H+T IN DC

CNT

Housing + Transportation Affordability in Washington, DC
Full Report

PREPARED BY
THE CENTER FOR NEIGHBORHOOD TECHNOLOGY

JULY 2011

COVER: L'ENFANT PLAZA METRO Photo by Andertho

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ABOUT THE CENTER FOR NEIGHBORHOOD TECHNOLOGY

CNT's mission is to promote more livable and sustainable urban communities. For over 30 years, the Center for Neighborhood Technology (CNT) has taken a holistic, solution-oriented approach that reflects a commitment to both cities and nature. CNT is a creative think-and-do tank that combines rigorous research and analysis with effective actions that offer paths to scale. We have tackled a wide range of issues, always with an eye toward simultaneously improving the environment, strengthening the economy, and advancing equity. We work across disciplines and issues, including transportation and community development, energy, natural resources, and climate change.

CNT has a strong reputation as a leader in promoting urban sustainability—the more effective use of existing resources and community assets to improve the health of natural systems and the wealth of people, today and in the future. CNT is a recipient of the 2009 MacArthur Award for Creative and Effective Institutions.

CNT has pioneered map-based tools that enable citizens, communities, service providers, and policymakers to communicate issues, understand needs, and create more effective implementation plans for urban sustainability.

More information about CNT is available at www.cnt.org.

Foreword

The Center for Neighborhood Technology (CNT) is known for groundbreaking work regarding the effects of neighborhood characteristics on a household's transportation costs. But CNT's original efforts on the DC region were based on increasingly dated statistics from the 2000 US Census and did not have the benefit of local data such as the region's bus network and land use patterns. The Office of Planning (OP) believes it is critical to understand how the region's housing and transportation costs changed throughout the decade beginning in 2000, with particular emphasis on the turbulent period between 2006 and 2008—when gasoline prices spiked and the recession began to really bite in our region. During that time some outer jurisdictions experienced drops in the median home sales price of 41%, while the District's median sales price dropped by only 2%; this happened while real gas prices grew by 18%. Though some areas of the region's housing market are showing signs of recovery, as the nation's economy improves, gas prices are once again very likely to grow faster than inflation and to stress the budgets of many households living in car-dependent neighborhoods.

OP is excited to present CNT's work to citizens, stakeholders, and elected officials of the region. The study has several potential policy implications for our region as it grows. Some of those implications: how a better mix of land uses could help reduce transportation costs; how future transit expansions could best serve to lower household transportation expenses; and how to identify locations where an investment in affordable housing might provide the most value for lower income households. OP hopes that the study will spark a serious discussion of ways to ensure the economic resilience of households and local governments as the region develops.

Sincerely,

Harriet Tregoning
Director, DC Office of Planning

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L'ENFANT PLAZA METRO
Photo by Chris Metcalf

Introduction to H+T

Significance of Transportation Costs and the Lack of Transparency

Today, the real estate market knows how to incorporate the value of land into the price of the home—based on its location and proximity to jobs and amenities—but there is less clarity about how the accompanying transportation costs also contribute to the desirability of a location. In most cases, the very same features that make the land and home more attractive, and likely more expensive per square foot, also make the transportation costs lower. Being close to jobs and commuter transit options reduces the expenses associated with daily commuting. And being within walking distance of an urban or suburban downtown or neighborhood shopping district allows a family to replace some of their daily auto trips with more walking trips. Walking, bicycling, taking transit, or using car sharing instead of driving a private automobile reduces gasoline and auto maintenance costs, and may even allow a family to get by with one less automobile.

By contrast, places where single-family homes are more "affordable" are often found in outlying areas where land is cheaper. However, the lack of amenities and access to necessities common in these neighborhoods often results in households having transportation costs that are much higher and can often outweigh the savings on housing costs. In many of the areas where households "drive to qualify" for affordable housing, transportation costs can exceed 32% of household income, making it, at times, a greater burden than housing. Conversely, for some communities where households benefit from less automobile dependency, transportation can represent as little as 10% of household income.[1]

1. High and low transportation expenditure percentages calculated from the 337 metropolitan areas presented on the H+T Affordability Index website (http://htaindex.cnt.org).

This information gap on location efficiency, which is measured here as the cost of transportation associated with each place, leads to unexpected financial burdens and time constraints for households, poor location decisions by developers, and missed and misplaced opportunities for municipalities. Furthermore, it leads to misinformed criticisms of the cost of building transit, since these critiques do not fully account for the benefits or take into account the hidden costs associated with sprawl and auto dependency. Not only are the high costs of transportation hidden, but so are the low costs, and therefore so is the inherent value of more convenient in-town urban, inner-suburban, and other urbanizing locations. Consequently, many of these convenient but undervalued areas suffer from disinvestment and lack the ability to attract new investment and redevelopment.

Expanding the Definition of Affordability

From an affordability perspective, the lack of transparency in transportation costs puts households at significant financial risk. Traditionally, a home is deemed affordable if its costs consume no more than 30% of a household's income. This measure, however, ignores transportation costs—typically a household's second largest expenditure[2] —which are largely a function of the area in which a household chooses to locate. This report proposes expanding the definition of housing affordability to include transportation costs to better reflect the true cost of households' location choices. Based on data from 337 metro areas, ranging from large cities with extensive transit (such as the New York metro area) to small metro areas with extremely limited transit options (such as Fort Wayne, IN), CNT has found 15% of the Area Median Income (AMI) to be an attainable goal for transportation affordability. By combining this 15% level with the 30% housing affordability standard, this report recommends **a new view of affordability,** one defined as **H+T costs consuming no more than 45% of household income.**

Considering housing and transportation costs in conjunction changes the picture of affordability significantly. Many areas in which low home prices make the area appear affordable are no longer so attractive when transportation costs are added to the equation. Conversely, areas in which housing prices may seem out of reach for many households can actually become more affordable when high levels of location efficiency allow households to experience significantly lower transportation costs.

