not completely solve the problems associated with aggregate measures of land use patterns. This is partially true. The 200-meter cell is not, of course, the smallest that could be used. A 100-meter or even 50-meter cell is smaller still. Even though they are smaller, hence can portray the built environment at an even finer level, at these levels the computing power required would be enormous; as it stands the power needed to handle the 200-meter grid is very large. Also, at some point a very small raster cell would add little value to the exercise at hand, at least with respect to the extra work that would be required to collect and analyze the enormous amount of additional data, in particular if data were needed at a sub-parcel level.

Finally, the edge problems that are associated with using aggregated data are addressed by using more than a single 200-meter grid cell as the unit of analysis for measurement. Since, as discussed above, people who are located at the edges of the cell may be influenced by the land use patterns of adjacent cells, SMARTRAQ will utilize a technique wherein the cells that surround, for example, one's place of residence or employment are included in the calculation of the value to be assigned to the central cell. Figure 20 shows a buffered area around each 200m grid cell. .

Values of mixed use, residential and employment density, intersection density, transit level of service, and regional accessibility were measured for each grid cell in the region based on the 401.41 acre / 49 cell area shown in the image below. Therefore, measures were developed based on each grid cell's unique context created by including three cells in each direction. The radial distance from the grid cell to the edge of the area of measurement is about 1/3 of a mile north to south and just slightly less east to west.

Figure 20: Buffered 200m grid cell



C. Levels of Spatial Aggregation

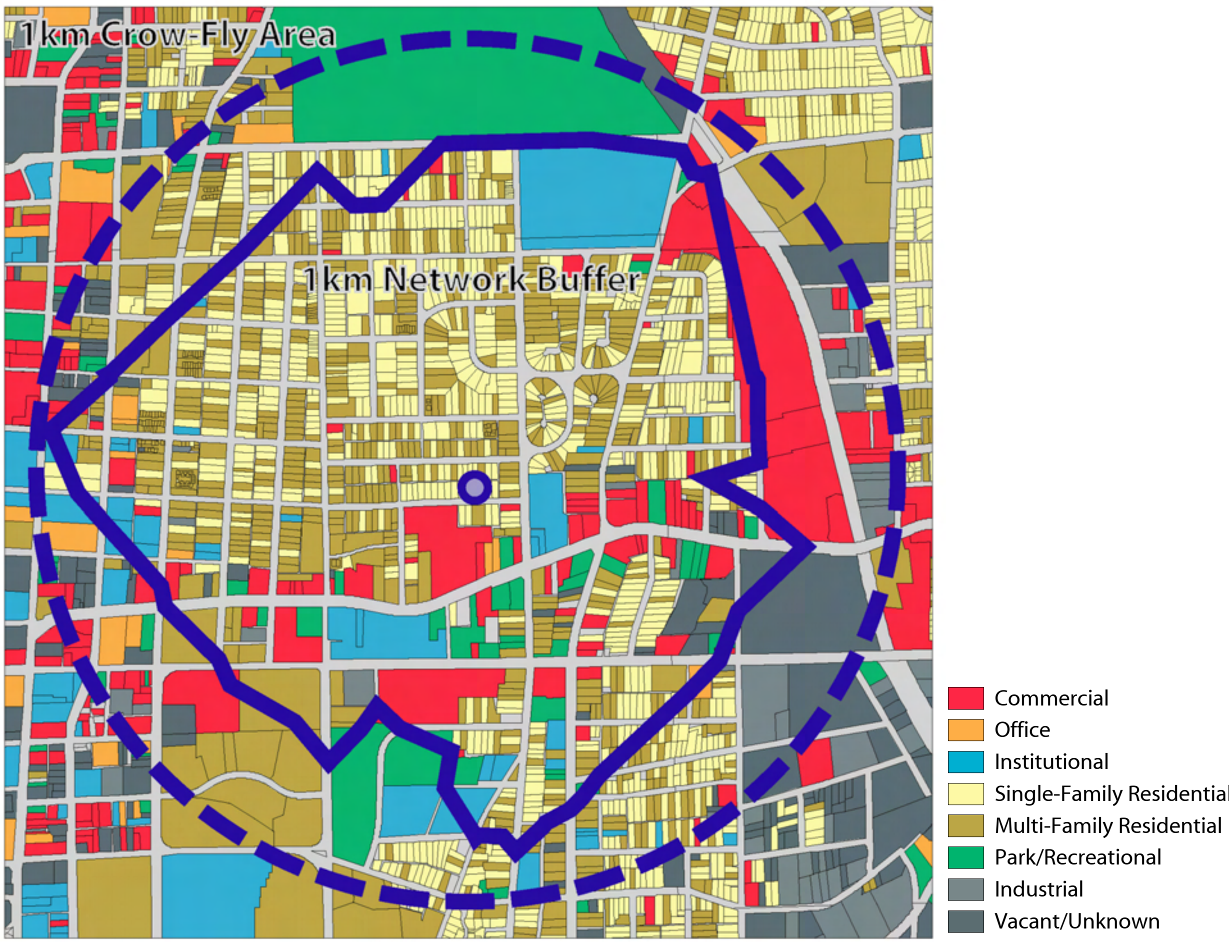
An additional level used by SMARTRAQ for calculating urban form data was the one-kilometer road-network-based buffer level around each participant's house and the locations they traveled to, as shown in Figure 21. While this is not a regional surface, like those described above, buffer size and shape was determined by the road network immediately around each location

Using geographic information system (GIS) software,[14] buffers were drawn around these locations along the street network. A service network consisting of roads within one kilometer of the household was used to define a compact service area accessible to the

[14] Network Analyst extension tool for ESRI's ArcView 3.2.

household. This area is, in most cases, substantially smaller than a crow-fly buffer, which consists of the area surrounding the household in a one-kilometer radius. The mean buffer size of those households completing the GPS survey was 241 acres, as compared to about 775 acres for a circle with a one kilometer radius. The minimum size was 17 acres and the maximum 518 acres.

Figure 21: One-kilometer network buffer



Below the processes to create three specific land use variables used in subsequent analyses are explained. Depending on the analysis values for these variables they are measured either at the 200m grid or the one kilometer buffer level.

1. Net Residential Density

Net residential density is the total number of housing units divided by residential land area. The number of housing units comes from Census block data and was aggregated or disaggregated (as needed) to the one kilometer location buffers and the 200 meter grid polygons. Residential acreage was derived from the ARC 2000 LandPro land cover data (from aerial photography). NRD is highest in traditional neighborhoods with small residential lot sizes and lower in neighborhoods with sprawling development and larger lot sizes.

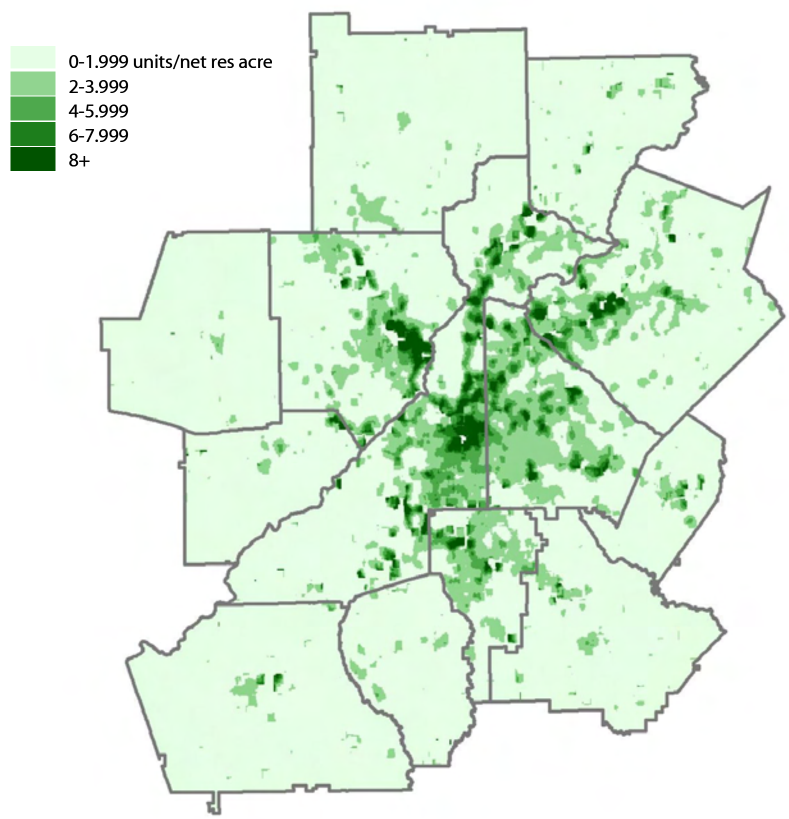
For the 200m grid geometry the process involved initially merging Census block (housing unit data) and the grid polygon using the X-tools (GIS extension) identity function. Next, using X-tools intersect function, the block and polygon data were merged to the ARC residential land cover polygons. A different process was needed for the 1km buffer geometry because of the possibility of the buffers of nearby location overlapping. In order to aggregate Census and land cover data to multiple buffers a point-polygon huber was developed[15]. The resulting database file, consisting of small sub-geometries of the grid hereafter called cells, was analyzed in the statistical software SPSS.

The total residential area acreage by block was aggregated and merged into a new variable field. This gave the acreage of only the residential area of the block. In SPSS, fields were created to find each cell's percent of total residential acres for blocks and residential polygons (acreage of cell/total residential acres of block; cell/total acreage of residential polygon). In a new field, the total housing units in each cell were found by multiplying the percent of total residential acres in the block for the cell by the number of housing units in the block. The housing unit and residential acreage data were aggregated to each polygon. Net residential density was calculated in a new field by dividing residential acreage by number of housing units per each grid unit.

[15] The huber script is compatible with ArcView and was used to spatially join data when many overlapping polygons existed. The one-kilometer buffers overlapped due to the close proximity of some households and therefore this script was necessary in order to assign parcel centroids (land use data) to each buffer. Please see the document "READ ME Many Point to Many Polygon Huber" for the script text.

The variation of NRD across the region is shown below in Figure 22. In order to show this regional surface of NRD, 200m grid values are used. Each grid cell has an NRD value that is the mean of it and 48 cells surrounding it. This 300,000+ cell surface allows a limitation of the one kilometer household based buffers to be overcome. The buffers were only drawn for the surveyed households, and therefore are not able to represent the entire region.

Figure 22: Net residential density by 49 grid cell buffer[16]



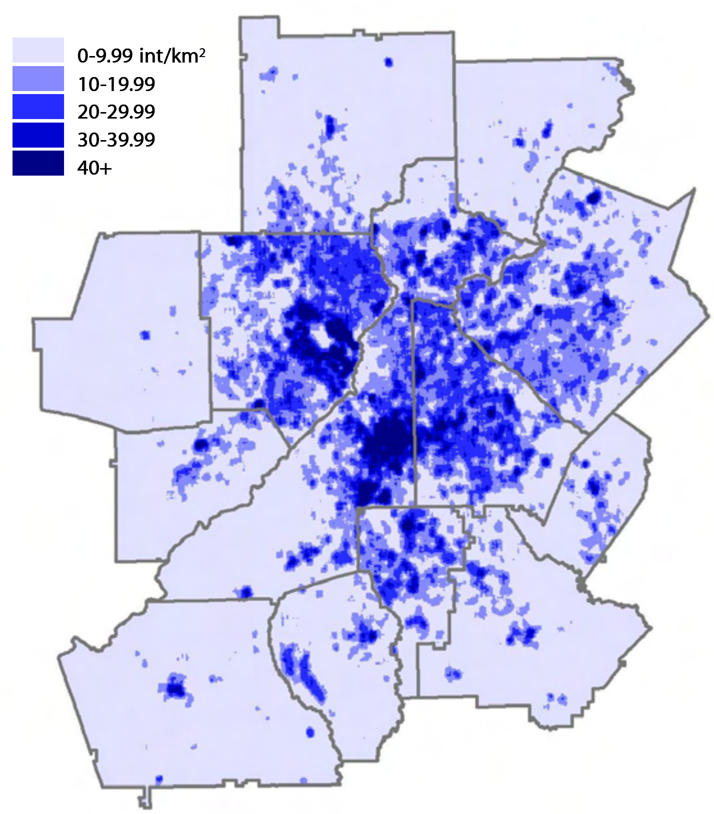
[16] Each 200m grid cell was buffered with its 48 adjacent cells. The mean value of NRD and other attributes for this block of 49 cells was averaged and assigned to the center cell.

2. Intersection Density

Intersection density, another indicator of urban form, impacts the walkability of a neighborhood. The number of intersections per area was determined using GIS and a valence count of three or more, meaning an intersection is where three or more roads meet (excluding controlled access interchanges and ramps intersection with surface streets).

This measure is highest in dense urban areas as shown in Figure 23, below. Increased intersection density allows more direct route choices, slows traffic, increases crosswalk options and creates, what is generally considered, a safer and inviting pedestrian environment.

Figure 23: Intersection density by 49 grid cell buffer



3. Mixed Use

The mixed-use factor takes into account the number of different land uses among three categories (residential[17], commercial, and office) as well as their relative amounts in terms of building floor areas. Building floor area data, by use type, from the parcel level land use database, version 1.5 were aggregated to the desired level. For the grid, it was a simple spatial join for the grid level, and, for the network buffers, a point-polygon operation was used to join the land use data. The mixed value is between zero and one. A greater mixed use value means more even distribution of the relative amount of floor area for the land uses present. A value of one means that the land uses present have equal amounts of total floor area. The formula that used is:

$$\text{Mixed Use} = \frac{-\text{sum}\left[Pn * \ln(Pn)\right]}{\ln(N)}$$

where N= the number of different land uses, value ranges from 0 to 3 (depending on how many land uses are present in at least one parcel)

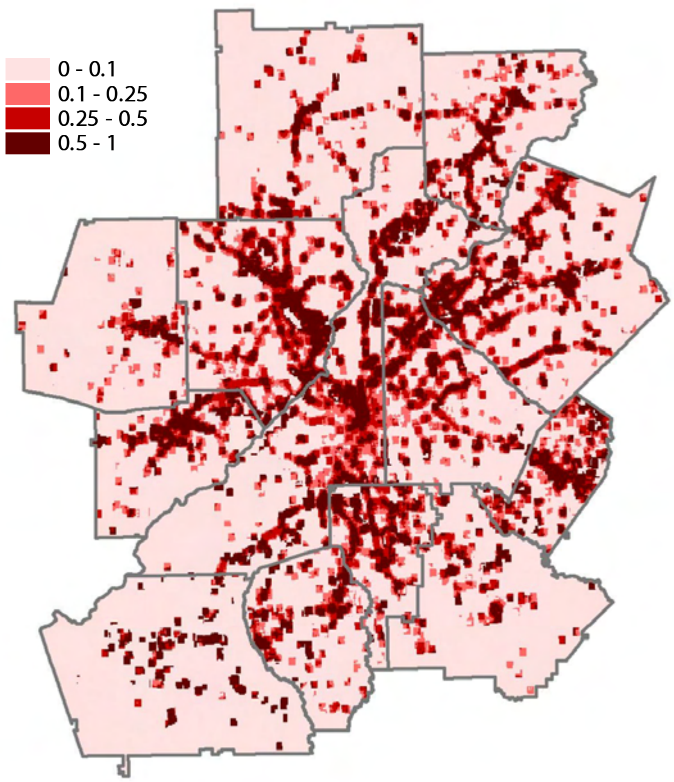
and (Pn) = the proportion of inhabited space in the nth land use, which is the following ratio:

$$\frac{\text{total estimated square footage of building floor area of } \textbf{A CERTAIN} \text{ land use type}}{\textit{total} \text{ estimated square footage of building floor area of for } \textbf{ALL} \text{ three uses}}$$

The regional distribution of mixed use is shown in Figure 24.

[17] The residential estimated square footage is the sum of multi-family, and single-family residential parcel square footages.

Figure 24: Use mix by 49 grid cell buffer



VIII. EMPLOYMENT ACCESSIBILITY

The accessibility analysis was designed to provide 200m grid level estimates of regional access to employment using various maximum threshold of travel distance or time. Network distance thresholds of 1 mile and 3 miles were used, and travel time thresholds of 5 minutes, 10 minutes, 15 minutes, and 30 minutes were used. The analysis used the TAZ-level employment data, the Atlanta Regional Commission's LANDPRO land cover database, the SMARTRAQ parcel level land use database, and the DLGF-TP+ road network. The analysis was conducted primarily using ESRI GIS software.

A. Disaggregated Employment Data

The employment data stored in the ARC's TAZ database was disaggregated to the 200m grid cells using two methods.

- Disaggregate 50% of the TAZ employment to the employable grid cells using an area weighting.
- Disaggregate the remaining 50% of the TAZ employment to the grid cells using a density surface generated from the parcel data (square footage * employment factor by use).

The employable land uses were determined from the ARC's LANDPRO database. Table 18 shows in bolded letters those LANDPRO land use categories assumed to contain employment sites.

Table 18: Employable categories, ARC LANDPRO data

Land Pro Data
AG_CONFINED
AG_CROPS
AG_ORCHARD
AG_OTHER
CEMETERIES
COMMERCIAL
EXPOSED_ROCK
FOREST
GOLF_COURSES
IND/COM
INDUSTRIAL
INST_INTENSIVE
LTD_ACCESS
PARKS
PARK_LANDS
QUARRIES
RESERVOIRS
RES_HIGH
RES_LOW
RES_MED
RES_MOBILE
RES_MULTI
RIVERS
TCU
TRANSITIONAL
URBAN_OTHER
WETLANDS

If a grid cell did not overlap one of the employable LANDPRO polygons, no employment was disaggregated to it. Since the LANDPRO database does not give any estimates of the intensity of the use, half of the employment was disaggregated using the employable area within the TAZ. Since the parcel database does contain estimates of use intensity (although not as comprehensively accurate as the LANDPRO), half of the employment was allocated based on an intensity of use density using an AML script.

B. Accessibility Measures

Employment accessibility values were generated for various network travel times and distances. Each grid cell was assigned an access point to the network using a 'densified' network. The 'densified' network consisted of public roads in the region with nodes at intersections, cul-de-sacs, region departure points, and along links that are longer than 500 meters. 'Thiessen' polygons were generated at each non-interstate and non-ramp network node (approximately 200,000 polygons). Any 200m grid centroid that fell within the boundaries of a Thiessen polygon was assigned an access point at that node. Therefore the nodes of the network now contained the number of employees accessible at their location.

From this point, the database was prepared to run an 'accessibility' function available in ARCINFO. AML code was written to run through each of the six accessibility measures (1 mile, 3 mile, 5 minutes, 10 minutes, 15 minutes, and 30 minutes).

After the accessibility measures were generated, a regional surface of accessibility values was generated using ARCGIS Spatial Analyst features. The surface values were then translated back to the grid cells to identify their values.

IX. SUMMARY

As a result of study components outlined above, the project's databases represent the first regional databases in the nation to incorporate detailed information on land use, travel choice, vehicle emissions, and predictors of human health. The next two chapters are based on analyses conducted at the trip and household level to identify specific characteristics of household travel, land use patterns, and vehicle emissions in the region. Chapter III provides detailed descriptions of each of the key land use, travel, vehicle emissions, and demographic factors that, as a system, interact creating the set of issues that the Atlanta region currently confronts. Chapter IV focuses on these interactions between demographics, land use, travel, and emissions.

CHAPTER III – DESCRIPTIVE ANALYSIS OF URBAN FORM, TRAVEL BEHAVIOR, & DEMOGRAPHIC VARIABLES

I. INTRODUCTION

This chapter provides descriptive results of the survey population demographics, travel behavior, vehicle emissions, various attitudinal data, and land use in the Atlanta region. Where possible, household-level results from the 10 county 1991 survey are contrasted with the 13 county 2001/2002 AHTS data. The 1991 household travel survey conducted by the Atlanta Regional Commission provided a foundation for development of the 2001/2002 SMARTRAQ project's design and methodology to study relationships between urban form, vehicle travel, and resulting emissions.

II. COMPARISON OF 1991 AND 2001/2002 TRAVEL SURVEY RESULTS

A. Sample Population Descriptive Results (unweighted)

As shown in Table 19, the 2001/2002 AHTS included many more households, therefore resulting in more people and trips being included in the final dataset than was the case for the 1991 survey. In 2001/2002, a larger dataset was needed to provide sufficient data across a wide range of urban form patterns in order to allow the analysis of the effect of urban form on travel behavior.

Table 19: Sample Population (unweighted)

	1991 survey (unweighted)	2001/2002 survey (unweighted)
Number of Households	2,433	8,069
Number of People	6,759	18,326
Number of People aged 5 or older	6,269	17,181
Total trips	23,308	116,750

Women make up a slight majority in both datasets, with the split between genders being basically identical across the surveys (Table 20).

Table 20: Gender Distribution (unweighted)

By Person	1990 survey		2001/2002 survey	
Gender	N (unweighted)	%	N (unweighted)	%
Female	3,262	51.36%	9,407	51.45%
Male	3,088	48.62%	8,877	48.55%
Total	6,351	261%	18,284	100%

The unweighted age distributions of both surveys are shown below in Table 21. The 1990 survey did not include children less than five years in age while the 2000/2001 survey included a small proportion (six percent) in this age group. In both surveys, the 35 to 59 age bracket was the most common, about 41 percent in each case.

Table 21: Age Distribution (weighted)

By Person	1990 survey		2001/2002 survey	
Age	N (unweighted)	%	N (unweighted)	%
Under 5			1,145	6.25%
5 to 19	1,477	23.26%	3,034	16.56%
20 to 34	1,440	22.67%	3,394	18.52%
35 to 59	2,623	41.30%	7,594	41.44%
60 and over	787	12.39%	2,851	15.56%
Missing	24	0.38%	308	1.68%
Total	6,351	100%	18,326	100%

Although special efforts were undertaken to increase low-income household participation for the 2001/2002 survey, the percentage of households in the five lowest income categories actually dropped from 1991 to 2001/2002, with the lowest income bracket (less than $10,000) decreasing by about 45% (Table 22). Despite this percentage drop, due to the much larger sample size of the 2001/2002 survey, the absolute numbers in the lower income categories are larger than in 1991. In both surveys, the largest percentage of respondents fell into the $60,000 or more category.

Table 22: Annual Household Income Distribution (unweighted)

By Household	1991 survey		2001/2002 survey	
Self-reported income category	N (unweighted)	%	N (unweighted)	%
Less than $10,000	171	7.03%	317	3.90%
$10,000 to $19,999	235	9.66%	624	7.70%
$20,000 to $29,999	338	13.89%	703	8.70%
$30,000 to $39,999	308	12.66%	702	8.70%
$40,000 to $49,999	301	12.37%	788	9.80%
$50,000 to $ 59,999	171	7.03%	1,043	12.90%
$60,000 or more	829	34.07%	3270	40.53%
Don't know	0	0.00%	214	2.70%
Refused	80	3.29%	408	5.10%
Total	2,433	100%	8,069	100%

The 2001/2002 survey contains twice as many (unweighted, percentage wise) single person households compared to the number of four or more person households (Table 23). However, when the data is weighted, the percentage distribution by household size is much more similar to Table 24. This is an indication of the effect of the over sampling of higher density areas in 2001/2002—smaller households are in higher density areas.

Table 23: Household Size Distribution (unweighted)

By Household	1991 survey		2001/2002 survey	
Household size	N (unweighted)	%	N (unweighted)	%
1 person HH	378	15.54%	2,416	29.90%
2 person HH	852	35.02%	3,365	41.70%
3 person HH	496	20.39%	1,175	14.60%
4+ person HH	707	29.06%	1,113	13.80%
Total	2,433	100%	8,069	100%

Table 24: Household Size Distribution (weighted)

By Household	1991 survey	2000/2001 survey
Household size	% (weighted)	% (weighted)
1 person HH	22.80%	23.79%
2 person HH	31.70%	31.01%
3 person HH	19.60%	17.90%
4 person HH	25.86%	27.30%
Total	100%	100%

Two car households represent similar percentages in the 1991 and 2001/2002 surveys, at 48.1 and 43.4 percent respectively. However, the more recent survey has a higher percentage of zero and one car households and fewer households with three or more, as compared to the 1991 survey population (Table 25). This distribution is of course influenced by the distribution of household size already shown in Table 23.

Table 25: Vehicle Ownership Distribution (unweighted)

By Household	1991 survey		2001/2002 survey	
Number of Vehicles	N (unweighted)	%	N (unweighted)	%
Zero	64	2.63%	428	5.30%
One	474	19.48%	2,505	31.00%
Two	1,170	48.09%	3,501	43.40%
Three	503	20.67%	1,204	14.90%
Four	152	6.25%	285	3.50%
Five+	70	2.88%	146	1.80%
Total	2,433	100%	8,069	100%

The distribution of residence type shown in Table 26 reflects the 2001/2002 survey's over sampling of higher net-residential areas, with it a higher percentage inclusion of apartments and attached single-family housing (town homes, condominiums, etc) as compared to the 1991 distribution.

Table 26: Residence Type Distribution (unweighted)

By Household	1991 survey		2001/2002 survey	
Residence Type	N (unweighted)	%	N (unweighted)	%
Single-Family Detached	2,019	82.98%	5,876	72.82%
Single-Family Attached	116	4.77%	879	10.89%
Apartment	240	9.86%	1,227	15.21%
Mobile Home	56	2.30%	49	0.61%
Other	2	0.08%	38	0.47%
Total	2,433	100%	8,069	100%

B. County Distribution

The 1991 household study area included the nine counties within the ARC jurisdiction at the time of the survey (Clayton, Cobb, DeKalb, Douglas, Fulton, Fayette, Gwinnett, Henry, and Rockdale Counties) and additional households in Cherokee and Bartow Counties. For the 2001/2002 survey, this area included Clayton, Cobb, DeKalb, Douglas, Fulton, Fayette, Gwinnett, Henry, and Rockdale Counties as well as Cherokee, Coweta, Forsyth and Paulding Counties. Bartow County was not surveyed. The 2001/2002 study area was expanded from the ARC regional counties (at present, 10 counties – the original nine plus Cherokee) to the 13 county ozone non-attainment zone designated by the U.S. Environmental Protection Agency (EPA). Table 27 below shows the unweighted distribution of households in both surveys.

Table 27: Distribution of Surveyed Households by County (unweighted)

By Household	1991 survey		2000/2001 survey	
County of Residence	N (unweighted)	%	N (unweighted)	%
2 County Area (Cherokee and Bartow)	199	8.18%	133*	1.60%
Clayton	192	7.89%	286	3.50%
Cobb	274	11.26%	1,536	19.00%
Coweta	0	0.00%	140	1.70%
DeKalb	354	14.55%	2,224	27.60%
Douglas	197	8.10%	60	0.70%
Fayette	209	8.59%	84	1.00%
Forsyth	0	0.00%	86	1.10%
Fulton	416	17.10%	1,975	24.50%
Gwinnett	198	8.14%	1,048	13.00%
Henry	195	8.01%	308	3.80%
Paulding	0	0.00%	55	0.70%
Rockdale	199	8.18%	134	1.70%
Total	2,433	100%	8,069	100%

*includes Cherokee only

Unlike the 1991 regional household travel survey, the 2001/2002 travel survey asked about household ethnicity. One of the questions contained in the recruitment interview concerned the ethnicity of the respondent – the adult who served as the respondent for the household was asked about his/her ethnicity. The answer provided was interpreted as the entire household's ethnicity. Table 28 shows the breakdown of households by ethnicity for the sample. The proportion of Latino/Hispanic households in the sample is higher than the Census indicates for the region (5.3% versus 4.3%), but for African-American and Asian/Pacific Islander households the sample proportions fell short of the Census data (27.4% versus 20.6% for African-American households, 2.7% versus 2.0% for Asian/Pacific Islander households). Nonetheless, the attention paid to the recruitment of low-income and minority households in the travel survey resulted in far more such households in the sample than would have been the case had the "traditionally underserved" component of the SMARTRAQ research program not existed. These claims are analyzed in detail in GRTA deliverable II.6.1: "Analysis of Travel Patterns of Traditionally Underserved Populations".

Table 28: Households by ethnicity

Ethnicity: distribution of HHs in sample	N (unweighted)	%
Black/African American	1,666	20.6%
Latino, Hispanic, Spanish	428	5.3%
Asian/Pacific Islander	160	2.0%
Native American	65	0.8%
White/Caucasian	5,590	69.3%
Other	116	1.4%
Don't know	12	0.1%
Refused	32	0.4%
Total	8,069	100%

C. Sample Population Descriptive Results (weighted)

Weighted descriptive statistics are provided here for several demographic, travel behavior, and land use variables (Table 29). For instance, the data for respondent age are classified by the following descriptors:

- mean / average value (average age of survey household residents);
- standard deviation or degree to which cases are clustered near the mean (percent of participants that are within 12 years of this average age);
- range as defined by the lowest and highest values (youngest to oldest participant); and
- unit in which the variable is measured (age is measured in years).

In 1991, the average participant was 38 years old. The average household had a income between $40,000 and $50,000, owned 2.18 vehicles, and contained 2.77 persons. In 2001, the average participant was: younger (34 years old), while the average household had about the same income, owned slightly fewer vehicles (1.78), and contained slightly fewer people (2.64 persons per household). On an average weekday in 1991, the typical household made 9.26 vehicle trips, traveled 82 miles, and its members combined spent more than three hours behind the wheel. On an average weekday in 2001, the average household made 7.90 trips, traveled 79.2 miles, and its members combined spent about two and a half hours driving.

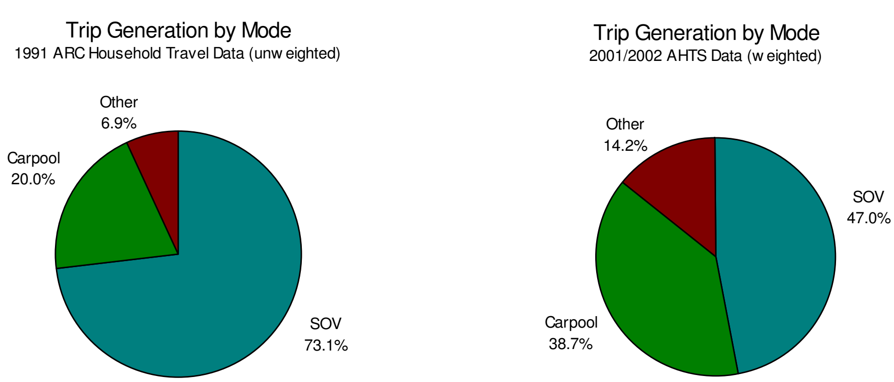
Table 29: 1991 and 2001 household level demographic variables (unweighted)

	1991 (unweighted)			2001/2002 (weighted)			
Variable	**Mean**	**Std. Dev.**	**Range**	**Mean**	**Std. Dev.**	**Range**	**Units**
Age	37.82	16.48	0 - 99	34.02	21.41	0 - 102	Person
Family Size (age 5 and up)	2.77	1.35	1 - 13	2.64	1.41	1 - 8	People per Household
Household Income	40 - 50	27	0 - 80+	40 - 50	26	0 - 100+	Thousands of Dollars
Vehicles per Household	2.18	1.03	0 - 8	1.78	1.00	0 - 8	Vehicles per Household

D. Travel Behavior

The 1991 AHTS does not capture sufficient quantities of non-motorized or transit trips to support valid analysis of these modes of travel. Walking, bicycling, and transit trips constituted less than 7 percent of total trips in the survey, and are designated as “other” in Figure 25. The 2001/2002 AHTS generated more than twice as many non-automobile trips, allowing initial analysis of these modes.

Figure 25: Trips per mode in the 1991 and 2001/2002 surveys



Other consists of school bus trips, transit, and walking
SOV = single occupant vehicle

Single occupant and carpool trips made in private vehicles account for 93 percent of the travel data in the ARC 1991 Household Survey and 86 percent of the travel data in the 2001/2002 AHTS. While the 2001/2002 survey collected travel data from both weekday and weekends, the 1991 survey only covered Monday through Friday. Results taken from weekend days are not included in the above mode split comparison. The comparative analysis of the 1991 and 2001/2002 data below therefore focuses on this commonly shared and large set of weekday vehicle travel data. The 2001/2002 data are weighted, or adjusted to reflect the actual demographic composition of the region, while the 1991 data are unweighted. Although the weighting system was unavailable for the 1991 results, it was used for the 2001/2002 survey in order to reflect the set of data used in complimentary SMARTRAQ reports. Table 30 provides basic descriptive characteristics of the household travel patterns observed in 1991 and in 2001.

Table 30: 1991 and 2001 household weekday travel descriptive results

	1991 (unweighted)			2001/2002 (weighted)			
Variable	**Mean**	**Std. Dev.**	**Range**	**Mean**	**Std. Dev.**	**Range**	**Units**
Number of Trips	9.26	6.08	1 - 41	7.90	5.76	1 - 52	Trips per Household
Trip Distance	8.88	9.16	0.2 - 73.4	10.02	13.21	1 - 245	Miles
Trip Time	20.80	13.82	2.26 - 130.62	19.88	15.15	1 - 85	Minutes
Number of Work Trips	2.04	1.13	1 - 8	1.47	1.45	0 - 16	Trips per Household
Work Trip Distance	12.02	10.46	0.34 - 60.76	14.32	17.44	1 - 340	Miles
Work Trip Time	24.62	15.56	2.26 - 116.34	26.15	18.20	1 - 115	Minutes
Number of Non-Work Trips	7.22	5.37	1 - 43	6.43	5.39	0 - 48	Trips per Household
Non-Work Trip Distance	7.13	7.96	0.2 - 73.4	9.02	12.10	1 - 202	Miles
Non-Work Trip Time	19.81	13.16	3.02 - 130.62	19.08	15.50	1 - 96	Minutes
Vehicle Miles Traveled	82.2	66.36	0 - 602.04	79.2	56.62	0 - 831	Miles per Household
Vehicle Hours Traveled	3.2	2.25	0 - 16.82	2.6	1.58	0 - 16.13	Hours per Household

In the area of work versus non-work travel, more than 75 percent of the trips taken were for non-work purposes in 1991. This rose to 81 percent in 2001/2002. One explanation for the rise is that in 1991 trips from work to home were often coded as “home trips” and not accounted for as work trips, whereas in 2001/2002 all trips to or from the workplace as well as trips designated as work-related in terms of activity were coded as work trips. Work trips in the survey were 68.6% longer in distance than non-work trips in 1991 and 58.8% longer in 2001/2002.

The average travel time to work was 24.62 minutes in 1991 and rose to 26.15 minutes in 2001/2002. The average travel time for non-work trips was 19.81 minutes in 1991 and remained stable at 19.08 minutes in 2001/2002. The average household spent 3.2 hours per day traveling in a private vehicle in 1991 versus only 2.6 hours in 2001/2002. This is due to a reduction in the number of trips per household, as the overall mean trip time has only decreased slightly, from 20.80 minutes in 1991 to 19.88 minutes in 2001/2002.

In 1991, a significant proportion of the trips taken were short in time with nearly 2,800 or 13 percent of the trips less than seven minutes in duration. In 2001, this percentage rose to 18 percent (16,591) of all trips. Further study indicates that a large proportion of these short trips are cold starts. Therefore, these short trips make a large contribution, on a per mile of travel basis, to regional air quality problems. More than a third of the vehicle trips taken in the Atlanta region were less than 15 minutes in duration in 1991 and 40 percent were less than 15 minutes in 2001. In 1991, 84 percent of all trips were less than 30 minutes long and in 2001, 74 percent were less than 30 minutes.

The average travel distance for all trips taken in the survey was nearly nine miles in 1991 and about ten miles in 2001. As previously indicated, work trips were longer than non-work trips in both surveys. In 2001, about 18 percent of trips, as compared to over 25 percent in 1991, were less than three miles in distance. Nearly half of the trips in the survey were less than five miles in distance in 1991 and about 30 percent of trips were less than five miles in 2001. The higher mean distances shown in Table 30 are a function of relatively few extremely long trips. In the 2001 survey, distances greater than three standard deviations above the mean (or 245 miles) were removed in order to decrease the affect of the outliers, one of which was 9,000 miles.

As indicated above, the average income per household in the 1991 survey was between $40,000 and $50,000 and in the 2001 survey the average income remained in the $40,000 to $50,000 category. In both surveys, the trip generation rates per household increase with income. However, the 1991 data shows that households earning more than $80,000 per year generate far fewer trips than lower income ranges.

The trip generation rate per household in both surveys increases as the number of vehicles available to household members increases (Figure 26); however the average number of household vehicle trips is less in 2001/2002 (9.3 in 1991, 7.9 in 2001/2002), in part due to a decrease in household size and number of household vehicles.

Figure 26: 1991 and 2001/2002 vehicle ownership and trip rates

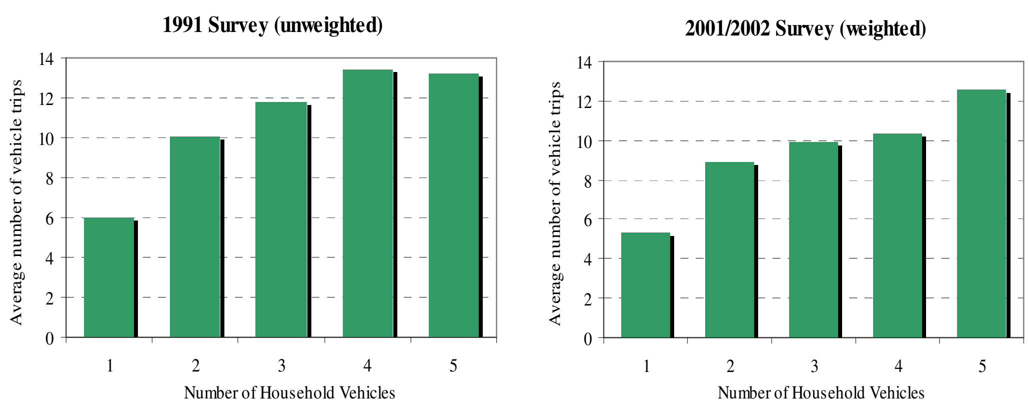


Table 31 and Table 32 provide county level averages for VMT per household and person for 1991 and 2001/2002 respectively. They should not be used to compare one county against another, rather to establish a baseline upon which future comparisons can be made for each county. It is important to note the miles traveled for the 1991 survey are self-reported by the survey participants. The miles in the 2001/2002 survey are estimated using the methodologies described in Chapter II. A consistent methodology is necessary to track changes over time.

Table 31: 1991 county level characteristics (unweighted)

COUNTY	HOUSE-HOLD SIZE	VEHICLES/ HOUSE-HOLD	MILES OF TRAVEL/ HH/ DAY	MILES OF TRAVEL/ PERSON/ DAY
Clayton	2.78	2.19	69.74	25.04
Cobb	2.78	2.17	77.10	27.78
DeKalb	2.64	2.02	61.80	23.44
Douglas	3.19	2.53	113.35	35.58
Fayette	3.12	2.48	104.00	33.35
Fulton	2.56	1.96	66.45	25.93
Gwinnett	2.92	2.29	85.09	29.17
Henry	3.02	2.56	99.42	32.90
Rockdale	3.00	2.47	92.88	30.96

Table 32: 2001 county level characteristics (weighted)

COUNTY	HOUSE-HOLD SIZE	VEHICLES/ HOUSE-HOLD	MILES OF TRAVEL/ HH/ DAY	MILES OF TRAVEL/ PERSON/ DAY
Cherokee*	2.69	2.03	90.35	42.14
Clayton	2.85	1.67	80.99	39.44
Cobb	2.61	1.89	76.64	36.81
Coweta*	2.45	1.85	105.58	47.53
DeKalb	2.65	1.58	71.09	35.44
Douglas	2.81	2.19	95.64	46.13
Fayette	2.85	2.37	99.91	40.75
Forsyth*	2.68	2.11	86.83	44.63
Fulton	2.46	1.43	61.88	32.67
Gwinnett	2.82	2.08	85.19	38.18
Henry	2.64	2.05	99.48	47.12
Paulding*	2.82	2.15	118.30	54.82
Rockdale	2.64	2.07	100.55	46.70
*Counties not included in the 1991 survey				

III. 2001 PERSON-LEVEL DESCRIPTIVES

A. Person-level travel behavior

This section aggregates trips to the person level and reports on average daily trip making. After application of the weights, the 18,326 participants in the survey are increased to 21,339 people. This section reports on only the 2001/2002 AHTS data set.

1. Trips per person

Since the definition of a completed household for survey data collection purposes was one in which travel and activity data were collected from all household members age five and older, the data presented in this section is for that age group. The 2,197 trips made by the 1,797 (weighted) survey participants who were 4 years old or younger are not included in these analyses; incidentally only 444 of the 1,797 children made trips.