2. Consumer Expenditure Survey from the Bureau of Labor Statistics, http://www.bls.gov/cex/home.htm

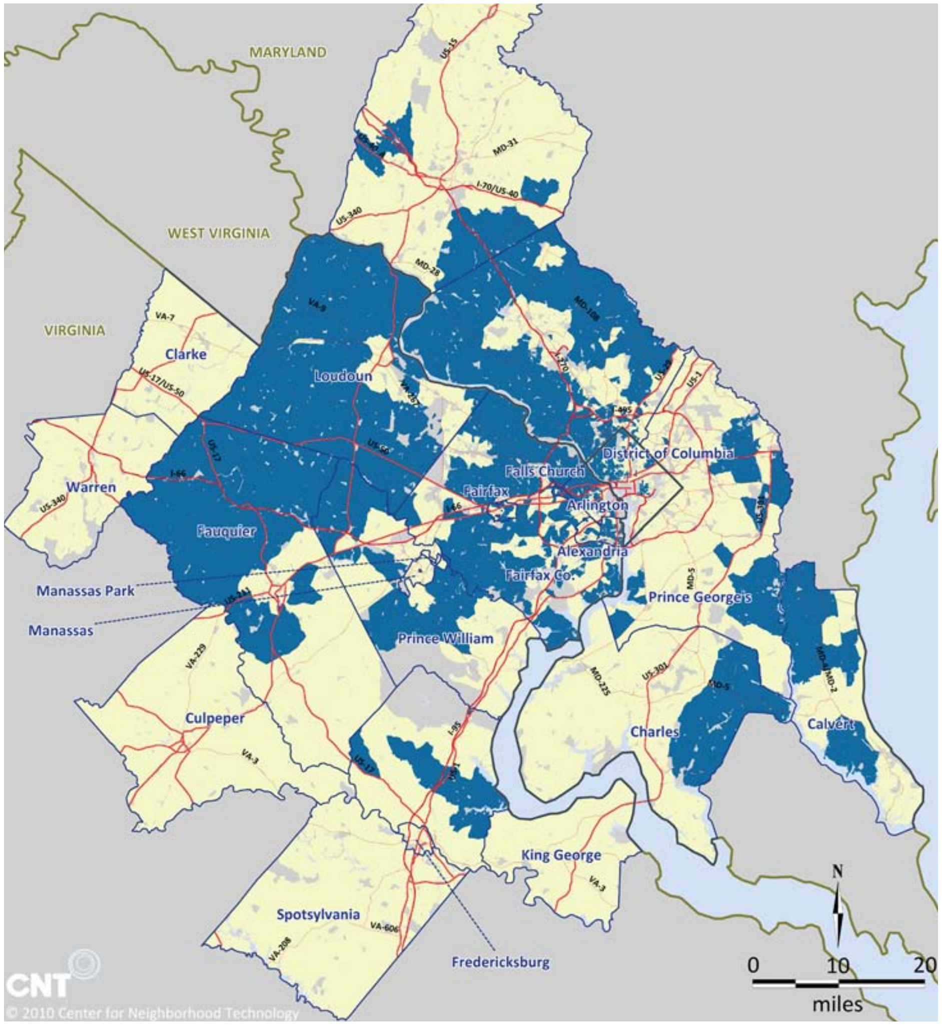
FIGURE 1
Traditional view of affordability: housing costs as a percentage of AMI