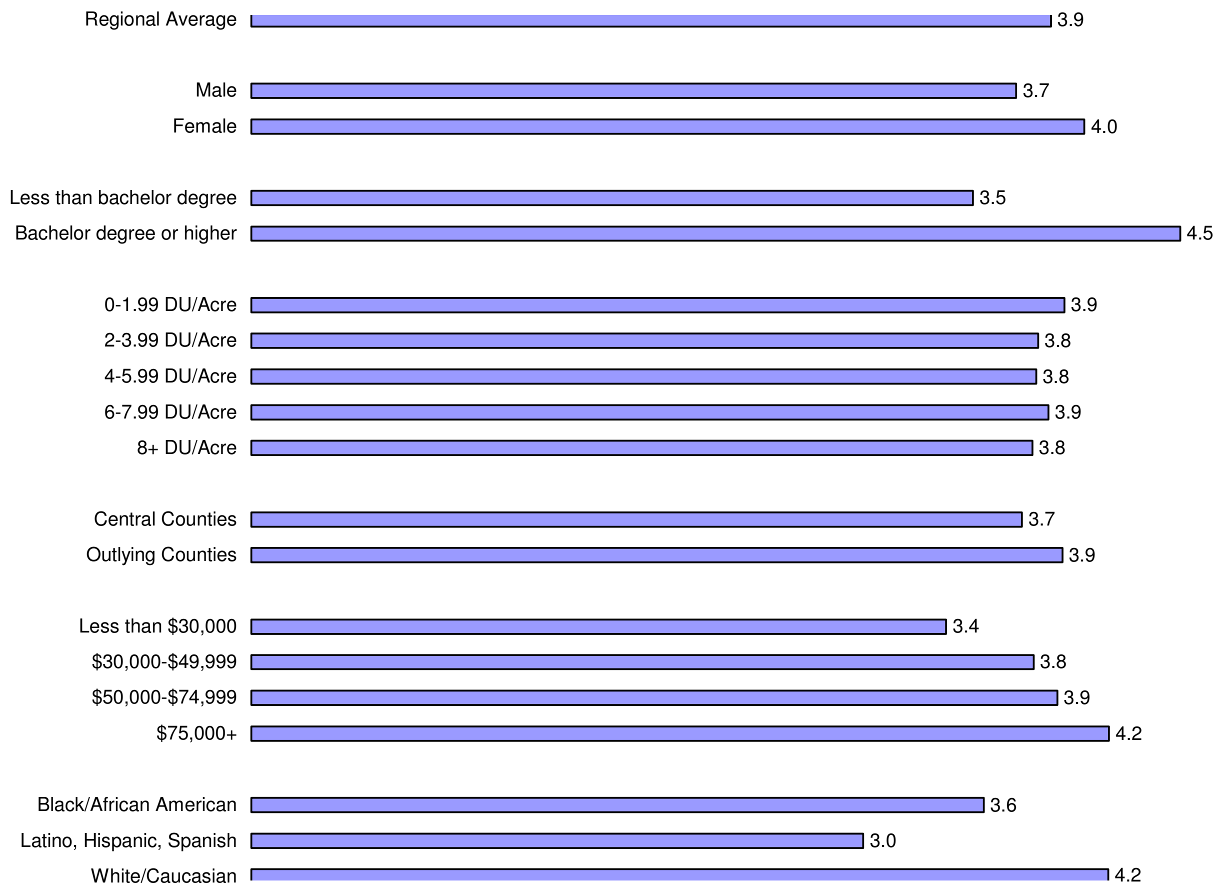
Excluding those individuals that did not report travel at all, the mean number of trips taken per person per day is 3.9.[18] The number of trips taken by survey respondents varies by the demographic characteristics of the respondents' household and personal attributes (Figure 27). NRD shows the least variation in trip making. In contrast, the most variation is generated by education level and ethnicity. Gender and regional location (center versus outlying counties) show similar differences. Males make 3.7 trips per day while females make 4.0 trips per day. Central county residents make 3.7 trips/day versus 3.9 trips/day for residents of outlying counties. More education (here defined as having an undergraduate degree or not) is associated with more trip making, with holders of Bachelor's degrees making 28% more trips per day on average compared to non-degree holders. Whites make 40% more trips than Latino/Hispanics, and 17% more than

[18] This daily average is the average of the day 1 and day 2 averages created based on people over 5 years old who travel more than zero times but less than 20.1 trips (mean plus 3 standard deviations) over the two day period.

African Americans. Finally, the highest income bracket (more than $75,000 annually) makes 24% more trips than the lowest income bracket (less than $30,000 annually).

Figure 27: Average number of trips per person per day

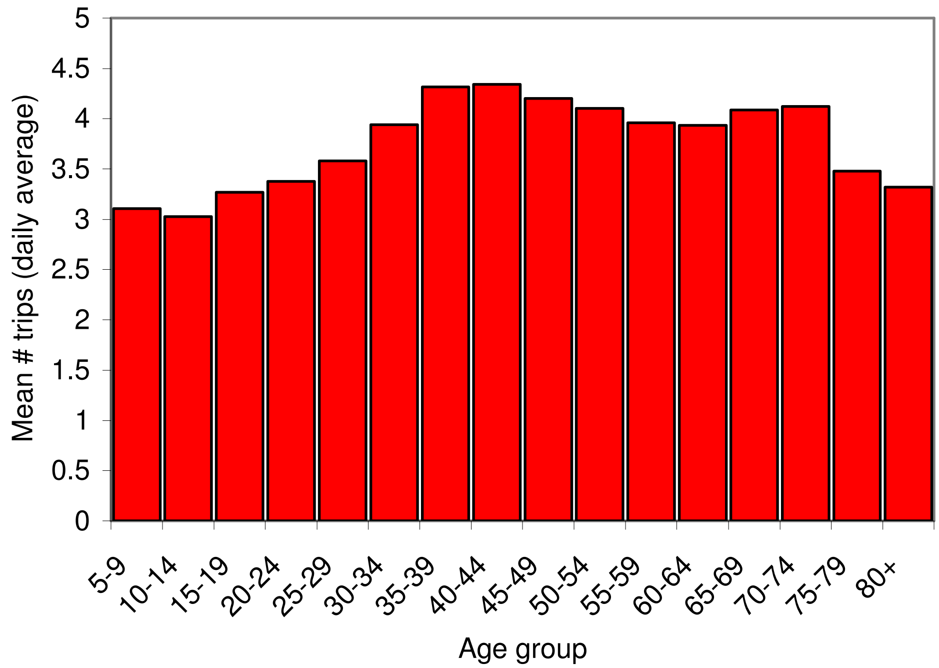
(Note: Observations are for people over 4 years old, who made at least one trip, average of day 1 and day 2 average. All modes. Weighted.)



As shown in Figure 28, people 35 to 44 years old, on average, travel more frequently than younger and older people, especially people over 75 years.

Figure 28: Mean daily number of trips per person by five year age increments

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. All modes. Weighted.)



2. Private Motor Vehicle

The average travel time, distance and emissions per person per day are provided below for people, five years and older, who made at least one trip over the two day reporting period as a driver or passenger of a private vehicle (auto, van or truck).[19] These values are estimated or modeled values, not self-reported or directly measured from the vehicles. Please see Chapter II for a description of the estimation methodologies.

Based on the estimated trip distances, Atlantans 5 years and older who make trips on a weekday travel an average of about 35 miles and slightly over an hour in private vehicles, which includes driving or riding in automobiles, trucks, and vans. These averages vary by regional location, household density level and income, and ethnicity, as shown in Figure

[19] An "average day" as represented here is an average of Day 1 and Day 2 averages.

29 and Figure 30. As would be expected, the distance traveled by people living in central counties with higher residential density is less than the regional average. The same is true for lower income non-white residents. Weekday trip distance and time decrease with increasing density, except for an increase from the 6-7.999 du/net res. acre to 8+ du/net residential acre range.

Figure 29: Average Weekday Daily Vehicle Miles of Travel per Person

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)

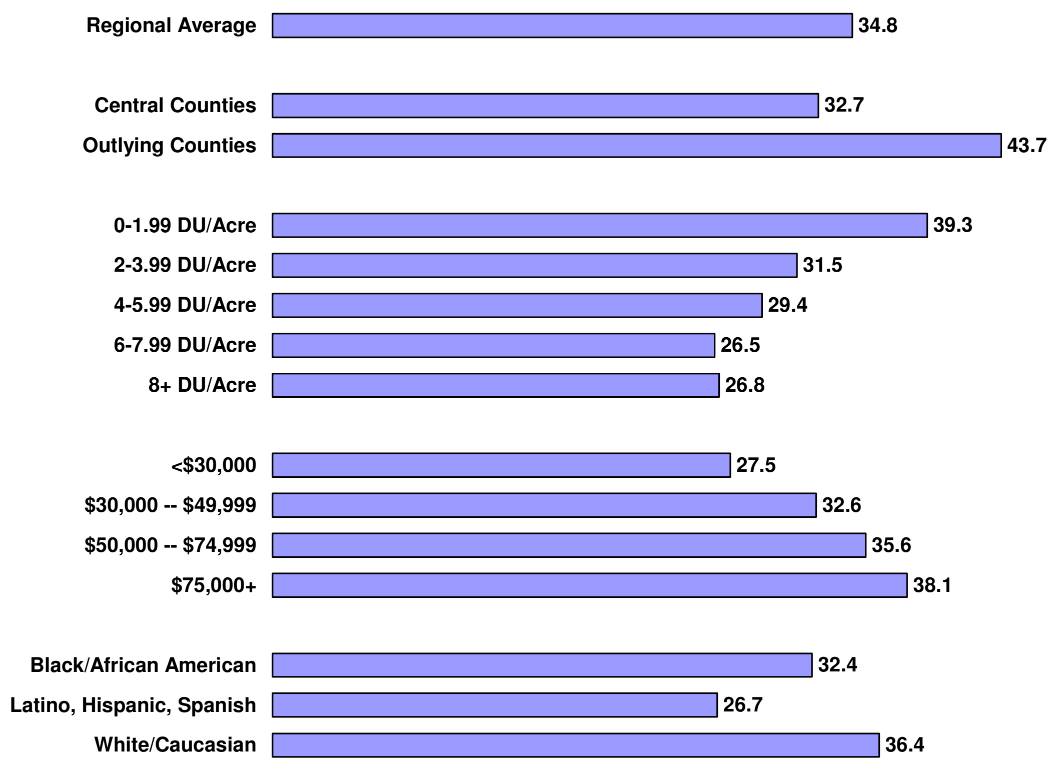
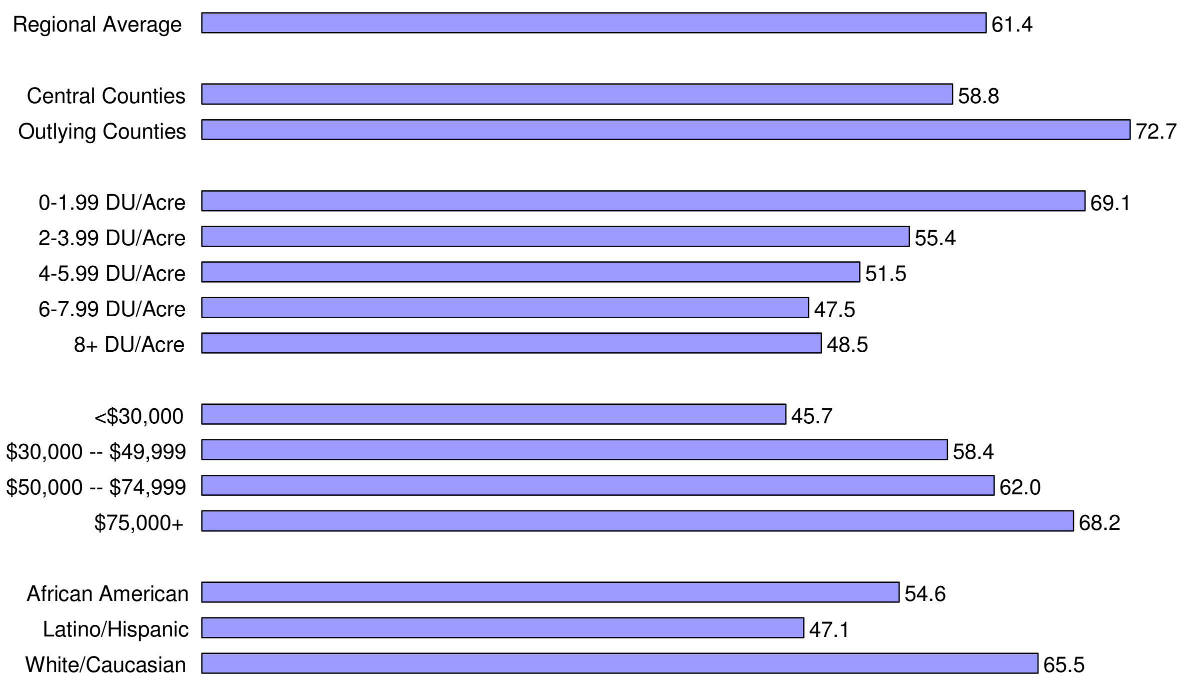


Figure 30: Average Weekday Daily Minutes of Travel per Person

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)[20]



Per person per weekday emissions estimates were calculated for four pollutants—oxides of nitrogen (NO_x), hydro-carbons (HC), carbon monoxide (CO) and carbon dioxide (CO_2) and are shown below in Figure 31 through Figure 34. The estimated emissions vary across the listed variables in a pattern similar to the vehicle miles traveled (VMT) figures above. This is expected since vehicle emission estimates are based largely on distance traveled, with other contributing factors including travel speed and vehicle type.

While people in the highest income range travel 39% more miles than the lowest income range, the emissions generated from these miles shows much less variation across income for NO_x, HC, and CO. Unlike for VMT, the income category with the highest per person

[20] Central Counties: Clayton, Cobb, DeKalb, Fulton and Gwinnett. Outlying Counties: Cherokee, Coweta, Douglas, Fayette, Forsyth, Henry, Paulding and Rockdale.

generation rate is the second to highest ($50,000 - $74,999), rather than the highest ($75,000+). The mean daily emission generation levels for people in this $50,000 - $74,999 income range is over 18% greater for all NO_x, HC, and CO than for people in the lowest income category. This percentage difference is less than is seen between the two groups for miles traveled—24%. A possible explanation for this may include the greater presence of newer vehicles in higher income households; the mean vehicle age is 3 to 4 years older in the lowest income bracket than in the highest income bracket households.

In contrast with the other pollutants, CO_2 does mirror VMT generation rates in two ways. The highest income category has the highest CO_2 emissions rate, and the variation across income categories is similarly large, 33% VMT and 37% CO_2. This is an expected result due to the method used by the emission estimation model (MOBILE 6). Unlike other pollutants, travel distance is the most critical single determinant of CO2 production[21]. CO_2 generation rate differences across ethnicity groups mirror that found in VMT generation.

[21] The MOBILE 6.2 guide says: "These emissions are estimated in a very simple fashion based on their fuel economy performance estimates built into the model or supplied by the user. Unlike most other MOBILE6 emission estimates, these CO2 emission estimates are not adjusted for speed, temperature, fuel content, or the effects of vehicle inspection maintenance programs." The default fuel economy is 22 mpg. With no variation in this rate, all the estimates are directly related to travel distance.

Figure 31: Grams of NO_x per person per weekday

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)

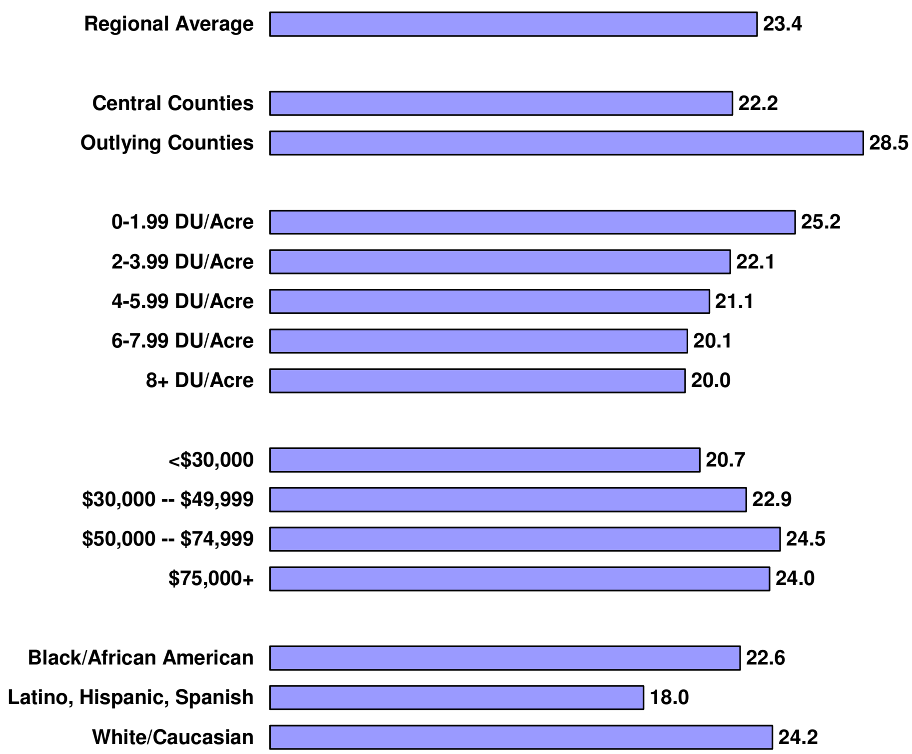


Figure 32: Grams of Hydro-Carbons per person per weekday

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)

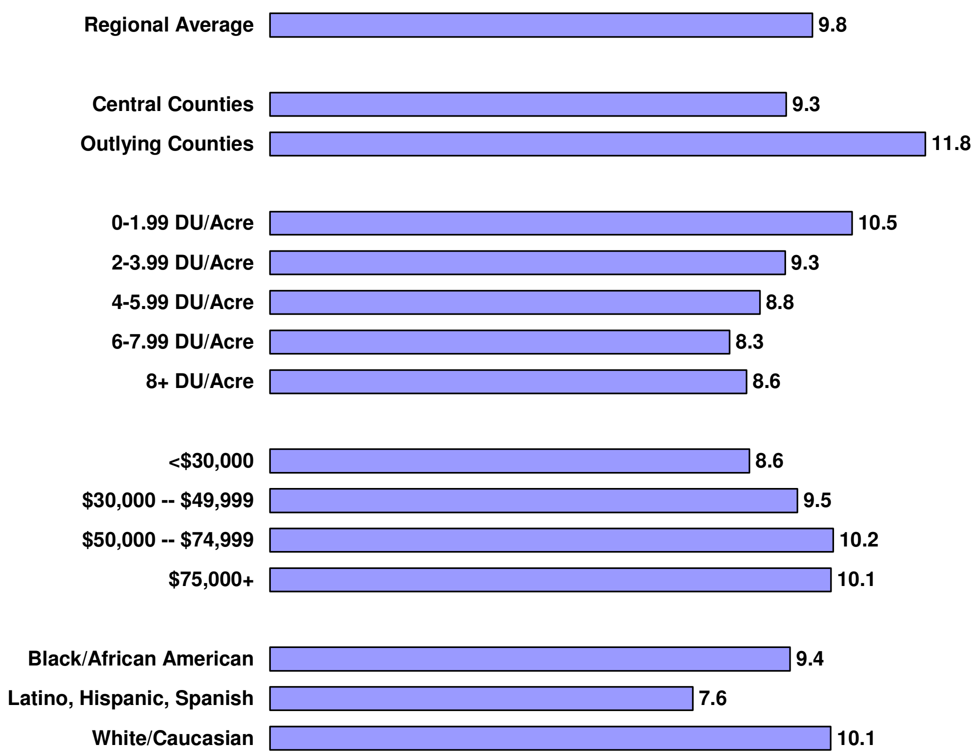


Figure 33: Grams of Carbon Monoxide per person per weekday

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)

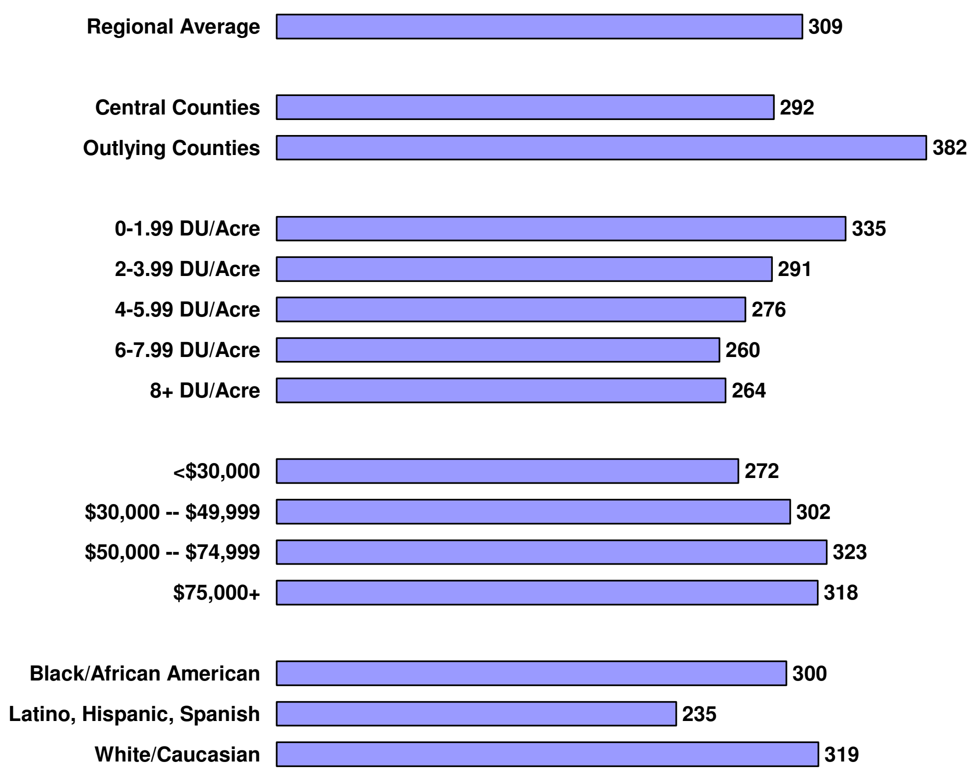
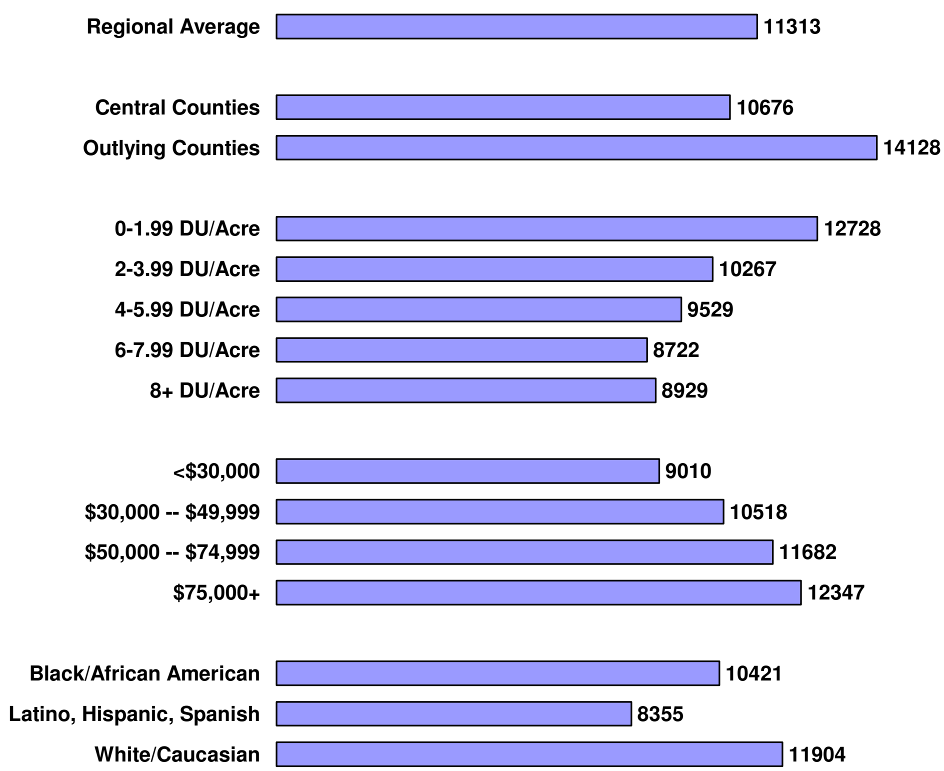


Figure 34: Grams of Carbon Dioxide per person per weekday

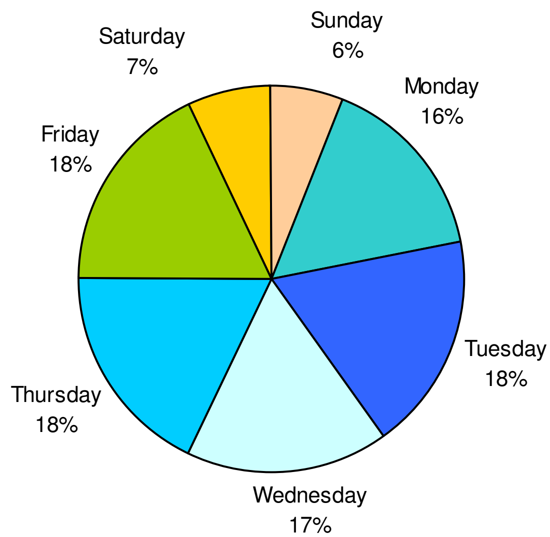
(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)



IV. WEEKEND TRAVEL

While the 1991 Household Travel Survey was restricted to behavior for one weekday, the 2001 AHTS also included weekend travel and took place over a two day period, with at least one day always falling on a weekday. Of the entire set of 126,304 trips (weighted) in the survey, about 13% occurred on a weekend, a relatively low proportion of total trips.

Figure 35: Trip distribution by time of day



Note: weekend travel was under-sampled relative to weekdays

Because weekend travel is reported by households assigned either a Friday/Saturday travel day pair or a Sunday/Monday pair, it is important to note that weekend travel was under-sampled relative to weekdays and the distribution of trips by day of week shown is not representative of reality. While the proportion of weekend travel may be low, having any weekend travel at all within a traditional household travel survey is an advancement over past practices. The SMARTRAQ survey data represents one of the first data collection efforts inclusive of weekend travel.

Table 33 below displays modes used by day of the week at the trip level. There is little variation Monday through Friday in the percentage of people using each mode. However, all modes show a change in percentage on the weekend. Private vehicles are used by more people on Saturdays (88%) than any other day, and Sunday the least (71%). Sunday transit users are a quarter of the weekday level. The percentage of people walking on weekends is slightly less than the rest of the week, suggesting a potential under-reporting of recreational trips made on foot. "Other" refers to school bus, taxi, and paratransit. These modes are used less on the weekend, which would be expected, especially for travel by school bus.

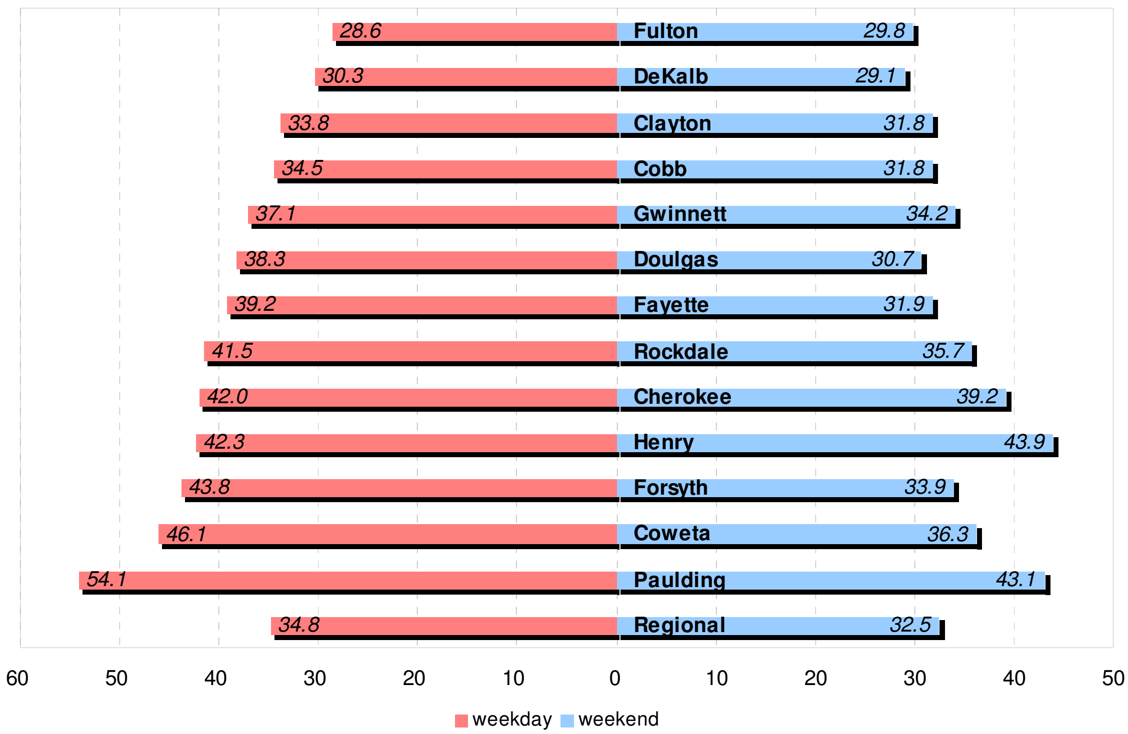
Table 33: Mode split by day of week

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Total Persons 5+ years old in Sample	6,742	6,873	6,502	6,705	6,297	2,878	3,085
Total People who took trips (**all modes**)	6,291	6,595	6,374	6,636	6,165	2,147	2,487
	93.3%	96.0%	98.0%	99.0%	97.9%	74.6%	80.6%
People who took private **vehicle** trips (% people who took trips)	4,765	4,958	4,798	4,986	4,591	1,888	2,179
	76.0%	75.0%	75.0%	75.0%	74.0%	88.0%	71.0%
People who took **transit** trips (% people who took trips)	234	263	237	241	260	62	44
	4.0%	4.0%	4.0%	4.0%	4.0%	3.0%	1.0%
People who took **bike** trips (% people who took trips)	16	14	20	15	11	6	17
	0.3%	0.2%	0.3%	0.2%	0.2%	0.3%	0.6%
People who took **walk** trips (% people who took trips)	433	486	531	525	541	127	175
	7.0%	7.0%	8.0%	8.0%	9.0%	6.0%	6.0%
People in sample who took trips by **other & unknown modes**	843	874	788	869	762	64	72
	13.0%	13.0%	12.0%	13.0%	12.0%	3.0%	2.0%

Weekday and weekend miles present the average miles traveled in a private vehicle on a weekday or a Saturday or Sunday. This means that people who did not drive, or were not a passenger in a private vehicle, are not included in this average. In order to calculate this measure, the distance for all private vehicle trips were summed for each respondent for day one and day two, producing a daily total miles traveled. Means were calculated for day one and day two. Respondents whose two day total miles traveled fell outside of three standard deviations of the mean were treated as outliers and not included in the analysis.

People travel in a private vehicle on the weekends almost as far as they drive during the week. In fact, the average VMT on a typical Saturday or Sunday is only 6% lower than the average VMT on a typical weekday (32.5 miles on the weekend and 34.8 miles on a weekday). On both weekdays and weekends, those people living in the central counties drive the least while those in the outer counties drive the furthest.

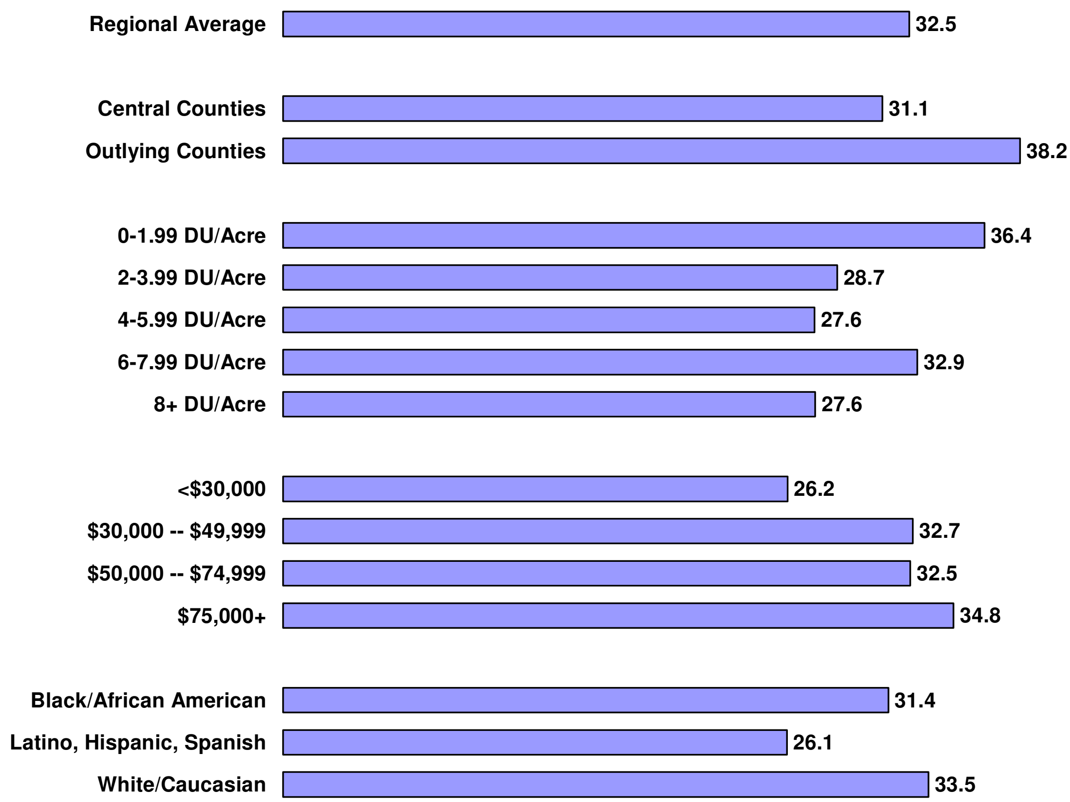
Figure 36: Weekday and weekend miles traveled



The variation of trip miles and time across income is somewhat less during the weekend compared to weekdays; for mileage the respective ranges are 26.2 – 34.8 miles and 27.5 – 38.1 miles (see Figure 37 and Figure 38). Comparing weekday and weekend distance and time values across regional location shows a narrowing of the difference between outlying and central counties. During the week, people who live in one of the eight outlying counties travel 34% more miles than central county residents, but on the weekend the difference decreases to 23% more. While residents in both regional locations drive less on the weekend, the rate of reduction is greater for those living in the outer counties than central counties, for mileage the difference is 14% vs. 5%. Unlike weekday travel, the trend of decreasing miles and time spent traveling is broken at the 6-7.99 du/net res. acre density range for weekend travel. However, it should be noted this range has the fewest observations in it (approximately 70) as compared to over 120 for the highest density range (8+ du/net res. acre) and over 800 for the lowest range (0-1.999 du/net res. acre). In terms of ethnicity, Latino/Hispanics travel, on average, the least number of weekday vehicle miles, and whites the most.

Figure 37: Average Weekend Daily Vehicle Miles of Travel per Person

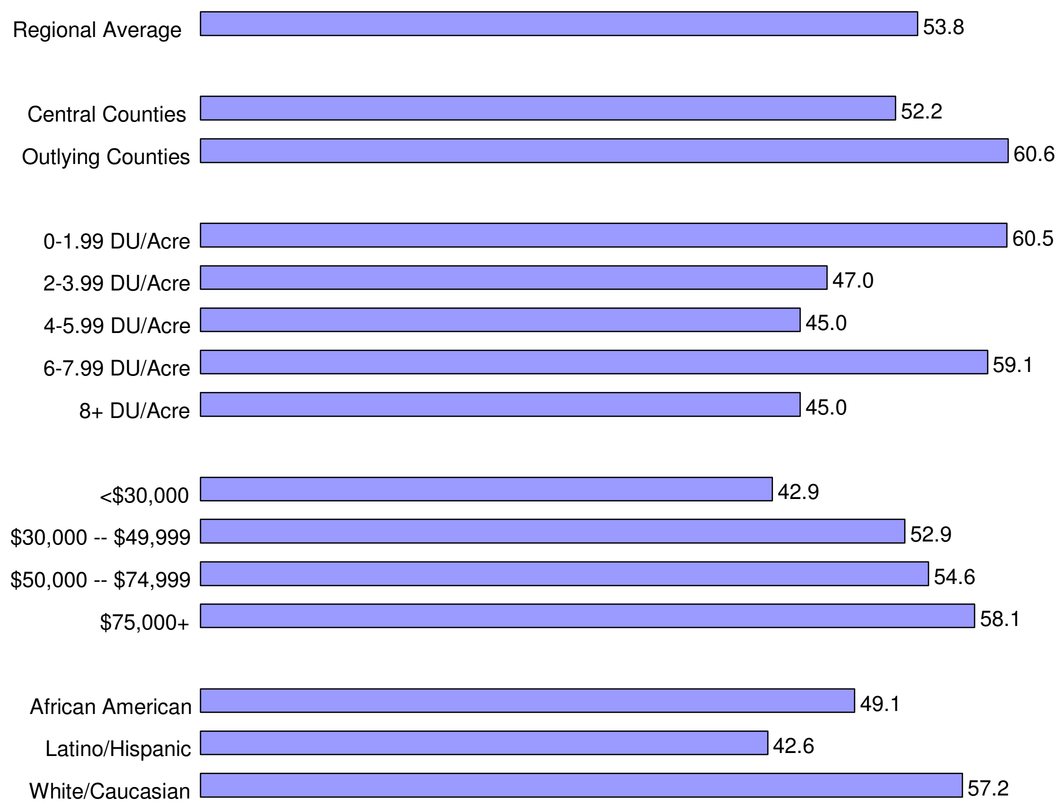
(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)[22]



[22] Central Counties: Clayton, Cobb, DeKalb, Fulton and Gwinnett. Outlying Counties: Cherokee, Coweta, Douglas, Fayette, Forsyth, Henry, Paulding and Rockdale.

Figure 38: Average Weekend Daily Minutes of Travel per Person

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. Private vehicle mode only. Weighted.)



The estimated NO_x, HC and CO emissions (Figure 39 through Figure 42) vary across regional location and ethnicity in a pattern similar to the weekend vehicle miles traveled (VMT) figures above; however, this is not the case for density and income. Carbon dioxide emission rate variation does follow the VMT pattern, for the reasons explained above.

While the lowest density category has both the highest VMT and the highest NO_x, HC and CO emission rates, the degree of disparity across the density ranges is less in the case of emissions than for VMT. For example, people in the lowest density range travel 37%

more miles on average than people in the highest density, but their NO_x generation is only 8% more, HC 4% more, and CO 7% more.

Comparing NO_x emission rates by net-residential density shows people in the three lowest density ranges on weekdays produce more than on weekends, 15% more for the two lowest and 10% more for the middle density range. The two upper ranges remained approximately the same, a 1% decrease for the 6-7.99 du/net res. acre range, and a trend reversing 4% increase for the highest range. Similar patterns hold for HC and CO emissions rates.

In addition, the trend of decreasing weekday daily per person emissions as density increased does not hold for weekend travel. People living in the middle density range (4-5.999 du/net res. acre) are estimated to produce the fewest emissions, with the lowest followed by the highest density range producing the most. In order to explain these unexpected results, additional analyses are necessary. The very existence of this anomaly indicates the value of collecting weekend travel data.

Figure 39: Grams of NO_x per person per weekend-day

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. All modes. Weighted.)

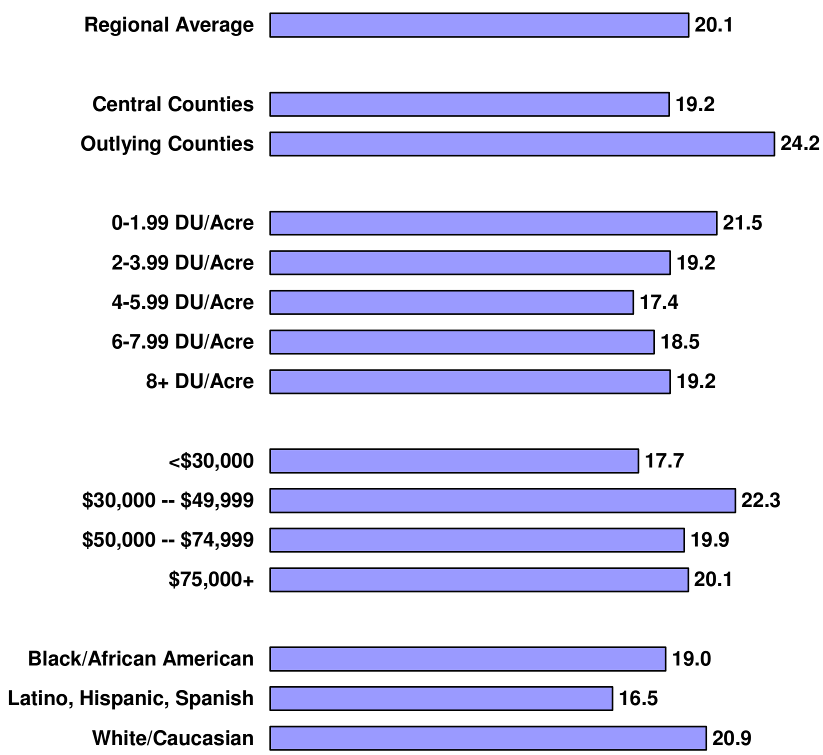


Figure 40: Grams of HC per person per weekend-day

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. All modes. Weighted.)

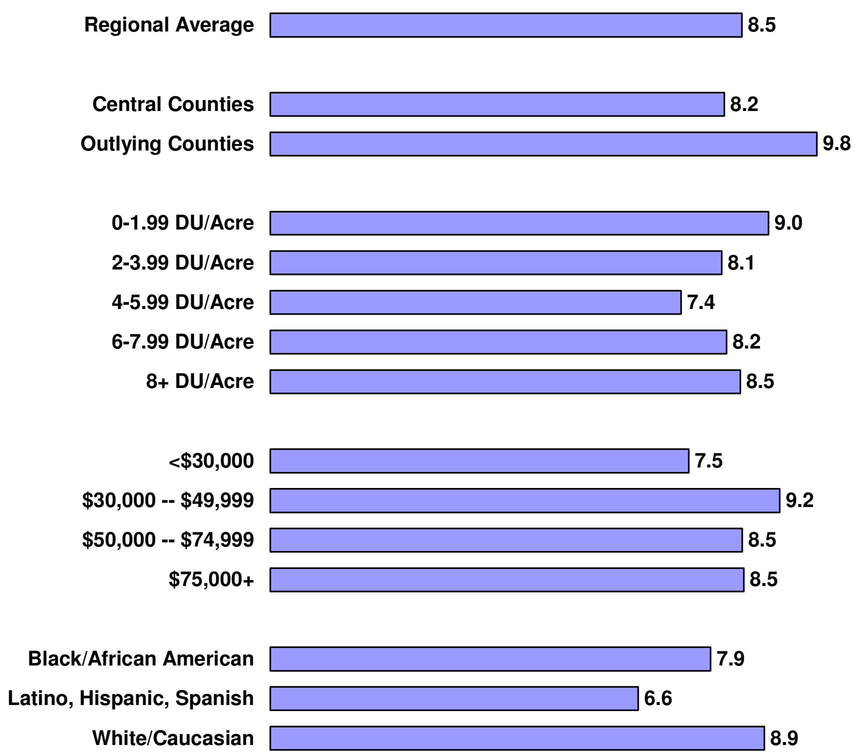


Figure 41: Grams of CO per person per weekend-day

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. All modes. Weighted.)