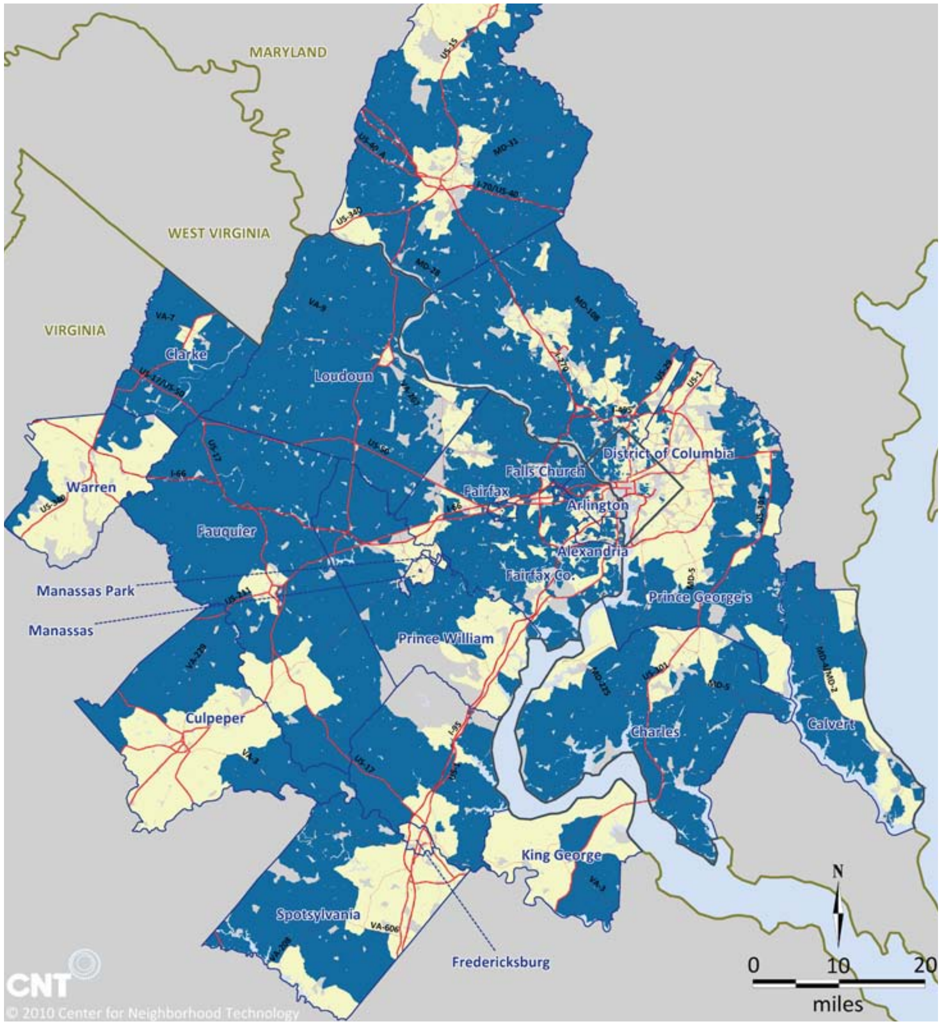
- <30 %
- 30 % +
- Insufficient Data

FIGURE 2
New view of affordability: H+T costs as a percentage of AMI

- <45 %
- 45 % +
- Insufficient Data

The maps below present the ***two views of affordability***: the traditional definition showing where average housing costs are deemed affordable for households earning the AMI (indicated by the areas shaded in yellow in figure 1); and the new view in which affordability is defined as average H+T costs consuming no more than 45% of AMI (fig. 2).[3] Between the two maps, the shift in areas from yellow to blue represent the change in areas with average costs affordable to the AMI-earning household when the measure of affordability is expanded to include transportation costs.





3. For the purposes of this research, a value of $87,623 has been utilized as AMI, representing the regional average of block group level household median incomes. Because this value was constructed as an average median for the study area, it differs from the HUD-defined AMI for a family of four.

Transportation Costs Vary by Location

FIGURE 3
Transportation cost model

6 NEIGHBORHOOD VARIABLES
Residential Density
Gross Density
Average Block Size in Acres
Transit Connectivity Index
Job Density
Average Time Journey to Work

3 HOUSEHOLD VARIABLES
Household Income
Household Size
Commuters per Household

↓

CAR OWNERSHIP
+ CAR USAGE
+ PUBLIC TRANSIT USAGE

↓

TOTAL TRANSPORTATION COSTS

The Center for Neighborhood Technology (CNT) has developed a unique tool, the Housing + Transportation (H+T®) Affordability Index, which has so far been applied to all 337 metro areas in the United States.

The transportation cost model, the T in the H+T Index, describes the relationship between independent neighborhood and household characteristics and three dependent variables: auto ownership, auto use, and transit use. Building off of years of research on location efficiency, the transportation cost model considers factors such as household density, average block size, transit access, job access and journey to work time and explains how they influence transportation behavior (see fig. 3).

These three factors of transportation behavior—auto ownership, auto use, and transit use—estimated at the neighborhood level, are combined to illuminate the cost of transportation associated with that location.

Neighborhood Variables

Six neighborhood characteristics are utilized in the transportation model to predict transportation behavior, as measured through auto ownership, auto use, and transit use. Household density (both residential and gross measures), average block size, transit access (as measured in the Transit Connectivity Index developed by CNT), job access, and average work commute time have all been found to be determining factors of transportation behavior. (The specific definitions of each measurement can be found in the Detailed Methods section.)

Household Variables

Three household characteristics have also been found to be significant indicators of transportation behavior: household income, household size, and the number of commuters per household. However, in the transportation model, these three variables are fixed at regional average values. Therefore, by holding these characteristics constant and examining transportation costs for the "typical household," this report focuses on and highlights the variation resulting from the built environment, or neighborhood characteristics. (See the Detailed Methods section for further explanation.)

Total Transportation Costs

The transportation model results with values estimating average auto ownership, auto use, and transit use, to which cost components are multiplied to estimate total household transportation costs. Auto ownership costs, for the purposes of this research, are defined as depreciation, finance charges, insurance, license, registration, and taxes (state fees). Auto use costs are composed of gas, maintenance, and repairs. Transit costs factor the average cost of transit use per household using a regional average price as derived from the National Transit Database. (See details in the Cost Components section of the Detailed Methods.)

FIGURE 3 REPEATED
Transportation cost model

6 NEIGHBORHOOD VARIABLES
Residential Density
Gross Density
Average Block Size in Acres
Transit Connectivity Index
Job Density
Average Time Journey to Work

3 HOUSEHOLD VARIABLES
Household Income
Household Size
Commuters per Household

CAR OWNERSHIP
+ CAR USAGE
+ PUBLIC TRANSIT USAGE

TOTAL TRANSPORTATION COSTS

Customizing the H+T Index for DC

DC CIRCULATOR
Photo by Fredo Alvarez

This project used the H+T Index and customized and recalibrated it to estimate housing and transportation costs in the Washington, DC, metropolitan area.

UPDATED DATA

The H+T Index, thus far, has primarily used 2000 US Census data. For this project, CNT also used American Community Survey (ACS) data from 2006–2008. The small-scale variation available in the 2000 Census data was therefore preserved while the ACS data enabled a more current consideration.

LOCAL DATA

The addition of detailed local datasets as independent variables can help improve the accuracy of the H+T analyses. To further expand existing H+T work in the DC region, this analysis was refined through the use of detailed datasets obtained from local agencies and organizations, along with national datasets, to serve as independent variables in the customized transportation model. Local datasets included regional bus networks and land use patterns.

MARKET RATE HOUSING COSTS

Another significant aspect of the customization of the Index was the incorporation of market rate housing costs. The original Index uses Selected Monthly Owner Costs (SMOC) and Gross Rent from the US Census to estimate housing costs. However, because SMOC represent the average costs for all households with a mortgage, regardless of the age of the mortgage, these values can diminish recent housing trends. To capture these housing market trends, multiple listing service (MLS) sales data were utilized to calculate average homeownership costs. Updated values for Gross Rent were utilized to capture renting costs.

Housing Costs

As the DC area is known for having a strong housing market, it is not surprising that average monthly housing costs are high throughout the region. As figure 4 shows, average housing costs are highest, exceeding $5,200 monthly, in the northwest areas of the District and spreading northwest into Fairfax and Montgomery counties. Costs are lowest in the eastern portion of the District, where average monthly housing costs of less than $1,200 can be found. Also, the furthest reaching areas of the region, such as Warren and Culpeper counties contain areas with average monthly housing costs of less than $1,200.

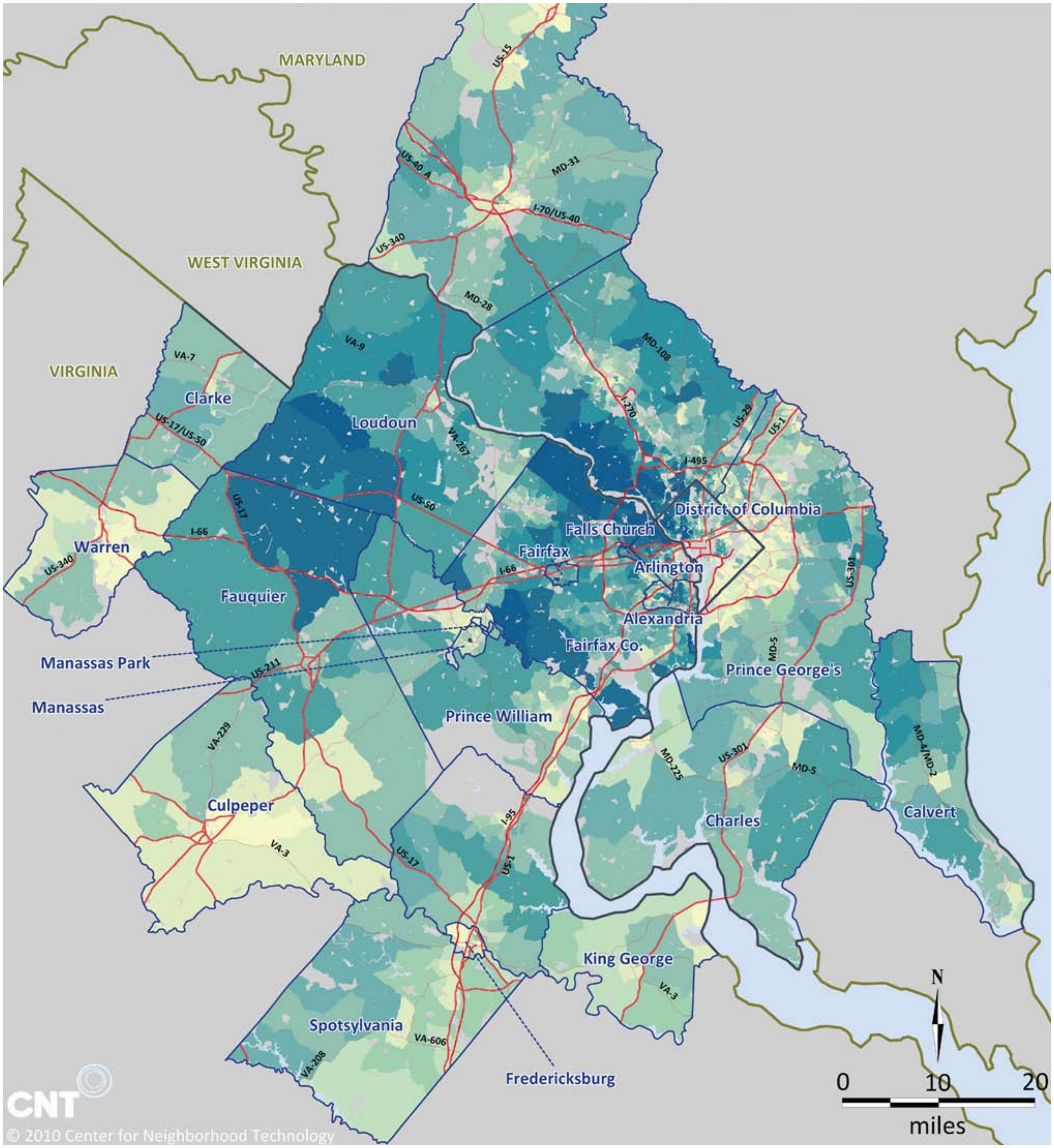


FIGURE 4
Average monthly housing costs

- < $1,200
- $1,200 to $1,400
- $1,400 to $1,500
- $1,500 to $1,600
- $1,600 to $1,900
- $1,900 to $2,200
- $2,200 to $2,700
- $2,700 to $3,600
- $3,600 to $5,200
- $5,200 +
- Insufficient Data

Transportation Costs

Transportation costs present a near converse image to housing costs (see fig. 5). Average transportation costs are lowest in the District of Columbia where households have convenient access to jobs and amenities. Households here, on average, own fewer cars and drive them less because they are largely able to walk, bike, and use transit to meet their daily needs. Areas of compact, mixed-use development outside of the District, such as in Arlington and parts of Fairfax counties, the I-270/Red Line corridor extending out through Montgomery County, in the center of Frederick County, and in Fredericksburg, also have development patterns that enable their residents to have lower transportation costs. Average transportation costs are highest in the dispersed, auto dependent areas of the region. Residents in the farthest-reaching counties of the region, such as Clarke, Warren, Calvert, and Charles, must rely on automobiles and drive long distances, creating high transportation expenditures.