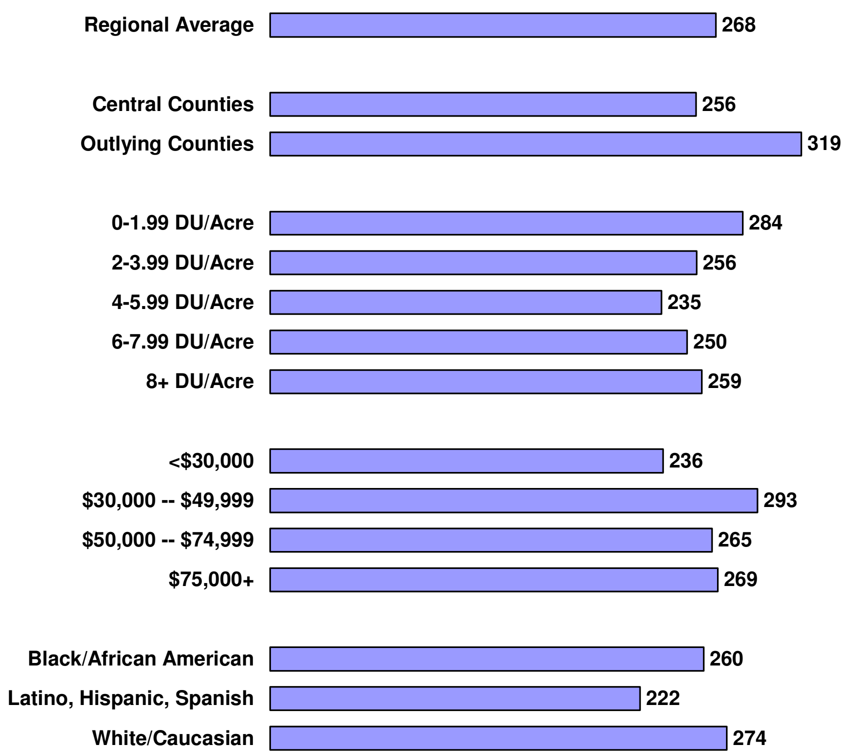
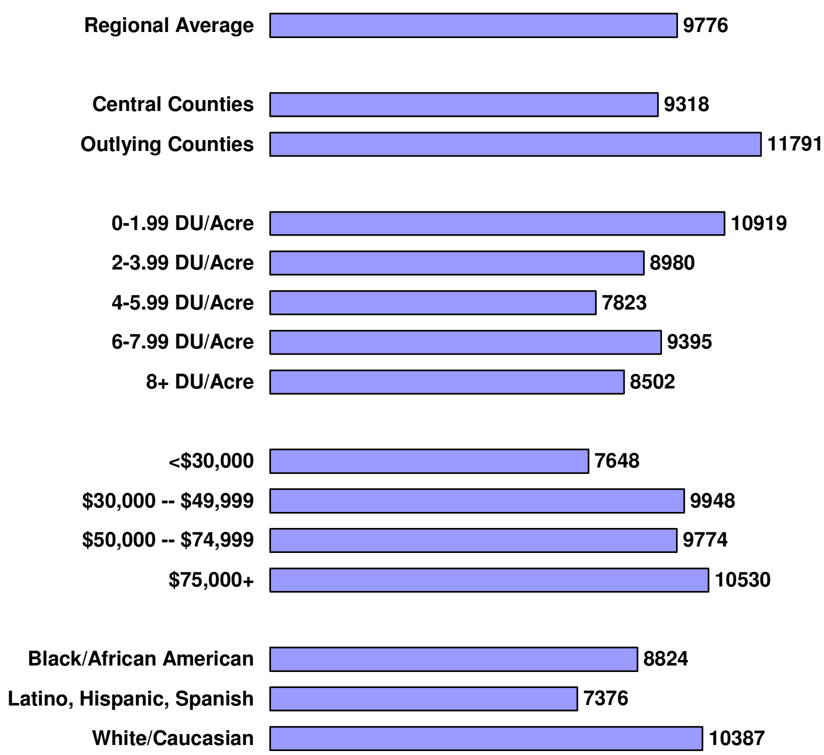


Figure 42: Grams of CO_2 per person per weekend-day

(Note: Observations are for people over 4 years old, who made at least one trip, but not more than 3 standard deviations from two day mean, average of day 1 and day 2 average. All modes. Weighted.)



V. 2001/2002 TRIP-LEVEL DESCRIPTIVES

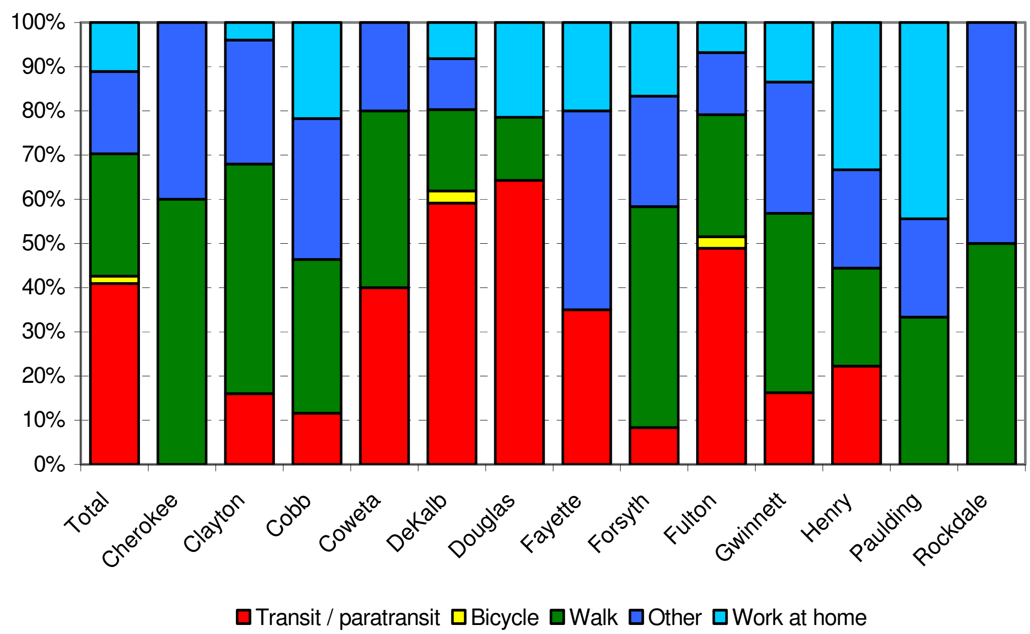
A. Home to work commute

As shown in previous tables, for each trip made over the two day reporting period participants indicated the mode used and estimated the travel time. Participants older than 17 years and who worked were also asked what their usual primary means of transportation to work was and how many minutes it usually took to get from home to work. Most respondents indicated that a personal vehicle was the usual mode to work.

When viewed at the county level, self-reported commute modes yield some unexpected results, as shown in Figure 43:

- Unusually high percentages of transit/paratransit use for two counties without a transit system, Douglas (6.23%) and Fayette (5.22%), as compared to Cobb (1.12%) which has a transit system; and that
- Forsyth, a less-urbanized county on the region's edge has the fourth highest walk percentage, 4.99%.

Figure 43: Self-reported commute mode-split by county, for modes other than the private vehicle



Average commute time by county, across all modes, varies from a low of almost 27 minutes in Fulton County to a high of about 36 to 38 minutes for the less urbanized, edge counties of Douglas, Fayette, Forsyth, Paulding, and Cherokee. Please see Table 34.

Table 34: Self-reported commute to work: time by county

	N People	Minimum	Maximum	Mean	Std. Deviation
Cherokee	139	0	230	35.6	37.2
Clayton	251	0	200	31.6	35.5
Cobb	710	0	300	28.4	26.8
Coweta	73	0	110	28.3	22.1
DeKalb	804	0	430	29.4	29.8
Douglas	132	0	105	38.3	32.3
Fayette	117	0	115	38.1	33.7
Forsyth	98	0	115	35.8	32.9
Fulton	936	0	230	26.6	28.1
Gwinnett	688	0	200	29.6	25.8
Henry	135	0	130	29.5	24.6
Paulding	102	0	130	37.4	26.3
Total	4,260	0	430	29.8	29.0

Note: all cases above three standard deviations from the mean removed.

VI. NETWORK-BASED DISTANCE AND TIME ESTIMATES

The 1991 survey included only self-reported distance and time data, which can be inaccurate due to many missing cases, respondent error, and difficulties in estimating automobile-based trip characteristics. In order to resolve problems found in self-reported distance and time data, an additional approach was adopted for the 2001/2002 study wherein estimates were made for every trip's duration and length using a network-based model. The consulting firm GeoStats, LP did this work under sub-contract to Georgia Tech. Chapter II describes in detail how, for motor vehicle trips, actual trip travel times and speeds for each trip were represented by the shortest network time path estimated from the 2000 ARC travel demand forecasting model. The goal was to identify the shortest time path from the reported origin to the reported trip destination over the appropriate network and thereby arrive at an estimated network time, distance and emissions produced for every trip.

A comparison of the mean and dispersion of trip distance and time for the self-reported data and the network estimates is shown in Table 35 (unweighted data). Interestingly, there is only a small distinction between the self-reported and network-based mean and sample deviation distances shown in the table. There is a larger gap between the self-reported and network-based trip times, although here the difference is not extreme (a 4 minute difference in means and a 2.8 minute difference in standard deviation).

Table 35: Self-reported versus network-based trip statistics (all trips, unweighted)

	N Valid Trips	Min	Max	Mean	Std. Dev.
Self-reported trip distance (miles)	79,636	1	44.0	8.1	8.2
Estimated network-based trip distance (miles)	102,504	0	39.1	8.3	8.0
Derived self-reported trip time (minutes)	113,663	1	77.0	19.0	14.0
Estimated network-based trip time (minutes)	97,714	0	57.8	15.0	12.2

Note 1: First all trips with endpoints outside the region eliminated, then trips longer than three standard deviations from the mean for the entire sample eliminated; for self-reported distance data, cases where distance reported in blocks eliminated.
Note 2: Derived self-reported time refers to the use of reported trip departure time and arrival time. Subtracting the departure from the arrival time derives the duration.
Note 3: Derived self-reported trip time contains all modes. Estimated network-based trip time contains only private vehicle (auto/van/truck driver and passenger), transit—MARTA bus/rail, CCT, and school bus.

While there is no way to determine (absent vehicle instrumentation data which would indicate the exact route, and therefore distance, and time traveled) which of the two types of measures are more accurate for determining trip distance and time, the expectation is that the modeled (network) time and distance estimates are more reliable; at the very least in the case of distance there are many fewer cases with missing data. Therefore, the time- and distance-based figures reported in this section are network-based estimates.

For all trips in the sample, on a weighted basis, the mean estimated network distance was 8.9 miles, the mean travel time was 15.1 minutes, and the average speed was 32.5 miles per hour (Table 36). As mentioned previously, the methodology used is explained in detail in Chapter II.

Table 36: Network-based trip statistics (all trips, weighted)

	N Valid Trips	Min	Max	Mean	Std. Dev.
Estimated trip distance in miles (network-based distance calculation)	104,724	0	41.5	9.0	8.4
Estimated trip time in minutes (network-based time calculation)	105,034	1	59.8	15.3	11.8
Estimated network-based trip speed (m.p.h.)*	96,803	0.06	69.5	31.6	10.3

Note: Only considers private vehicle (auto/van/truck driver and passenger), transit—MARTA bus/rail, CCT, and school bus. For distance and time variables, all trips greater than three standard deviations from the mean for the entire sample eliminated. For speed variable, trips eliminated from both distance and time were eliminated.
*Trip speed for motorized modes only, i.e. walking and bicycle trips are not included.

VII. ALTERNATIVE MODES OF TRANSPORTATION

A. Walking and bicycling

In 1991, walk trips were not included in analyses due to the small number of reported trips of this type. In 2001/2002, walking was the third most common travel mode used by survey respondents. According to the weighted results of the 2001/2002 travel survey, 4.8% (6,109) of trips were by walking, as compared to 5.3% by school bus and 86.8% either as a driver of passenger of a private vehicle. Even though there were more than twice as many trips made by walking than transit it was assumed that walk trips are under reported by survey respondents. Of the 21,339 people (weighted) five years or older in the survey, 19,227 reported making no walk trips over the two day reporting period. Ideally, people would report a trip when there is a mode change. For example, the walk from the bus station to the work site, and the walk from work to lunch were intended by the researchers to be considered trips, and likely would also be considered such by the participants. However, it may not be as likely that the following examples would be reported as walk trips—walking to a building cafeteria from an upper floor office, or walking from the automobile in a parking lot to a store. The likelihood of under reporting walk trips will be reviewed for a small subset of travel survey participants who wore a global positioning system recorder as part of the health and physical activity sub-survey. The results of this review will be part of another GDOT deliverable, #30.

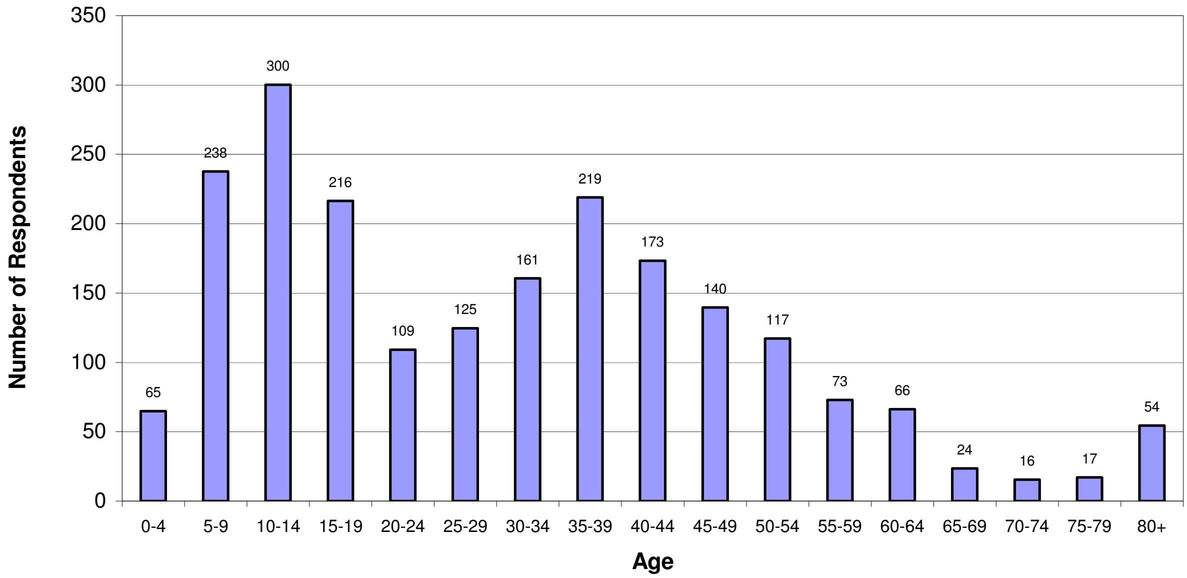
Very few bicycle trips were reported. Eighty-three people made 220 bicycle trips, 0.2% of the weighted total of trips. While the sample is very small for this mode, the tables below include bicycling data. A targeted survey for bicyclists is needed to obtain sufficient data to generalize to the larger bicycling population. The next sections provides a few tables describing demographic and household land use characteristics for this set of people who used a bicycle or walked at least once.

1. Demographics

Of the walkers participating in the survey, 54% were female and 46% were male (2,113 respondents, weighted). The weighted sample of bicyclists consists of 18% female and 82% male (83 respondents, weighted). This compares to 52.5% female and 47.2% male for the entire weighted survey population.

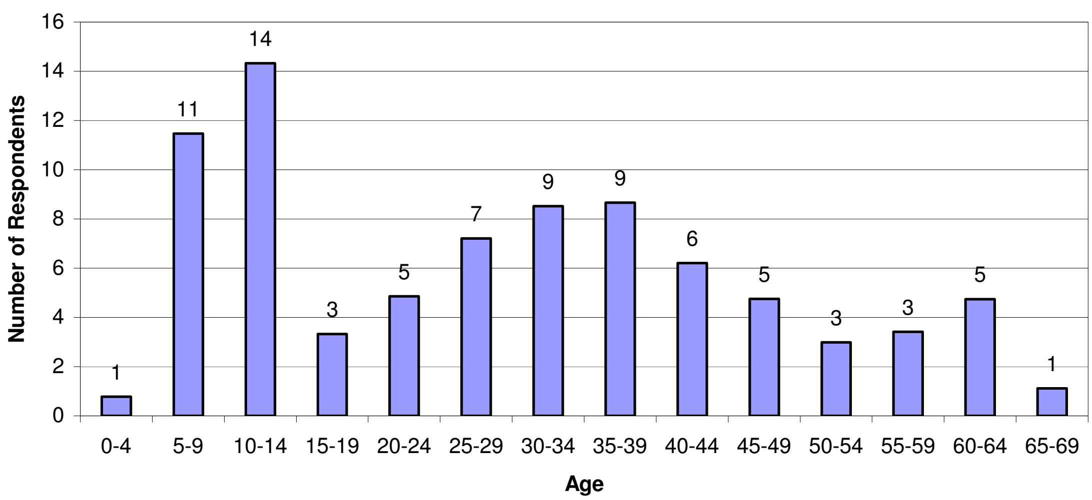
Of people who walked, the most prevalent age group is 10-14 years old, with 300 respondents or 14%. The age group 35-39 (219 people or 10%) is the peak of a normal curve. The left tail of the curve is the 20-24 (5%) age group and the right tail is the 70-74 (1%) age group.

Figure 44: Age distribution of walkers



The age distribution of bicyclists ranged from the 0-4 to the 65-69 age categories. The age group with the most respondents was 10-14, with 14 responses (17.3%). However, if ages are grouped in ten-year intervals, the group with the most bicyclists is 30-39. As Figure 44 illustrates, a normal curve is formed from age 15 to 54, with the peak at 30-39.

Figure 45: Age distribution of bicyclists



As Table 37 below illustrates, the ethnic distribution of the bicyclists and walkers is not similar to the overall surveyed population. The majority of the bicyclists are white, 72.2%, which is higher than in the surveyed population. Although the largest percentage of walkers is white, the percentage is lower than the percent surveyed, 45.2% versus 56.8%. In addition, African Americans are over represented in the walking category when compared to the survey population, 44.4% versus 32.6%. The percentages of walkers who are black (44.4%) and those who are white (45.2%) are very similar. In contrast, the percentage of Latino, Hispanic, Spanish and Asian/Pacific Islander bikers and walkers were consistent with survey data ethnic composition.

Table 37: Bicyclists and Walkers by Ethnicity

Ethnicity	Surveyed People (N = 19,546, weighted)	Bicyclists (N= 83 weighted)	Walkers (N= 2,113 weighted)
Black/African American	32.6%	15.8%	44.4%
Latino, Hispanic, Spanish	6.8%	6%	6.5%
Asian/Pacific Islander	1.6%	2.5%	2.1%
Native American	0.6%	0%	0.6%
White/Caucasian	56.8%	72.2%	45.2%
Other	1.2%	3.2%	0.7%
Don't know	0.1%	0%	0.1%
Refused	0.3%	0.3%	0.3%
Total	100%	100%	100%

Slightly over 10% of walkers live in households with an annual income less than $10,000, with nearly a quarter with household incomes less than $20,000, please see Table 38. Compared to the entire household survey sample (21,339 people weighted), where five percent of people living in households with annual income of less than $10,000, walkers are over represented in this range. For the entire survey the percentage under $20,000 is 12.5%. Walkers are again over represented in this lower income range. Over 37% of bicyclists in this sample have an annual household income of $100,000 or more; which is more than twice that of walkers (15.5%). A larger sample size for bicyclists is needed to investigate whether this is an oddity of the sample and, in general to gain more understanding of the income levels for these mode users.

Table 38: Bicyclists and Walkers by Annual Household Income (weighted)

Annual Household Income	Surveyed People (N = 21,339 weighted)	Bicyclists (N= 83 weighted)	Walkers (N= 2,113 weighted)
Less than $10,000	5.0%	3.2%	10.2%
$10,000 to $19,999	7.5%	9.3%	12.2%
$20,000 to $29,999	9.9%	7.7%	14.8%
$30,000 to $39,999	10.9%	11.3%	9.2%
$40,000 to $49,999	9.7%	8.4%	7.9%
$50,000 to $ 59,999	10.2%	6.8%	8.5%
$60,000 to $74,999	11.5%	5.3%	10.3%
$75,000 to $99,999	15.0%	10.9%	11.5%
$100,000 or more	20.3%	37.1%	15.5%
Total	100%	100%	100%

Bicyclists and walkers more commonly than the surveyed population have no household vehicles, and fewer multiple vehicles. Walkers more often own a single vehicle. Please see Table 39.

Table 39: Bicyclists and Walkers Users by Household Vehicle Ownership

Number of household vehicles	Surveyed People (N = 19,546, weighted)	Bicyclists (N= 83 weighted)	Walkers (N=2,050 weighted)
Zero	6.0%	14.4%	17.8%
One	24.6%	21.9%	32.5%
Two	45.0%	28.6%	36.3%
Three	17.7%	33.2%	11.5%
Four	4.8%	0.8%	1.6%
Five+	1.9%	1.1%	0.4%
Total	100%	100%	100%

2. Trip Distance

The distances for a large number of walk trips (about 48%) as reported by the participants were in units of “blocks.” Lacking a method to convert blocks into miles, program researchers developed an objective means of determining walk and bicycle trip distance, previously described in Chapter II.

Using this methodology, a distance in miles was determined for 4,899 of the 6,109 walk trips. A distance estimate was not determined for any trip without address-matched geo-coded trip end locations. Successfully geo-coding trip ends requires participants to provide sufficient and accurate address information.

As shown in Table 40, below, the mean walk distance for the 4,806 trips is slightly less than 1 mile (0.93 miles).[23] The longest estimated distance, within three standard deviations of the mean, was 12.18 miles. Compared to the 1,186 trips for which the survey participants' self-reported distance is in miles, the mean and maximum are similar – 1.2 miles and 11.7 miles respectively[24].

The methodology also provided distance estimates for 174 of the 220 bicycle trips, with a mean distance of nearly 1.7 miles and a maximum of 12.3 miles. This distance estimate is based on the shortest distance between each trip's origin and destination. Compared to the 132 trips with participant-reported distances in miles, the mean is 3.4 miles and the maximum 23 miles. These differences may indicate the most direct route (shortest distance path), but the shortest is not the one always chosen by bicyclists.

Table 40: Self-Reported and Estimated Distances

		N trips	Mean distance	Maximum distance
Walk trips	Self-reported distance	1,186	1.2	11.7
	Estimated distance	4,806	0.93	12.18
Bicycle trips	Self-reported distance	132	3.4	23
	Estimated distance	174	1.7	12.3

[23] Ninety-three walk trips estimated to be longer than 20 kilometers (12.4 miles) are not included in the mean distance determination, because they were approximately three standard deviations above the mean walk distance for the entire set of estimated trips.

[24] Two walk trips have a self-reported distance of 100 miles. These are not included in this analysis due to the unlikelihood of their accuracy.

3. Average Daily Walk Trip Rate

The size of the larger sample of walk trips allows for a greater amount of descriptive analyses compared to bicycle trips. This next section describes average daily walk trip rates cross-tabulated by demographics and net-residential density.

Of those who walked at least one trip over the two day survey period, little variation across income was seen in trip rate. The highest average daily walk trips per person are attributed to the less than $30,000 income bracket (2.1) and the lowest is attributed to the $75,000 or more income bracket (1.9).

Table 41: Mean Daily Walk Trips per Person by Household Income

(Individuals over four years of age and less than 19.9 trips, or three standard deviations above the mean, over the two-day period)

	Percent of Total Walk Trips	Mean Daily Trip Rate per Walker
Less than $30,000	42.0%	2.1
$30,000-$49,999	17.0%	2.0
$50,000-$74,999	17.5%	2.0
$75,000+	23.5%	1.9

African Americans and whites had the highest percentage of walk trips, followed by Latino/Hispanics (Table 42). Latino/Hispanics, on average, made the most daily walk trips, followed closely by the other two ethnicities.

Table 42: Mean Daily Walk Trips per Person by Ethnicity

(Individuals over four years of age and less than 19.9 trips, or three standard deviations above the mean, over the two-day period)

	Percent of Total Walk Trips	Mean Daily Trip Rate per Walker
Black/African American	44.5%	2.0
Latino, Hispanic, Spanish	8.7%	2.2
White/Caucasian	42.5%	2.0

Although individuals in households with two household vehicles made the highest number of walk trips, the highest average daily trip rate was made by individuals with zero household vehicles. As illustrated in Table 43, average daily trip rates decreases as the number of household vehicles increases, with an exception at five vehicles, which is based on a small percentage of all the trips.

Table 43: Mean Daily Walk Trips per Person by Number of Household Vehicles

(Individuals over four years of age and less than 19.9 trips, or three standard deviations above the mean, over the two-day period)

Number of Vehicles	Percent of Total Walk Trips	Mean Daily Trip Rate per Walker
0	21.3%	2.3
1	32.5%	2.0
2	34.8%	2.0
3	10.0%	1.9
4	1.0%	1.7
5	0.2%	2.0
6	0.1%	1.7

The average daily trip rate of walkers, by net residential density, ranged from 1.8 to 2.3 trips per day per person reporting one or more walk trips. The lowest average trip rate occurred for households located in an NRD of 0 – 2 dwelling units per acre. The highest average trip rate occurred for households in both an NRD of 6 - 8 and 8+.

Table 44: Mean Daily Walk Trips per Person by NRD

(Individuals over four years of age and less than 19.9 trips, or three standard deviations above the mean, over the two-day period)

Net Residential Density (du/net res. acre)	Percent of Total Walk Trips	Mean Daily Trip Rate per Walker
0 – 1.999	24.0%	1.8
2 – 3.999	30.0%	2.0
4 – 5.999	17.8%	2.0
6 – 7.999	6.7%	2.3
8+	21.4%	2.3

The average daily trip rate of walkers, by county, ranged from 1.6 to 2.7 trips per day per person reporting one or more walk trips. The lowest average trip rate occurred in Paulding County, which was also the county with the lowest percentage of walk trips. The highest average trip rate occurred in Forsyth County, although it only had 2.4% of the walk trips. Fulton and DeKalb, the counties with the highest percent of walk trips, had the second and third highest average trip rates, 2.2 and 2.1, respectively. Overall, the average trip rate for all the counties was approximately 2.0 trips per day.

Table 45: Average Daily Walk Trip Rate per Person by County

(Individuals over four years of age and less than 19.9 trips, or three standard deviations above the mean, over the two-day period)

	Percent of Total Walk Trips	Mean Daily Trip Rate per Walker
Cherokee	1.0%	1.9
Clayton	5.6%	1.7
Cobb	9.3%	1.9
Coweta	1.2%	1.7
DeKalb	27.2%	2.1
Douglas	0.7%	1.8
Fayette	2.5%	1.9
Forsyth	2.4%	2.7
Fulton	42.2%	2.2
Gwinnett	6.2%	1.6
Henry	0.6%	1.9
Paulding	0.2%	1.6*
Rockdale	1.1%	1.9

*Paulding average is for day 1 only, no trips were reported on day 2

VIII. TRANSIT TRAVEL

The 1991 survey did not provide adequate transit trip data due to the small number of trips of this type. In 2001/2002, however, transit was the fourth most common travel mode used by survey respondents. The weighted results of the 2001/2002 travel survey show that 2.1% (3,066) of trips were by transit, as compared to 4.8% (6,109) by walking, 5.3% by school bus and 86.8% by private vehicle.

A. Demographics

Below, in Table 46 through Table 49, the 896 people (over five years of age) who used transit at least once over the two-day survey reporting period are compared with the entire survey population. Transit users are over twice as often African American, 2.5 times as likely to have household annual incomes under $20,000 or live in the two highest NRD levels, and six times as often live in a household with no vehicles.

Table 46: Transit Users by Ethnicity

Ethnicity	% Surveyed People (N = 19,546, weighted)	% Transit Users (N = 896, weighted)
Black/African American	32.6%	67.3%
Latino, Hispanic, Spanish	6.8%	4.7%
Asian/Pacific Islander	1.6%	1.3%
Native American	0.6%	0.4%
White/Caucasian	56.8%	25.5%
Other	1.2%	0.5%
Don't know	0.1%	0%
Refused	0.3%	0.2%
Total	100%	100%

Table 47: Transit Users by Annual Household Income (weighted)

Annual Household Income	% Surveyed People (N = 19,546, weighted)	% Transit Users (N = 896, weighted)
Less than $10,000	4.8%	10.7%
$10,000 to $19,999	7.5%	19.6%
$20,000 to $29,999	9.8%	20.1%
$30,000 to $39,999	10.8%	9.9%
$40,000 to $49,999	9.9%	8.6%
$50,000 to $ 59,999	10.1%	6.8%
$60,000 to $74,999	11.7%	7.2%
$75,000 to $99,999	14.8%	7.0%
$100,000 or more	20.7%	10.1%
Total	100%	100%

Table 48: Transit Users by NRD

Net Residential Density (du/net res. acre)	% Surveyed People (N = 19,546, weighted)	Transit Users (N: Weighted)	% Transit Users (N = 896, weighted)
0 – 1.999	48.6%	152	17.0%
2 – 3.999	28.3%	321	36.0%
4 – 5.999	11.6%	185	20.7%
6 – 7.999	4.1%	67	7.5%
8+	7.4%	168	18.8%
Total	100%	893	100%

Table 49: Transit Users by Household Vehicle Ownership

Number of Household Vehicles	% Surveyed People (N = 19,546, weighted)	% Transit Users (N = 896, weighted)
Zero	6.0%	37.1%
One	24.6%	30.9%
Two	45.0%	24.4%
Three	17.7%	6.6%
Four	4.8%	0.8%
Five+	1.9%	0.2%
Total	100%	100%

B. Household Proximity to Transit

The Atlanta Regional Commission has developed a database of 200-meter grid cells covering the entire region. Each of these cells has been assigned the road-network based shortest distance to the nearest transit rail stop and the nearest transit stop (of any type, rail or bus). The grid that each of the surveyed households is in has been identified and the mean distances from these grids to the nearest transit stop is shown in Table 50. The presence of the MARTA transit system in Fulton and DeKalb counties is the reason why households in those two counties are so much closer to transit, on average, than in other counties. Only the transit stop score for Cobb County approaches the scores for Fulton and DeKalb, due to the presence of Cobb County Transit.

Table 50: Mean distance in miles from households in sample to rail stations and transit stops, by county

County	Mean distance to nearest rail station (miles)	Mean distance to nearest transit stop (miles)
Cherokee	18.2	9.0
Clayton	7.6	3.9
Cobb	10.2	1.8
Coweta	24.7	10.7
DeKalb	2.6	0.5
Douglas	15.2	7.6
Fayette	15.7	10.0
Forsyth	20.6	9.3
Fulton	2.5	0.6
Gwinnett	12.4	8.5
Henry	19.0	12.2
Paulding	21.8	12.2
Rockdale	15.5	7.8

C. Transit Trip Distance and Duration

For many of the rail transit trips in the database, the estimated network distance was calculated between points that are not actually stations. This is mainly due to the reporting of several trips as one transit trip. For instance, a respondent might use alternative forms of transportation for access and egress to a train station and mistakenly report the individual trips as one heavy rail trip. One indicator of someone not reporting a trip to or from the rail transit system is if they provide a trip end location that is not a rail station. Trips may also be inaccurately matched in the geo-coding process, which generates false network distances.

In order to more accurately estimate the distance for rail transit trips, the origin and destination were plotted in GIS for each trip for which the survey participant indicated rail was the mode. These points were spatially joined to the nearest MARTA rail stations. Some trip end locations only had coordinates for the centroid of a city or zip code location because of a lack of complete information provided by the participant. These locations were not matched using the spatial join.

When possible, data from another question in the survey regarding the route of the transit trip was used to clean the data and provide location data for the unmatched points. Using a day-of-week and time-of-day specific rail times and a distance matrix provided by MARTA, the distance and time for each pairing of stations was determined and the data appended to the trip data. In cases where a transfer between the east-west and north-south lines was required, a transfer wait time was added. This value was calculated, per MARTA's recommendation, by dividing in half the system headway at the time the trip was taken. Travel distances and times made by bus and paratransit were estimated using the methodology described in Chapter II.

A distance in miles was able to be determined for 2,622 transit trips. As explained above, a distance estimate was not determined for any trip without address-matched geo-coded trip end locations, which requires the participants to provide sufficient location information.

The mean transit distance for the 2,622 trips is 7.42 miles.[25] The longest estimated distance, within three standard deviations of the mean, was 29.0. Compared to the self-reported distances, in miles, for 1,413 trips the mean and maximum are higher – with self-reported values of 8.8 miles and 50.0 miles respectively.

The mean estimated transit time is 14.5 minutes with a maximum of 49 minutes[26]. The trip duration as calculated from self-reported departure and arrival times is generally quite a bit longer. The mean duration is 35.0 minutes and the maximum 2.25 hours

[25] Seventy-seven transit trips estimated to be longer than 31.7 miles (51.0 kilometers) are not included in the mean distance determination, because they were approximately three standard deviations above the mean transit distance for the entire set of estimated trips.

[26] Forty-two transit trips estimated to be longer than 49.2 minutes are not included in the mean travel time determination, because they were approximately three standard deviations above the mean transit time for the entire set of estimated trips.

(105.0 minutes).[27] This disparity is not unexpected. The estimated transit times do not include the time waiting for the arrival of the bus or train, nor do they include transfer times from bus to bus or between a bus and train; as stated above it does include train to train transfer times. The bus transit times are simply the shortest time path along the road network between the trip's origin and destination.

D. Average Daily Transit Trip Rate

This next section describes average daily transit trip rates cross-tabulated by demographics and net-residential density. On average people five years or older who rode transit at least once over the two day survey period took transit slightly over twice per day. The mean number of daily transit trips they took varied little with income. The highest levels, over $75,000, had the lowest daily average, 1.9 trips. The majority of transit trips were taken by those with incomes of less than $30,000, indicating lower income brackets are more likely to ride transit, although not much more frequently than other transit riders of higher incomes.

Table 51: Mean Daily Transit Trips per Person by Household Income

	Percent of Total Transit Trips (weighted)	Mean Daily Trip Rate per Rider (weighted)
Less than $30,000	53.1%	2.2
$30,000-$49,999	19.4%	2.3
$50,000-$74,999	14.6%	2.3
$75,000+	12.8%	1.9

African Americans make up the majority of total transit trips, with about 72% of trips made by this demographic group. The ethnic groups with the lowest trip rates were Latino, Hispanic, Spanish and white with 2.0 daily trips.

[27] Forty-four transit trips estimated to be longer than 105.0 minutes are not included in the mean self-reported travel time determination, because they were approximately three standard deviations above the mean transit time for the entire set of estimated trips.

Table 52: Mean Daily Transit Trips per Person by Ethnicity

	Percent of Total Transit Trips (weighted)	Mean Daily Trip Rate per Rider (weighted)
Black/African American	71.7%	2.2
Latino, Hispanic, Spanish	4.5%	2.0
White/Caucasian	21.0%	2.0
Other	2.8%	2.6

Individuals in households with zero household vehicles made the highest percentage of transit trips, as well as the second highest number of trips per day. Individuals with zero household vehicles also had the highest average daily transit trip rate. Average daily trip rates decrease as the number of vehicles increases from zero to two. The average transit trip rates peak at three vehicles due to the small sample size (59.1 people weighted) of transit riders with three vehicles.

Table 53: Mean Daily Transit Trips per Person by Number of Household Vehicles

Number of Vehicles	Percent of Total Transit Trips (weighted)	Mean Daily Trip Rate per Rider (weighted)
0	42.9%	2.4
1	30.1%	2.2
2	20.7%	1.9
3	5.6%	2.3
4	0.6%	1.7
5+	0.1%	1.8

The average daily trip rate of transit riders, by net residential density, ranged from 1.9 to 2.3 trips per day. The lowest average trip rate occurred for households located in the least dense level. People living in the two highest density levels and, unexpectedly, the 2-3.999 du/net res. acre level had the highest average trip rates.

Table 54: Mean Daily Transit Trips per Person by NRD

Net Residential Density (du/net res. acre)	Percent of Total Transit Trips (weighted)	Mean Daily Trip Rate per Rider (weighted)
0 – 1.999	13.9%	1.9
2 – 3.999	37.9%	2.3
4 – 5.999	19.8%	2.1
6 – 7.999	7.9%	2.3
8+	20.4%	2.3

The average daily trip rate of transit riders, by county, ranged from 0.5 to 2.2 trips per day per person reporting one or more transit trips (Table 55). Trip-level county assignment is done by the home-county of the trip maker; in other words trips are not necessarily assigned a county by the county the trip occurs in. The lowest average trip rate occurred in Cherokee County, where respondents did not report any transit trips at all. The highest average trip rates occurred in Fulton County and DeKalb County, which also made up over 85% of all trips. As a percentage of all trips (all modes) made by county, the two MARTA transit system counties, DeKalb and Fulton, have the largest share (5.2% and 5.5%), by a substantial amount. Interestingly Clayton, Douglas and Fayette all have a larger percentage of transit trips as a percentage of total trips than Cobb, which unlike the others (at the time of the survey) has local and express bus service.

Table 55: Average Transit Trip Rate by County

	Percent of Total Transit Trips (weighted)	Mean Daily Trip Rate per Rider (weighted)	Transit Trips as % of Total Trips by County
Cherokee***	N/A	N/A	N/A
Clayton	2.4%	1.9	0.9%
Cobb	4.4%	2.0	0.6%
Coweta**	0.1%	1.5	0.1%
DeKalb	37.0%	2.2	5.2%
Douglas	1.0%	2.1	0.9%
Fayette	1.8%	2.1	1.5%
Forsyth*	0.1%	0.5	0.1%
Fulton	48.9%	2.2	5.5%
Gwinnett	3.8%	1.8	0.6%
Henry	0.3%	2.0	0.2%
Paulding*	0.0%	0.5	0.0%
Rockdale**	0.2%	0.6	0.2%

*Forsyth average is for day 1 only, no trips were reported on day 2.
**Coweta, Paulding and Rockdale average is for day 2 only, no trips were reported on day 1.
*** There were no transit trips reported for Cherokee County.

IX. PERSON-LEVEL ATTITUDINAL RESPONSES

A unique aspect of the 2001/2002 Atlanta regional household travel survey is the inclusion of a series of questions concerning respondent attitudes toward urban form, transit use, and other issues. These questions assess how respondents felt about their neighborhoods, public transportation, and alternative transportation programs in the workplace.

A. Attitudes toward public transportation

A series of questions asked respondents about how frequently they used public transportation and what types of urban form conditions would encourage them to use public transportation more frequently. Respondents 15 years and older were asked how often they had used public transportation in the past week. The mean response to this question was 0.45 times per week (after removing outliers three standard deviations above the mean) with a standard deviation of 1.6 times.

A follow-up question asked those respondents who did not ride transit in the past week (7,426 respondents, weighted): “To encourage you to use public transportation, which places would be important to have near public transportation centers?” Table 56 shows that about 38% of the respondents still indicated that they would not use public transportation under any circumstance. This means that over 60% of the respondents indicated that at least one type of destination located near public transportation would encourage them to use public transportation. Over 30% of people indicated a grocery or retail store, bank/credit union, doctor/health clinic, or sports facility would be important to have near transit. Schools and parks were not seen as important to have near transit.

Table 56: Percent of respondents indicating which types of places would be important to have near transit (multiple responses allowed)

Place type	% indicating important to them (weighted)
Grocery store	34.9%
Retail store	32.5%
Day care	12.3%
Bank / credit union	31.7%
Doctor / health clinic	32.2%
Restaurant	31.6%
School	0.0%
Sports facility	30.1%
Park	0.0%
None	37.9%

A final question in the series asked one randomly selected adult per household older than 15 years how easy it was to use public transportation to access various types of places from home, the findings from which are shown in Table 57.

Most respondents from the entire surveyed population indicated that it was very difficult to access various destinations using public transit; in contrast, less than 20% indicated that it was “very easy” to get to most of the listed destinations by transit. School access was the exception, but here the small number of responses (161) to this sub-category must be considered when interpreting the numbers; additionally, it is possible that many of the respondents considered the school bus a public transportation mode, and answered the question accordingly (school buses are not considered to be public transportation in this analysis).

In contrast to the larger sample population, 30% and more of transits users (people who reported at least on transit trip during the survey period) found it very easy to get to the various destinations, with a much smaller percentage (around 20%) indicating access being very difficult.

Table 57: Ease of access from home using public transportation

	Rating (%)									
	very easy		somewhat easy		somewhat difficult		very difficult		Total responses*	
	Entire Surveyed Population	Transit Users Only	Entire Surveyed Population	Transit Users Only	Entire Surveyed Population	Transit Users Only	Entire Surveyed Population	Transit Users Only	Entire Surveyed Population	Transit Users Only
Ease of getting to bank	18.1	37	12.9	25.4	13.4	11.4	55.6	19.6	6,741	468
Ease of getting to school	28.7	62.2	27.6	8.1	12.4	6	31.3	0	161	25
Ease of getting to grocery store	19.8	37.5	11.4	18.5	12.7	13.3	56.1	24.3	6,723	468
Ease of getting to nearest park	17.9	31.6	11	18.6	13.7	13.4	57.4	22.9	6,427	468
Ease of getting to nearest shopping mall	14.9	29.7	14.5	22.7	15.1	16.7	55.6	22.3	6,726	468

*Variation in total due to all people choosing not to answer all the questions.