As an example, a household owning two automobiles (at an average annual cost of $5,598 per auto), driving a total of 20,000 miles annually (at an average cost of 5.5 cents per mile), and never taking transit has average annual transportation costs of $12,296. Compared to this, a household owning one automobile, driving 10,000 miles annually, and spending $100 per month on transit has annual transportation costs of $7,348, or nearly $5,000 less.

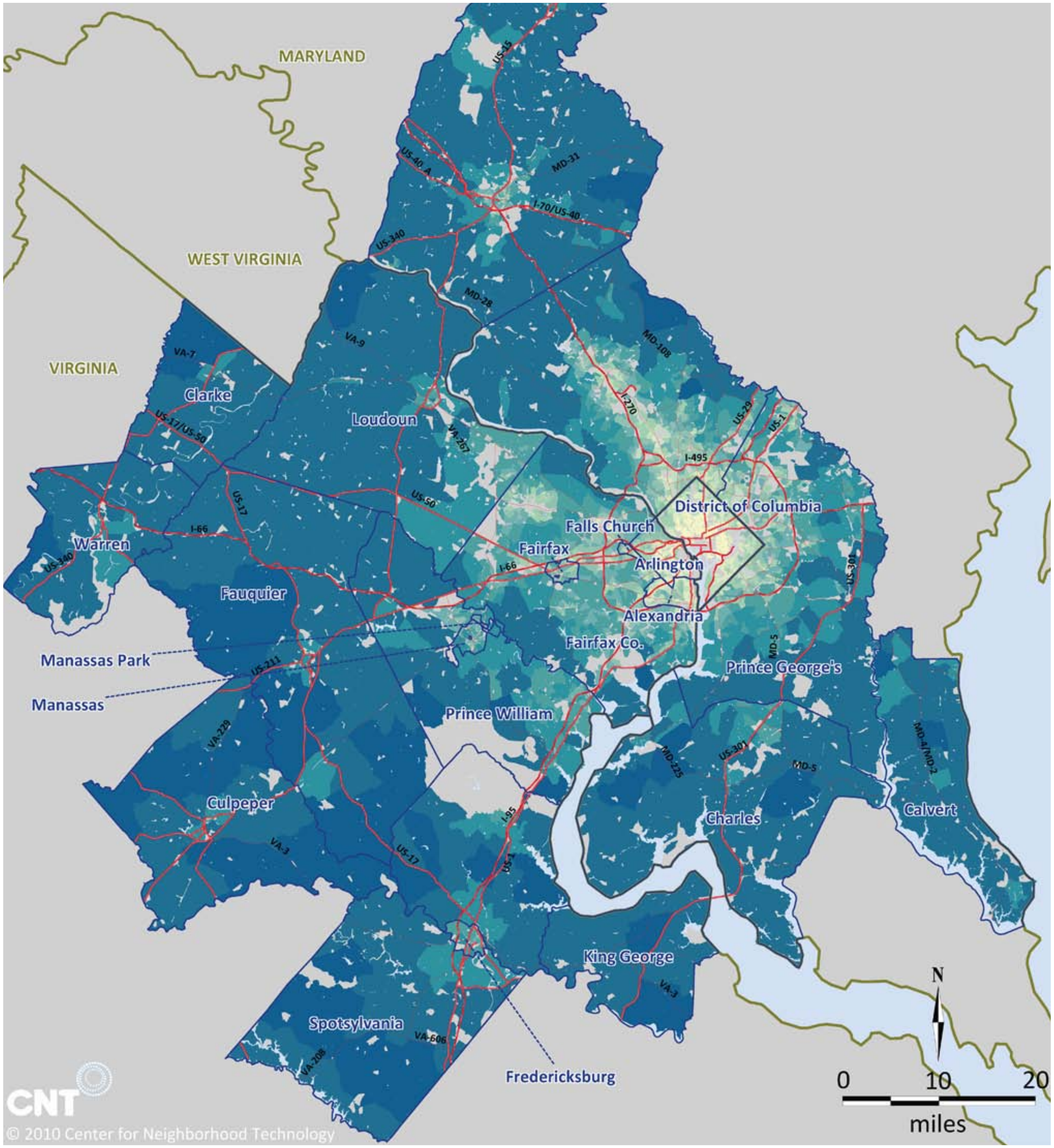


FIGURE 5
Average monthly transportation costs, as modeled for the AMI-earning household

- < $920
- $920 to $1,020
- $1,020 to $1,100
- $1,100 to $1,170
- $1,170 to $1,230
- $1,230 to $1,280
- $1,280 to $1,370
- $1,370 to $1,500
- $1,500 to $1,770
- $1,770 +
- Insufficient Data

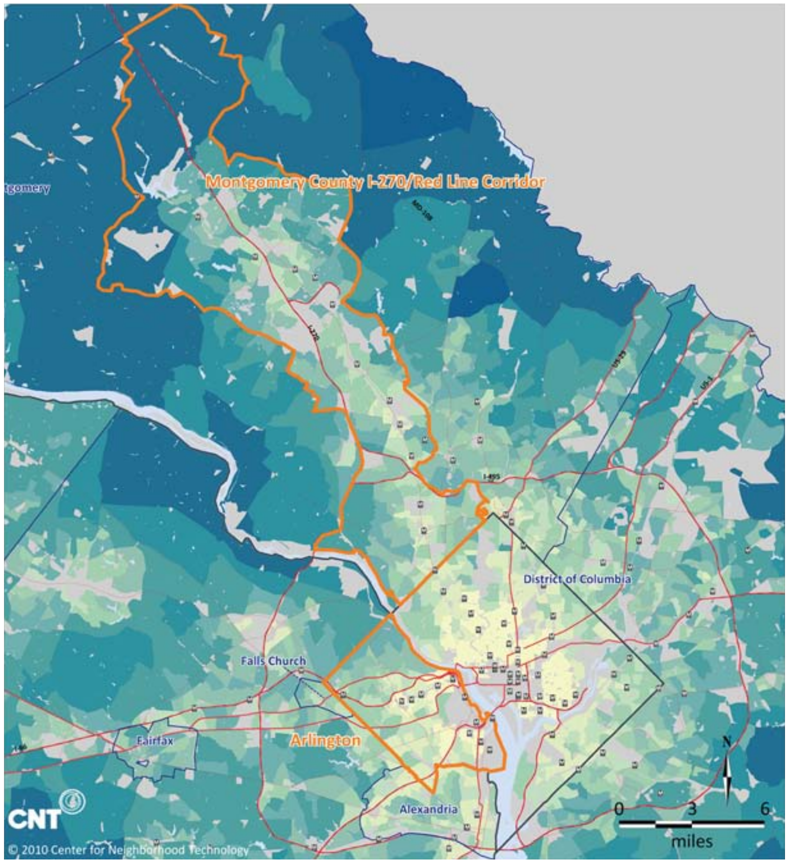


FIGURE 6
Average monthly transportation costs, as modeled for the AMI-earning household

- < $920
- $920 to $1,020
- $1,020 to $1,100
- $1,100 to $1,170
- $1,170 to $1,230
- $1,230 to $1,280
- $1,280 to $1,370
- $1,370 to $1,500
- $1,500 to $1,770
- $1,770 +
- Insufficient Data

Local Case Study Examples

Figure 6 shows the average monthly transportation costs, focusing in on the Montgomery County I-270/Red Line corridor and Arlington County. While Montgomery County has been effective at directing development along the corridor and protecting the surrounding farmland, average transportation costs are higher than they are in Arlington County. To help explain this disparity, table 1 below shows average values for the six neighborhood characteristics significant in determining transportation costs. Residential and gross density in Arlington are both higher, transit access is higher, and average blocks are smaller, suggesting that Arlington is a more walkable, bikeable, and transit-oriented area with more destinations in close proximity. Perhaps the most significant difference is in job access. With its greater proximity to the District and the high concentration of jobs there and in Arlington, commuters have less distance to travel and more transit options.

Comparing both the Montgomery County I-270/Red Line corridor and Arlington County to the region as whole, however, highlights the impact of focused, location-efficient development on overall transportation costs. As shown in the table below, households in these central communities have lower average transportation costs than the region as a whole. Higher density development and smaller block sizes are factors contributing to these lower transportation costs. Transportation costs in Arlington County are significantly lower than the regional average due to high levels of transit connectivity and job access.

	Montgomery County I-270/ Red Line Corridor	Arlington County	Full Region
Average Monthly Transportation Costs	**$1,177**	**$975**	**$1,246**
Average Residential Density (HHs/Res. Acre)	**4.2**	**7.6**	**3.9**
Average Gross Density (HHs/Land Acre)	**1.9**	**5.8**	**0.5**
Average Block Size (Acres)	**22.4**	**8.4**	**75.5**
Average Transit Connectivity Index	**1,199**	**3,529**	**1,420**
Average Job Access (Gravity Index)	**51,754**	**120,881**	**54,052**
Average Time for Journey to Work (Mins.)	**31.1**	**26.2**	**33.1**

TABLE 1
Average values for neighborhood characteristics

While the Montgomery County I-270/Red Line corridor and Arlington County provide good regional comparisons, nowhere in the region illustrates location efficiency as well as the District of Columbia. All of these factors—high density, small blocks, extensive transit access, high job concentrations, and short commute times—come together to enable households in the District to own fewer cars and drive them less. Households here benefit from convenient access to goods, services, and general daily needs in a non-auto dependent setting, therefore experiencing significantly lower transportation costs than their surrounding regional neighbors.

COLUMBIA HEIGHTS AND TENLEY TOWN

While DC, as a whole, is an extremely location-efficient area, much variation exists within it. Table 2 and figure 7 provide a comparison between the neighborhoods of Columbia Heights and Tenley Town. Both neighborhoods have Metro stations, but three factors distinguish Columbia Heights and save residents over $160 per month in estimated transportation costs. First, known for row houses and apartment buildings, Columbia Heights has significantly higher residential density. Second, it is half the distance to the jobs in the core of downtown as well as close to Howard University and Washington Hospital Center. Finally, while each has a Metro station, Columbia Heights also has access to four more bus routes.

FIGURE 7
Average monthly transportation costs, as modeled for the AMI-earning household

- < $840
- $840 to $940
- $940 to $1,000
- $1,000 to $1,040
- $1,040 to $1,080
- $1,080 to $1,120
- $1,120 to $1,180
- $1,180 to $1,230
- $1,230 to $1,300
- $1,300 +
- Insufficient Data

	Columbia Heights	Tenley Town	DC
Average Monthly Transportation Costs	$840	$1,003	$922
Average Residential Density (HHs/Res. Acre)	26.6	5.9	10.7
Average Gross Density (HHs/Land Acre)	22.6	3.2	7.0
Average Block Size (Acres)	5.0	5.3	6.7
Average Transit Connectivity Index	9,161	4,307	5,477
Average Job Access (Gravity Index)	200,150	106,238	171,717
Average Time for Journey to Work (Mins.)	31.4	28.6	30.2

TABLE 2
Average values for neighborhood characteristics

Determining Factors: What Drives Transportation Costs?

AVERAGE AUTOS PER HOUSEHOLD AND RESIDENTIAL DENSITY

As the examples below illustrate, residential density is a key determinant of transportation costs. Specifically, residential density tends to affect the number of automobiles households own. A comparison of figures 8 and 9 show this trend: households, on average, own fewer autos where residential density is high; and where residential density is low, households own more automobiles.