Given the increased rates at which people living in higher NRD areas use public transportation, it is logical to assume that responses to the accessibility question would also vary by NRD. This is the case, as shown in Table 58. People in the highest NRD areas provided consistently lower (easier) average ratings to the "ease of access" question when compared to people in the lowest NRD areas (i.e., the mean response from people in the highest NRD areas was consistently closer to the "very easy" end of the rating categories than that from people in the lowest NRD areas).

Table 58: Comparative responses to ease of access to places using public transportation question (mean response for people living in lowest and highest NRD areas, weighted)

	Average rating by NRD (1="very easy"; 2="somewhat easy"; 3="somewhat difficult"; 4="very difficult")				
	0 – 1.999 du/net res. acre	2 – 3.999 du/net res. acre	4 – 5.999 du/net res. acre	6 – 7.999 du/net res. acre	8+ du/net res. acre
Ease of getting to bank	3.53	2.88	2.57	2.44	2.27
Ease of getting to school*	3.19	2.62	2.07	2.83	1.88
Ease of getting to grocery store	3.48	2.84	2.63	2.6	2.63
Ease of getting to nearest park	3.53	2.98	2.49	2.58	2.32
Ease of getting to nearest shopping mall	3.54	2.96	2.67	2.61	2.33

* Only 161 total responses to this response category

B. Attitudes toward employer-provided transportation programs and services

The survey included questions about employer-provided transportation programs and services, such as subsidized parking or transit passes, telecommuting, and bicycle storage. An initial question asked respondents to indicate whether their employer offered any programs and services from a list of such items (Table 59). Respondents reported that flexible work schedules were the most common form of employer-provided program or service (51.4% of all respondents answering this question). Only 17.3% of people indicated that their employer subsidized their parking. However, in comparison, parking was reported to be free for 93% of the 14,073 (weighted) trips to work made during the two day reporting period. It is assumed that people did not consider free parking as subsidized.

Table 59: Respondent assessment of employer-provided programs and services

	% Indicating employer offers program/service (weighted)
Subsidized parking	17.3%
Free / subsidized transit costs	16.2%
Flexible work schedule	51.4%
Telecommuting	22.1%
Carpool / vanpool assistance	14.2%
Guaranteed ride home	10.1%
Bicycle storage	16.2%
Don't know	10.1%
Refused	2.6%
None	22.5%

Two follow-up questions asked, first, how often the respondent used any indicated programs or services, and, second, how likely the respondent would be to use any programs or services that they had indicated their employer did not provide. Of those who indicated that the employer offered the program or service, subsidized parking was used most frequently, followed closely by flexible work schedules, and subsidized transit (Table 60).

Table 60: Frequency of use per week of employer-provided programs and services

	N (weighted)	Min	Max	Mean	Std. Dev.
Subsidized parking	851	0	12	3.0	2.4
Free / subsidized transit costs	804	0	10	2.0	2.6
Flexible work schedule	2509	0	12	2.9	2.3
Telecommuting	1087	0	10	1.3	2.0
Carpool / vanpool assistance	715	0	10	0.6	1.7
Guaranteed ride home	503	0	10	0.9	2.0
Bicycle storage	818	0	7	0.1	0.6

Of those who answered that their employer did not provide a program or service, Table 61 shows that people indicated that they would be most likely to use a flexible work schedule if offered the choice (46.1%), followed by telecommuting (35.6%), a guaranteed ride home (26.6%), subsidized parking (24.6%), and free or subsidized transit costs (22.5%). The least likely option was bicycle storage (still, the percent indicating they would be “likely” or “somewhat likely” to use this service – a combined 15.1% – suggests that bicycle-friendly accommodations might yield a significant increase in bicycle commuting *relative* to its current level (less than 1% of all commute trips). About the same percentage of respondents (almost 50% in both cases) indicated that they would “not likely” use subsidized parking or free/subsidized transit.

Table 61: Likelihood of using employer-provided programs and services if offered

	Subsidized parking	Free / subsidized transit costs	Flexible work schedule	Tele-commuting	Carpool / vanpool assistance	Guaranteed ride home	Bicycle storage
likely	24.6%	22.5%	46.1%	35.6%	19.9%	26.6%	7.1%
somewhat likely	13.5%	16.5%	15.6%	12.9%	22.9%	19.0%	8.0%
not likely	48.7%	49.1%	21.7%	38.0%	47.6%	43.6%	75.2%
Don’t know	11.2%	10.3%	13.5%	11.0%	8.0%	9.3%	8.1%
Refused	1.9%	1.6%	3.1%	2.6%	1.5%	1.5%	1.7%
Total	100%	100%	100%	100%	100%	100%	100%

C. Evaluation of one’s neighborhood and neighborhood influence on walking

A series of questions asked one randomly selected adult per household, 2240 individuals (weighted) in all, to evaluate their neighborhood in terms of a variety of qualitative indicators and to assess the walkability of their neighborhood as a consequence. Results are presented in the following tables.

For all respondents, Table 62 shows that nearly 40% rate their neighborhood as “excellent” (a rating of 1) with respect to being near major roads and interstates. About 37% indicate that their neighborhood is easy to walk in, followed by “near shops and services” (33%), “school quality” (32.6%), and “low crime” (31.5%). At the other end of the spectrum, over 40% of the sample respondents say that their neighborhood rates a “poor” (a rating of 5) for being near public transit, while “closeness to job” receives a poor rating for 23.5% of respondents. Only small percentages of respondents gave the other factors a poor rating.

Table 62: Evaluation of neighborhood quality

(percent of respondents; 1 = "Excellent"; 5 = "Poor")

	1	2	3	4	5	DK	RF	Total
Affordability	30.3	22.6	24.7	9.9	7.3	3.6	1.5	100%
Ease of walking	36.9	17.6	16.1	11	13.5	3.2	1.6	100%
Closeness to job	26.1	16.7	17.4	11.5	23.5	3.1	1.7	100%
Near public transit	20.7	11.4	10.1	9.5	42.2	4.5	1.6	100%
Near major roads / interstates	39.5	26.8	16.3	6.6	6.1	3	1.6	100%
Near shops / services	33	28	19.6	7.9	7	2.9	1.7	100%
School quality	32.6	20.3	15.8	6.4	6.5	16.2	2.1	100%
Near outdoor recreation	28.8	23.9	21.8	10.7	8.3	4.8	1.6	100%
Low crime	31.5	28.4	19.5	8.8	1	7.5	3.3	100%

Not surprisingly transits users (people who reported at least one transit trip during the survey period) rate the proximity of transit to their neighborhood as excellent at a much higher rate, than the entire surveyed population, and similarly far fewer, on a percentage basis, rate it poor; please see Table 63.

Table 63: Evaluation of neighborhood quality: proximity to public transit, transit users and entire sample

	% Transit Users Only	% Entire Surveyed Population
Excellent	49.9%	20.7%
2	14.5%	11.4%
3	13.2%	10.1%
4	6.0%	9.5%
Poor	12.4%	42.2%
Don't know	3.6%	4.5%
Refused	0.5%	1.6%

The evaluation of neighborhood quality becomes clearer when answers are compared to the NRD levels of respondents' neighborhoods. As shown in Table 64, there are important differences across NRD levels for every response category. For respondents living in the least dense neighborhoods, satisfaction was substantially higher for neighborhood affordability, school quality, and crime than for those respondents living in higher density neighborhoods (where higher satisfaction is indicated by a lower average score). Additionally, for the categories "near shops and services" and "near outdoor recreation", satisfaction was unexpectedly marginally higher for people living in the lowest density areas than in the highest density ones.

Conversely, respondents living in the highest density neighborhoods were more satisfied with ease of walking and proximity to employment, public transit, and major roads/interstates. The different responses to the transit proximity category are as expected given the Atlanta region's limited transit system coverage: those living in the highest density areas gave an average response of 2.1, whereas those in the least dense areas gave an average score of 4.3. Finally, while respondents in higher density areas did indicate a higher degree of satisfaction with walking conditions in their neighborhood, the difference in scores between the lowest and highest density areas (2.6 to 2.4 respectively) is not as great as might be expected. If the question had distinguished between ease of walking for utilitarian (e.g. travel to shop or work) versus recreational (e.g. evening strolls or walks for exercise) reasons, people in different density levels may have reported a greater variation for ease of walking in their neighborhood.

Table 64: Evaluation of neighborhood quality by NRD

(percent of respondents; 1 = "Excellent"; 5 = "Poor")					
	0 – 1.999 du/net res. acre	2 – 3.999 du/net res. acre	4 – 5.999 du/net res. acre	6 – 7.999 du/net res. acre	8+ du/net res. Acre
Affordability	2.2	2.4	2.7	2.7	2.9
Ease of walking	2.6	2.4	2.2	2.4	2.4
Closeness to job	3.1	2.9	2.7	2.6	2.5
Near public transit	4.3	3.1	2.4	2.4	2.1
Near major roads / interstates	2.3	2.0	1.9	1.9	1.7
Near shops / services	2.2	2.2	2.4	2.3	2.3
School quality	2.0	2.3	2.5	2.8	2.6
Near outdoor recreation	2.4	2.5	2.4	2.5	2.4
Low crime	1.8	2.2	2.4	2.6	2.6

Some light is shed on the latter issue by responses to a question on destinations that are within a 10-minute walk of home (Table 65 and Table 66). A surprisingly high percentage of the 7,589 respondents indicated that restaurants, grocery and retail stores, day care centers, sports facilities, banks, and doctors' offices were within a 10-minute walk (over 20% in all cases, rising to 44.1% for restaurants). Almost one-third of all respondents indicated that none of the listed destinations were within a short walking distance from home.

Table 65: Evaluation of neighborhood walkability: extent of destinations within 10-minute walk of home

Destination	% Indicating within 10 minutes (weighted)*
Grocery store	37.3%
Retail store	28.4%
Day care	28.9%
Bank / credit union	30.5%
Doctor / health clinic	22.5%
Restaurant	44.1%
Sports facility	28.3%
None of these	31.2%

*Total Responses 7,589

The influence of urban form on walkability is brought into some focus by looking at responses across NRD. For people living in the lowest density areas, the percent of respondents indicating that destinations are within a short walk is consistently lower than those living in higher density neighborhoods. The percent of respondents in the lowest density category (0-1.9999 du/net res. acre) responding that there are no destinations within a short walk is much higher (46.2%) than all other categories. Conversely, those in the highest density category (8+ dwelling units per residential acre) often responded that a destination was within a short walk at a rate twice that of those living in the lowest density category – this is true for grocery and retail stores, banks, doctors' offices, and restaurants. In addition to the difference at the extremes of density for these four destinations, there was a substantial increase moving from the lowest density level to the next (0-3.999 du/net res. acre). While nearly twice as many people in the highest density level as compared to those in lowest level report "sports facility, field, court or track" within a ten minute walk, in Table 64 the same people rate the quality of their neighborhood similarly for "nearness to outdoor recreation." Sports facility, etc. and outdoor recreation apparently denote very different land uses to the respondents.

Table 66: Neighborhood walkability: destinations within 10-minute walk of home by NRD

	NRD (weighted)				
	0 – 1.999 du/net res. acre	2 – 3.999 du/net res. acre	4 – 5.999 du/net res. acre	6 – 7.999 du/net res. acre	8+ du/net res. acre
Grocery store	27.2%	43.5%	43.1%	49.7%	52.1%
Retail store	19.2%	32.7%	34.0%	43.9%	43.6%
Day care	22.5%	34.9%	32.3%	33.3%	34.9%
Bank/Credit Union	21.1%	33.7%	37.3%	44.4%	50.4%
Doctor/health clinic	15.4%	24.8%	27.2%	32.3%	38.8%
Restaurant	28.9%	50.0%	58.7%	63.8%	68.5%
Sports facility, field, court or track	22.8%	27.9%	34.9%	39.9%	40.5%
None	46.2%	24.3%	18.3%	9.3%	9.5%
Don't know	2.7%	3.2%	3.8%	2.6%	3.4%
Refused	0.8%	1.1%	0.8%	1.3%	1.0%

X. PHYSICAL ACTIVITY SUB-SURVEYS

Provided here are summaries of the four sections contained in a separate SMARTRAQ report, #VII.30, provided to the GDOT.

A. Physical activity questionnaire

The health and physical activity data from 816 people reported on here was collected through a sub-survey of the larger Atlanta 2001 and 2002 activity-based household travel survey (AHTS) and consisted of a sample area of the 13-county metropolitan area. Participants in the sub-survey received a paper questionnaire and one of two personal equipment packages—an activity monitor or an electronic travel diary (ETD).

The physical activity questionnaire consists of three primary sections—walking, bicycling, and social interaction. The unweighted findings include:

1. Walking

- Walking frequency varied positively with increased neighborhood net residential density. The NRD of the 81.5% of respondents who walk at least once per week is 4.9 housing units/ net-residential acre, compared to 10.2 for the 7.3% daily walkers.
- Residents of high density neighborhoods walk more in their own community, while residents of low density neighborhoods walk more frequently elsewhere.
- Respondents living in neighborhoods with a high mix of residential, commercial and office land uses (and also high density) tended to strongly agree there were destinations such as services and shops within walking distance of their home. Respondents living in areas with a lower mix of uses (and less density) strongly disagreed with this statement.
- The largest proportion of obese individuals (body mass index >=30) is in the category of respondents that do not walk at all in a given week, and unexpectedly

the second highest proportion is associated with daily walkers. The group of people who walk three to six times per week had the lowest obesity percentage.

2. Bicycling

- The frequency of bicycling and the presence of bicyclists in a neighborhood both increase with residential density. While most respondents (74.9%) do not ride a bicycle at all, 24.8% (N=202) ride a bicycle at least once per week but not every day.
- While relatively few people surveyed actually ride a bicycle on a regular basis, 86.5% reported seeing bicyclists present in their neighborhood at least once per week, indicating that most neighborhoods are able to support at least some bicycling.
- Although people that bicycle at least once per week tend to live in higher density, more mixed neighborhoods, the conditions for bicycling are not necessarily better there. People in high density neighborhoods tended to disagree with the statement “there are good road conditions for bicycling in my neighborhood. Those that agreed with the statement generally live in lower density neighborhoods.

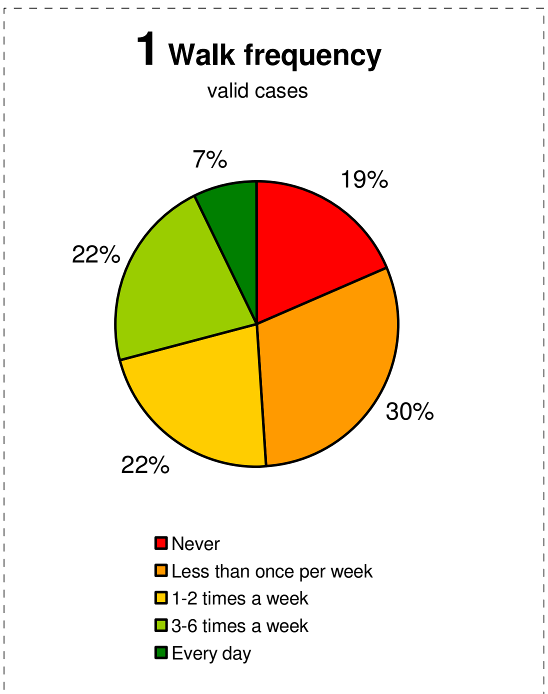
3. Social Interaction

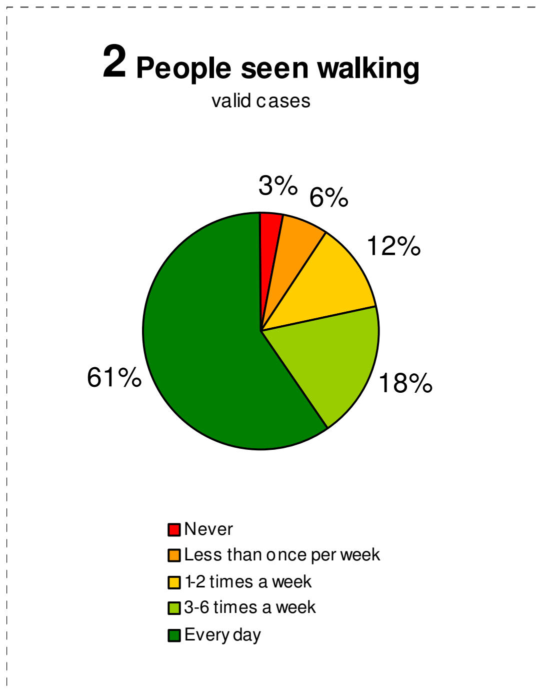
- Slightly over half of respondents reported knowing seven or more neighbors. All but 5.7% know at least one neighbor.
- Despite denser living conditions, the number of neighbors known tended to be inversely related to mean net residential density. The lowest NRD was actually calculated for the set of respondents that know seven or more neighbors. The highest NRD was found for those that know only one or two neighbors.
- Similarly, use mix tended to be highest for those that strongly disagreed or disagreed with the statement “living in my neighborhood gives me a sense of community.” Mix tended to be lowest for those that agreed with the statement. A blend of commercial, office and residential uses also does not appear to

necessarily ensure a sense of community. NRD was highest for those that strongly disagreed or disagreed and highest for those that agreed. Despite the more compact living conditions of a higher NRD neighborhood, the close proximity of neighbors does not necessarily instill a sense of community.

The first question in the physical activity survey inquired how often the respondent walks or jogs in his or her neighborhood. Overall, 81.5% of respondents reported that they walk at least once per week (shown below in Figure 46A). Only 7.3% of the respondents in the survey reported that they walk every day. A high proportion of respondents in the survey (96.8%) stated that they see others walking in their neighborhoods at least once per week and a majority (59.9%) see pedestrians on a daily basis (Figure 46B).

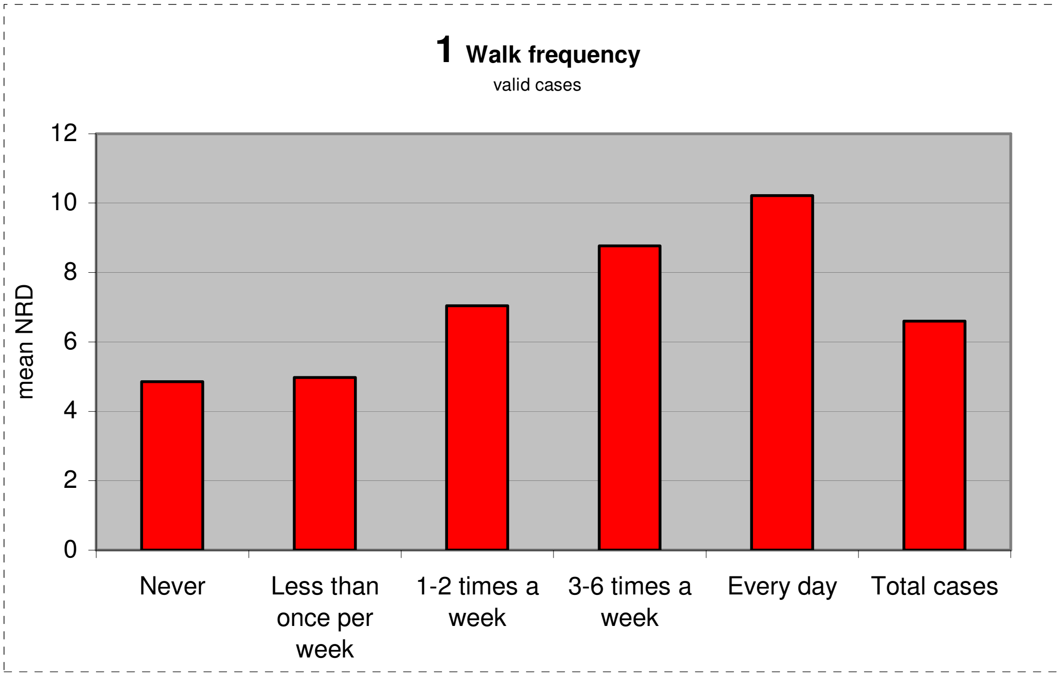
Figure 46A PAQ (Question 1, left) and B (Question 2, right)





Respondents that reported walking less than once per week or not walking at all had the lowest mean net residential densities at the one-kilometer network buffer level, about 4.9 units/net res. acre (Figure 47). Those that reported walking at least once per day had the highest mean net residential density at about 10.2 units/net res. acre, about twice that of the non-walkers.

Figure 47: PAQ Question 1



Variations in mean body mass index (BMI) did not significantly vary with frequency of walk trips, however the percentage of individuals with a BMI greater than or equal to 30 varied greatly[28]. A person with a BMI of 30 or greater is considered have a very high amount of body fat in relation to lean body mass, and is considered obese, according to the National Institutes of Health.

The percentage of obese respondents out of total respondents in each individual walk frequency category is shown below in Figure 48. The largest proportion of obese individuals occurred in the category of respondents that do not walk at all in a given week. The proportion decreased with walk frequency until the category of people walking three to six times per week, when it steadily rose with increased walk frequency.

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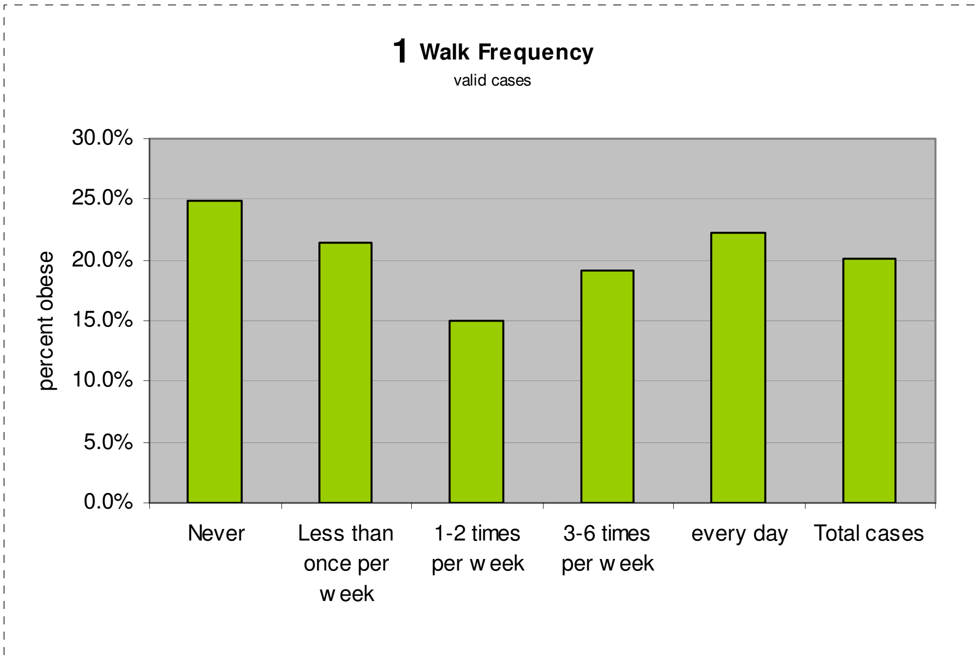
[28] Body Mass Index (BMI): a measure of an adult's weight in relation to his or her height, specifically the adult's weight in kilograms divided by the square of his or her height in meters

Higher incidences of obesity occurred in the categories of non-walkers and, unexpectedly, very frequent walkers. While this question asked about walk frequency it does not provide information on duration or level of exertion, both of which are important determinants of the health impacts. Like all the other questions reported on here this question relies on self-reported data.

Figure 48: PAQ Question 1



B. GPS-based travel survey

The GPS-based physical activity component of SMARTRAQ developed and tested a person-based methodology to objectively collect the spatial and temporal aspects of urban travel, especially non-motorized travel.

Of the 2,214 GPS trips self-reported by respondents, 88.5% were made by automobile, 0.3% bicycle, 0.6% bus and train and 5.6% walk. These 144 walk trips were made by 62 of the 186 people who completed all three parts of the survey. Given that 124 people had no reported walk trips, large numbers of walk trips continue to go undetected even, with the equipment package used, and the data analysis methodologies employed. are likely another mode based on the travel speeds.

Walk trips, more than any other mode, were not self-reported by participants on the PDA portion of the ETD survey. Approximately thirty-seven percent of all walk trips were unreported, as compared to 23.5% for automobile trips, a difference of over 50%.

Based on fewer than 28 observations per age category, walk trip distances and durations increased with age until the 45-49 age group, falling sharply for 50-54 year olds and leveling off around 0.6 miles for 55-64 year olds.

Unexpectedly, the findings across household urban form seem to indicate that people who live in areas considered to be less walkable (lower net-residential density, intersection densities and mixed use) walk faster, longer and farther than people living in more walkable areas. These findings are based on walk trip data that becomes very limited when distributed across four to five categories of urban form, with as few as seven trips.

The number of walk trips as a percentage of all trips increases with net residential density (NRD), except for the two highest levels, which also have the fewest observations (Table 67). Walk trip frequency was highest for the 4-5.999 units/net residential acre category, followed by 6-7.999 units/net residential acre. Surprisingly the highest and second lowest density ranges have similar numbers of trips and frequencies. The fewest mean walk trips were made by households in the lowest net residential density.

Table 67: Mean numbers of daily walk trips by NRD (1km network buffer level)

Residential units/net residential acre	Mean number of daily GPS trips		% Walk trips	N people
	All modes	Walk		
1-1.999	4.70	0.20	4.10%	85
2-3.999	4.95	0.32	6.50%	50
4-5.999	4.90	0.66	13.50%	28
6-7.999	5.15	0.57	11.10%	7
8+	4.53	0.35	7.60%	16
Total	**4.80**	**0.33**	**6.80%**	**186**

Walk trip frequency, as a percent of all trips, increased with increasing intersection density, with one exception (Table 68). There is a significant decrease at the 10-19.999 int/km^2 category. Walk frequency in the highest range is nearly twice that of the lowest.

Table 68: Mean numbers of walk trips by intersection density (1km network buffer level)

Intersection/square kilometer	Mean number of daily GPS trips		% Walk trips	N people
	All modes	Walk		
0-9.99	5.46	0.29	5.30%	12
10-19.99	4.50	0.07	1.50%	29
20-29.99	5.03	0.27	5.40%	35
30-39.99	4.99	0.35	7.00%	46
40+	4.54	0.46	10.20%	64
Total	**4.80**	**0.33**	**6.80%**	**186**

The use mix factor produced the following results at the one-kilometer network buffer level (please see Chapter II for further discussion of the calculation). Percentage of walk trips increased with increased use mix until the 0.5+ category, which produced the lowest percentage of walk trips overall (Table 69). The highest use mix category also displayed the lowest mean number of total trips and the lowest mean number of walk trips.

Table 69: Mean numbers of walk trips by use mix (1km network buffer level)

Use Mix	Mean number of daily GPS trips		% Walk trips	N people
	All modes	Walk		
<0.1	4.55	0.24	5.4%	78
0.1 - 0.25	5.84	0.53	9.1%	31
0.25 - 0.5	5.32	0.53	10.0%	33
0.5+	4.10	0.17	4.2%	44
Total	**4.80**	**0.33**	**6.8%**	**186**

In addition to collecting more data to increase the sample sizes, another future improvement on for urban form analysis is to consider it at the origins and destinations together, rather than just for the participant's home location. This consideration of the urban form of both trip end points could provide additional insight into the effect of urban form on travel duration and distance.

XI. SMARTRAQ PARCEL-LEVEL LAND USE DATA

The purpose of this section is to provide descriptive statistics of the land use characteristics of the region using version 1.5 of the SMARTRAQ land use database. As discussed at the outset of this report, a major component of the SMARTRAQ research program was the construction of a parcel-level land use database for the thirteen counties in the study area. Variables in the database are listed in

Table 70. The data was assembled by the Georgia Tech Center for Geographic Information Systems (CGIS) using local and regional information sources.

The land use database was created by linking tax assessor data with parcel location data (represented as parcel centroids). The centroid locations were generated from information provided to CGIS by each county. In most counties, the square footage of structures on the parcel was incomplete. For these records, an estimated square footage field was calculated using regression equations that estimated size based on the assessed value for commercial, industrial and office properties. Please see Chapter II for more information on this process. In addition to the regional database, the CGIS has created individual databases for each county within the study area.

Table 70: Land Use Database Variables

Variable	Description
SHAPE	Object shape
PARCELID	Property ID
TAXVALUE	Assessed tax value ($) of property
YRBUILT	Effective year built
ACREAGE	Acreage of parcel
TOTALSQFT	Total square footage of structures
ESTSQFT	Estimated total square footage of structures from regression model
LANDUSE	Land use code
IMPVALUE	Improvement value ($) of all structures on property
COUNTY	County name

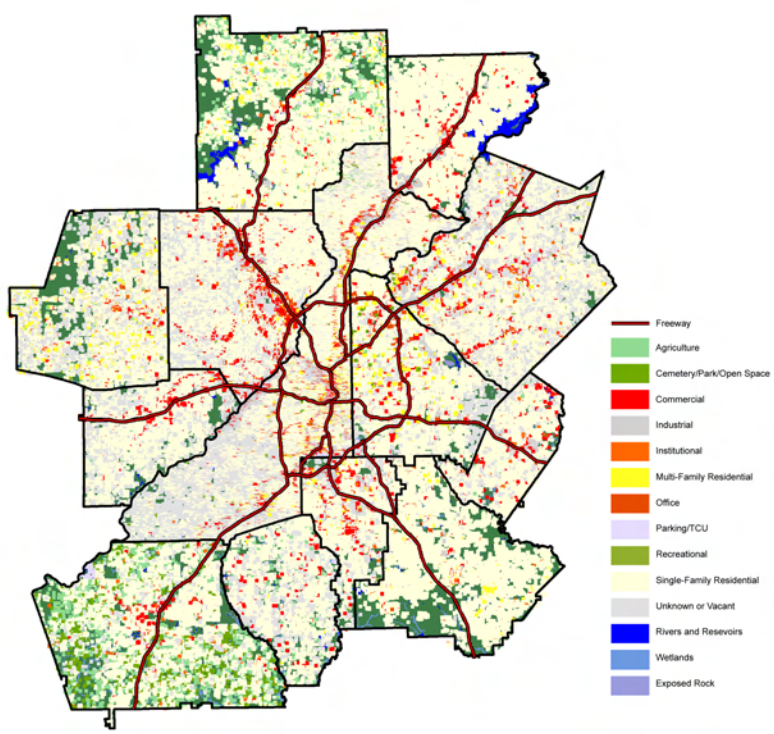
The database contains 13 types of land uses, listed in Table 71. A land use types is associated with each parcel in the database.

Table 71: Land Use Type Descriptions

Land Use Type	Description
Agriculture	Property actively used in agriculture
Cemetery / Park / Open space	Public parks, cemeteries and open spaces
Commercial	Wholesale and retail trade
Industrial	Manufacturing, light industry and warehousing
Institutional	Government or other institutional uses
Mobile Home	Single mobile home or mobile home park
Multi-Family Residential	Apartment or other attached housing units
Office	High and low-rise offices
Parking / TCU	Parking lot or structure, transportation, communication or utility use
Recreational	Golf course or other recreation area
Single-Family Residential	Owner occupied, detached housing unit
Unknown	Use could not be determined
Vacant	Undeveloped parcel

Figure 49 shows the general distribution of land uses across the Atlanta region as revealed by coloring the parcel centroids to reflect their land use classification. Even at this scale it is possible to identify a number of fairly well defined clusters of commercial and office uses. Downtown is, of course, prominent, but there are also visible clusters in Midtown, Buckhead, Cumberland/Galleria and Perimeter Center as well as some of the smaller city centers, such as Marietta, Lawrenceville and Decatur. Major transportation corridors, such as the Interstate 75 and 85, Peachtree Industrial Boulevard and GA-400 are highlighted by the pattern of commercial and industrial uses along them. Fulton Industrial area is also evident from its cluster of industrial uses. A fair amount of green space is evident at the margins of the region and along the Chattahoochee River, particularly in South Fulton and Douglas Counties. To provide a more realistic picture of land use intensity, this analysis will be replicated using square footage data or each land use, once it has been sufficiently cleaned to be reliable.

Figure 49: Parcel-level Land Use from the Regional Perspective



A. Parcel count

There are 1,140,284 parcels in the thirteen-county study area. As shown in Table 72, the most parcels are contained in Fulton (20.1% of regional total), Cobb (16.9%), DeKalb (16.4%), and Gwinnett (14.9%) Counties. The least are in Rockdale (2.5% of regional total) and Paulding (2.7%) Counties.

Table 72: Parcel count by county

	Number	% of total
Cherokee	52,955	4.6%
Clayton	64,926	5.7%
Cobb	192,584	16.9%
Coweta	32,565	2.9%
DeKalb	187,153	16.4%
Douglas	33,319	2.9%
Fayette	32,903	2.9%
Forsyth	39,554	3.5%
Fulton	229,458	20.1%
Gwinnett	170,023	14.9%
Henry	45,373	4.0%
Paulding	31,074	2.7%
Rockdale	28,397	2.5%
Regional total	1,140,284	100%

By type of land use, Table 73 shows that single-family residential parcels are the most common, by far, in the region, accounting for 82.1% of all parcels. Vacant parcels are the second most common, at 7.7% of the total. In order, the next most common are multi-family residential (3.0%), commercial (2.8%), and industrial (1.0%) parcels. Parcels with unknown use types constitute 1.2% of the total. Therefore, residential parcels (single- and multi-family housing plus mobile homes) constitute 85.6% of all parcels in the region.

Table 73: Parcel count by land use type

	Number	% of total
Agriculture	2,824	0.2%
Cemetery / Park / Open space	1,857	0.2%
Commercial	31,763	2.8%
Industrial	10,899	1.0%
Institutional	5,975	0.5%
Mobile Home	5,369	0.5%
Multi-Family Residential	34,345	3.0%
Office	5,344	0.5%
Parking / TCU	3,069	0.3%
Recreational	824	0.1%
Single-Family Residential	936,012	82.1%
Unknown	14,081	1.2%
Vacant	87,922	7.7%
Regional total	1,140,284	100%

B. Parcel size (acreage)

Of the 1.14 million parcels in the region, only 571,141 contain valid acreage observations (parcels that have been assigned acreage data greater than zero). This problem is due to the incompleteness of many of the county-level tax assessor databases. Of the 571,141 parcels with valid acreage data, the mean parcel size is 3.17 acres (with a minimum observation of 0.02 acres, a maximum of 37,461 acres, and a standard deviation of 55.2 acres). The mean is slightly misleading, as large observations skew the data – as shown in Table 74, approximately half the parcels are a half acre or smaller, with only 25% of the observations above 1.2 acres in size.

Table 74: Parcel size – data quartiles

Quartile	Parcel size (acres)
25	0.3
50	0.51
75	1.19

Table 75 shows the mean acreage per parcel for each land use type. Logically, agricultural parcels constitute the largest type of parcel on average, followed by cemeteries/parks/open space and recreational parcels. Residential parcels are the only types of parcels that are smaller, on average, than the regional mean of 3.17 acres for all parcel types. The mean for single-family residential parcels is 2.15 acres.

Table 75: Average parcel size by land use type

Land use type	Acreage mean	% difference from regional mean
Agriculture	64.33	1931.6%
Cemetery / Park / Open space	43.99	1289.3%
Recreational	13.63	330.5%
Unknown	7.83	147.3%
Vacant	6.51	105.7%
Industrial	5.40	70.6%
Institutional	4.95	56.4%
Commercial	4.42	39.4%
Mobile Home	4.41	39.3%
Parking / TCU	4.23	33.7%
Office	3.68	16.1%
Single-Family Residential	2.15	-32.2%
Multi-Family Residential	1.75	-44.8%

Further insight into parcel size is gained by breaking the distribution of parcels down by county, as shown in Table 76. The largest average parcel sizes tend to be in outlying counties, while the smallest tend to be closer to the region's core. Again, this makes sense as, generally speaking, land is both more expensive closer to the region's center and is more heavily urbanized (meaning that the parcel mix has shifted from larger, undeveloped types of parcels such as agricultural parcels to smaller, developed parcels such as housing or commercial operations). In order of ranking, Henry, Coweta, Fayette, and Cherokee counties have the largest average parcel sizes, while Fulton and Gwinnett have the smallest. As heavily developed as DeKalb is, it is surprising its mean is not lower

Table 76: Average parcel size by county

County	Acreage mean	% difference from regional mean
Henry	23.18	632.2%
Coweta	16.23	412.6%
Fayette	10.73	238.8%
Cherokee	8.60	171.5%
Douglas	8.17	158.0%
Paulding	6.96	119.8%
Clayton	4.14	30.7%
DeKalb	3.58	13.1%
Cobb	3.52	11.3%
Forsyth	3.28	3.6%
Rockdale	3.17	0.0%
Gwinnett	1.31	-58.6%
Fulton	1.26	-60.1%

In terms of aggregate parcel size, the following tables (Table 77 and Table 78) show the distribution by type of land use and county. Single-family residential parcels account for over half (52.7%) of the acreage in the region, followed by vacant parcels (19.5%), agricultural parcels (9.3%), and commercial parcels (6.6%).

Table 77: Total acres by land use type

Land use type	Total acres	% of total
Agriculture	169,051	9.3%
Cemetery / Park / Open space	52,435	2.9%
Commercial	119,427	6.6%
Industrial	53,610	3.0%
Institutional	25,610	1.4%
Mobile Home	16,929	0.9%
Multi-Family Residential	27,450	1.5%
Office	15,517	0.9%
Parking / TCU	10,464	0.6%
Recreational	10,263	0.6%
Single-Family Residential	953,334	52.7%
Unknown	1,965	0.1%
Vacant	352,379	19.5%
Total	1,808,434	100%

The total parcel acreage reported by each county as well as the total actual acreage of the entire county is shown below in Table 78. As indicated, large counties such as Cobb and DeKalb have very low total acreage reported compared to the actual acreage, while Paulding County actually over-reported its parcel acreage. The parcel-level database indicates that Fulton County contains the most acreage in the region, followed closely by Cherokee, Gwinnett, and Paulding counties (Table 78). The four largest counties in terms of actual acres are Fulton, Coweta, Cherokee and Gwinnett. The smallest are Clayton, Cobb, and DeKalb counties. The smallest three counties in terms of actual acreage are Rockdale, Clayton and Douglas. A couple of important points must be made in this context, however. First, as noted above, the database contains only about 570,000 parcels (out of 1.14 million) that contain acreage information. Second, by definition, the parcel-level database excludes areas not defined as "parcels", including for instance highways and roads. The result is that the database does not contain acreage information about the entire land area of the region. Additionally, as the database is assembled from county data, errors at the county level may skew the results regarding parcel acreage by land use type or by county. For instance, if county X systematically underreports acreage information, that county's acreage vis-à-vis the regional total will be reduced. Similarly, if counties Y and Z systematically under report the acreage of commercial parcels, the amount of commercial acreage will be reduced at the regional level.

Table 78: Total reported acres by county

County	Total reported acres	% of total	Actual acres	% of actual total
Cherokee	221,933	12.3%	278,129	10.8%
Clayton	37,391	2.1%	92,532	3.6%
Cobb	41,505	2.3%	220,715	8.6%
Coweta	200,170	11.1%	285,023	11.0%
DeKalb	62,865	3.5%	173,551	6.7%
Douglas	95,732	5.3%	127,420	4.9%
Fayette	73,102	4.0%	127,674	4.9%
Forsyth	128,472	7.1%	158,403	6.1%
Fulton	263,288	14.6%	342,306	13.3%
Gwinnett	220,315	12.2%	279,647	10.8%
Henry	184,271	10.2%	207,276	8.0%
Paulding	208,314	11.5%	202,534	7.9%
Rockdale	71,076	3.9%	84,648	3.3%
Total	1,808,434	100%	2,579,857	100%

Table 79, below, shows the percent of valid acreage data available by county and land use type. While counties such as Forsyth and Gwinnett provided nearly 100 percent acreage data, Cobb and DeKalb counties provided less than ten percent each. As shown in Table 78, these tax assessors reported very little of the actual acreage of the county. Land uses such as agriculture, recreational and industrial had the most complete acreage data. These land use types also have relatively large mean acreages, as shown in Table 75. Unknown parcels, multi-family residential, and single-family residential parcels had the lowest percentages of valid acreage data.

Table 79: Percent of Parcels with valid acreages by county and land use type

County	Parcels	% of total parcels with valid acreage	Land use	Parcels	% of total parcels with valid acreage
Cherokee	27,140	51.25%	Agriculture	196	6.94%
Clayton	55,892	86.09%	Cem / Park / Open	665	35.81%
Cobb	180,806	93.88%	Commercial	4,713	14.84%
Coweta	20,232	62.13%	Industrial	973	8.93%
DeKalb	169,592	90.62%	Institutional	803	13.44%
Douglas	21,600	64.83%	Mobile Home	1,532	28.53%
Fayette	26,089	79.29%	Multi-Family Res.	18,641	54.28%
Forsyth	380	0.96%	Office	1,122	21.00%
Fulton	20,826	9.08%	Parking / TCU	598	19.49%
Gwinnett	2,058	1.21%	Recreational	71	8.62%
Henry	37,425	82.48%	Single-Family Res.	492,167	52.58%
Paulding	1,145	3.68%	Unknown	13,830	98.22%
Rockdale	5,958	20.98%	Vacant	33,832	38.48%
Region	569,143	49.91%	Region	569,143	49.91%

Another interesting set of questions involves the distribution and size of parks and open space by county. As indicated in Table 75 and Table 77 above, the average "Cemetery / Park / Open space" (designated here as "parks and open space") is 44 acres in size, with a total amount of 52,435 acres for the region. As seen in Table 80, the largest average parcel sizes are in Coweta, Clayton, and DeKalb counties, while there are four counties – Fayette, Forsyth, Henry, and Rockdale – with an average parcel size of zero acres for this land use type (see discussion of valid parcel count below).