FIGURE 8
Average autos per household, as modeled for the AMI-earning household

- <1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 1.9
- 1.9 to 2.0
- 2.0 to 2.1
- 2.1 to 2.2
- 2.2 to 2.3
- 2.3 to 2.5
- 2.5 +
- Insufficient Data

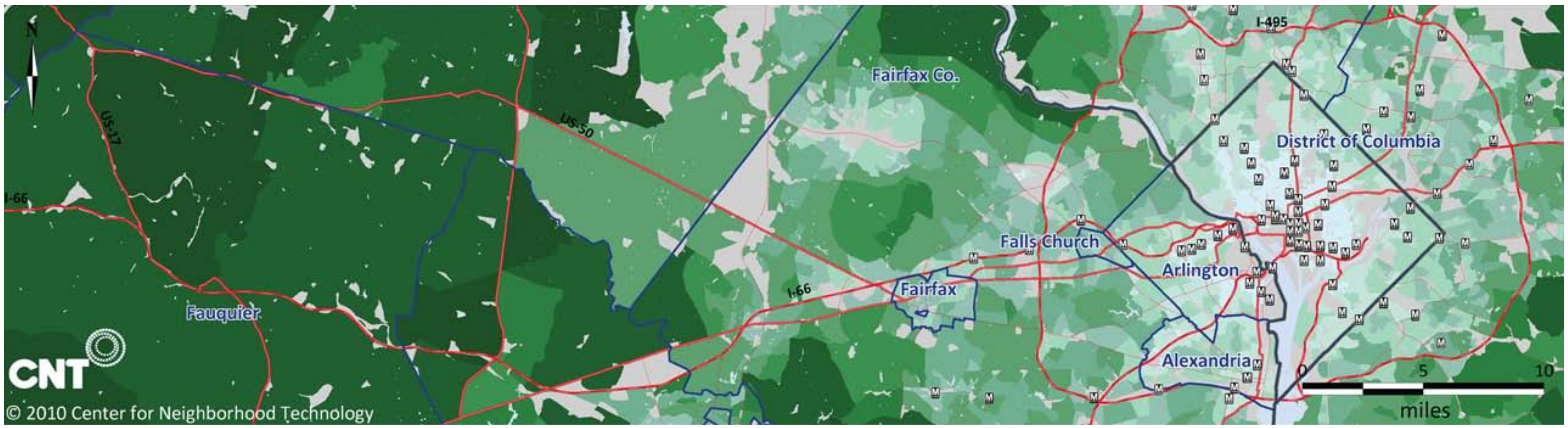
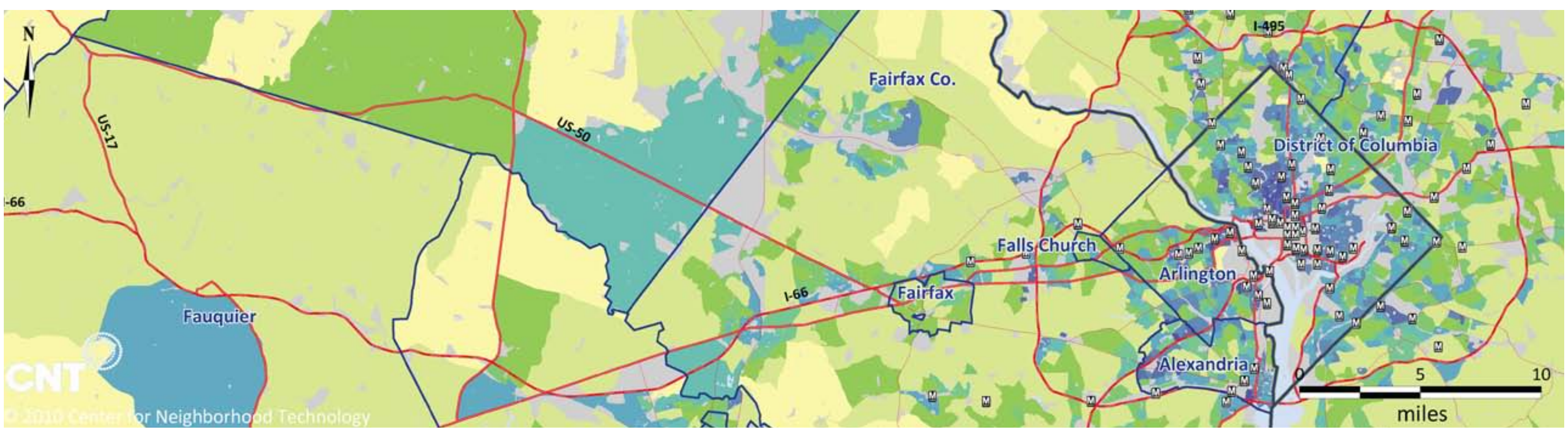


FIGURE 9
Residential density, households per residential acre

- <1
- 1 to 3
- 3 to 4
- 4 to 5
- 5 to 6
- 6 to 7
- 7 to 12
- 12 to 20
- 20 to 36
- 36 +
- Insufficient Data



AVERAGE TRANSIT USE AND TRANSIT CONNECTIVITY INDEX

Another component of transportation costs is average transit use, specifically as a means of transportation to work. While higher transit use clearly leads to higher costs the for transit portion of overall transportation costs, it is important to note that these costs are extremely small relative to the reduction in auto use and auto ownership costs resulting from increased transit use. Not surprisingly, the maps below (figs. 10 and 11) show the strong correlation between transit use and transit access, as measured by the Transit Connectivity Index developed by CNT. In the core of the region in the District, households experience the greatest transit access, and therefore utilize it the most.