Table 80: Mean parks and open space parcel acres, by county

County	Mean parcel size (acres)	% of regional mean
Coweta	54.52	23.9%
Clayton	30.57	-30.5%
DeKalb	24.43	-44.5%
Paulding	15.30	-65.2%
Fulton	11.02	-75.0%
Douglas	10.21	-76.8%
Gwinnett	7.20	-83.6%
Cherokee	4.52	-89.7%
Cobb	1.55	-96.5%
Fayette	0	-100.0%
Forsyth	0	-100.0%
Henry	0	-100.0%
Rockdale	0	-100.0%

In aggregate, Table 81 shows that the great majority of the region's acreage classified as parks and open space is in Coweta County, at 94% of the regional total of such parcels. This unexpected result likely results from the different methods used by counties to classify land uses. Moreover, the parks and open space in Coweta constitute nearly 25% of that county's total acreage. Fulton County is a distant second, with 1,619 acres of parks and open space constituting 3.1% of the regional parks/open space total and only 0.6% of Fulton's total area. Still, Fulton's total is several times more than all other remaining counties. Again, four counties have a total of zero acres classified as parks and open space (Fayette, Forsyth, Henry, and Rockdale), while an additional four counties – Cherokee, Douglas, Paulding, and Cobb – have less than 100 acres so classified.

Table 81: Total parks and open space acreage by county

County	Total parks and open space acres	% of county's total acreage	% of regional parks and open space acreage
Coweta	49,175	24.6%	93.8%
Fulton	1,619	0.6%	3.1%
Clayton	642	1.7%	1.2%
Gwinnett	597	0.3%	1.1%
DeKalb	195	0.3%	0.4%
Cherokee	86	0.0%	0.2%
Douglas	71	0.1%	0.1%
Paulding	46	0.0%	0.1%
Cobb	3	0.0%	0.0%
Fayette	0	0.0%	0.0%
Forsyth	0	0.0%	0.0%
Henry	0	0.0%	0.0%
Rockdale	0	0.0%	0.0%

The number of "valid count" parcels (parcels above zero acres) per county is shown in Table 82. The list is consistent with the above observations, with Coweta County having the most parcels by far (902), followed by Fulton County. Again, this result may be a product of the different methods used by counties to classify land uses. There are eight counties on the list with fewer than ten such parcels.

Table 82: Valid parcel count (acreage > 0), parks and open space, by county

County	Valid parcel count
Coweta	902
Fulton	147
Gwinnett	83
Clayton	21
Cherokee	19
DeKalb	8
Douglas	7
Paulding	3
Cobb	2
Fayette	0
Forsyth	0
Henry	0
Rockdale	0

C. Age of construction

The year in which structures on a parcel were constructed also provides important information. The land use database contains the age in which the structure(s) on the parcel were built; some 911,000 of the 1.14 million parcels in the database (80.5%) contain year built data. In the Atlanta region, the extremely high growth rates of the 1980s and 1990s are reflected in the parcel data. While the oldest structure in the database was recorded as having been built in 1790, the mean parcel in the region was developed in 1975, with a standard deviation of 19.3 years. Table 83 clarifies the impact of Atlanta's explosive recent development: only a quarter of the region's parcels were built before 1964 and only 50% before 1980. In contrast, fully a quarter of the region's parcels have been built since 1989.

Table 83: Age of construction – data quartiles

Quartile	Parcel age (date of construction)
25	1964
50	1980
75	1989

Table 84and Table 85 break down the age of construction by land use type and county, respectively. As is shown in Table 84, the newest parcels (on average) fall into the categories of mobile homes, office, industrial, and single-family residences, all of which have a mean age of 1975 or later. The oldest parcels on average are those with an unknown land use type, agricultural parcels, and vacant parcels.

Table 84: Mean age of construction by land use type

Land use type	Mean age	% difference from regional mean
Unknown	1957	-0.9%
Agriculture	1961	-0.7%
Vacant	1961	-0.7%
Parking / TCU	1963	-0.6%
Commercial	1967	-0.4%
Multi-Family Residential	1970	-0.2%
Recreational	1971	-0.2%
Institutional	1972	-0.1%
Cemetery / Park / Open space	1973	-0.1%
Single-Family Residential	1975	0.0%
Industrial	1975	0.0%
Office	1975	0.0%
Mobile Home	1980	0.2%

Table 85 provides some insight into the spatial and temporal distribution of parcels in the region. In only Fulton and DeKalb counties are the mean ages of parcels greater than the mean for the region (1975). While this is a logical finding, given that Fulton and DeKalb are the two counties at the very center of the region, what is perhaps somewhat surprising is the relative youth of development in all other counties, including all counties immediately adjacent to Fulton and DeKalb counties. For six counties – Forsyth, Gwinnett, Henry, Fayette, Paulding, and Cherokee – the mean age is after 1980.

Table 85: Mean age of construction by county

County	Mean age	% difference from regional mean
Fulton	1963	-0.6%
DeKalb	1968	-0.4%
Clayton	1975	0.0%
Coweta	1976	0.0%
Douglas	1978	0.1%
Cobb	1978	0.2%
Rockdale	1979	0.2%
Cherokee	1981	0.3%
Paulding	1981	0.3%
Fayette	1982	0.3%
Henry	1983	0.4%
Gwinnett	1983	0.4%
Forsyth	1984	0.4%

D. Assessed tax value

The mean assessed tax value, or value of the land and structures on it, for all parcels in the region is $159,024 (approximately 1.1 million parcels have tax value data in the database, or 96.7% of the parcels), with a standard deviation of $947,969. The large standard deviation is reflective of the extreme value of some large office, commercial, and industrial parcels – the highest recorded value for a single parcel in the database is $180 million.

Table 86 shows mean assessed tax value by land use type, ordered from the highest to lowest value. Logically, those parcels that are operated for business or institutional purposes have the highest average value – office parcels have a mean value of $2.16 million, institutional and industrial parcels are at $0.9 million, while recreational, commercial, and parking/TCU parcels all average more than $500,000. At the other end of the spectrum are mobile homes, vacant parcels, and single-family residences.

Table 86: Mean assessed tax value by land use type

Land use type	Mean assessed tax value	% difference from regional mean
Office	$2,163,962	1260.8%
Institutional	$929,211	484.3%
Industrial	$877,039	451.5%
Recreational	$783,136	392.5%
Commercial	$581,769	265.8%
Parking / TCU	$578,247	263.6%
Multi-Family Residential	$367,764	131.3%
Agriculture	$140,014	-12.0%
Unknown	$132,662	-16.6%
Cemetery / Park / Open space	$131,976	-17.0%
Single-Family Residential	$117,962	-25.8%
Vacant	$89,455	-43.7%
Mobile Home	$46,257	-70.9%

Table 87 shows the breakdown of assessed tax value by county, in descending order of value. Fulton County dominates the ranking, with a mean value nearly $84,000 higher than the next county on the list, Fayette County. Fulton's sizable advantage in this respect is due to the concentration of office, commercial, and institutional parcels in the city of Atlanta and north Fulton County (the mean office parcel is $4 million more than any other County); however, it should be noted that part of the explanation also lies in the fact that the mean value for single family homes is highest in Fulton County. With the notable exception of Fayette County, all of the counties that are in the southern half of the region are at the bottom of the list, underscoring the observation that Atlanta's growth, and therefore the majority of its wealth, has centered upon the city of Atlanta and the region's northern counties.

Table 87: Mean assessed tax value by County

County	Mean assessed tax value	% difference from regional mean
Fulton	$241,520	51.9%
Fayette	$157,685	-0.8%
Cobb	$157,057	-1.2%
DeKalb	$153,569	-3.4%
Gwinnett	$151,760	-4.6%
Forsyth	$145,952	-8.2%
Cherokee	$124,760	-21.5%
Rockdale	$118,595	-25.4%
Clayton	$112,770	-29.1%
Henry	$109,264	-31.3%
Douglas	$104,371	-34.4%
Coweta	$91,714	-42.3%
Paulding	$66,497	-58.2%

E. Improved value

The improved value field in the land use database refers to the appraised value of all buildings, permanent structures or other developments on a parcel, whereas the assessed tax value includes both structures and the value of the property. Whereas 96.7% of parcels include tax values, approximately 82% of the parcels in the database have a an improved value greater than zero. The regional mean is $129,301, with a standard deviation of $877,364. As was the case with assessed tax value, this wide variation is due to the extremely high value of some commercial, office, institutional, and industrial properties. Table 88 and Table 89 show the mean improved value by land use type and county.

Table 88, which shows the mean improved value by land use type, is very similar to the table showing assessed tax value by land use type. Those activities with the highest improved value are parcels that have an economic use, such as commercial, industrial, and office properties, or are parcels associated with public sector and non-profit institutions such as government buildings and universities. At the bottom of the list are residential properties (except multi-family residential), farms, and cemeteries/parks/open space.

Table 88: Mean improved value by land use type

Land use type	Mean assessed tax value	% difference from regional mean
Office	$1,744,175	1248.9%
Institutional	$803,965	521.8%
Industrial	$713,756	452.0%
Parking / TCU	$504,351	290.1%
Recreational	$498,048	285.2%
Commercial	$426,989	230.2%
Multi-Family Residential	$296,396	129.2%
Vacant	$219,066	69.4%
Unknown	$111,636	-13.7%
Single-Family Residential	$93,961	-27.3%
Cemetery / Park / Open space	$72,550	-43.9%
Agriculture	$50,574	-60.9%
Mobile Home	$23,724	-81.7%

As shown in Table 89 the county ordering parallels that for the assessed tax value category. Again, Fulton County sits atop the list by a wide margin, with a difference in means between itself and the next county, Fayette, of over $50,000. Again, the differential between Fulton County and other counties is due to the concentration of large office, commercial, institutional, and other parcels in Fulton. Interestingly, while the mean improved value for single-family housing in Fulton County is high, Fulton ranks second behind Fayette County.

Table 89: Mean improved value by County

County	Mean assessed tax value	% difference from regional mean
Fulton	$185,230	43.3%
Fayette	$132,954	2.8%
DeKalb	$130,495	0.9%
Cobb	$123,379	-4.6%
Gwinnett	$121,412	-6.1%
Forsyth	$119,242	-7.8%
Rockdale	$105,319	-18.5%
Henry	$98,425	-23.9%
Clayton	$98,075	-24.2%
Cherokee	$97,028	-25.0%
Douglas	$89,868	-30.5%
Paulding	$58,797	-54.5%
Coweta	$3,042	-97.6%

F. Land value

The land value field in the land use database refers to the tax value of the property less the improvement value of any structures. Approximately 82% of the parcels in the database have a valid calculated value for this field (where tax value and improvement value are greater than zero). The regional mean is $45,846, with a standard deviation of $226,316. This variation is due to the wide variation in parcel size and in land prices across the region. Table 90 and Table 91 show the mean land value by land use type and county.

Table 90 shows the mean land value by land use type. All residential types of parcels (multi- and single-family residential parcels and mobile home parcels) have the lowest average land values, in part because of the small average size of these parcels.

Table 90: Mean land value by land use type

Land use type	Mean land value	% difference from regional mean
Office	$490,113	969.0%
Recreational	$427,764	833.0%
Parking / TCU	$309,470	575.0%
Commercial	$284,959	521.6%
Industrial	$268,382	485.4%
Institutional	$256,577	459.6%
Agriculture	$116,032	153.1%
Cemetery / Park / Open space	$102,355	123.3%
Vacant	$98,608	115.1%
Multi-Family Residential	$79,195	72.7%
Unknown	$75,556	64.8%
Single-Family Residential	$30,634	-33.2%
Mobile Home	$23,654	-48.4%

As shown in Table 91, the mean land value for parcels in Fulton County is the highest in the region, about $33,000 more than Forsyth County. Again, the most expensive parcels on average tend to be in counties located in northern part of the region, while the least expensive parcels on average tend to be in the southern part of the region and/or on the region's periphery.

Table 91: Mean land value by county

County	Mean land value	% difference from regional mean
Fulton	$83,083	81.2%
Forsyth	$49,864	8.8%
Cobb	$44,774	-2.3%
Gwinnett	$42,043	-8.3%
Cherokee	$39,099	-14.7%
Fayette	$36,077	-21.3%
Coweta	$33,911	-26.0%
DeKalb	$33,547	-26.8%
Rockdale	$27,467	-40.1%
Henry	$27,316	-40.4%
Douglas	$24,875	-45.7%
Clayton	$24,537	-46.5%
Paulding	$16,628	-63.7%

G. Single-family residential parcels

Given the preponderance of single-family housing (hereafter "SFH") in the region, it is important to assess the characteristics of single-family parcels in the land use database more closely. To review, 82.1% of all parcels in the region are SFH parcels. The mean SFH total square footage is 1,920 square feet, with a standard deviation of 1,359 square feet. Half of the SFH parcels in the database have a square footage over 1,704 square feet, and a quarter are 2,308 square feet or larger.

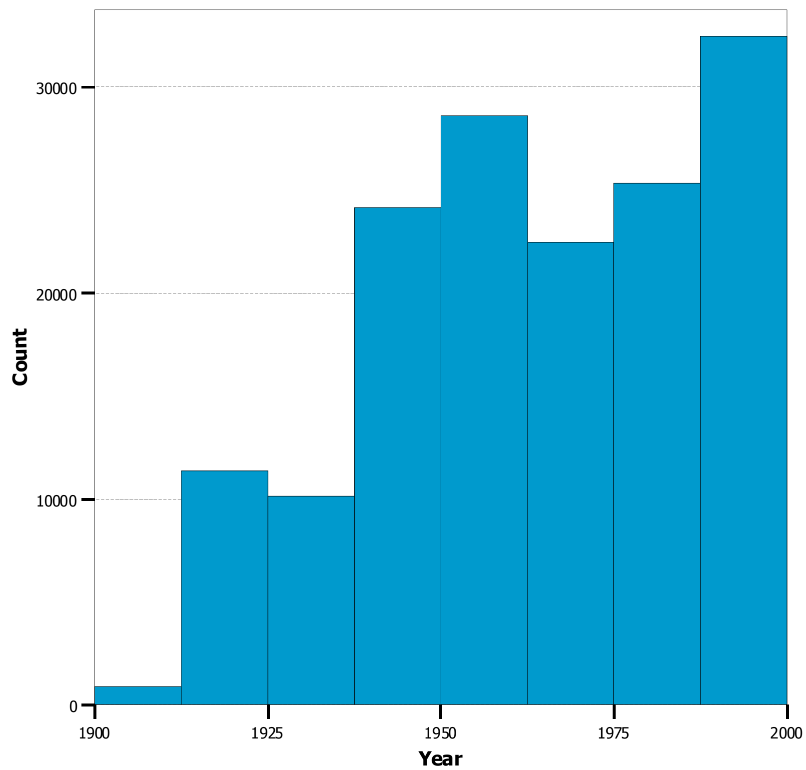
At the regional level, the mean SFH parcel was constructed in 1975, with a standard deviation of 19 years. As can be inferred from Table 92, the rate of SFH construction has accelerated greatly in the past two decades at the regional level: fully 20% of the region's SFH have been constructed since 1991, and 40% since 1985. Conversely, only 20% of SFH parcels were constructed before 1960.

Table 92: Age of construction, single family households, region – data quintiles

Quintile	Parcel age (date of construction)
20	1960
40	1974
60	1985
80	1991

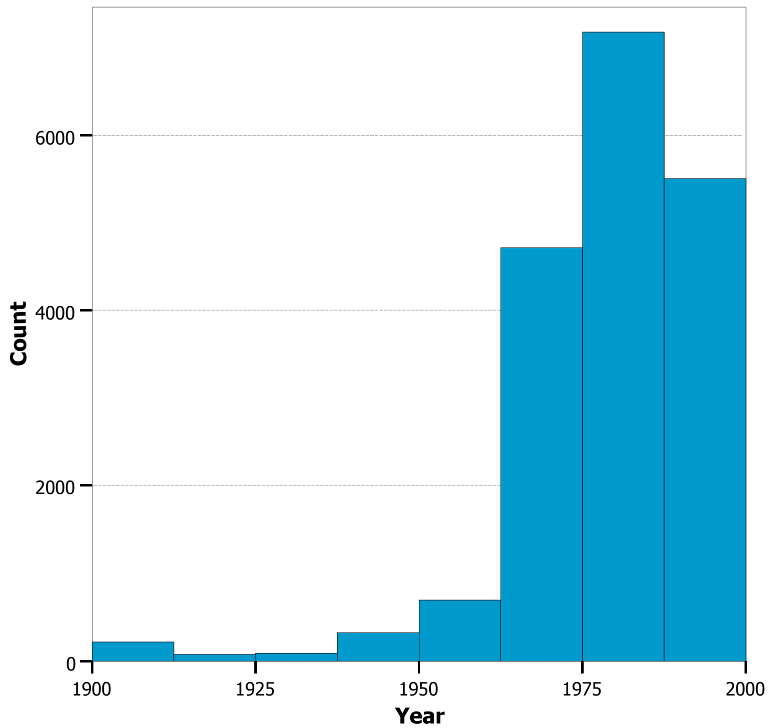
When breaking down the age of development by decade and by county, one can identify at least three patterns. The first occurred in the central counties of the region, namely Fulton, DeKalb, and Clayton Counties, which were the first to experience rapid SFH development. Here, as illustrated in Figure 50, intensive development began even before World War II and accelerated rapidly in the decades immediately following the war (in this figure as in the following two figures, the graph shows the number of parcels by age of development in the county). In Fulton, the pace of development has not slackened during the past two decades, owing in large part to the presence of undeveloped land in the rapidly growing northern tier of the county. DeKalb's experience has been similar, but the pace of development has slowed during the 1980s and 1990s, presumably due to the lack of developable land in northern DeKalb County.

Figure 50: Timeline of SFH development (year built), Fulton County



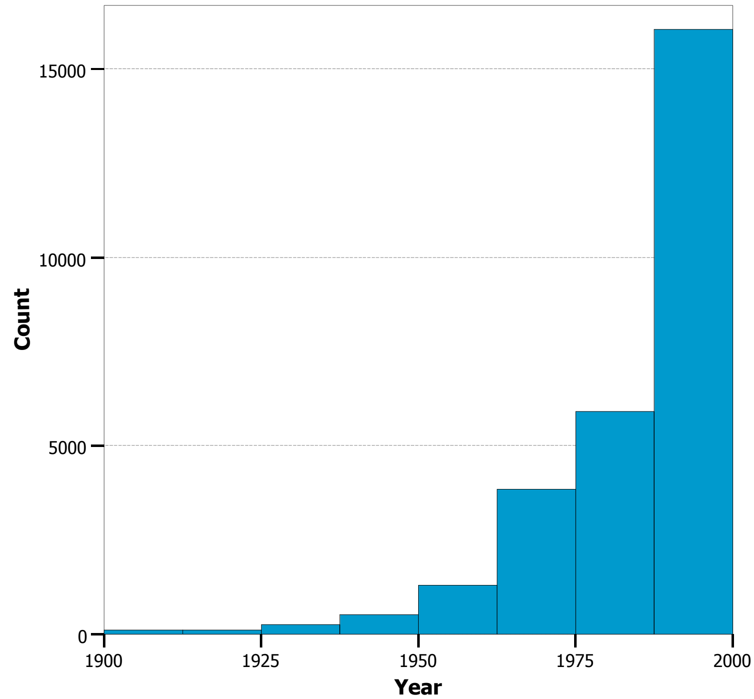
A second pattern occurred in those counties that experienced rapid development beginning around 1970 and continuing into the 1980s. Here, illustrated by the experience of Rockdale County in Figure 51, development proceeded rapidly during these decades but leveled off slightly during the 1990s and into the 21st century. Other counties that have experienced similar patterns include Cobb, Douglas, and Fayette.

Figure 51: Timeline of SFH development (year built), Rockdale County



A final development pattern at the county level centers on those counties that have experienced recent and rapid growth in SFH development. In these counties, most of which are on the regional periphery, SFH construction was slow through most of the twentieth century. Beginning in the 1980s or 1990s, however, construction accelerated at an astonishing rate. To illustrate, Figure 52 shows the timeline of development for Forsyth County. SFH construction was very slow through mid-century, then began to increase slowly from the 1950s through the 1970s. However, during the 1980s and especially the 1990s, development increased rapidly. Other counties that have experienced similar development patterns include Cherokee, Coweta, Gwinnett, Henry, and Paulding counties.

Figure 52: Timeline of SFH development (year built), Forsyth County



The mean SFH parcel size for all observations is 2.15 acres, which is 32% below the regional mean for all parcels. However, this figure is not representative of the typical SFH parcel, as illustrated in Table 93; the median parcel is slightly less than a half acre, and only 25% of all SFH parcels are over one acre in size.

Table 93: SFH parcel size, region – data quartiles

Quartile	Parcel size (acres)
25	0.3
50	0.48
75	1.0

Given the very large acreage mean for the region, it is prudent to assume that some of the largest acreage values for SFH parcels in the database may be erroneous (e.g., the largest recorded acreage for an SFH parcel is 9,918 acres); even if the acreage of such parcels has been correctly recorded, their size skews the mean to a deceptive extent. As a result, in the remainder of this analysis all observations above three standard deviations have been removed. After doing so, the regional SFH parcel mean is 1.62 acres, with a standard deviation of 4.45 acres; the maximum parcel size is reduced from 9,918 acres to 63.4 acres. The percentile distribution remains unchanged.

A breakdown of SFH parcel size by county illustrates the tendency toward larger plots in outlying counties. As shown in Table 94, the smallest average parcel size is in Fulton County, with a mean size of 0.7 acres, followed by Gwinnett and Rockdale Counties. At the other end of the spectrum are Henry, Fayette, Coweta, Douglas, and Cherokee Counties, all with average parcel sizes above four acres. Also shown in the table are median SFH parcel sizes. Perhaps the most noticeable difference is the discrepancy between the mean and median parcel sizes for DeKalb, Paulding, and Forsyth counties. In these counties, large parcels clearly have skewed the mean. DeKalb has a mean acreage of 3.08 acres but one of the smallest median acreages, at 0.60 acres, indicating a few very large parcels exist.

Table 94: Mean SFH parcel size by county

County	Mean acreage	Median acreage
Henry	11.01	6.16
Fayette	6.80	4.56
Coweta	4.78	3.00
Douglas	4.37	2.00
Cherokee	4.11	1.55
DeKalb	3.06	0.60
Paulding	3.03	0.88
Clayton	2.60	1.05
Forsyth	2.27	0.63
Cobb	2.20	1.20
Rockdale	1.70	0.58
Gwinnett	0.77	0.43
Fulton	0.70	0.36

Note: observations above 3 standard deviations from the mean eliminated.

Discrepancies between the mean and median figures in Table 94 indicate a need to assess SFH parcel sizes by percentile. Table 95 through Table 101 provide quartiles by county.

Seven of the 13 counties are shown in order to illustrate the remarkable degree of difference across counties with respect to SFH parcel size. Table 95 through Table 98 show the quartiles for the four core counties. The breakdowns for Fulton and Gwinnett counties are nearly identical, with a median SFH size of about 0.4 acres. The figures for DeKalb County are slightly different, with a median SFH size of about 0.6 acres and 3.2 acres at the 75th percentile, which is a figure much higher than for either Fulton or Gwinnett. Cobb County has the highest median figure, at 1.2 acres, indicating that there are many more SFH parcels above 1 acre in Cobb than in DeKalb, despite the latter's higher mean.

Table 95: Fulton County SFH parcel size – data quartiles

Quartile	Parcel size (acres)
25	0.22
50	0.36
75	0.6

Table 96: Gwinnett County SFH parcel size – data quartiles

Quartile	Parcel size (acres)
25	0.3
50	0.43
75	0.59

Table 97: DeKalb County SFH parcel size – data quartiles

Quartile	Parcel size (acres)
25	0.27
50	0.63
75	3.23

Table 98: Cobb County SFH parcel size – data quartiles

Quartile	Parcel size (acres)
25	0.6
50	1.2
75	2.5

While a general observation can be made that mean and median SFH parcel sizes are lower towards the center of the region and higher on the periphery, there are unusual variations at the county level. For instance, Table 99 and Table 100 show the quartiles for Clayton and Douglas counties, two counties that are near the regional center (they abut Fulton County) and experienced their most rapid development at roughly the same time periods (see above) but nonetheless have very different mean and median parcel sizes. Clayton County's SFH parcels are about half the size of Douglas County parcels at each quartile level. This divergence in SFH sizes may be due, of course, to a variety of factors, including zoning codes and other regulatory instruments, housing market conditions, and land costs.

Table 99: Clayton County SFH parcel size – data quartiles

Quartile	Parcel size (acres)
25	0.52
50	1.05
75	2.8

Table 100: Douglas County SFH parcel size – data quartiles

Quartile	Parcel size (acres)
25	1.0
50	2.0
75	5.0

Finally, Table 101 shows values for Henry County. The largest SFH parcel sizes are in this county, where the median size is 6.16 acres and a quarter of all parcels are over 15 acres in size. Even the SFH size at the 25th percentile is 4.0 acres. Again, as with the observations made above, these figures reflect the relative cost of land as well as possible market conditions (e.g., wealthier households may be seeking larger lots further from the city). Additionally, it is likely that these extreme figures are driven in part by municipal zoning codes requiring large lot sizes.

Table 101: Henry County SFH parcel size – data quartiles

Quartile	Parcel size (acres)
25	4.0
50	6.16
75	15.0

Despite its importance in many planning and modeling applications, presence of tax assessor determined building square footage values varied among counties and land use types. Forsyth County, for example, lacked square footage data for about 93% of all parcels, Henry County reported the area of every building. Among land use types, industrial and commercial properties tended to be lacking in data. To correct the data shortage, CGIS calculated estimated square footage for all missing records that were missing this information. The estimated square footages were produced by dividing the parcel's assessed value by an estimated value per square foot according to land use type. The per square foot values were estimated using linear regressions of square footage on assessed values. The regressions used for each county are described in Chapter II. Separate equations were developed for office, commercial and industrial properties.

CHAPTER IV – ASSESSMENT OF RELATIONSHIPS BETWEEN ASPECTS OF URBAN FORM, TRAVEL CHOICE, AND AIR QUALITY

I. INTRODUCTION

This chapter builds on the descriptive analyses provided in the previous. Presented here are results from inferential models linking measures of urban form with measures of travel behavior and air quality. The results presented in this chapter are seen as core findings of the SMARTRAQ program, supporting the ability to test hypotheses over how urban form impacts modal choice, vehicle miles of travel, vehicle hours of travel, and the formation of ozone precursors (Oxides of Nitrogen and Hydro-Carbons or Volatile Organic Compounds). At the outset, the study was based on the premise that more compact, mixed use environments with interconnected street networks are associated with reduced vehicular travel and harmful emissions. Results are presented based on the following primary outcome variables:

- **Modal choice** – four discrete choice multinomial logit models were developed predicting the choice to travel on foot, by car alone, in a carpool, and by transit for home based work, home based other, non-home based work, and non-home based other trip types.
- **Vehicle miles of travel** – a linear multiple regression model was developed to test the relationships between measures of urban form and aspects of socio-demographics on distances traveled
- **Vehicle hours of travel** - a linear multiple regression model was developed to test the relationships between measures of urban form and aspects of socio-demographics on time spent traveling
- **Oxides of nitrogen** -- a linear multiple regression model was developed to test the relationships between measures of urban form and aspects of socio-demographics on grams of oxides of nitrogen (NO_x) produced per person.
- **Volatile organic compounds** -- a linear multiple regression model was developed to test the relationships between measures of urban form and aspects of socio-demographics on grams of volatile organic compounds produces per person.

Each of these analyses are presented below beginning with a literature review section. Following are descriptive statistics explaining measures of central tendency and dispersion of the sample by key variables, results from inferential model testing, and analysis of the results.

II. A REVIEW OF THE LITERATURE

The relationship between urban form and transportation mode choice has been studied for at least fifty years (Mitchell and Rapkin 1954), but surprisingly we know very little about the effect of the built environment on travel behavior (Boarnet and Crane 2001). Though we may not fully understand why, we do know that there are substantial differences in travel behavior depending on where people live. Traditional neighborhoods, broadly defined as neighborhoods built pre-World War II, tend to have walking, cycling, and transit chosen as a transportation mode more often than more recently built suburbs. What is it about our built environment that fosters these choices?

Travel decisions depend on the individuals (and/or their families), the type of trip, the characteristics of each mode choice, as well as the built environment. In order to find the independent effect of the built environment on travel decisions, we must control for these other factors. Individual characteristics, socio-demographics variables,[29] directly affect transportation mode choice through preferences and resources. But more importantly in the context of this study, socio-demographic factors vary over space. Therefore, it is possible that urban form effects on travel behavior may be due to the socio-demographics of urban form rather than urban form itself. Stead (2001) states that the often-excluded dimension of socio-demographics may make the relationship between urban form and travel behavior spurious: "land-use characteristics are associated with different socioeconomic factors, which also have an effect on travel patterns" (Stead 2001: 500). Studies that have controlled for socio-demographic factors have found significant relationships between urban form and modal choice. The link between the built environment and modal choice is explained through the spatial variation in socio-demographic factors and appears not to be spurious but is somewhat "mitigated."

Both Cervero and Kockelman (1997) and Kockelman (1997), using the same data set, find a significant relationship between the built environment and mode choice, but the

[29] We use the term socio-demographic to represent both socio-demographic and socioeconomic variables.

magnitude of the effects of the built environment were small relative to those of socio-demographics; McNally and Kulkarni (1997) find a weak, though significant, relationship between transportation mode choice and urban form; and Badoe and Miller (2000) find that once socio-demographic variables are factored into the analysis, the effect of the built environment variables declines. To date, the vast majority of these analyses have been based on datasets that were stratified based on the socio-demographic factors with little thought about capturing any variation in urban form. Therefore, it becomes somewhat of a self fulfilling prophecy that the socio-demographic factors would be more significant. SMARTRAQ is the first travel survey to date to systematically capture households from a range of urban form conditions. This was particularly important given the fact that the Atlanta region is dominated by low density single use environments that do not support walking and transit. This research suggests that by placing urban form at the same level of importance at the front end, when data collection is being conducted, hypothesized relationships between the built environment and travel decisions will be substantiated.

Even if the magnitude of the built environment's effect on transportation mode choice were to be relatively less than socio-demographic factors, removing it from the statistical analysis will still remove a confounding set of independent variables. From a theoretical standpoint, measurements of both socio-demographic and urban form must be at an appropriate scale. Socio-demographic variables, for example, are best specified and measured at the individual or household level because these are the decision-making units (Boarnet and Crane 2001). Similarly, urban form variables must be measured at a scale that is meaningful to the decision-makers. With a few noticeable exceptions (Cervero 1991; Cervero1996; Boarnet and Sarmiento 1998), most empirical studies use coarse or aggregate data in their analysis (Steiner 1995; Handy 1996a; Handy 1996b). Transit zones and census tracts, the most common scale of measurement for urban form variables, are large relative to the individual decision-maker and is subject to the modifiable areal unit problem or MAUP (Openshaw 1984): if the boundaries of the spatial units are reorganized, there is potential for radical changes in the variable values and, hence, any inferences based on those variables. Additionally, urban form is usually measured only at one trip end, the origin or home of the individual. This may be a considerable problem because the origin of many trips is not the home. Frank and Pivo (1995) show that measuring urban form at both trip ends significantly improves the predictive and explanatory power in transportation mode choice models—a specification rarely used in the formulation of mode choice (Cervero 2002).

The characteristics of each mode are also important factors in the decision-making process—trade-offs that regulate the demand for each mode choice (Handy 2002). The most measurable of these factors considering the trade-offs or relative attractiveness of each mode choice set is time needed to travel. In any cross-sectional analysis of travel behavior, the relative marginal prices of transportation mode choices are constant and forced into the constant term in a regression analysis. The choice of mode for a particular trip is, among other factors, a function of the convenience (i.e. time needed to travel) for each mode. Alternatively, relative transportation times of competing modes are also good measures of convenience. Formal travel demand models that consider these costs (see Train 1986 and Small 1992 for literature reviews) typically ignore variables that measure the built environment. More recent work in this framework (see Boarnet and Crane 1998; Boarnet and Crane 2000; Boarnet and Sarmiento 1998; Crane and Crepeau 1998) includes measures of the built environment finding them to be significant. However, aside from showing that mode choice and trip generation are sensitive to relative costs, results from these studies are not generalizable enough to translate into policy decisions.

Crane (2000) classifies studies of the relationship between urban form and travel behavior into three methods of analysis: descriptive studies, simulation studies, and multivariate statistical studies. Descriptive studies, though instructive because they use actual behavioral data, are limited because they only provide an accounting of travel behavior; simulation studies, which have the benefit of not being bound to data limitations, are restricted to hypothetical impacts due to changes in policy and behavior;

finally, multivariate statistical studies have the benefit of the descriptive studies using actual travel behavioral data, but aim to explain behavior based on theoretically derived determinants.

Multivariate statistical analyses of transportation mode choice (e.g. car, transit, walk, cycle) have increasingly become more popular and better specified, most probably due to the availability of high quality data. Socio-demographic data, included in almost all recent empirical studies, are typically measured at the individual or household level through census data or travel survey questionnaires (Ewing and Cervero 2001). Urban form variables, most commonly measured at the transit zone or census tract level, have become more differentiated with respect to the specific attributes of the built environment and, therefore, are becoming increasingly able to inform policy on the effects of those particular urban form characteristics on travel behavior (Ewing and Cervero 2001). Handy (1996b) has noted that many variables used to asses the effect of the built environment on travel behavior are too general, not allowing for actual characteristics of the built environment to be investigated. The built environment variables, regardless of the scale of measurement, typically used to measure the effects of urban form are population density, employment density, accessibility, connectivity, and land use mix.

A. Density

Both population and employment density have mixed empirical results—employment density is not used as extensively as residential density (Badoe and Miller 2000). Measured as the number of persons, housing units, or jobs per unit area, the mixed results are likely due to density capturing or being a proxy for other characteristics of the built environment (Handy 2002). Since dense neighborhoods vary both within and between cities, the measures of density mean different things in different applications. With this in mind, it is no wonder that consistent results have not emerged in the literature. Despite the inconsistency, some studies do find that density is the most important urban form variable in predicting transportation mode choice (see Cervero 1996; Newman and Kenworthy 1989), but other studies are less conclusive. However, there does appear to be a consistent result from studies on transportation mode choice that include transit: Cervero and Gorham (1995), Messenger and Ewing (1996), Cervero and Kockelman (1997), and Ross and Dunning (1997) all find that the share of the transit mode choice, and to a lesser extent walking, increases with density. Especially if the policy goal is to get people out of their cars, the question is, then, what aspects of density matter most?

As noted by Badoe and Miller (2000), this result may be due to the high correlation between employment density and transit service—transit is typically not a viable choice away from centers of employment. Additionally, Frank and Pivo (1995) find that employment density at the destination is just as important as population density at the origin, perhaps even more important, in the choice to walk or take transit. Therefore, a measure of transit service (accessibility) is needed to control for this effect to see if density continues to affect these transportation mode choices. Unfortunately, this measure is not included in many studies, mainly due to availability. However, when transit service is included in the analysis, it is often found to play a significant role in mode choice (Badoe and Miller 2000).

B. Connectivity

Studies that employ density, population and/or employment, typically ignore connectivity, measured either through accessibility or street design. Defined as "how well connected a given location is with activities of a given type (work opportunities, shopping destinations, etc.), usually in terms of how much a given activity is located how close to the location in question" (Badoe and Miller 2000: 251), connectivity is important for transportation mode choice simply for the reason that density itself is of no use for choosing non-automotive modes if there is no good access to the destination—walking requires close proximity (Handy 1996a). Simulation studies, although now somewhat dated (see Curtis et al 1984; Peiser 1984; McNally and Ryan 1993) show that travel behavior is as sensitive to street design as land use patterns.

C. Land Use Mix

Just as connectivity is a necessary condition for density such that individuals require accessibility to their destinations, it is not sufficient without the existence of the destinations themselves. Land use mix, usually defined in terms of the existence or evenness of the distribution of multiple land uses (residential, commercial, industrial, etc.) in the same geographical area, directly captures the existence of these destinations since the measures imply variety. Cervero (1989) and Cervero and Kockelman (1997), both using factor analysis, calculate composite measures of land use mix finding that non-automotive transportation mode choices are made with increases in land use mix. Factor analysis is used in an attempt to minimize the effect of the high degree of co-linearity found between urban form variables, but since these measures are, by definition, a combination of many land use characteristics, it is difficult to generalize these results. Using land use measures at the census tract and transit zone levels, Frank and Pivo (1995) and Kockelman (1997) find that non-automotive transportation mode choices increase with land use mix. These results are more generalizable, but are susceptible to the critique of the modifiable areal unit problem, discussed above, possibly explaining the differences in the strength of the results in both studies. Additionally, in both studies the socio-demographic variables play the strongest role in predictive and explanatory power.

D. Scale of Measurement

The strongest results for the implications of travel behavior from land use mix come from studies employing "micro" measures of land use mix. Two studies by Cervero (1996, 1991) measure land use mix relative to the individual decision-makers' residences. Rather than using the aggregate measure of the census tract, the degree of land use mix and the presence of a neighborhood stop are measured at different distances from the homes of each individual (Cervero 1996). Just as in previous studies, these studies find increases in non-automotive travel with increases in land use mix, but are also able to decompose the effect of land use mix due to their disaggregate nature. Transit and walking trips are more likely to be chosen where commercial land uses and neighborhood shops are nearby. Increased density does increase the use of non-automotive modes, but the land use mix effect is greater for walking and cycling—land use mix measured near the home is understandably not a dominant factor for the automotive mode choice.

Clearly, measuring urban form at a scale more relevant to the individual decision-maker allows for greater precision in measuring the impacts on transportation mode choice. Empirical work is needed that measures urban form at this scale for both the trip origin and destination, incorporates socio-demographic variables measured at the individual or household level, and considers the characteristics of the transportation choices themselves.

E. Vehicle Miles and Hours of Travel

VMT is often used as a summary statistic of vehicular travel demand (Frank 2000a). Less frequently reported are hours of travel and time spent in a car. SMARTRAQ research shows that additional time spent driving is associated with increased air pollution, as demonstrated below, and increased odds of being obese. Every additional 30 minutes of time spent in a car per day are associated with a 3 percent increase in the odds of being obese (Frank et al 2004) and more prone to onset of a chronic disease (Mohdad et al 2003). This section reports on the empirical results from the descriptive and inferential assessment of each of these two continuous measures of travel and how they are related with urban form.

Considerable research has been conducted documenting significant relationships between travel distance and the arrangement of activities within the urban environment (Holtzclaw et al 2002; Ewing and Cervero 2001). Elasticities from these studies, documenting urban form / VMT relationships, have been integrated into sketch planning tools, such as the INDEX model that was used for the LCI analyses presented below. Specifically, studies have found that VMT per person and household is inversely associated with the compactness of the urban environment in which we live (Dunphy and Fischer 1996; Ewing and Cervero, 2001), levels of land use mix or distances between complementary land uses (Frank et al 2000), and the degree to which streets are interconnected and offer direct routes between destinations (Sarmiento and Boarnet 1998). This analysis of the SMARTRAQ data confirms the hypotheses that increased levels of mixed use, density, and street connectivity results in lower levels of vehicle miles of travel and offers Atlanta specific evidence of the degree of reduction in VMT that may be found to occur in association with specific increases in mix use, density, and street network connectivity when controlling for socio-demographic covariates.

Two limitations of the VMT analysis are that vehicular travel is also impacted by transit level of service and by regional location. Future assessments should take these two factors into account. Transit level of service is, however, addressed directly in the modal choice analysis presented above. Distances traveled within a vehicle may be a function of the variation of transit level of service; however, much of the region in which the survey is conducted is not served by public transportation at all. Regional location is also addressed through accessibility to employment within the mode choice analysis. The Atlantic Station Modeling process demonstrated that the location, whether it be a central or peripheral area in which development is located, impacts the miles of travel that are generated (Hagler Bailley 1999). The same proposed development generated considerably lower VMT in the central location of the Atlantic Station (AS) site as shown in Table 102.

Table 102: Regional Vehicle Miles Traveled

Site	Regional total (VMT/day)	Associated with site (VMT/day)	Site VMT difference from AS
Atlantic Steel	139,172,200	340,300	
Sandy Springs	139,221,572	389,672	14.5%
Cobb/Fulton	139,339,398	507,498	49.1%
Henry County	139,350,097	518,197	52.3%

Therefore, findings presented below are only capturing the localized effect of urban form characteristics around each participant's place of residence on their miles of travel. As noted, there are other important factors to consider, including the regional location or degree of centrality in which a given household is located. From an urban planning perspective, both regional location (where) and design (how) impact travel distances. A compact mixed use development with connected streets located at the region's periphery will likely generate more miles of travel than a similar development located in a more central area.

The next section describes the methods and results of predictive models for mode choice, VMT, vehicle hours of travel (VHT), NOx, and VOCs (hydro-carbons).

III. MODE CHOICE MODELING

A. Dependent Variables

From the complete data set, our sample is selected based on valid responses (by trip makers at least 18 years old) for the variables employed in estimation; the final sample is 5,386 households, 7,641 household members, and 42,225 trips. A breakdown of trip travel modes in this sample is contained inTable 103. Transportation mode choice is dominated by automotive travel (approximately 91 percent), followed by non-motorized travel (approximately 6 percent), and transit (approximately 3 percent). In order to avoid estimation difficulties arising from alternative mode choices in the base model, discussed below, the transportation modes are collapsed into the following categories: automotive (automobile driver, automobile passenger, taxi, and motorcycle), transit (Metro Atlanta Rapid Transit Authority, MARTA) heavy rail, MARTA bus, Cobb Community Transit (CCT; both bus and dial-a-ride services), and non-motorized travel (bicycle and walk). Automotive travel is separated into single-occupancy (SOV) and high-occupancy (HOV) vehicles.

Table 103: Travel mode frequencies, by trip type

		Frequency	Percent	Valid Percent	Cumulative Percent
Home-based work trips	SOV	3511	84.8	84.8	84.8
	HOV	352	8.5	8.5	93.3
	Transit	127	3.1	3.1	96.4
	Walk/Bike	150	3.6	3.6	100
	Total	4140	100	100	
Home-based non-work trips	SOV	4360	51.4	51.4	51.4
	HOV	3428	40.4	40.4	91.7
	Transit	88	1.0	1.0	92.8
	Walk/Bike	613	7.2	7.2	100
	Total	8489	100	100	
Non-home-based work trips	SOV	2966	70.2	70.2	70.2
	HOV	739	17.5	17.5	87.7
	Transit	124	2.9	2.9	90.6
	Walk/Bike	395	9.4	9.4	100
	Total	4224	100	100	
Non-home-based non-work trips	SOV	14523	57.2	57.2	57.2
	HOV	8357	32.9	32.9	90.2
	Transit	921	3.6	3.6	93.8
	Walk/Bike	1571	6.2	6.2	100
	Total	25372	100	100	

B. Independent Variables

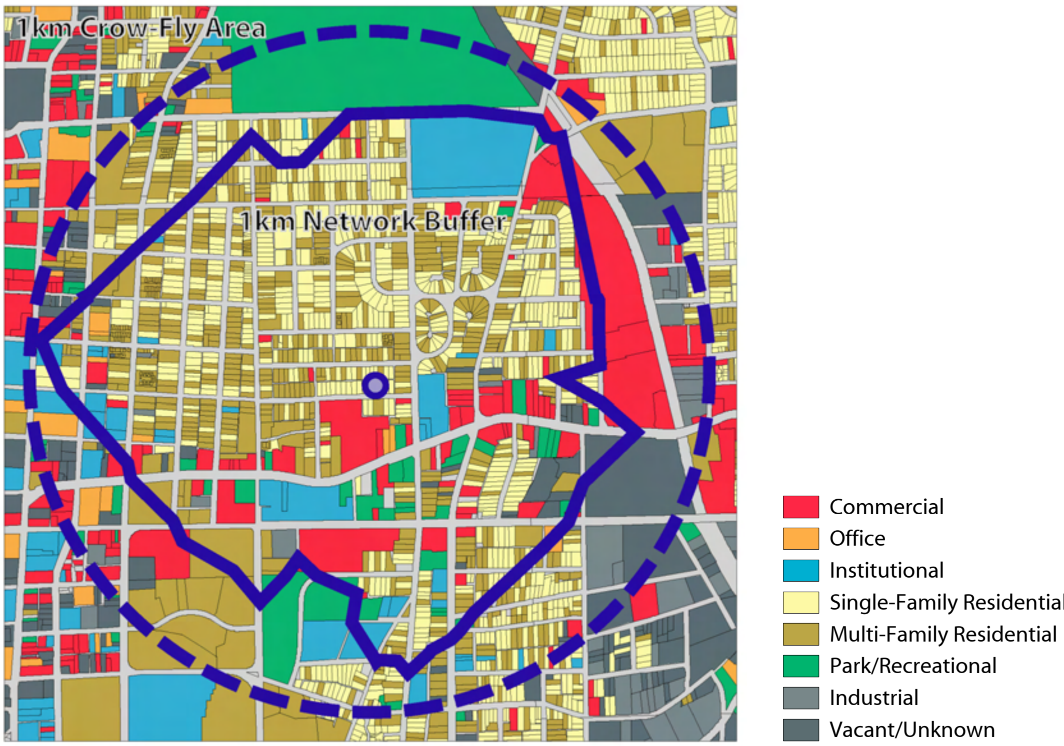
In order to control for socio-demographic characteristics that have been found as the most important predictors of transportation mode choice, the decision-maker's age, automobile availability, household size, education, and household income are included in the model. Automobile availability is the number of vehicles per household driver's licenses; household size is the number of household members; education is categorical (less than high school, high school graduate, some college, vocational/technical, undergraduate degree, graduate/professional degree); household income is also categorical, with eight categories below $100 000 and one above. For the descriptive statistics reported below (Table 104), the education categories are converted into years and the median value of each income category is used.

As stated above, the characteristics of each mode are also important predictors of transportation mode choice because they consider the relative trade-offs of each mode. To control for these trade-offs, traffic analysis zone (TAZ) to TAZ transportation times, provided by the Atlanta Regional Commission on over 1600 TAZs for the Metro Atlanta region, are included for each trip. Transportation time, rather than transportation distance, is used because the TAZ to TAZ data have both peak (rush hour) and off-peak travel times for each mode and each trip has the time of day for the trip. Trip times for HOV, transit, and non-motorized travel are measured relative to the SOV transportation time to give a measure of the relative cost of taking one mode over SOV. Other transportation characteristics include whether the trip maker participates in the transportation demand management (TDM) program, which provides various incentives for individuals and their employers to reduce automotive dependency in order to reduce traffic congestion and improve air quality. Work and non-work trips are separated as they have been found to be qualitatively different from one another (Handy 1996a), as are home-based and non-home-based trips. This breaks the sample described above into four subsamples: home-based work, home-based non-work, non-home-based work, and non-home-based non-work.

The variables used to measure the built environment are street networks (the density of intersections), net residential density (number of households per residential acre), employment density (number of jobs per acre), job accessibility (number of jobs accessible, by mode, within a specified period of time from the trip origin), and the degree of land use mix. Street network variables, often excluded from analyses of transportation mode choice, affect transportation choices by measuring connectivity and proximity; these variables are expected to be negatively associated with the automotive mode and positively associated with transit and non-motorized travel (Badoe and Miller 2000; Crane 2000).

Net residential and employment density, calculated using GIS software (ArcView GIS 3.2, ESRI Inc., Redlands, CA), are usually thought of as surrogates for other measures of urban form that promote walking (through the provision of places to walk to) as a transportation mode choice and are therefore expected to have a positive impact on the choice for transit and non-motorized travel (Ewing et al. 2003; Handy 1996).

Figure 53. Street Network Buffer



Job accessibility from the origin is measured by counting the number of jobs that can be reached within 15 minutes by automobile and by transit. The SOV transportation mode choice is expected to be positively associated with higher levels of automobile job accessibility—negatively related to transit and non-motorized travel. Similarly, transit and walking trips are more likely to be chosen where commercial land uses and neighborhood shops (high degree of jobs) are nearby as measured by job accessibility through transit.

The measure of land use mix, calculated with the GIS software, ($LUM = -\sum_{i=1}^{n} p_i \ln p_i \big/ \ln n$), where p_i is the proportion of estimated square feet assigned to land use i and n is the number of different land uses, represents the evenness of the distribution of square feet across three types of land uses within a 1 kilometer network distance (1 kilometer of street network travel versus a 1 kilometer crow fly distance from the trip end, see Figure 53) from each trip end: residential, commercial, and office. *LUM* ranges from zero to one, with zero representing a single land use environment such as a residential neighborhood and one representing an even distribution of square footage across all three land uses. This frame of reference enables the testing of systematic variation between the trip ends with a varying degree of non-residential use within a walkable distance. The inclusion of both trip ends for all of the built environment variables in the analysis of transportation mode choice has proven to be powerful, when employed (Frank and Pivo 1995). Therefore, all of the built environment variables employed in this analysis are measured at both trip ends. Our hypothesis is that trip ends located in areas with more commercial and other non-residential land use are more often associated with walk trips for individuals to accomplish their daily activities. Therefore, land use mix is expected to have a positive impact on transit and non-motorized travel.

Despite the expected positive relationship between these built environment variables and the choice to use transit or non-motorized travel as a transportation mode, there is a difficulty that arises when measuring marginal effects in a regression context. As stated above, increasing the number of destinations in a particular place—whether the number of destinations is measured through a density variable, job accessibility, or land use mix—may not be particularly useful without a corresponding increase in connectivity, and vice versa. Increasing density, either residential or employment, through the construction of apartment/office towers alone may decrease the walkability of an area by crowding out other types of destinations, just as increasing connectivity without increasing the number of destinations may decrease the walkability of an area by increasing road traffic (decreasing pedestrian safety). Therefore, if multiple measures of the built environment are included in the same statistical model it would not be surprising the find negative relationships between transit and non-motorized transportation choices and measures that are supposed to promote them.

In fact, preliminary statistical analyses found these negative relationships for some measures of the built environment in some of the trip sub-samples. Though interesting in its own right, the purpose of this study is to measure the effect of the built environment on transportation mode choice. If, from a theoretical level, what we consider to be a built environment that promotes transit use and non-motorized travel is to be tested at an empirical level, we need a variable that captures this type of built environment in its totality. At the same time, however, we need to be cognizant of the limitations of previous aggregate (i.e. proxy) measurements of the built environment.

Therefore, in order to construct a measure of walkability, we use the built environment variables (net residential density, land use mix, and connectivity) that are all measured at the 1 kilometer network buffer level from the actual trip origin and destination points, as described above. To avoid difficulties in interpretation due to different measurements, each variable is turned into a z-score. Finally, the walkability index is constructed by adding the z-score values of the three measures of the built environment. The highest values of this index have consistently high measures of *all* built environment variables, with penalties imposed on the index if not all the built environment variables are at a similar level. These penalties (imposed on a dense and highly mixed area with poor connectivity, for example) account, theoretically, for the negative relationships expected, and found, between the built environment and the transit and non-motorized travel mode choices. The result is a measurement of the built environment that allows for a test of the theory that is measured at a scale relevant to the decision maker. This variable is expected to have a positive relationship with transit use and non-motorized travel and a negative or insignificant relationship with HOV.

C. Statistical Analysis

The multinomial logit (MNL) model, developed by McFadden (1981), is used to model transportation mode choices that include all of the choice attributes, decision-makers' characteristics, and built environment variables in what is called a random utility model—an application of microeconomic choice theory. People make their choices among alternatives to maximize their net benefit, with that choice being based on the individual's characteristics (income, automobile ownership, age, etc.) and on the characteristics of the competing modes (travel times, distances, etc.)—all contribute to the decision (Kennedy 2003). Of course, given this paper's emphasis on the built environment, the characteristics of the trip origins and destinations such as population density, employment density, land use mix, and connectivity in transportation mode choice are also incorporated into the analysis. The probability of each alternative being chosen depends on its net benefit, as well as the net benefit of all the other alternatives. The alternative with the largest net benefit has the greatest probability of being chosen. The result of estimation is the probability of each transportation mode choice being made as a linear function of the variables in the model (Kennedy 2003).

The probability that a transportation mode is chosen ($Y = J$) is given by:

$$\text{Prob}(Y = J) = \frac{e^{X\beta_i}}{1 + \sum_{i=1}^{J} e^{X\beta_i}}$$

where $J + 1 \equiv$ the number of alternatives; e is the natural exponential function; X is the matrix of independent variables thought to affect the choice of search block, based on criminological theory; and β is the vector of estimated parameters. Since there are multiple alternatives, estimation provides a β-vector for all but one of the alternatives—the probability of the remaining alternative is one minus the sum of the other probabilities. It should be noted that given the nonlinear nature of the probability function, β cannot have its ordinary least squares (OLS) interpretation of the marginal effect of X on Y. If a marginal effect is desired, the difference in probabilities when changing a variable x_i should be calculated, but interpreted with caution as the probability difference will not remain constant with different starting values for x_i (Greene 2000).

The method of estimation is not the same as OLS and, therefore, there is no R^2 to measure goodness of fit: rather than minimizing the squared errors (least squares) through the choice of β, the logistic regression maximizes a likelihood function by choosing β. There is, however, a Pseudo R^2 for logistic regression provided by McFadden (1974), the likelihood ratio index:

$$LRI = 1 - \frac{\ln L}{\ln L_0} \ , \qquad (2)$$

where ln L is the log-likelihood function with all the model parameters from the model and ln L_0 is the log-likelihood function only including a constant term. As with the measure of R^2, this index is bounded between 0 and 1.

D. Mode Choice Results

In this section, descriptive statistics and inferential model results are presented for home based work, home based non-work, non-home based work, and non-home based other trip types.

1. Home Based Work

Descriptive demographic statistics are reported in Table 104 on age, educational attainment, income, household size, and having a driver's license. The most frequently reported TDM strategy used is a flexible work schedule, however some of the participants report telecommuting. Respondents indicate that their work destinations are denser and we objective assess them to be more walkable across a variety of measures of urban form.

Table 104: Home-based work trip descriptives, n = 4140

	Mean	Std.Dev.	Minimum	Maximum
Age	41.58	12.51	18.00	91.00
Education	Some College	n/a	< High School	Graduate
Income	$45 000	$20 000	< $10 000	> $100 000
Household Size	2.32	1.20	1.00	8.00
Vehicles per Household Driver's License	1.09	0.42	0.00	6.00
TDM, Car Subsidy	0.11	0.31	0.00	1.00
TDM, Bus Subsidy	0.06	0.24	0.00	1.00
TDM, Flexible Schedule	0.25	0.44	0.00	1.00
TDM, Telecommuting	0.06	0.24	0.00	1.00
TDM, Car Pool	0.01	0.11	0.00	1.00
Origin Job Accessibility, Car	13636.20	12988.00	4.00	85481.00
Origin Job Accessibility, Transit	19797.80	29824.30	1.00	172794.00
Origin, Net Employment Density	17.62	21.94	0.00	181.70
Destination, Net Employment Density	40.08	47.76	0.05	190.89
Origin, Walkability	0.56	1.64	-3.05	7.91
Destination, Walkability	1.20	2.20	-3.05	15.63
HOV, Relative Time	0.84	0.10	0.54	1.00
Transit, Relative Time	3.78	4.03	0.11	27.49
Non-motorized Travel, Relative Time	4.70	2.35	0.00	29.13

Results from the LOGIT model of home-based work travel are presented in Table 105.

Table 105: Model Results: Home-based work trips

	HOV	Transit	Walk/Bike
Constant	1.365 (1.98)	11.569 (8.13)	
Age	-0.019 (-4.09)	-0.013 (-1.73)	
Education	-0.198 (-5.03)	-0.284 (-3.89)	
Income	-0.056 (-2.12)	-0.396 (-7.93)	-0.273 (-4.56)
Household Size	0.228 (6.15)	0.237 (3.50)	
Vehicles per Driver's License	-1.161 (-6.65)	-2.984 (-11.27)	-0.918 (-3.05)
TDM, Car Subsidy	-0.754 (-2.163)	-1.868 (-3.45)	-2.019 (-2.79)
TDM, Bus Subsidy		1.660 (3.71)	
TDM, Flexible Schedule			0.952 (3.57)
TDM, Telecommuting		0.847 (1.95)	-1.060 (-1.97)
TDM, Car Pool	1.515 (4.16)		
Origin Walkability		-0.331 (-3.84)	
Destination Walkability		0.184 (4.58)	0.152 (2.06)
Origin Job Accessibility, Car		-0.309 (-2.99)	-0.361 (-3.30)
Origin Job Accessibility, Transit		0.179 (3.85)	0.107 (2.19)
Destination, Net Employment Density	-0.004 (-2.27)	0.009 (4.56)	
HOV, Relative Time		-4.357 (-3.85)	5.180 (2.17)
Transit, Relative Time	-0.037 (-2.64)	-0.353 (3.99)	
Non-motorized Travel, Relative Time		-0.294 (-4.54)	-1.639 (-11.02)
Pseudo R-squared = 0.298			

Note. T-statistics are reported in parentheses.

The model developed a Pseudo R – squared of 0.298. Relative to driving alone, HOV usage decreases with age, income, educational attainment, presence of a driver's license, paid parking as a subsidy, and as employment density increases. HOV increases with carpool coordination and support, and with household size and as the relative travel time via transit increases. Transit usage also decreases with age, income, educational attainment, presence of a driver's license, and paid parking as a subsidy. In addition, transit usage decreases with job accessibility via car at the home trip end, and the relative travel time of HOV, non-motorized, and of transit itself, as would be expected. Transit usage increases with increases with household size, bus subsidy, telecommuting, destination walkability, and origin job accessibility via transit. Walking decreases with income, drivers license, car subsidy, ability to telecommute, origin job accessibility via car, and increases in the relative non-motorized travel time.

2. Home Based Non-Work

Descriptive demographic statistics are reported in Table 106 on age, educational attainment, income, household size, and having a driver's license. While less relevant than work related travel, the most frequently reported TDM strategy related with home based non-work travel mode choice was a flexible work schedule. TDM strategies were related with non-work travel due to predispositions toward certain modes of travel overall and synergies between work and non-work travel choice.

Table 106: Home-based non-work trip descriptives, n = 8489

	Mean	Std.Dev.	Minimum	Maximum
Age	46.34	16.40	18.00	96.00
Education	Some College	n/a	< High School	Graduate
Income	$45 000	$20 000	< $10 000	> $100 000
Household Size	2.44	1.22	1.00	8.00
Vehicles per Household Driver's License	1.08	0.44	0.00	5.00
TDM, Car Subsidy	0.06	0.23	0.00	1.00
TDM, Bus Subsidy	0.04	0.19	0.00	1.00
TDM, Flexible Schedule	0.16	0.37	0.00	1.00
TDM, Telecommuting	0.05	0.21	0.00	1.00
TDM, Car Pool	0.01	0.09	0.00	1.00
Origin Job Accessibility, Car	13571.60	13268.40	47.00	85481.00
Origin Job Accessibility, Transit	19020.90	27349.30	1.00	172794.00
Origin, Net Employment Density	17.20	20.56	0.00	166.90
Destination, Net Employment Density	23.11	31.60	0.01	190.89
Origin, Walkability	0.49	1.58	-3.11	7.91
Destination, Walkability	0.77	1.99	-3.27	15.66
HOV, Relative Time	0.90	0.09	0.57	1.00
Transit, Relative Time	4.27	5.67	0.07	36.71
Non-motorized Travel, Relative Time	3.72	2.20	0.00	28.15

Results from the LOGIT model of home-based work travel are presented in Table 107.

Table 107: Model Results: Home-based non-work trips

	HOV	Transit	Walk/Bike
Constant		4.776 (3.37)	3.415 (2.29)
Age	-0.008 (-4.56)	-0.026 (-4.04)	-0.026 (-6.41)
Education		-0.240 (-3.27)	-0.085 (-2.11)
Income		-0.257 (-4.93)	-0.128 (-4.80)
Household Size	0.426 (21.47)		0.284 (6.53)
Vehicles per Driver's License	-0.317 (-5.18)	-2.025 (-7.63)	-0.871 (-5.68)
TDM, Car Subsidy	0.222 (1.68)		-0.622 (-2.02)
TDM, Bus Subsidy			1.435 (4.74)
Origin Walkability	0.045 (2.21)		0.123 (2.50)
Destination Walkability	-0.050 (-3.26)	0.125 (3.14)	
Origin Job Accessibility, Car	-0.063 (-2.49)		
Origin Job Accessibility, Transit		0.089 (2.15)	
Destination, Net Employment Density		0.012 (5.99)	
HOV, Relative Time	-0.553 (-1.76)		
Transit, Relative Time		-0.121 (-2.71)	-0.095 (-6.66)
Non-motorized Travel, Relative Time	0.067 (5.31)	0.133 (3.04)	-1.706 (-21.99)
Pseudo R-squared = 0.211			

Note. T-statistics are reported in parentheses.

HOV or carpooling decreases for home based non-work travel with age, prevalence of a driver's license, destination walkability, origin job accessibility, and as HOV travel time increases relative to SOV. HOV or carpooling for home based non-work travel is primarily a function of, and increases with, household size (t = 21.47), TDM car subsidy, origin walkability, and the relative travel time for non-motorized travel. Transit usage decreases with age, education, income, and prevalence of a driver's license, and the time required for transit relative to SOV travel. Transit usage increases with destination walkability, origin job accessibility via transit, destination net employment density, and the relative non-motorized travel time as compared with an SOV. Non-motorized usage decreases with age, education, income, and prevalence of a driver's license, TDM car subsidy, and the relative travel time on transit (t = -6.66) and on foot as compared with SOV (note that this last variable was the primary explanatory factor (t = -21.99)).

3. Non-Home Based Work Travel

Descriptive demographic statistics are reported in Table 108 on age, educational attainment, income, household size, and having a driver's license.

Table 108: Non-home-based work trip descriptive, n = 4224

	Mean	Studded.	Minimum	Maximum
Age	43.36	11.23	18.00	81.00
Education	Some College	n/a	< High School	Graduate
Income	$45 000	$20 000	< $10 000	> $100 000
Household Size	2.46	1.15	1.00	8.00
Vehicles per Household Driver's License	1.13	0.43	0.00	4.00
TDM, Car Subsidy	0.09	0.29	0.00	1.00
TDM, Bus Subsidy	0.06	0.24	0.00	1.00
TDM, Flexible Schedule	0.26	0.44	0.00	1.00
TDM, Telecommuting	0.08	0.27	0.00	1.00
TDM, Car Pool	0.01	0.11	0.00	1.00
Origin Job Accessibility, Car	20693.80	18302.50	31.00	148004.00
Origin Job Accessibility, Transit	32321.30	43441.50	3.00	172794.00
Origin, Net Employment Density	30.80	41.32	0.01	189.28
Destination, Net Employment Density	37.39	46.96	0.01	188.77
Origin, Walkability	1.02	2.25	-3.13	15.64
Destination, Walkability	1.14	2.19	-3.15	15.63
HOV, Relative Time	0.88	0.10	0.60	1.00
Transit, Relative Time	4.25	5.57	0.10	38.18
Non-motorized Travel, Relative Time	3.83	2.52	0.00	37.59

The most frequently reported TDM strategy related with non-home-based work travel mode choice was also a flexible work schedule. Walkability and net employment density, at origins and destinations, were significantly related with non-home based work travel. LOGIT model results for non-home based work travel are presented in Table 109.

Table 109: Model Results: Non-home-based work trips

	HOV	Transit	Walk/Bike
Constant		12.521 (7.01)	3.675 (1.98)
Age	-0.026 (-6.29)		
Education			0.132 (2.04)
Income		-0.251 (-4.87)	-0.147 (-3.55)
Household Size	-0.066 (-1.97)		0.130 (2.01)
Vehicles per Driver's License		-1.758 (-5.58)	-0.549 (-2.39)
TDM, Car Subsidy		-2.252 (-5.07)	-1.909 (5.28)
TDM, Bus Subsidy		3.090 (9.52)	2.259 (6.49)
TDM, Car Pool	2.084 (7.76)		
Origin Walkability		0.108 (3.08)	0.084 (2.22)
Destination Walkability		0.155 (3.88)	0.075 (1.76)
Origin Job Accessibility, Car			0.076 (3.71)
Destination, Net Employment Density		0.006 (3.02)	0.007 (3.83)
HOV, Relative Time		-9.969 (-6.52)	
Transit, Relative Time	0.028 (3.84)	-0.288 (-2.89)	
Non-motorized Travel, Relative Time	-0.057 (-2.74)	-0.301 (-3.51)	-1.394 (-12.67)
Pseudo R-squared = 0.267			

Note. T-statistics are reported in parentheses.

HOV or carpooling decreases for home based non-work travel with age, household size, and as non-motorized travel time increases relative to the travel time by SOV. HOV or carpooling for non-home based work travel is primarily a function of, and increases with, carpool incentives (t = 7.76) and also as the relative travel time via transit increases relative to SOV. Transit usage decreases income, and prevalence of a driver's license, the presence of subsidized or free parking, and as the relative travel time via transit, HOV, and non-motorized travel increase relative to the SOV. Transit usage increases the time required for transit relative to SOV travel. Transit usage increases primarily with a transit subsidy (t = 9.52), origin and destination walkability, and destination employment density. Non-motorized travel decreases with income, prevalence of a driver's license, and TDM car subsidy, and most importantly, as the relative travel time via non-motorized travel increases relative to the SOV (t = -12.67)). Non-motorized travel for non-home based work increases with educational attainment, household size, transit subsidy, origin and destination walkability, origin employment accessibility and destination net employment density.

4. Non-Home Based Non Work Travel

Descriptive demographic statistics are reported in Table 110 on age, educational attainment, income, household size, and having a driver's license. While less relevant than work related travel, the most frequently reported TDM strategy related with non-home based non-work travel mode choice was again, having a flexible work schedule.

Table 110: Non-home-based non-work trip descriptive, n = 25372

	Mean	Std.Dev.	Minimum	Maximum
Age	45.61	14.92	18.00	96.00
Education	Some College	n/a	< High School	Graduate
Income	$45 000	$20 000	< $10 000	> $100 000
Household Size	2.43	1.20	1.00	8.00
Vehicles per Household Driver's License	1.09	0.42	0.00	6.00
TDM, Car Subsidy	0.07	0.25	0.00	1.00
TDM, Bus Subsidy	0.05	0.22	0.00	1.00
TDM, Flexible Schedule	0.19	0.39	0.00	1.00
TDM, Telecommuting	0.05	0.22	0.00	1.00
TDM, Car Pool	0.01	0.09	0.00	1.00
Origin Job Accessibility, Car	19603.80	18245.60	31.00	148004.00
Origin Job Accessibility, Transit	30084.80	40612.40	0.00	172794.00
Origin, Net Employment Density	28.73	38.71	0.01	190.89
Destination, Net Employment Density	21.93	30.09	0.00	189.42
Origin, Walkability	0.89	2.12	-3.27	15.70
Destination, Walkability	0.67	1.93	-3.22	15.69
HOV, Relative Time	0.90	0.09	0.52	1.00
Transit, Relative Time	4.50	5.77	0.07	39.11
Non-motorized Travel, Relative Time	3.84	2.46	0.00	93.38

TDM strategies were related with non-work travel due to predispositions toward certain modes of travel overall and synergies between work and non-work travel choice. Interestingly, origin exceeded destination net employment density for non-home based work trips. LOGIT model results for non-home based non-work travel are in Table 111.

Table 111: Model Results: Non-home-based non-work trips

	HOV	Transit	Walk/Bike
Constant	-0.620 (-2.88)	6.444 (11.18)	1.762 (1.96)
Age	-0.003 (-3.01)	-0.021 (-7.59)	-0.018 (-7.03)
Education	-0.033 (-3.37)	-0.223 (-8.33)	-0.133 (-5.49)
Income	-0.018 (-2.77)	-0.218 (-12.22)	-0.175 (-10.80)
Household Size	0.268 (24.29)	0.255 (9.33)	0.267 (10.25)
Vehicles per Driver's License	-0.314 (-8.38)	-1.477 (-14.51)	-0.832 (-8.97)
TDM, Car Subsidy	-0.350 (-4.64)	-2.499 (-9.93)	-1.091 (-5.89)
TDM, Bus Subsidy		2.040 (14.42)	1.388 (8.56)
TDM, Flexible Schedule	-0.183 (4.34)	0.238 (2.50)	
TDM, Telecommuting		0.391 (2.25)	
TDM, Car Pool	0.696 (5.37)	-2.306 (-2.29)	
Origin Walkability	-0.047 (-5.09)	0.154 (10.57)	0.081 (4.45)
Destination Walkability		0.141 (9.09)	0.068 (3.59)
Origin Job Accessibility, Car	-0.070 (-5.64)	-0.054 (-1.83)	
Origin Job Accessibility, Transit		0.116 (10.96)	0.089 (7.74)
Destination, Net Employment Density	0.003 (3.91)	0.014 (14.99)	0.007 (6.93)
HOV, Relative Time	0.642 (3.51)	-4.256 (-8.62)	2.266 (2.63)
Transit, Relative Time	-0.007 (-2.89)	-0.118 (-6.48)	-0.055 (-6.91)
Non-motorized Travel, Relative Time		-0.102 (-4.39)	-1.304 (-32.01)
Pseudo R-squared = 0.188			

Note. T-statistics are reported in parentheses

HOV or carpooling decreases for home based non-work travel with age, education, income, prevalence of having a driver's license, provision of free or subsidized parking –

or other car subsidies – and origin walkability, origin job accessibility, and as the relative travel time via transit increases relative to driving alone. HOV or carpooling for non-home based work travel is primarily a function of, and increases with household size (t = 24.29), with having a flexible work schedule and carpooling programs. Transit usage decreases with age, educational attainment, income, prevalence of a driver's license, the presence of subsidized or free parking, carpool programs, origin employment accessibility, and as HOV, transit and non-motorized travel times increase relative to SOV travel, transit subsidy (t = 14.42), flexible work schedule, telecommuting, and origin and destination walkability. Transit usage increases the time required for transit relative to SOV travel. Transit usage increases primarily with a transit subsidy (t = 9.52), origin and destination walkability (very significant), and origin job accessibility and destination net employment density (also very significant). Non-motorized travel decreases with age, educational attainment, income, prevalence of a driver's license, and TDM car subsidy, as the relative travel time via transit increase as compared with the SOV, and most importantly, as the relative travel time via non-motorized travel increases relative to the SOV (t = -32.01). Non-motorized travel for non-home based non-work travel increases with household size, transit subsidy, origin and destination walkability, origin employment accessibility, destination net employment density, and as the relative travel time via HOV increases as compared with SOV travel.

5. Modal Choice Results

All four models produced reasonable Pseudo R^2 measures, given that the data are cross-sectional: the non-work trips have more modest measures (0.19 and .21) than the work trips (0.27 and 0.30). The first result consistent across the four sub-samples worth noting is the presence, or lack thereof, of the built environment variables (walkability, job accessibility, and employment density) depending on transportation mode choice. Transit use consistently has the greatest number of significant built environment, followed, by walk/bike. In the case of based-based work trips, the built environment does not matter at all for the HOV transportation mode choice.

As expected from previous studies, socio-demographic variables are significant predictors of transportation mode choice. In many cases, these variables are the most statistically significant variables in the models. Age, education, income, and vehicle availability all have negative relationships with HOV, transit, and walk/bike indicating a positive association with SOV. Household size, on the other hand, has a positive association with HOV, transit, and walk/bike. This relationship is of no surprise as holding the remaining variables, which includes vehicle availability, constant necessarily forces household members to travel together (HOV) or choose alternative modes (transit, walk/bike).

Travel demand management (TDM) variables, not surprisingly, have their expected effects on work trips: car subsidies decrease HOV, transit, and walk/bike; bus subsidies increase transit use, as well as walk/bike travel; car pool subsidies increase HOV use; flexible scheduling and telecommuting generally increases both transit use and walk/bike travel. A more interesting result is the effect that the TDM programs have on non-work travel: bus subsidies, flexible scheduling, and telecommuting all promote transit use and walk/bike travel for non-work trips. Therefore, TDM programs have benefits for decreases in vehicle travel outside of their intention. In this manner, the TDM variables may be viewed as behavioral variables with the interpretation that people who participate in TDM programs alter their behavior (i.e. own less automobiles, live closer to transit, etc.).

The walkability index, measured at both the origin and destination of each trip, largely has its expected positive association with transit use and walk/bike travel, and a negative or insignificant association with HOV. That is, areas that jointly have high residential density, even distributions of land use, and high levels of connectivity promote transit use and walk/bike travel, while simultaneously discouraged automotive travel. This relationship is most apparent for transit use in based-based non-work trips.

Figure 54: Probability of transit use due to changes in walkability

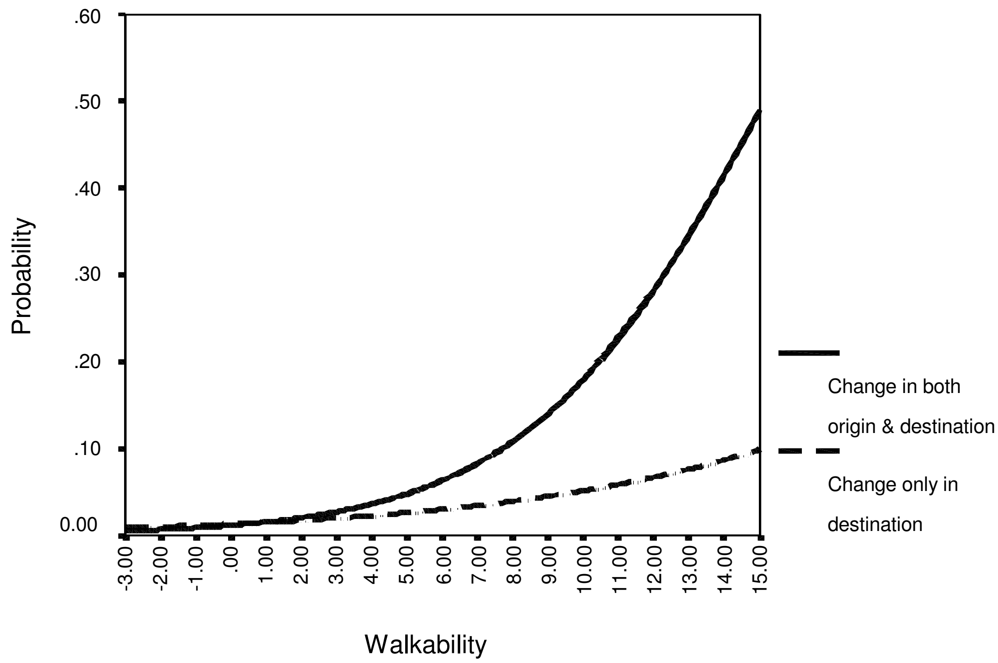
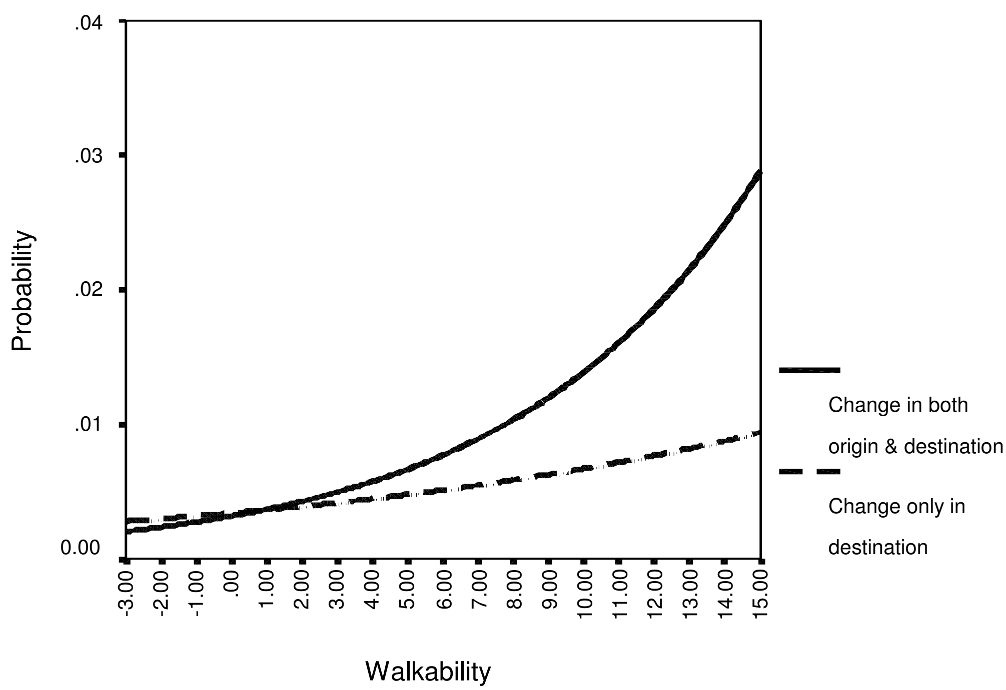


Figure 55: Probability of walk/bike travel due to changes in walkability



As seen in Figure 54, increasing walkability, at the destination only, from its minimum to its maximum increases the probability of transit use from essentially zero percent (almost 1.5 percent at the average value) to approximately 10 percent at its maximum value—all other variables are held constant at their mean values. When walkability is increased at both the origin and the destination, the probability of transit use rises to almost 50 percent. Figure 55 also shows these same effects for the probability of walk/bike travel, with lower absolute changes: 1 percent for increased destination walkability and 3 percent for increased origin and destination walkability. These are, admittedly, extreme examples because walkability is forecast to its maximum value, but the implications for policies that promote increases in walkability are clear: the development of areas that are walkable (i.e. a connected, dense, and mixed use area) will reduce automobile dependency.

Job accessibility generally has its expected associations with the three transportation modes: increases in automobile accessibility has a negative or insignificant effect on transit use and walk/bike travel and increases in transit accessibility has a positive association with both transit use and walk/bike travel—employment density holds the same relationships. Finally, as expected, an increase in the relative time of a particular mode decreases the probability of it being chosen as a mode of transportation.

The long history of studies on transportation mode choice has shown that where people live and work (make their decisions to travel) affect which transportation mode is chosen. Using travel diary data and measurements of the built environment captured at the "micro scale" that is relevant to the individual decision maker, this paper finds that a strong positive association between measures of walkability and transportation mode choice exist. The combination of using non-aggregated built environment variables, socio-demographic variables, and characteristics of the transportation modes integrates the methods used by travel demand models, urban planning, and geography. Socio-demographic characteristics continue to play a significant role in transportation mode choice, but now built environment variables rival their statistical significance as well as their predictive power.

IV. VEHICLE MILES AND HOURS OF TRAVEL

A. Linear Regression Methodology

Using person level travel data from the 2001/2002 AHTS four linear regression models were developed to estimate per capita, average vehicle miles and hours traveled, and emissions for weekday travel by driving age people. Trips made by personal motor vehicle or bus (MARTA, CCT or school) are included in these models.

The initial data set the models are built from includes the 14,527 (unweighted) people 16 years or older from the 8,069 household survey. The models use both demographic and household-based urban form variables. The demographic variables were self-reported by the participants. The trip time, distance and emissions values were calculated using participant-reported trip origin and destination locations, time of day of travel, mode used, and vehicle age. Please see Chapter II for details on the estimation processes.

The VMT and VHT model datasets include only those people for whom distance and time values were present for all trips made (all modes, even though these models are only for vehicular travel) across the weekdays of the two day period in which they recorded their travel behavior. The emissions models datasets had one additional selection criteria of including only people who used a single vehicle for all their vehicle trips. This requirement was necessary in order to allow vehicle age to be considered in the daily emissions model. These final data sets range from 7,261 to 8,670 people, depending on the model. Table 113 through Table 120 show the descriptive statistics for each model's weighted sample population. Table 112 provides the descriptive statistics for the entire AHTS sample over 15 years old.

The regression models also use three urban form variables—mixed use, net-residential density (NRD) and intersection—for the area around each person's home. Mixed use is a continuous variable and NRD is ordinal, with five ranges corresponding to the stratification criteria used in the larger AHTS[30] in all four models. Intersection density is a continuous variable for the VMT and VHT models, but for the emissions models is ordinal with five ranges[31].

Table 112: Descriptives for AHTS (> 15 years old, data weighted), & regional urban form

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Household size: person level	15,642	1	8	3.045	1.437
Total household vehicles: person level	15,642	0	5	1.984	1.023
Income: person level	15,642	11	19	16.000	2.511
Drivers License	15,549	1 (yes)	2 (no)	1.12	.327
Vehicle age	14,169	0	78	7.406	6.151
	recoded	0	78	7.000	
Mix3: regional, using 200m grid buffers	314,774	0	1.000	0.149	0.262
intersection density (square KM): regional, using 200m grids	314,774	0	452.569	8.297	20.562
	recoded	1	5	1	
NRD: regional, using 200m grid buffers	154,580	0	3153.255	1.740	9.434
	recoded	1	5	1	

Once each model's sample was identified, but before summing daily total VMT, VHT and emissions for each person in the dataset, the trip level values were adjusted in two ways. The first adjustment was to create a daily average value of those variables for each trip. This average was created by dividing the trip value by the number of weekdays (either one or two) in that person's two day travel reporting period. The second adjustment was to divide those values by the number of people traveling together. For bus travel, occupancy was assumed to 20, for off-peak travel, and 50 for peak travel. For personal motor vehicle travel occupancy was the driver plus all passengers. After making these two adjustments a weekday total was summed for each variable for each person.

[30] NRD range #1 is 0 – 1.999 dwelling units per net-residential acre; #2 is 2 – 3.999 du/net res. acre; #3 is 4- 5.9999 du/net res. acre; #4 is 6 – 7.999 du/net res. acre; and #5 is 8+ du/net res. Acre.
[31] Intersection density range #1 is 0-9.999 intersections per square kilometer; #2 is 10 – 19.999 ints/sq. km; #3 is 20 – 29.999 ints/sq. km; #4 is 30 – 39.999 ints/sq. km, #5 is 40+ ints/sq. km.

These final values were used as the dependent variables in each of the models shown in Table 114**.**

1. Describing the VMT Relevant Variables

Table 113 describes measures of central tendency and dispersion for the variables in which we found significant relationships with VMT.

Table 113: VMT model variable descriptives

Variable	N (people)	Minimum	Maximum	Mean	Std. Deviation
VMT, daily average, travel party size adj. (SOV, HOV, bus--MARTA, CCT, school)	8613	0.006	103.915	28.236	22.317
Household Size	8613	1	8	2.579	1.231
Total Household Vehicles	8613	0	8	2.111	0.994
Income *	8613	11	19	16.202	2.209
Drivers License	8613	1	2	1.052	0.222
Use Mix	8613	0.000	1.000	0.276	0.306
Intersection Density	8592	0.864	207.421	33.893	16.705
NRD	8613	1	5	2.155	1.289
Valid N (listwise)	8592				

* A value of 16.14 for income corresponds with approximately $50,000 per year.

The statistics reported in Table 113 are for the whole sample used to create the models. Mean VMT per person in the study was found to be 28.23 miles per day, 2.5 persons per household and 2.1 vehicles per household. Most persons had a driver's license. The average level of land use mix was .27 on range of 0-1. Mean number of intersections per square kilometer was 33.89, and the mean net residential density was 2.1 or just over 2 dwellings per acre – meaning that nearly half of the sample reside on ½ acre or larger lots.

2. Modeling VMT, Socio-demographics, and Urban Form

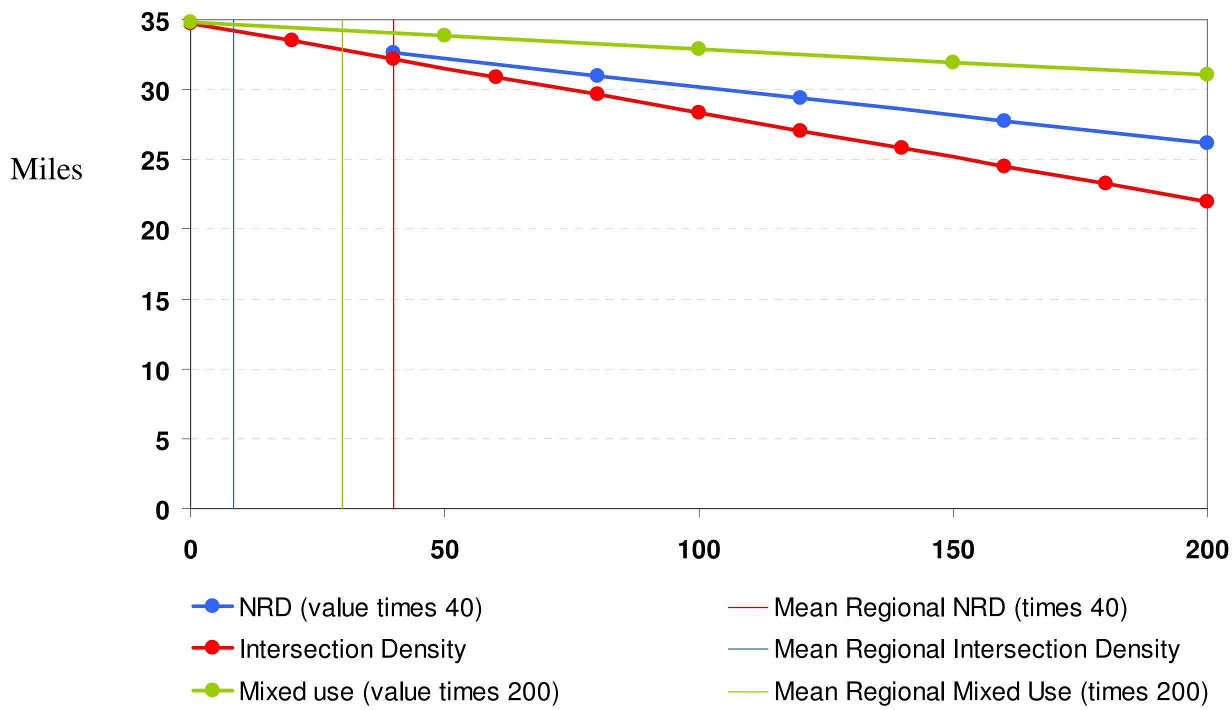
Each of the statistically significant variables are presented in the following ordinary least squares regression model.

Table 114: VMT regression model

VMT Model: weekday, daily per person average (miles) [sum of SOV, HOV & bus (MARTA , CCT & school) trips]						
Variables	**Variable Type**	**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		B	Std. Error	Beta		
(Constant)		36.84866	2.374755		15.51682	1.42E-53
Household Size	continuous	-1.03031	0.208368	-0.05679	-4.94467	7.77E-07
Total Household Vehicles	continuous	0.824251	0.275999	0.03672	2.986426	0.002831
Income*	ordinal	1.144492	0.112675	0.113288	10.15743	4.2E-24
Drivers License**	dummy variable	-18.586	1.085907	-0.18495	-17.1157	1.33E-64
Use Mix	continuous	-3.74321	0.878615	-0.05141	-4.26035	2.06E-05
Intersection Density	continuous	-0.06405	0.015257	-0.04794	-4.19791	2.72E-05
NRD***	ordinal	-1.61672	0.229225	-0.09343	-7.05298	1.89E-12
Adjusted R square	0.100					
* Income ordinal variable	11 = <$10,000; 12 = $10,000 - $19,999; 13 = $20,000 - $29,999; 14 = $30,000 - $39,999; 15 = $40,000 - 49,999; 16 = $50,000 - 59,999, $60,000 - $74,999, 18 = $75,000 - $99,999; 19 = $100,000+					
** Drivers license dummy variable	1 = yes, have a license; 2 = no license;					
*** NRD ordinal variable	1 = 0 – 1.999 dwelling units per net-residential acre; 2 = 2 – 3.999; 3 = 4- 5.999; 4 = 6 – 7.999; 5 = 8+					

All variables in the VMT regression model, except the total number of household vehicles and household income are inversely related to VMT. Amongst urban form variables, an ordinal measure of NRD, whereby households were grouped between 0-2, 2-4, 4-6, 6-8, and 8+ dwelling units per net-residential acre had the strongest relationship with VMT (T= -7.05). Findings shown in Figure 56 indicate the relative change in VMT that would be associated with increases in net residential density, intersection density, and mixed use. Each of the three urban form variables (mix, density, and connectivity) were found to be associated with VMT. However, density was noted to have the strongest association with VMT (t= -7.05) in keeping with findings from previous studies. Mixed use (t=-4.26) and intersection density (t=-4.20) are also significantly associated with VMT. While strength of association is an important predictor, there is also the slope or degree of change in VMT that would be associated with each unit of change in each of the urban form predictors. Rather than attempt to state which variable is the most important or yields the greatest reduction in VMT, it is more precise to discuss how each of the variables relates with VMT.

Figure 56: VMT Model--urban form changes, when all other variable = regional mean



As seen in Figure 56, all three variables are collapsed onto the same scale for this purpose, but we caution the reader to avoid making simple comparison between variables – moreover, that a steeper slope is associated with a stronger association with VMT. This figure was created by holding all other variables constant at their AHTS or regional average. In order to display all variables on the same scale the NRD values are multiplied by 40, and the use mix values by 200. The regional average for each of these variables is noted towards the far left of the image, documenting that in all of the case, the nature of the skewed distribution of land use towards a lower density, single use, and disconnected environment. From this figure, it is possible to begin to interpret the reductions in VMT that might be associated with increases in each of these urban form variables, when holding all other factors in the model constant at their regional average value. Based on a direct interpretation of the slopes within the regression model, it is possible to do a similar thing. For example, each jump in net residential density range (e.g. from 0-2 to 2-4) dwellings per acre, is associated with a reduction of 1.61 miles per capita. On average, this would represent a 5.7 percent reduction in VMT given that the average person travels 28.24 miles per day. Similar estimated can be developed for increases in land use mix and intersection density as well. The results of the VMT model are applied in a subsequent section based on the LCI modeling process for the Atlanta Regional Commission.

V. TRAVEL TIME

Travel time was measured in minutes per day for the two-day period of the travel survey for all trips taken by all modes of travel. An average was taken for the total travel time across these two days for each participant. Travel time used in this report, reflects the actual travel network performance based on the time of day and direction of flow of travel for each trip taken. As presented in Chapter II, a shortest path was taken between self reported trip origins and destination and congested speeds were assigned to each link of each vehicle based trip using on the facility type and time of day of travel. A summation of the total travel time in minutes was conducted for each of over 107,000 trips taken. This rigorous procedure was taken in order to achieve the most objective and realistic assessment of travel time possible.

One of the primary considerations of the SMARTRAQ project was to develop a measurement of the ways in which Atlantans spend their time as a measurement of their overall quality of life. While we have just begun to explore the many aspects of time use, time spent driving has been found to be a significant predictor of obesity in the recently released SMARTRAQ paper, Obesity Relationships With Community Design, Physical Activity, and Time Spent in Cars, published in the American Journal of Preventive

Medicine. Time spent driving is also a good predictor of traffic congestion, and vehicle emissions generated per capita and household. Table 115 provides a detailed description of the key explanatory variables of vehicle based travel time in minutes.

Table 115: Travel Time Model Variable Descriptives

Variable	N (people)	Minimum	Maximum	Mean	Std. Deviation
daily total average vehicle time traveling (minutes)	8670	0.025	165.83	48.83439	34.79861
Household Size	8670	1	8	2.581776	1.23104
Total Household Vehicles	8670	0	8	2.114302	0.995997
Income *	8670	11	19	16.20427	2.208929
Drivers License	8670	1	2	1.051557	0.221144
Use Mix	8670	0	0.999981	0.27513	0.306343
Intersection Density	8646	0.863902	207.4206	33.80153	16.73752
NRD	8670	1	5	2.149712	1.288013
Valid N (listwise)	8670				

* A value of 16.14 for income corresponds with approximately $50,000 per year.

The mean number of minutes of vehicle-based travel per day per person in the study was found to be 48.83; however with a large standard deviation of 34.79; half of the participants spent more than 48.83 minutes, and a third upwards of 83.62 minutes per day in vehicles. As with the vehicle miles of travel analysis, average household size was 2.5 persons and most households have two vehicles. Most participants had a driver's license. The average level of land use mix was .27 on range of 0-1; a relatively low value. Mean number of intersections per square kilometer was 33.80, and the mean net residential density was 2.1 or about 4 dwellings per acre – meaning that nearly half of the sample reside on ¼ acre or larger lots.

Table 116 presents a multiple regression model of average weekday vehicle minutes of travel per participant per day.

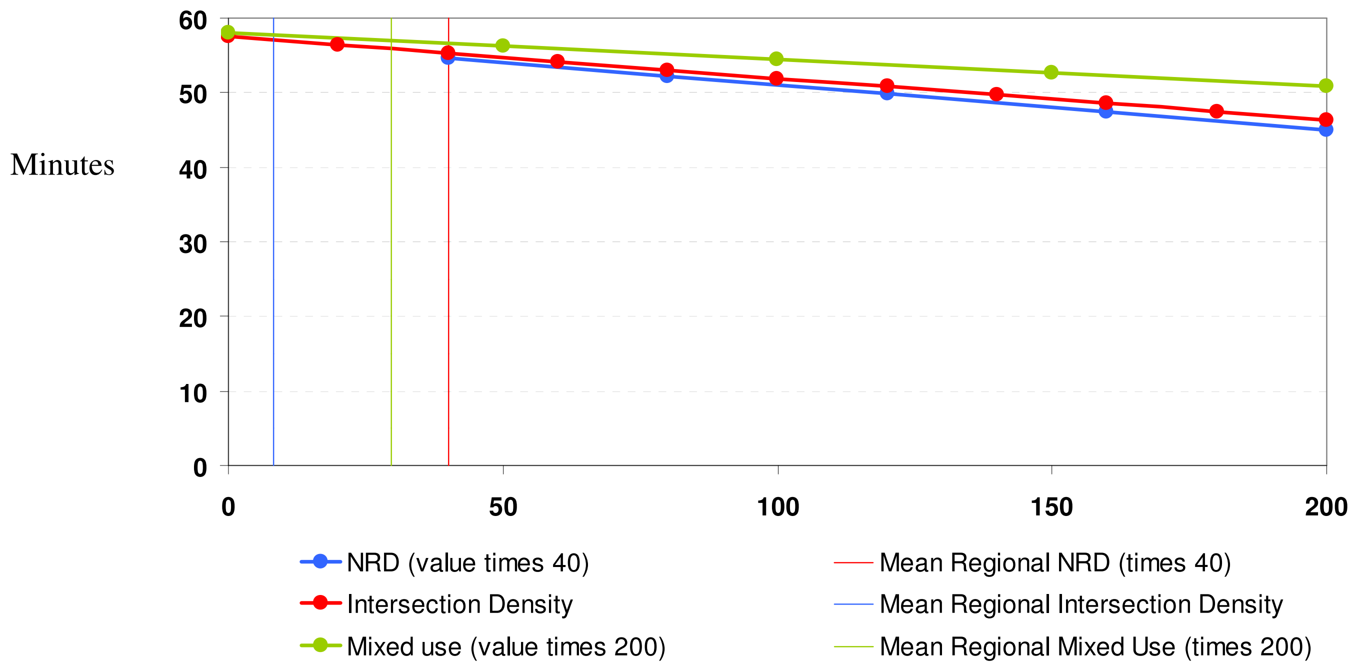
Table 116: Vehicle Based Travel Time in Minutes (Regression model)

VHT Model: weekday, daily per person average (hours) [not travel party size adjusted]						
Variables	**Variable Type**	**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		B	Std. Error	Beta		
(Constant)		57.198	3.649		15.675	0.000
Household Size	continuous	-1.606	0.320	-0.057	-5.019	0.000
Total Household Vehicles	continuous	1.177	0.423	0.034	2.783	0.005
Income*	ordinal	2.254	0.173	0.143	13.027	0.000
Drivers License**	dummy variable	-32.559	1.672	-0.207	-19.473	0.000
Use Mix	continuous	-7.294	1.350	-0.064	-5.402	0.000
Intersection Density	continuous	-0.056	0.023	-0.027	-2.372	0.018
NRD***	ordinal	-2.388	0.353	-0.088	-6.767	0.000
Adjusted R square	0.120					

* Income ordinal variable	11 = <$10,000; 12 = $10,000 - $19,999; 13 = $20,000 - $29,999; 14 = $30,000 - $39,999; 15 = $40,000 - 49,999; 16 = $50,000 - 59,999, $60,000 - $74,999, 18 = $75,000 - $99,999; 19 = $100,000+
** Drivers license dummy variable	1 = yes, have a license; 2 = no license;
*** NRD ordinal variable	1 = 0 – 1.999 dwelling units per net-residential acre; 2 = 2 – 3.999; 3 = 4- 5.999; 4 = 6 – 7.999; 5 = 8+

Like the VMT model above, all but two of the variables are inversely related to VHT. This similarity with VMT would be expected due to the high degree of co-variation between these two metrics of urban travel. Time spent in a car increases with vehicle ownership, but is also very strongly associated with income, and decreases if one does not have a driver's license (t = -19.43). Of the three urban form variables, NRD has strongest association with vehicle based travel time, followed by mixed use and then intersection density. As would be expected, all of the urban form variables are inversely associated with vehicle minutes of travel, however, the rate of decline in vehicle minutes of travel co-varies unique with each variable, and on difference scales. For example, every unit of increase in net residential density (e.g. from 2-4 to 4-6 dwellings per acre) is associated with a 2.38 minute reduction in the average of minutes of vehicle based travel per person. This translates into a 4.8 percent reduction in vehicle based travel time for this modest increase in residential density.

Figure 57: Vehicle Based Travel Time in Minutes



This figure was created by holding all other variables constant at their AHTS or regional average. In order to display all variables on the same scale, the NRD values are multiplied by 40, and the use mix values by 200. The regional average for each of these variables is noted towards the far left of the image, documenting that in all of the case, the nature of the skewed distribution of land use towards a lower density, single use, and disconnected environment. From this figure, it is possible to begin to interpret the reductions in vehicle based minutes of travel per day associated with increases in each of these urban form variables, when holding all other factors in the model constant at their regional average value. The results of the vehicle minutes of travel per day model are applied in a subsequent section to three activity centers which are part of the Atlanta Regional Commission's Livable Centers Initiative planning program.

VI. VEHICLE EMISSIONS

Vehicle emissions were modeled in grams of oxides of nitrogen and volatile organic compounds associated with each segment of each vehicle-based trip (see Chapter II). This project builds upon the dissertation work of Dr. William Bachman, with GeoStats, LP, and previous studies that have established a disaggregate behavioral link between urban form, travel choice, and vehicle emissions in Seattle (Frank et al 2000) and in Atlanta (Frank et al 1999). However, it adds three critical components missing from these previous assessments:

- A disaggregate measurement of the built environment around every participants place of residence,
- A micro scale assessment of emissions of each link of each trip to capture a more realistic assessment of travel speed for each link of each trip by facility type; and
- Capturing of vehicle model, and year within the modeling framework.

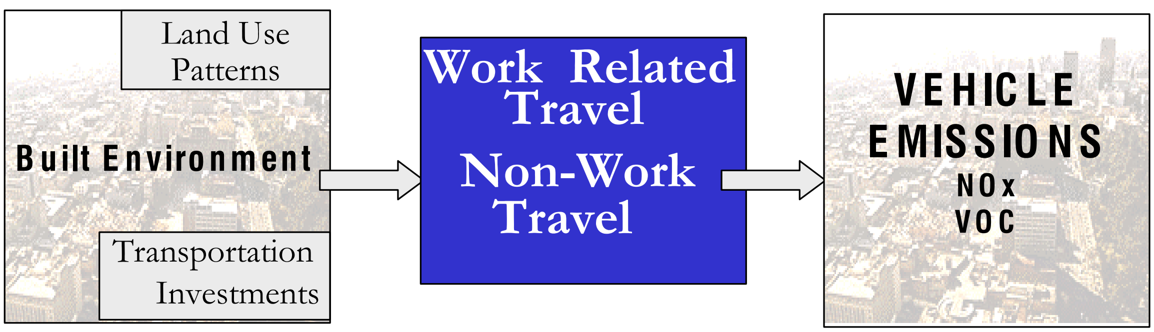
These improvements are critical to understanding how emissions actually vary based on travel and underlying urban form conditions.

Emissions associated with each trip were aggregated to the person level and then associated with the urban form characteristics of each person's place of residence. NO_x and VOCs are known as ozone "precursors." The metropolitan Atlanta region is a severe non-attainment area for ozone, and it is this relationship between transportation and air quality that has been a central theme of the SMARTRAQ program. A conformity lapse in the late 1990s in the Atlanta Region led to the realization that solely adjusting the mix of transportation investments, within political reason, would not alone meet Clean Air Act requirements. Adjustments to land use, through increased concentration of projected growth into centers were made resulted in reduced miles of travel through increased transit modal split and shorter trip lengths. As a result, the Atlanta Regional

Commission's Transportation Improvement Program and Long Range Plan were found to be in conformance with federal clean air requirements.

The models presented above document how residential density, land use mix, and street network design relate with vehicle miles and hours of travel when controlling for demographic factors. However, the understanding that land use plays an obvious role in shaping travel well precedes these results. For this reason, the SMARTRAQ household travel survey was designed to collect a sufficient sample of households from a variety of urban environments ranging from the most to the least in supportive of driving, walking, or taking transit. Capturing households from a wide range of land use patterns is particularly important with respect to modeling vehicle emissions. The following flow diagram (Figure 58) provides a highly simplistic depiction of a linear line of reasoning over how the built environment impacts travel for both work and non-work purposes, which in turn impacts vehicle emissions.

Figure 58: Conceptual Model

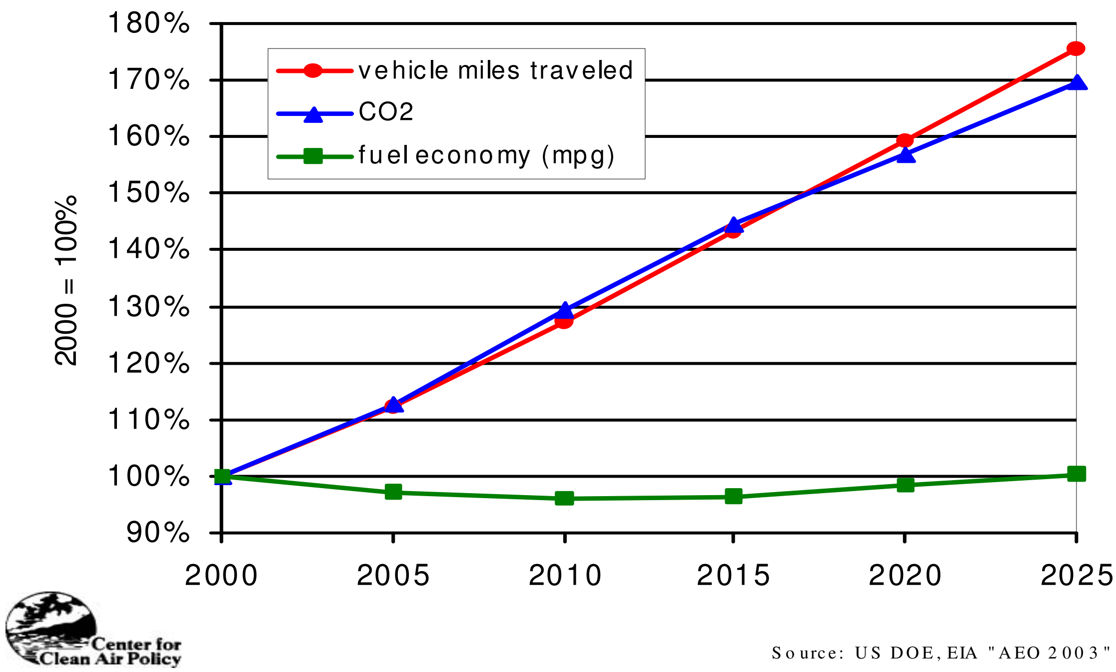


However, vehicular travel impacts emissions generation in a variety of ways, including the modal operation of the engine, duration or distances traveled in hot stabilized or cold start modes of operation, acceleration rates, duration and intensity of warm soaks when vehicles are stationary, and through speed of travel. Obviously, type and age of the vehicle is a significant correlate of emissions per unit of distance traveled. Having this information available is highly unique and is included in this assessment. With the exception of warm soaks, all of the factors noted above are directly or indirectly factored into the modeling procedure and applied to the assessment of vehicle emissions in this study. Details of the methodology used to capture vehicle emissions on a per trip segment – by facility type basis – are provided in Chapter II.

Given that Atlanta is a non-attainment area for ozone, the study focused on NO_x and VOCs. Models are shown below that demonstrate the relationships between travel patterns and emissions directly, with the understanding that the built environment influences these travel patterns (vehicle miles and duration of travel) and indirectly impacts vehicle emissions. However, we have also noted that there appears to be some other effects of the built environment on vehicle emissions that is not captures in these measures of travel choice. In particular, all of the urban form measures have a significant relationship with vehicle emissions after travel duration and distance are taken into account. Therefore, we have provided a multi-stage set of models to explain these complex interactions for both VOCs and NO_x. Descriptive and then inferential models are provided linking the formation of NO_x and VOCs with travel and urban form below.

The total miles of travel within the Atlanta region has increased in association with population growth. Therefore, gains made in the efficiency of the fleet on a per mile basis are being offset by the sheer increase in volume of travel on a per capita and total population basis. This concept is best conveyed in the following diagram which projects growth in VMT and CO2 emissions relative to anticipated gains in fuel economy over the next 20 years averaged across the United States.

Figure 59: VMT Growth, CO2, and Fuel Economy



Gains in overall fuel economy, at least according to the United States Department of Energy, are projected to be non-existent to 2025. Recent increases in sales of sport-utility-vehicles and other fuel inefficient vehicles gives this projection some relevance.

However, countervailing forces exist. The June 2004 cover of National Geographic states *The End of Cheap Oil* as its lead article, which in turn provides an in-depth account of the problem that readily available sources of fossil fuel are rapidly dwindling while global demand is climbing exponentially. The article further documents that at a minimum, the cost of bringing remaining abundant sources of fossil fuel to market is expected to rise dramatically in the coming decade (Appenzeller). Taken in concert with dramatic increases in per capita demand for oil in China, a nation of 1.3 billion who recently outlawed bikes on the streets of their largest city, it would seem a conservative postulation that the cost of fossil fuel will increase. Further, the order of magnitude of this increase may be sufficient to actually cause some rethinking the role of the private vehicle. As documented above, several things need to be accomplished to reduce vehicle use, including careful consideration to how land use decisions are made, and how transportation investments support specific types of land use decisions and growth within central or more outlying areas of a region.

While the source of the increase in demand suggested in Figure 59 are debatable, projected increases in VMT at the regional scale due to growth in population are clearly significant and will impact energy consumption, greenhouse gas emissions, and the formation of ozone through increased NO_x and VOC production. How much of this projection will be offset by global markets and supplies of crude oil is beyond the scope of this report, however, this context is a critical underpinning to national security and planning for the new millennia. It is with this backdrop that we delve into how the relationships between aspects of the built environment and travel patterns impact two precursor's to ozone formation, NOx and VOCs.

A. Oxides of Nitrogen

Atlanta is known as a NO_x limited region, whereby NOx is the limiting factor in the formation of ozone. This is due to the abundance of biogenically provided VOC's in the form of a thick vegetative cover. Descriptive statistics are presented in Table 117 of the variables found to be significantly related with per capita generation of NO_x for a valid sample of 7284 participants. The mean grams of NO_x per person per day was estimated at 23.49 grams. This estimate takes into account stoichiometric operation (hot stabilized) as well as cold start emissions. This number is somewhat lower than previous estimates based on fleet turnover for cleaner vehicles, and better estimates of actual emissions at lower vehicle speeds.

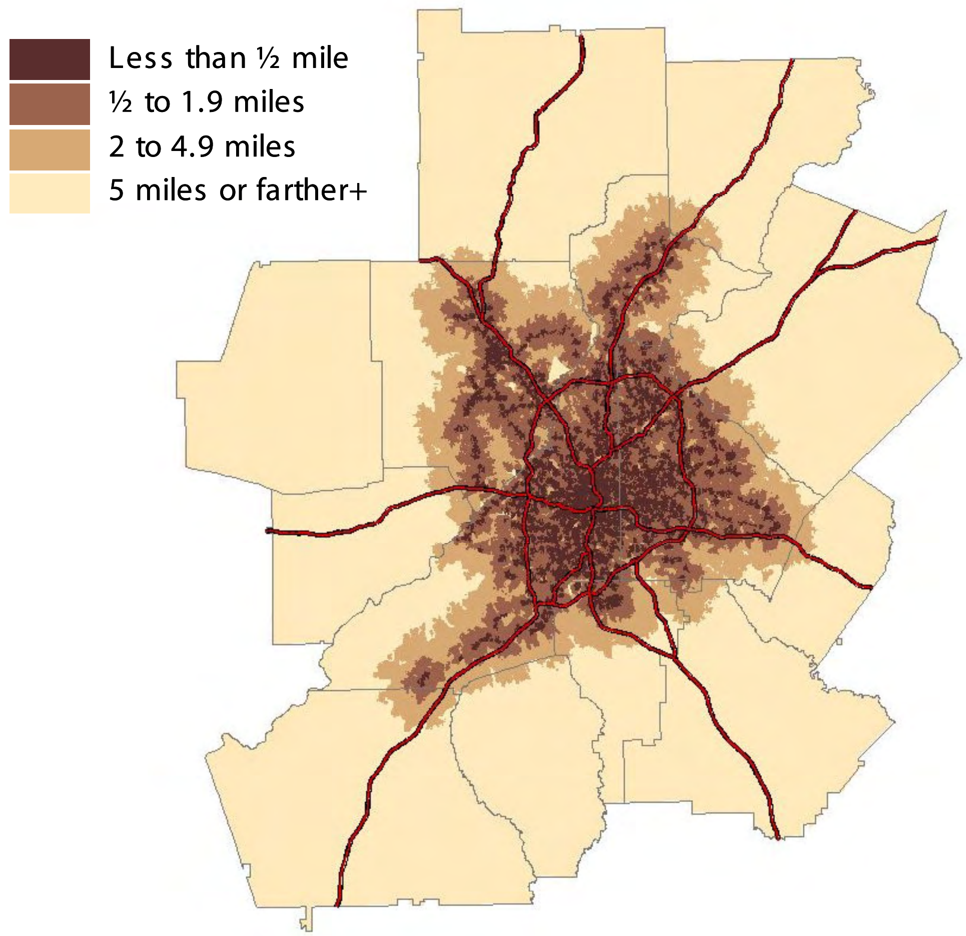
Table 117: NO_x model variable descriptives

Variable	N	Minimum	Maximum	Mean	Std. Deviation
daily average (total NOx/ number of days)	7284	0.019	99.464	23.492	19.348
Household size	7284	1	8	2.563	1.243
Total household vehicles	7284	0	8	2.079	0.995
Income*	7284	11	19	16.146	2.223
Drivers License	7284	1	2	1.047	0.211
Vehicle Age	7284	0	26	6.143	4.288
Use Mix	7284	0.000	1.000	0.279	0.308
Intersection Density	7261	1.000	5.000	3.631	1.179
NRD	7284	1	5	2.166	1.293
Distance to transit (HSTRANDI)	7284	.007	30.264	4.17871	5.55195
Household 15 minute grid-level accessibility	7284	.000	85480.950	9244.269	11669.175
Daily average sum vehicle miles traveled (SOV, HOV, bus – MARTA, CCT, school)	7284	.01	211.57	28.3949	24.136
Daily average sum minutes spent traveling (SOV, HOV, bus – MARTA, CCT, school)	7284	.03	279.51	48.2591	36.145
Valid N (listwise)	7261				

* a value of 16.14 for income corresponds with approximately $50,000 per year.

The mean number of persons per household in the sample was 2.56 and the average household had 2 vehicles. The mean vehicle age for participants in the survey was 6 years old. The mean level of land use mix was 0.279 on a scale of 0-1. The mean residential density was 2.167 – which corresponds with the range of 2 and 4 dwellings per acre. The mean number of intersections per kilometer was assigned an ordinal value of 3.6, which corresponds with the range of between 20 and 30 intersections within the one kilometer network buffer around each household. The mean distance to transit was just over 4 miles for the participants within the survey, but as noted the standard deviation was well over this mean, largely as a result of the fact that much of the region is not served by transit. This is a critical point and is conveyed visually in Figure 60.

Figure 60: Distance to transit using local road network



The average person could reach 9,244 jobs within a 15 minute commute from where they live, and averaged 28.39 miles. The average time spent in a car was 48.25 minutes.

Final results from a two stage model predicting the variation in per capita NO_x emissions are shown in Table 118. The first stage model included only socio-demographics and explained 14.9 percent of the variation in grams of NO_x. As household size increases, the per capita generation of NO_x declines, meaning that living in a larger home is associated with less per capita emissions. This result extends from the fact that each vehicle trip's emissions were divided by the number people in the vehicle. Ownership of vehicles and income were positively associated, while not having a driver's license was inversely associated with NO_x emissions. Vehicle age carried most of the association with NO_x emissions (t = 31.86).

Adding in urban form variables (stage 2 and shown in Table 118) resulted in a significant inverse association for density, mix, and connectivity. That is, as residential density, intersection density, and land use mix increase, the emissions of NO_x declined. The adjusted R square for this model was 0.1618 – or approximately 16 percent of the variation in NO_x production per person is explained through the variables included within the model. In an additional model, the inclusion of both distance to transit (positively associated with NO_x (t = 9.24)) and employment accessibility (inversely associated with NO_x (t = -.4.08)) resulted in net residential density and intersection density becoming insignificant. However, land use mix remained significant suggesting that even after accounting for distance to work, that access to non-work destinations has a limited but significant relationship with overall emissions on a per capita basis.

Table 118: NO_x regression model (demographics, urban form)

NO_x Model: weekday, daily per person average (grams)						
[weekday average daily NO_x for people over 15 years old]						
Variables	**Variable Type**	**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta		
(Constant)		16.621	2.296		7.239	4.999E-13
Household Size	continuous	-0.903	0.188	-0.058	-4.794	1.67E-06
Total Household Vehicles	continuous	0.626	0.255	0.032	2.456	0.0140651
Income*	Ordinal	0.784	0.104	0.090	7.537	5.413E-14
Drivers License**	Dummy variable	-8.874	1.039	-0.097	-8.539	1.628E-17
Vehicle Age	continuous	1.602	0.049	0.356	32.490	2.62E-216
Use Mix***	continuous	-3.790	0.794	-0.061	-4.773	1.854E-06
Intersection Density	continuous	-0.779	0.192	-0.048	-4.050	5.175E-05
NRD****	Ordinal	-0.686	0.204	-0.046	-3.360	0.0007836
Adjusted R square	0.1618					

* Income ordinal variable	11 = <$10,000; 12 = $10,000 - $19,999; 13 = $20,000 - $29,999; 14 = $30,000 - $39,999; 15 = $40,000 - 49,999; 16 = $50,000 - 59,999, $60,000 - $74,999, 18 = $75,000 - $99,999; 19 = $100,000+
** Drivers License dummy variable	1 = yes, have a license; 2 = no license;
*** NRD ordinal variable	1 = 0 – 1.999 dwelling units per net-residential acre; 2 = 2 – 3.999; 3 = 4- 5.999; 4 = 6 – 7.999; 5 = 8+
**** Intersection Density ordinal variable	1 = <10 intersections/square kilometer; 2 = 10 – 20; 3 = 20 – 30; 4 = 30 – 30; 5 = 40+

It is surmised that the reason that urban form variables were directly related with per capita NO_x emissions stems from systematic associations between land use and travel distance and speed that predict emissions. However, these factors were not included in the models described above in order to show this seemingly direct relationship between urban form and transportation related NO_x emissions. Adding VMT (t = 132.52) as an additional independent variable with demographics and vehicle age (t = 74.20) resulted in an R-square increase to 75.0 percent (Table 119).

Table 119: NOx regression model (demographics, VMT)

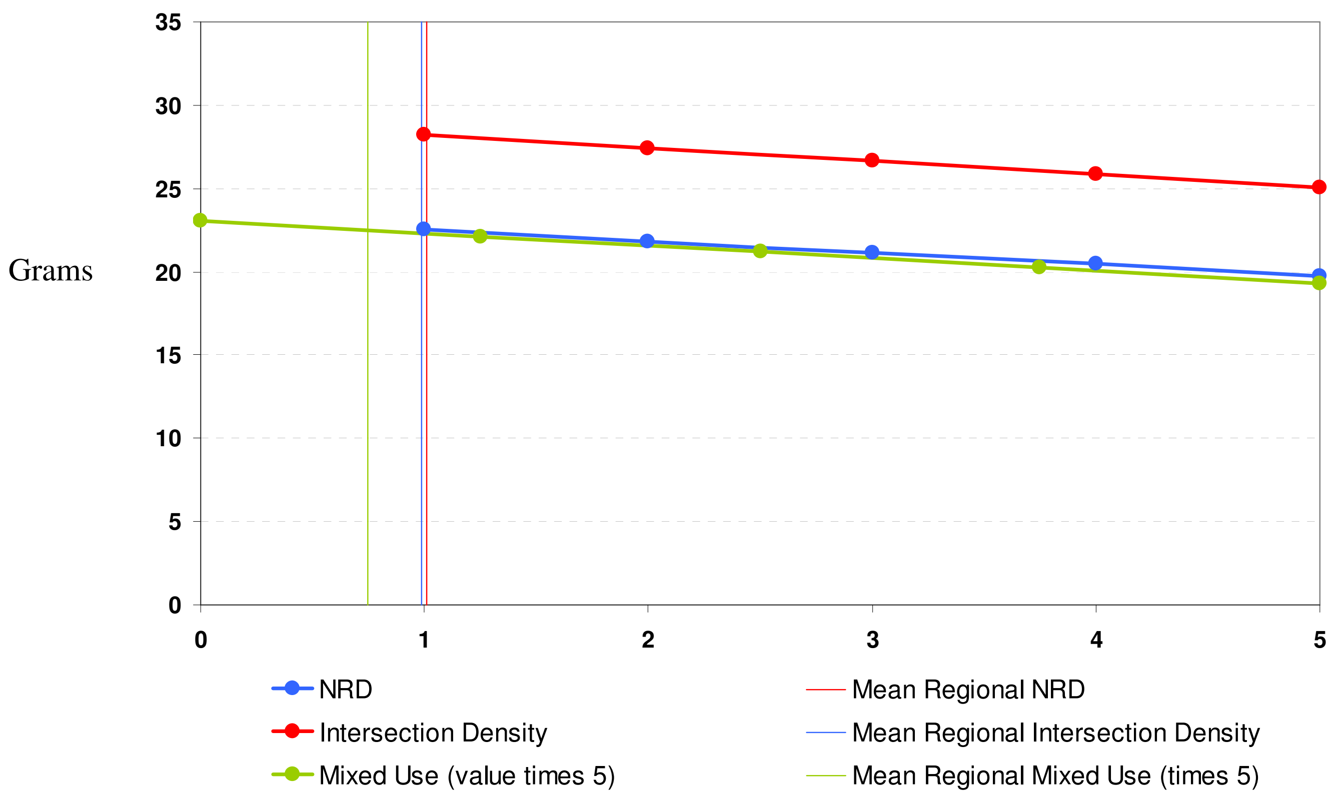
NO_x Model: weekday, daily per person average (grams)						
[weekday average daily NO_x for people over 15 years old]						
Variables	**Variable Type**	**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		B	**Std. Error**	**Beta**		
(Constant)		-10.403	1.181		-8.806	0.000
Household Size	continuous	-0.213	0.102	-0.014	-2.087	0.037
Total Household Vehicles	continuous	-0.117	0.136	-0.006	-0.864	0.388
Income*	Ordinal	0.044	0.057	0.005	0.776	0.438
Drivers License**	Dummy variable	3.030	0.575	0.033	5.271	0.000
Vehicle Age	continuous	2.011	0.027	0.446	74.201	0.000
VMT (daily ave. sum vehicle miles traveled (SOV, HOV, bus--MARTA, CCT, school)	continuous	0.650	0.005	0.811	132.515	0.000
Adjusted R square	0.75					
* Income ordinal variable	11 = <$10,000; 12 = $10,000 - $19,999; 13 = $20,000 - $29,999; 14 = $30,000 - $39,999; 15 = $40,000 - 49,999; 16 = $50,000 - 59,999, $60,000 - $74,999, 18 = $75,000 - $99,999; 19 = $100,000+					
** Drivers License dummy variable	1 = yes, have a license; 2 = no license;					

However, urban form variables were found to be insignificant after VMT or VHT was added to the NO_x model suggesting that nearly all of the explained variation between urban form and transportation-related NO_x emissions is attributable to distance traveled. It is curious to note that the significance of vehicle age increased with the addition of VMT suggesting some interactions between these two vectors. Conversely, the significant of vehicle age declines with the inclusion of the urban form measures suggesting some opposite effects of urban form. In particular, increased levels of density and connectivity are associated with more central older urban communities where income may be lower and vehicles may be older. This may be the exact opposite of the presence of newer cleaner cars in wealthier outlying suburban locations where per capita VMT is the greatest. Therefore, the effect of urban form on per capita emissions, even when taking VMT into account, may be muted by the systematic changes in vehicle age in different types of land use patterns.

However, as Table 118 above shows, the urban form variables remained significant after vehicle age and the demographic factors were already entered as explanatory variables. Previous studies holding vehicle type constant, revealed more significant relationships between urban form and vehicle emissions. As shown above, each of the urban form variables impacts VMT. Obviously, reduction or increase in VMT translates into more or less NO_x. This is due to the fact that much of the variation in NO_x is associated with hot stabilized operation as opposed to cold start activity (Frank et al 2000b).

Figure 61 is for illustrative purposes and demonstrates graphically that incremental increases in each of the three urban form variables are associated with reductions in NO_x.

Figure 61: NO_x Emissions in Relation With Urban Form



While assumed to be somewhat parallel, the units have been significantly shifted to fit all three urban form variables on a single scale. These relationships are based on Table 118, where VMT is not included, but demographics and vehicle age are included in the model. Increases in each of the urban form variables are associated with a steady reduction in NO_x.

B. Volatile Organic Compounds (VOCs)

Whereas the primary source of NO_x is through hot stabilized operations, VOCs are largely generated through engine start activity. The average participant generated 9.75 grams of VOC per day. The mean number of persons per household in the sample was 2.56 and the average household had 2 vehicles. The mean vehicle age for participants in the survey was 6 years old. The mean level of land use mix was 0.279 on a scale of 0-1. The mean residential density was 2.167 – which corresponds with 2 to 4 dwellings per acre. The mean number of intersections per kilometer was assigned an ordinal value of 3.6; which corresponds with between 20 and 30 intersections within the one kilometer network buffer around each household. The mean distance to transit was just over 4 miles.

Table 120: VOC Model Variable Descriptives

Variable	N	Minimum	Maximum	Mean	Std. Deviation
daily average (total VOC/number of days)	7332	0.006	43.122	9.746	7.111
Household size	7332	1	8	2.565	1.244
Total household vehicles	7332	0	8	2.081	0.995
Income*	7332	11	19	16.144	2.221
Drivers License	7332	1	2	1.046	0.210
Vehicle Age	7332	0	26	6.137	4.204
Use Mix	7332	0.000	1.000	0.278	0.308
Intersection Density	7309	1.000	5.000	3.625	1.181
NRD	7332	1	5	2.161	1.292
Distance to transit (HSTRANDI)	7332	0.007	30.264	4.21465	5.58807
Household 15 minute grid-level accessibility	7332	0	85480.95	9215.919	11667.526
Daily average sum vehicle miles traveled (SOV, HOV, bus – MARTA, CCT, school)	7332	0.01	211.57	29.002	24.94477
Daily average sum minutes spent traveling (SOV, HOV, bus – MARTA, CCT, school)	7332	0.03	279.51	49.0232	37.05048
Valid N (listwise)	7309				

* a value of 16.14 for income corresponds with approximately $50,000 per year.

The mean person in the sample (n=7332) could reach over 9,200 jobs within a 15 minute commute, traveled 29 miles per day and 49 minutes per day in vehicles. The following regression model demonstrates a significant relationship between each of the urban form variables and per capita generation of VOC's. Again, as shown with NO_x, increases in household size were found to be associated with reductions in per capita VOCs. Increased vehicle ownership and income were found to be associated with increased emissions. While these two variables are highly correlated, it was clearly income that had the strongest association with VOC generation. Not having a driver's license is associated with a significant reduction, while vehicle age has the strongest positive association with per capita VOC generation (t = 29.64). Land use mix, intersection density, and net residential density each had significant inverse relationships with the variation in per capita VOC production.

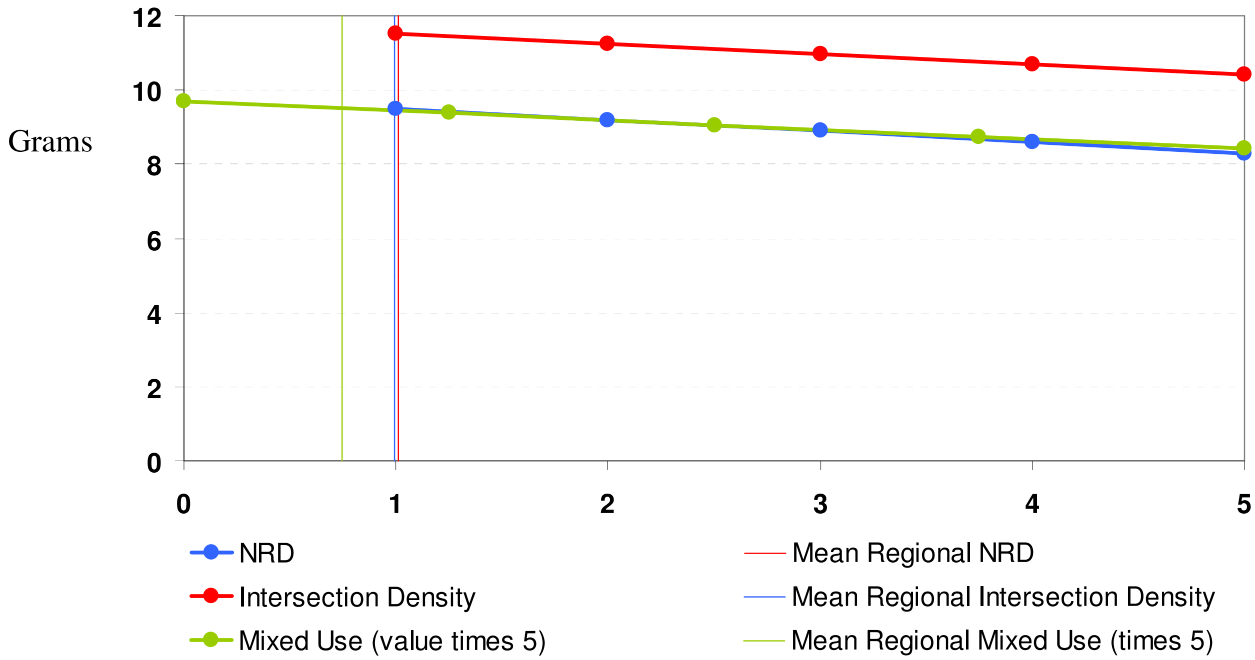
Table 121: VOC regression model

HC Model: weekday, daily per person average (grams) [weekday average daily HC for people over 15 years old]						
Variables	**Variable Type**	**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		B	Std. Error	Beta		
(Constant)		8.269	0.846		9.770	2.071E-22
Household Size	continuous	-0.380	0.069	-0.067	-5.494	4.056E-08
Total Household Vehicles	continuous	0.365	0.094	0.051	3.888	0.0001018
Income*	ordinal	0.292	0.038	0.091	7.609	3.118E-14
Drivers License**	dummy variable	-4.148	0.383	-0.123	-10.817	4.576E-27
Vehicle Age	continuous	0.549	0.019	0.325	29.635	2.38E-182
Use Mix***	continuous	-1.270	0.293	-0.055	-4.341	1.441E-05
Intersection Density	continuous	-0.306	0.071	-0.051	-4.326	1.538E-05
NRD****	ordinal	-0.274	0.075	-0.050	-3.648	0.0002666
Adjusted R square	0.155					

* Income ordinal variable	11 = <$10,000; 12 = $10,000 - $19,999; 13 = $20,000 - $29,999; 14 = $30,000 - $39,999; 15 = $40,000 - 49,999; 16 = $50,000 - 59,999, $60,000 - $74,999, 18 = $75,000 - $99,999; 19 = $100,000+
** Drivers License dummy variable	1 = yes, have a license; 2 = no license
*** NRD ordinal variable	1 = 0 – 1.999 dwelling units per net-residential acre; 2 = 2 – 3.999; 3 = 4- 5.999; 4 = 6 – 7.999; 5 = 8+
**** Intersection Density ordinal variable	1 = <10 intersections/square kilometer; 2 = 10 – 20; 3 = 20 – 30; 4 = 30 – 30; 5 = 40+

As was the case with NO_x, increases in each of the urban form variables were found to be associated with modest reductions in VOCs. For the purposes of this graphical depiction, all of the other variables were held constant at their average value.

Figure 62: VOC Emissions in Relation With Urban Form



VII. APPLICATION OF REGRESSION MODEL

A. LCI Site

These models, and variants of these models developed from these data were used to evaluate the travel and emissions impact of implementing plans developed by the City of Marietta, the West End community in the city of Atlanta, and Perimeter Center developed through the ARC's Livable Center Initiative program. This element of the SMARTRAQ project was done under contract with the Georgia Regional Transportation Authority.

The set of analysis were based on three LCI sites, the City of Marietta (Cobb County), Perimeter Center (DeKalb and Fulton Counties) and the West End (City of Atlanta). These sites were chosen based on their regional location (center, suburban, and exurban locations); development typology (e.g., transit-oriented development [TOD], activity center, town center); county representation; and data availability. For each site, three cases were analyzed – the current land use, transportation and air quality conditions and two alternative futures – one envisioned through the LCI planning process and the other the status quo, or current trend.

For purposes of applying these person-level models to the LCI sites three demographic profiles are used. Household size, vehicles, and income are assumed for each profile. The profiles in Table 122 provide a range of reasonable demographic combinations, and each (not considering vehicle age) represents over 100 actual people in the AHTS dataset used to create the models. In general terms the profiles represent a low income, single person (#1), a person from a middle income family with one child (#2), and a person from an upper income household with no children.

Table 122: Demographic Profiles

Demographics	Person #1	Person #2	Person #3
HH annual income	$10,000 - $19,999	$50,000- $59,999	$100,000+
HH size	1	3	2
Licensed driver?	Yes	Yes	Yes
HH # of vehicles	1	2	3
Vehicle age	8.00	6.00	2.00

The values shown in Table 123 were determined for the three urban form variables for each site, for each case (base, LCI, status quo), nine cases total. For additional details on the value determination process please see the SMARTRAQ report to GRTA called "Before and After Study Livable Centers Initiative" (reports III.1-III.4).

Table 123: Urban form values

Urban Form Variable			Marietta	Perimeter	West End
Intersection Density		# per square kilometer	56.23	13.27	49.79
		Ordinal code value	5	2	5
Net Residential Density	Base	Dwelling units/net-residential acre	5.43	5.27	11.11
		Ordinal code value	3	3	5
	LCI	DU/net res. acre	6.55	8.66	10.46
		Ordinal code value	4	5	5
	Status Quo	DU/net res. acre	3.94	5.25	11.11
		Ordinal code value	2	3	5
Mixed Use	Base	Indexed value between 0 & 1, with 1 = to most evenly mixed	0.73	0.72	0.72
	LCI		0.88	0.87	0.85
	Status Quo		0.71	0.75	0.56

No additional streets were assumed for the futures of any sites, therefore, intersection densities within each site are held constant into the future.

Entering the values from Table 122 and Table 123 into the regression models produces the results shown in Figure 63through Figure 66. In the case of implementing the LCI plan each person at each site, on a daily average, is estimated to travel fewer vehicle miles and hours, and produce fewer emissions than in the base or status quo cases. For all profiles and for each site, except Perimeter Center, the status quo future results in more travel and emissions compared to the base case. For Perimeter Center there is little change from the base to status quo future.

For example, Table 124 shows that person #1 (low-income, single) living in Marietta in the base case is estimated to add on an average weekday (travel-party-size adjusted) 20.6 miles and 35.7 minutes of demand on the road network, and produce 21.2 grams of NO_x and 8.8 grams of HC/VOCs. However, if this person lived in the status quo Marietta future, vehicle miles would increase 8% (1.7 miles), time would increase 7% (2.5 minutes), and emissions would increase as well. Contrast that with the travel demand of this person living in a future where the Marietta LCI plan was fully implemented. In this future this person's vehicle miles would decrease 10.7 % (2.2 miles), time would decrease 9.8% (3.5 minutes), and NO_x and HC would decrease (1.8% and 5.6%, respectively).

The combination of demographic profile and site case which produces the lowest travel demand (17.3 miles, and 30.4 minutes) and emission (19.2 grams NO_x and 8.0 gram HC/VOC) is person #1 living in the West End's LCI future. Person #3 (high-income, couple) living in current conditions in Perimeter Center travels the most miles (32.0) and longest time 54.6 (minutes) on an average weekday. However, it is the person with the oldest car who produces the most emissions. Person #1 living in Perimeter Center (base and status quo cases) creates the most NO_x (23.2 grams) and HC (9.6 grams) of any other person in any other site case. In fact, even though person #1, in every case, drives the least they also produce the most emissions. The lower travel amounts are over whelmed by having the oldest car of the three profiles. Vehicle age is a significant factor in the emissions models.

The percentage change experienced by each person varies by site case and across sites (Table 125). The greatest reduction in VMT across all profiles and site cases (16.2%) is experienced by person #1 living in the Perimeter Center LCI future case, as compared to base conditions. The greatest increase is experienced by person #1 (8.3%) living in the Marietta status quo future. In fact, the Perimeter Center LCI future produces the greatest reductions in time spent traveling (person #1) and emissions produced (person #3). This is due to Perimeter's LCI future representing the biggest departure, of the three sites, from current conditions, primarily through the increase in residential density.

The greatest increases in travel and emission are always associated with comparing Marietta current conditions and its status quo future, which assumes a decline in residential density. For travel distance and time person #1 in Marietta sees the biggest increase, 8.3% and 7.2% respectively. For emissions, person #3 experiences the greatest increase, 5.0% for NO_x and 4.3% for HC.

Figure 63: Vehicle miles of travel, average weekday

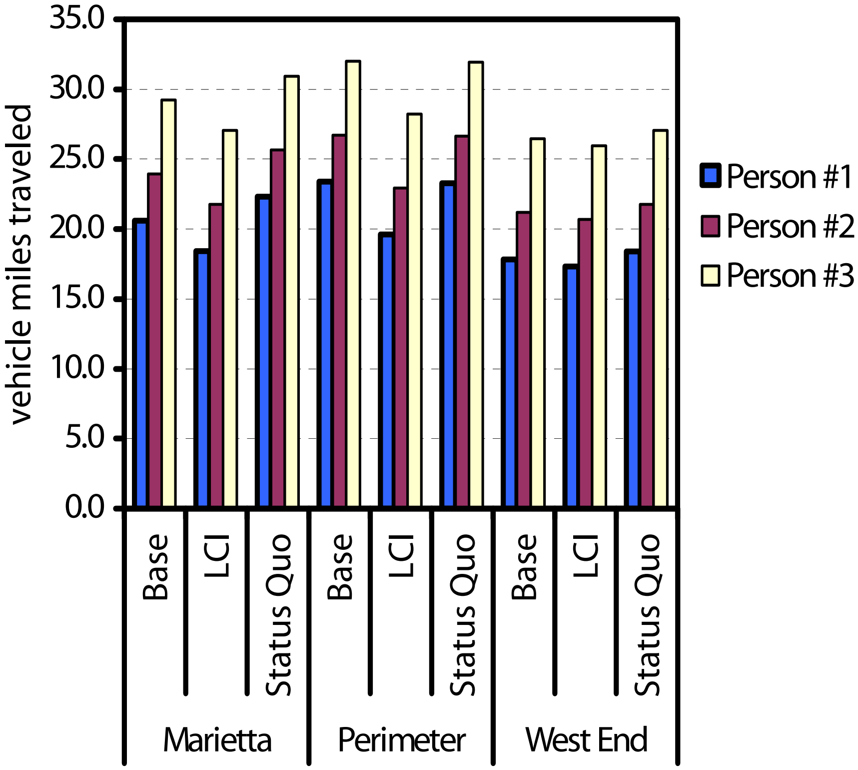


Figure 64: Vehicle travel time, average weekday (minutes)

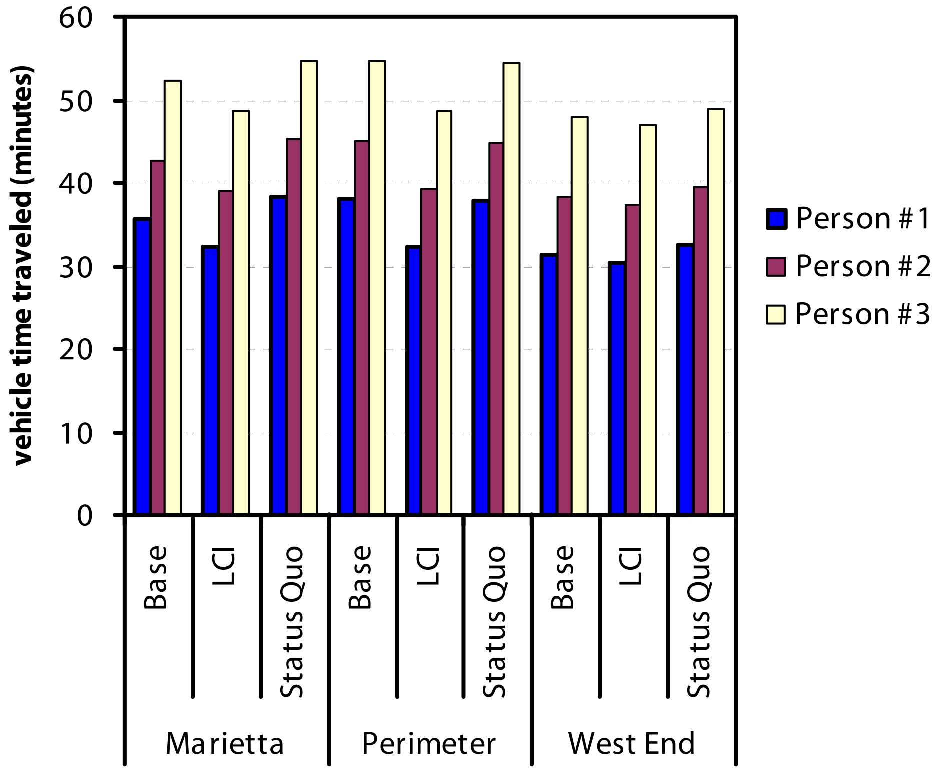


Figure 65: NO_x emissions produced, average weekday (grams)

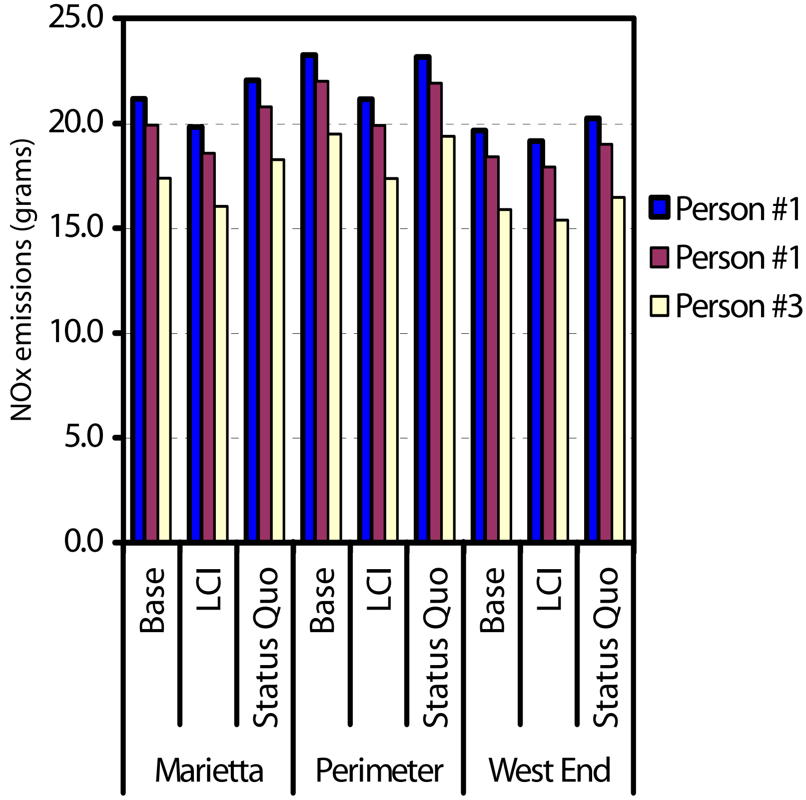


Figure 66: VOC (HC) emissions produced, average weekday (grams)

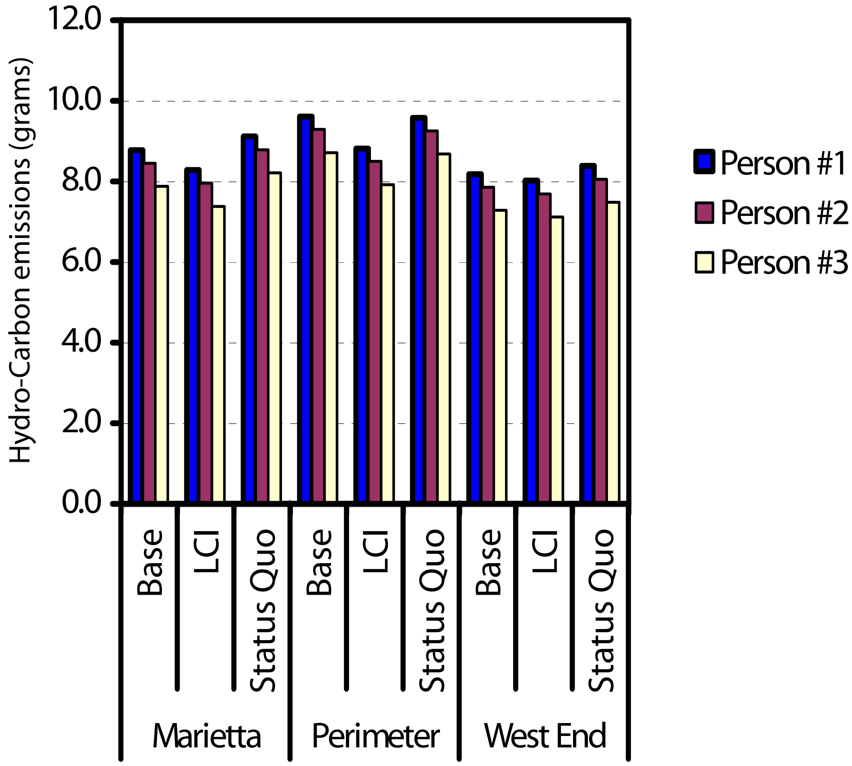


Table 124: Numerical results from regression models

Person #1	Case	Vehicle Miles Traveled	Vehicle Travel Time (minutes)	NOx (grams)	HC (grams)
Marietta	Base	20.6	35.7	21.2	8.8
	LCI	18.4	32.2	19.8	8.3
	Status Quo	22.3	38.2	22.0	9.1
Perimeter	Base	23.4	38.1	23.2	9.6
	LCI	19.6	32.3	21.1	8.8
	Status Quo	23.3	37.9	23.2	9.6
West End	Base	17.8	31.3	19.6	8.2
	LCI	17.3	30.4	19.2	8.0
	Status Quo	18.4	32.5	20.2	8.4
Person #2					
Marietta	Base	23.9	42.6	19.9	8.5
	LCI	21.8	39.2	18.6	8.0
	Status Quo	25.7	45.2	20.8	8.8
Perimeter	Base	26.7	45.1	22.0	9.3
	LCI	22.9	39.2	19.9	8.5
	Status Quo	26.6	44.9	21.9	9.3
West End	Base	21.2	38.3	18.4	7.9
	LCI	20.7	37.3	17.9	7.7
	Status Quo	21.8	39.4	19.0	8.1
Person #3					
Marietta	Base	29.2	52.2	17.4	7.9
	LCI	27.1	48.7	16.0	7.4
	Status Quo	30.9	54.7	18.3	8.2
Perimeter	Base	32.0	54.6	19.5	8.7
	LCI	28.2	48.8	17.4	7.9
	Status Quo	31.9	54.4	19.4	8.7
West End	Base	26.5	47.8	15.9	7.3
	LCI	26.0	46.9	15.4	7.1
	Status Quo	27.0	49.0	16.5	7.5

Table 125: Percent change of regression model results

Person #1	Case	Vehicle Miles Traveled	Vehicle Travel Time (minutes)	NOx (grams)	HC (grams)
Marietta	LCI to Base	-10.6%	-9.8%	-6.4%	-5.7%
	Status Quo to Base	8.3%	7.2%	4.1%	3.8%
Perimeter	LCI to Base	-16.2%	-15.3%	-9.1%	-8.3%
	Status Quo to Base	-0.4%	-0.5%	-0.4%	-0.3%
West End	LCI to Base	-2.8%	-3.1%	-2.5%	-2.0%
	Status Quo to Base	3.3%	3.6%	3.0%	2.4%
Person #2					
Marietta	LCI to Base	-9.1%	-8.2%	-6.8%	-5.9%
	Status Quo to Base	7.1%	6.0%	4.4%	4.0%
Perimeter	LCI to Base	-14.1%	-13.0%	-9.6%	-8.6%
	Status Quo to Base	-0.3%	-0.4%	-0.4%	-0.3%
West End	LCI to Base	-2.3%	-2.5%	-2.7%	-2.1%
	Status Quo to Base	2.8%	3.0%	3.2%	2.5%
Person #3					
Marietta	LCI to Base	-7.5%	-6.7%	-7.8%	-6.3%
	Status Quo to Base	5.8%	4.9%	5.0%	4.3%
Perimeter	LCI to Base	-11.8%	-10.7%	-10.8%	-9.1%
	Status Quo to Base	-0.3%	-0.3%	-0.5%	-0.4%
West End	LCI to Base	-1.9%	-2.0%	-3.1%	-2.3%
	Status Quo to Base	2.2%	2.4%	3.7%	2.7%

B. Regional Change

As an additional means to further understand the level of change necessary from regional urban form means to achieve reductions in vehicle travel and subsequent emissions the following scenario was explored. Each model was used four times, systematically increasing the current average values for regional urban form (residential and intersection densities and mixed use) each time, while holding the demographic ones constant. The output is the daily mean VMT, VHT, NO_x and VOC for the regionally average person, both in terms of demographics and urban form. In three subsequent model runs, the urban form variables were all increased by 150%, 200% and 300% regionwide or within a given location.

Table 126 shows the resulting reductions in VMT, as compared to the mean base-case range from 4 to 17%. The same was done with the three other models (VHT, NO_x and HC/VOC), with results being similar. NO_x has both the lowest maximum reduction and the smallest change across the urban form multipliers.

Table 126: VMT reduction due to urban form value increases, from region mean

% Reduction of travel & emissions	Current regional average person base value	Regional urban form mean multiplier		
		1.5	2	3
VMT (miles)	32	-4%	-8%	-17%
VHT (minutes)	54	-4%	-7%	-15%
NO_x (grams)	14.4	-3%	-5%	-11%
HC/VOC (grams)	11.4	-3%	-7%	-13%

It is important to note that this is purely a simulation based on the results of the linear regression models. Assumptions of a uniform change in NO_x of VOCs due to incremental increases across any of the urban form variables does not necessarily reflect how these relationships manifest themselves in reality. Thus, a certain level of density or mixed use, or connectivity may be required before people decide that walking is preferable to driving. This would be similar to what is often referred to as a “tipping point” or a “threshold.”

The region is projected to grow by over two million people over the next 25 years. With the Atlanta region based results of SMARTRAQ providing a better understanding of how urban form affects travel and emissions, this future growth could be “used” in two ways. The form of the new development could reduce per capita daily travel and emissions produced by these newcomers. Secondly, by strategically locating new development, it could be used to help reduce demand for vehicle travel of the region’s current population. Accomplishment of this objective requires new residential and employment development be integrated with existing development in ways which increase NRD, use mix and intersection densities of existing developed areas.

CHAPTER V – SUMMARY AND RECCOMMENDATIONS

I. DATA, TOOLS, METHODOLOGIES AND FINDINGS

The SMARTRAQ research project provides the Atlanta region, and the nation, with a tremendous wealth of recent local data, methods to collect and analyze it, and results to guide future transportation, land use, and community health planning decision making and policy development. In addition to data collection and analysis, the SMARTRAQ datasets provide the region with a nationally unique set of interlocked travel behavior, land use, attitudinal, and physical activity information for a very large local population sample. Through the work of the SMARTRAQ project, the Atlanta Household Travel Survey (AHTS) used to collect activity and travel data from 8,069 households during 2001 and 2002 resulted in:

- A travel survey that is activity-based;
- An intentional over-sampling of households in higher-density residential areas,
- Collection of travel data for Saturdays and Sundays, in addition to the standard weekday coverage;
- Travel data from children 5 years and older;
- Representation of travel patterns across ethnicities and income levels; and
- Sub-surveys covering health and physical activity data, subjective assessments and preferences regarding community design and travel options and trip-level spatial data indicating the exact route taken.

Inclusion of all these elements in the survey design allowed the SMARTRAQ project to make substantial contributions to the current travel demand forecasting process, including expanded data to update and define trip generation base rates, and supporting data that can be used for more specific model needs, such as mode choice. The combination of the activity-based travel survey and the parcel-level regional land use database developed through SMARTRAQ provide a good foundation and are recommended to continue to be used by the region to further explore development of next-generation travel forecasting models. For more information about applications of SMARTRAQ results to the regional travel demand modeling process, please see report number V.21 provided to the Georgia DOT.

The parcel-level land use database enabled the testing of relationships between land use, travel behavior, and resulting vehicle emissions. For more about current applications and proposed future enhancements to the land use database, please see the report produced by the Georgia Regional Transportation Authority, under contract to the Georgia DOT. Paramount to the discussion of future enhancements is the need to consider how frequently the land use database is updated, what information is collected, and who is responsible for the collection, distillation, and dissemination of the database.

Research presented in this report demonstrates the importance of land use to reduce vehicle miles and time traveled, and vehicular production of oxides of nitrogen and volatile organic compound emissions. Specifically, findings at the personal travel level demonstrate that travel patterns and emissions are sensitive to residential density, land use mix, and the level of street connectivity. As expected, increases in each of these measures are associated with decreases in vehicular travel and emissions when controlling for socio-demographic factors. These findings are important as they provide empirical evidence of these connections and elasticities for inferring the relative changes in travel or emissions commensurate with specific changes in urban form. In summation, the findings suggest addressing regional concerns for unhealthy air quality and increasing vehicle travel will be best served through a somewhat denser, more mixed use, and interconnected form of development.

This work provides analytical support for the value of the Atlanta Regional Commission's (ARC) Livable Centers Initiative which helps foster greater livability in existing activity and employment centers by focusing growth there along with a share of transportation investment. A detailed analysis of the effects of the LCI plans on travel and emissions, as well direct application of SMARTRAQ data and findings, is documented in report #III.2,3,4 provided to GRTA.

Findings presented here also support ARC's and GTRA's developments of regional impact (DRI) processes, which, pursuant to state law, evaluate aspects of development that impact, among other things, travel. These aspects include site design, density, mix of uses, pedestrian systems, and transit access. The findings compliment the recently completely work by the Metro Atlanta Chamber of Commerce's Quality Growth Task Force which promotes additional housing at multiple price-points in the region's centers and along its corridors, links transportation infrastructure spending decisions with land use decisions, prioritizes greenfield development that leverages existing and programmed infrastructure, and provides more market choices and saves more open space.

Findings from this study and from work conducted elsewhere in the nation provide directions for altering local land use actions to reduce vehicle dependence and emissions. Based on these results, five major policy-level recommendations emerge:

1. *Matching Growth and Regional Transportation*--Focusing a portion of new growth into existing and emerging urban centers in order to achieve higher levels of density, land use mix and connectivity and providing adequate infrastructure for pedestrian, bicycling, and transit travel could be effective strategies to complement other regional efforts to improve traffic congestion and air quality. Supportive land use policies in combination with regional transportation investments targeted at increasing the desirability and accessibility of carpooling, transit, and non-motorized travel could have a positive effect on altering travel patterns and reducing mobile source emissions.

2. *Land Use is Local* -- Land use strategies are required to address the unique social and physical characteristics of central, suburban, and ex-urban areas of the region. Strategies are required that speak to the unique sets of issues associated with retrofitting existing communities, such as providing quality pedestrian and bicycle linkages between existing residential, office, and commercial uses already located in proximity to one another. In emerging communities, it is critical to provide travel options to the car for both local

and regional needs. This can be achieved by situating residential, commercial, office, and recreational/open space land uses within close proximity to developing transit corridors and park and ride facilities.

3. *Mixed Use, Density, and Connectivity are Synergistic* -- Land use policies required to reduce auto dependence need to encourage both proximity (density and mixed use) and connectivity. The consolidation and intermixing of land use combined with increased street connectivity offers an important part of the solution to improve air quality. However, increasing the levels of density and land use mix alone will not yield effective changes in travel patterns without increased connectivity for local access on foot and by bike, and without a regional transit system that is competitive, in terms of time and/or out of pocket cost, with the private vehicle.

4. *Market Preferences* – Results of the SMARTRAQ market survey suggest a significant latent demand (30 percent) for more walkable environments. These results are further supported from observations of higher appreciation rates for in-town development and through expressed demands for projects recently opened in the region's core. These choices could be further enhanced if buyers were supplied with prices that are competitive with other options. Changes to lending policies and to development regulations could enable this underlying demand to be realized in the form of increased supply of residential developments that afford alternative travel choices for work and non-work purposes.

5. *Education and Empowerment* – The general public as well as the professional development and transportation communities could benefit by being made more aware of the improvements to quality of life that can be achieved through increased pedestrian and transit investments, more carpooling, ridesharing and employer incentives and more permissive development

regulations. Lending institutions and builders, if better apprised of the market for smart growth – and the success of such new developments, could be less averse to risk such developments. Through ongoing educational efforts, improved air quality and overall physical health can be improved.

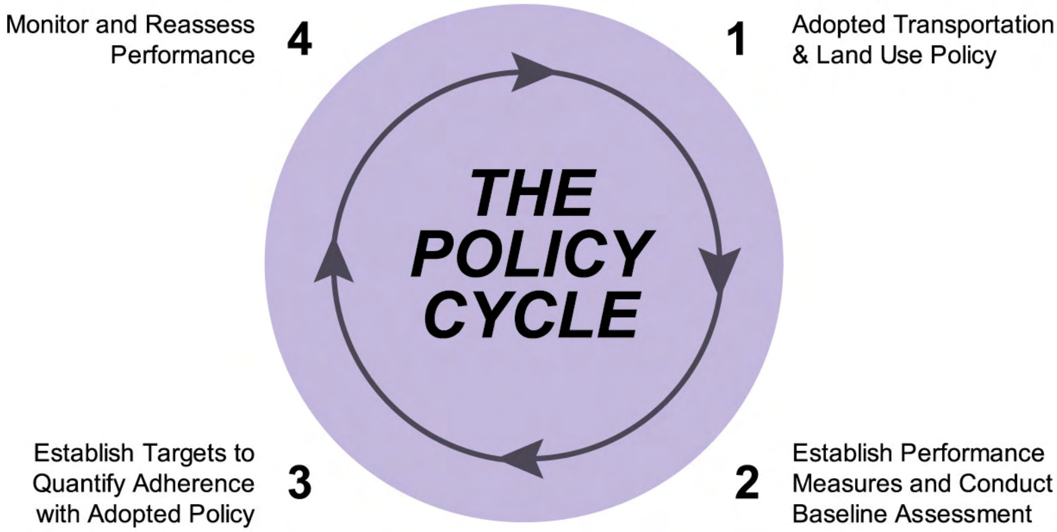
Public policies, such as recommended above, and public investment require linking goal-based performance measures with investment decisions at a programmatic level. The SMARTRAQ research effort provides an extensive range of performance measures possible.

II. PERFORMANCE MONITORING

The ability to track changes in land use, household travel, and household emissions over time provides the ability to determine how well regional air quality and transportation mobility policy-based objectives are being met. This information could be used to establish incentives encouraging local, regional, and state consistency with the adopted policy and vision through transportation investment.

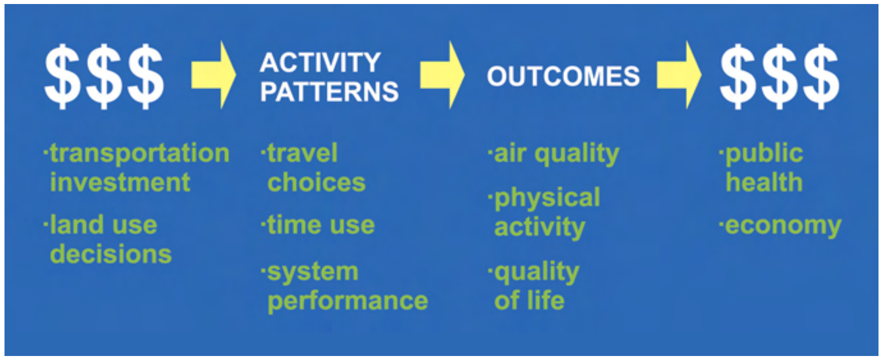
Performance monitoring provides the feedback required for decision makers to better navigate towards desired outcomes (Poister 1982). It was well understood that without such systematic feedback, there is little ability to monitor consistency between adopted policy and action. While policy is important as a tool to establish a vision based on collectively held values, it is the actual transportation investments and land use decisions that impact the quality of life for today's and tomorrow's residents of the Atlanta region. Figure 67, the Policy Cycle, shows this intended usage of performance monitoring in SMARTRAQ to inform policy development and implementation.

Figure 67: The Policy Cycle



The approach taken by SMARTRAQ for development of recommended performance measures is summarized here, and discussed in detail in the SMARTRAQ report #I.A.5 provided to GRTA. The approach provides an important framework for evaluation and development of policies addressing the multiple environmental and health related outcomes of transportation investment and land development activities. Figure 68 provides a conceptual basis for how transportation investment impacts human activity patterns which in turn correspond with environmental and health related outcomes. These outcomes translate back into costs and benefits in terms of economic development created through transportation and land development investments that are balanced against considerations of public health, safety, and welfare.

Figure 68: The Impacts of Transportation Investment



A four-tiered approach to the development and grouping of performance measures is shown in Figure 69. The foundation of the pyramid is the built environment (Tier I) that is created through transportation investment and land use actions. These actions directly impact our transportation choices, travel patterns and physical activity (Tier II). Subsequently, our travel behavior and choices can directly impact the environment (Tier III). Our quality of life (Tier IV), which rest at the top of the pyramid, is impacted by the interactions of the lower tiers. Decisions made that impact the built environment directly impact travel choices, which impact the environment, and subsequently our quality of life. The performance pyramid is a metaphor for how transportation investment and land use actions "actualize" our regional quality of life. Table 127 through Table 130 list specific performance measures contained in each tier.

Figure 69: Performance Pyramid

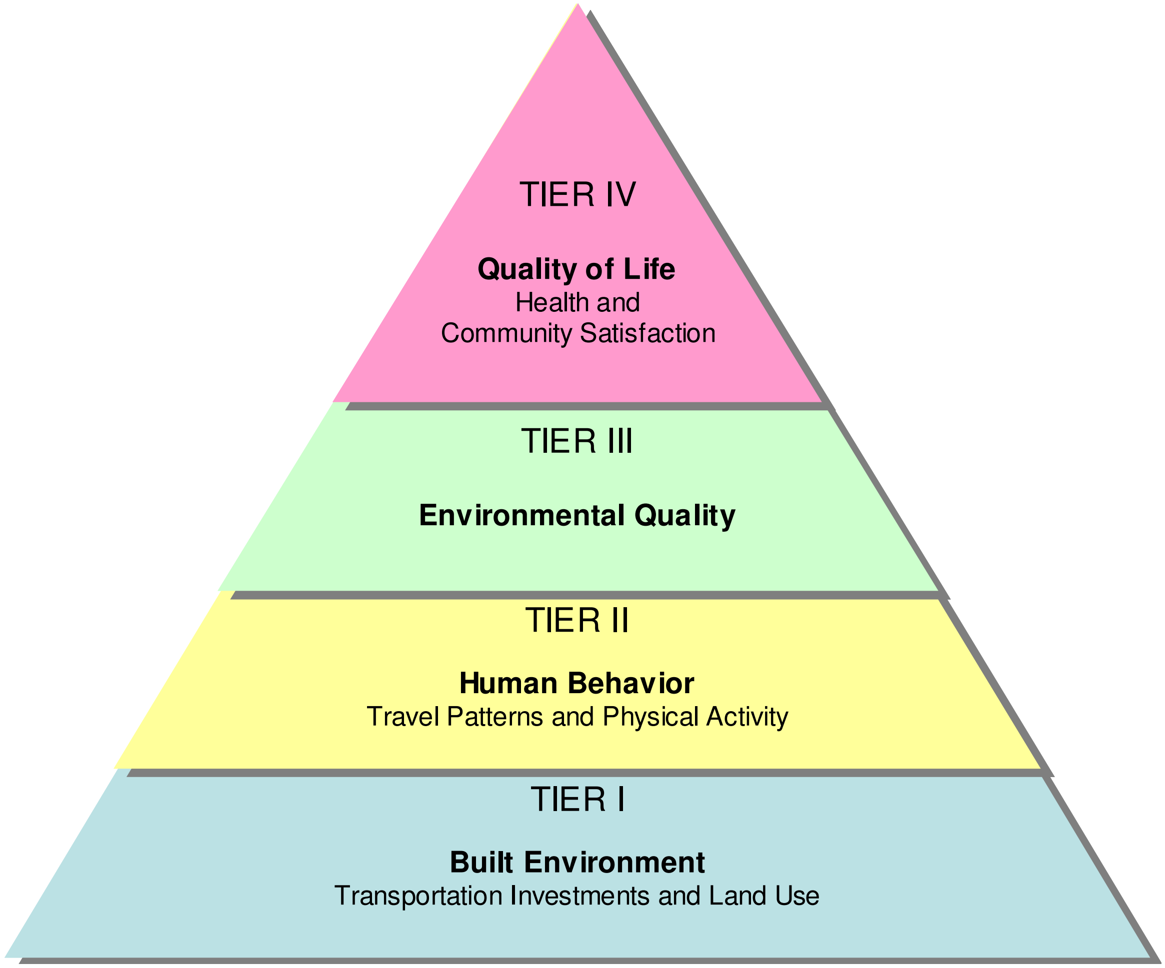


Table 127: Tier I: Built Environment Performance Measures

Land Use Mix – Extent of Variation in Land Uses
Density – Number of Households per Residential Acre
Connectivity – Number of Intersections per Square Kilometer
Proportion of each county at various levels of Mix, Density, and Connectivity
Local Accessibility
Regional Mobility
Transit Accessibility – Mean Distance (Miles) to Transit Stop
Rail Accessibility – Mean Distance (Miles) to Rail Station
Transit Accessibility – Distance (Miles) to Transit Stop
Rail Accessibility – Distance (Miles) to Rail Station
Acres of Land Consumed by Development

Table 128: Tier II: Behavioral Measures

Transit Use by County
Transit Use by NRD, Income, and Ethnicity
Transit Use in DeKalb, Fulton, Clayton, and Cobb counties by NRD, Income, and Ethnicity
Vehicle Travel
Per Capita Daily Vehicle Miles of Travel: Weekdays by County
Per Capita Daily Vehicle Miles of Travel: Weekdays by NRD, Income, and Ethnicity*
Per Capita Daily Vehicle Miles of Travel: Weekend by County*
Per Capita Daily Vehicle Miles of Travel: Weekend by NRD, Income, and Ethnicity*
Per Capita Daily Vehicle Miles of Travel by Purpose*
Average Miles Traveled from Home to Work*
Mode Split: Proportion of Trips by Mode
Mode Split of Walkable Trips (less than 1/2 mile)
Frequency of Walking to Local Services
Frequency of Walking to Local Services by Type of County
Moderate and Vigorous Physical Activity – Regional Average
Moderate Physical Activity – Each County
Proportion of Population Engaging in Moderate Physical Activity by County
Proportion of Population Engaging in Moderate Physical Activity by NRD, Income, and Ethnicity

Table 129: Tier III: Environmental Measures

Atlanta 1-Hour Ozone Standard Attainment Status
Atlanta 8-Hour Ozone Standard Attainment Status
Ozone Days
Per Capita Grams of NO_x produced per day (Weekday) by County
Per Capita Grams of NO_x produced per day (Weekday) by NRD, Income, and Ethnicity
Per Capita Grams of VOCs produced per day (Weekday) by County*
Per Capita Grams of VOCs produced per day (Weekday) by NRD, Income, and Ethnicity

Table 130: Tier IV: Quality of Life Measures

Satisfaction with Neighborhood –Lot Size and Distance to School/Work –Home Size and Trip Distance –Walkable Shops and Services? –Car Space and Biking Space –Mix of Housing Types and Level of Activity –Cul-de-sacs and Connected Streets –Connectivity, Distance to Work, and Traffic Level
Average Number of Minutes Spent Driving from Home to Work
Per Capita Daily Minutes of Vehicle Travel (Weekdays) by County
Per Capita Daily Minutes of Vehicle Travel (Weekdays) by NRD, Income, and Ethnicity
Per Capita Daily Minutes of Vehicle Travel (Weekends) by County
Neighborhood Connection (overall)
Neighborhood Connection by NRD
Neighborhood Connection by County Type
Factors Influencing Walking by County Type
Important Factors for Choosing Neighborhood
Satisfaction with Neighborhood Factors
Rate of Obesity

For those measures selected for continued use, ongoing data collection and assessment of performance, at the desired levels of aggregation, are needed to support a continuous cycle of informed and responsive policy development. The data presented here is only a base-line of measures from the years 2001-2002. For this work to lead to more informed transportation and land use decision-making within the Atlanta Region, three additional things will need to occur:

- A commitment to updating a core set of measures on a periodic basis, which aligns with the regional transportation planning process, such as every 3 years;
- Targets be established for each core indicator in a way that constitutes a consistent link with established policy; and
- Real feedback and adjustments between reporting on adopted measures and targets and actual transportation investment and land development actions.

III. FUTURE APPLICATIONS

The SMARTRAQ data collection methods, the data itself, and the methods developed to analyze these data are largely new. A great deal of additional work can, and no doubt will, be done to analyze these data. These analyses will be based on interests in specific populations, and specific transportation, land development, environmental, and public health issues. Ultimately, these analyses will result in predictive models that can be applied within decision making processes within the Atlanta region and elsewhere. The ARC has already made good use of the travel survey data in its travel model update. GRTA is using the parcel data and has the entire project database to track performance of key policy indicators. GRTA will need to determine which variables make the most sense to track over time and will be able to adapt methods for data collection from those provided by SMARTRAQ to suit its own needs. Most of all, this body of work is dynamic and should be viewed as part of an ongoing process.

Recommendations to meet ongoing challenges to balance quality of life, environmental health, and economic prosperity will be extrapolated from the findings that are presented from this research. In addition to informing future research designs through the findings resulting from this research, the existence of these data will support future research efforts. For example, data collected in this project provides a basis for future researchers to determine appropriate sample size requirements across travel behavior (trip generation, miles traveled) and urban form attributes (residential density, street connectivity and land use mix). SMARTRAQ serves as a model for the integration of transportation, land use, environment, and public health and provides a set of approaches upon which to build future research efforts in metropolitan areas in Georgia and elsewhere in North America.

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