FIGURE 10
Average percentage journey to work by transit, as modeled for the AMI-earning household

- <1 %
- 1 to 4%
- 4 to 7%
- 7 to 9%
- 9 to 11%
- 11 to 14%
- 14 to 18%
- 18 to 24%
- 24 to 33%
- 33% +
- Insufficient Data

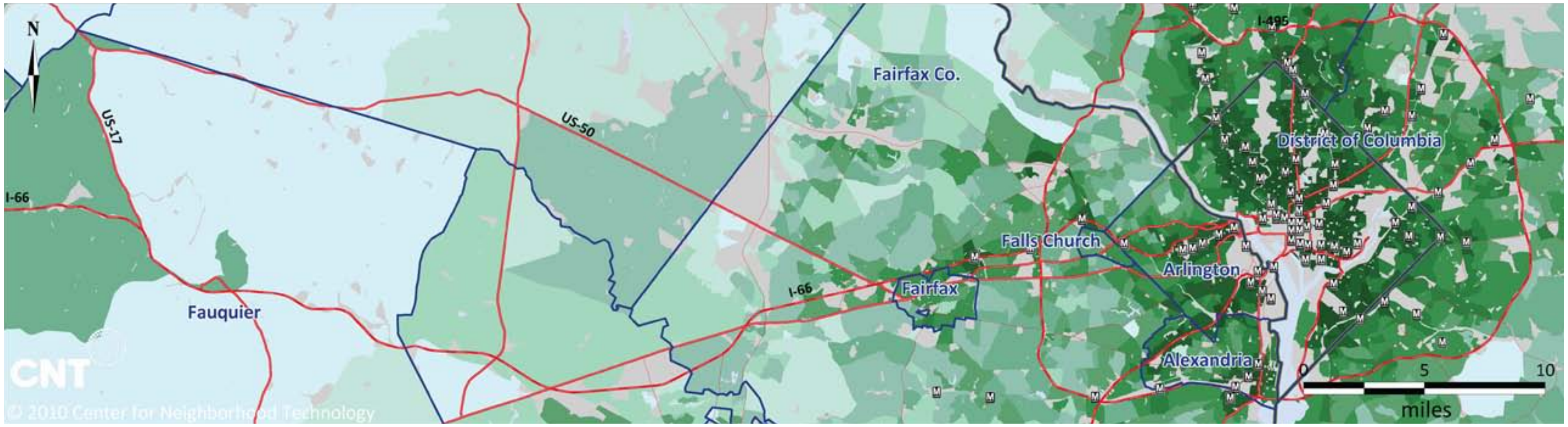
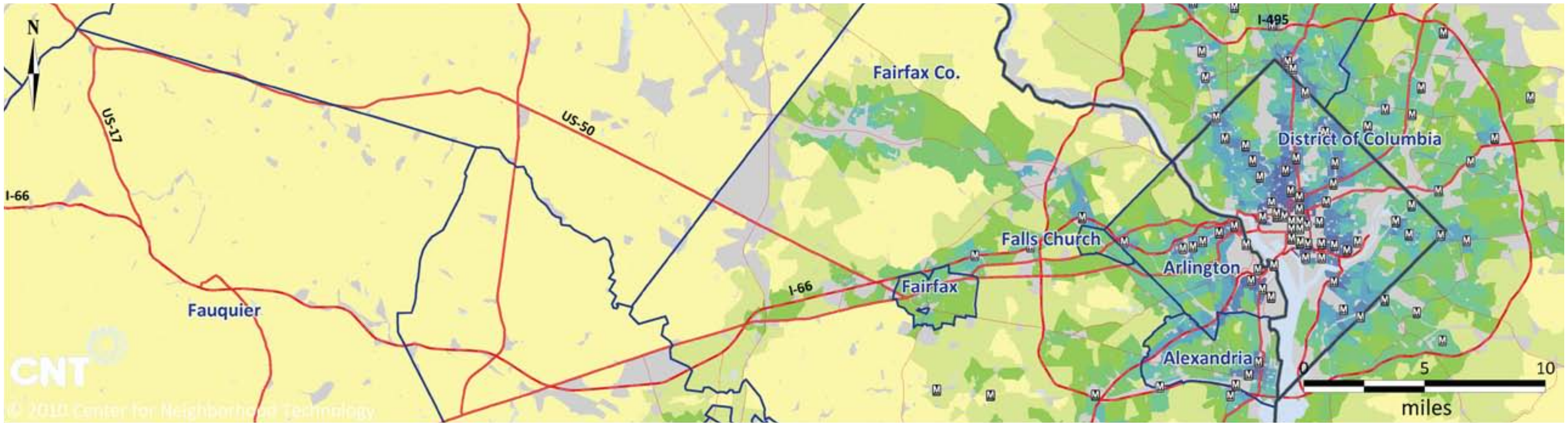


FIGURE 11
Transit Connectivity Index

- Low
- Moderate
- High
- Insufficient Data



AVERAGE AUTO USE AND AVERAGE BLOCK SIZE

The third component of transportation costs is auto use, or vehicle miles traveled (fig. 12). Like auto ownership, household density is the largest determinant of vehicle miles traveled. Average block size (fig. 13) is also an important determinant of auto use. As the maps below show, smaller block areas correspond to lower average vehicle miles traveled. Smaller blocks typically mean greater street connectivity, more intersections, and shorter routes between points, thus enabling households to drive fewer miles.

FIGURE 12
Average annual vehicle miles traveled per household, as modeled for the AMI-earning household

- <14,100
- 14,100 to 15,900
- 15,900 to 17,300
- 17,300 to 18,500
- 18,500 to 19,800
- 19,800 to 21,300
- 21,300 to 22,700
- 22,700 to 26,100
- 26,100 to 34,800
- 34,800 +
- Insufficient Data

FIGURE 13
Average block size in acres

- <10
- 10 to 20
- 20 to 30
- 30 to 50
- 50 to 80
- 80 to 150
- 150 to 250
- 250 to 390
- 390 to 800
- 800 +
- Insufficient Data

Bringing It All Together: H+T

H+T Costs as a Percentage of Income

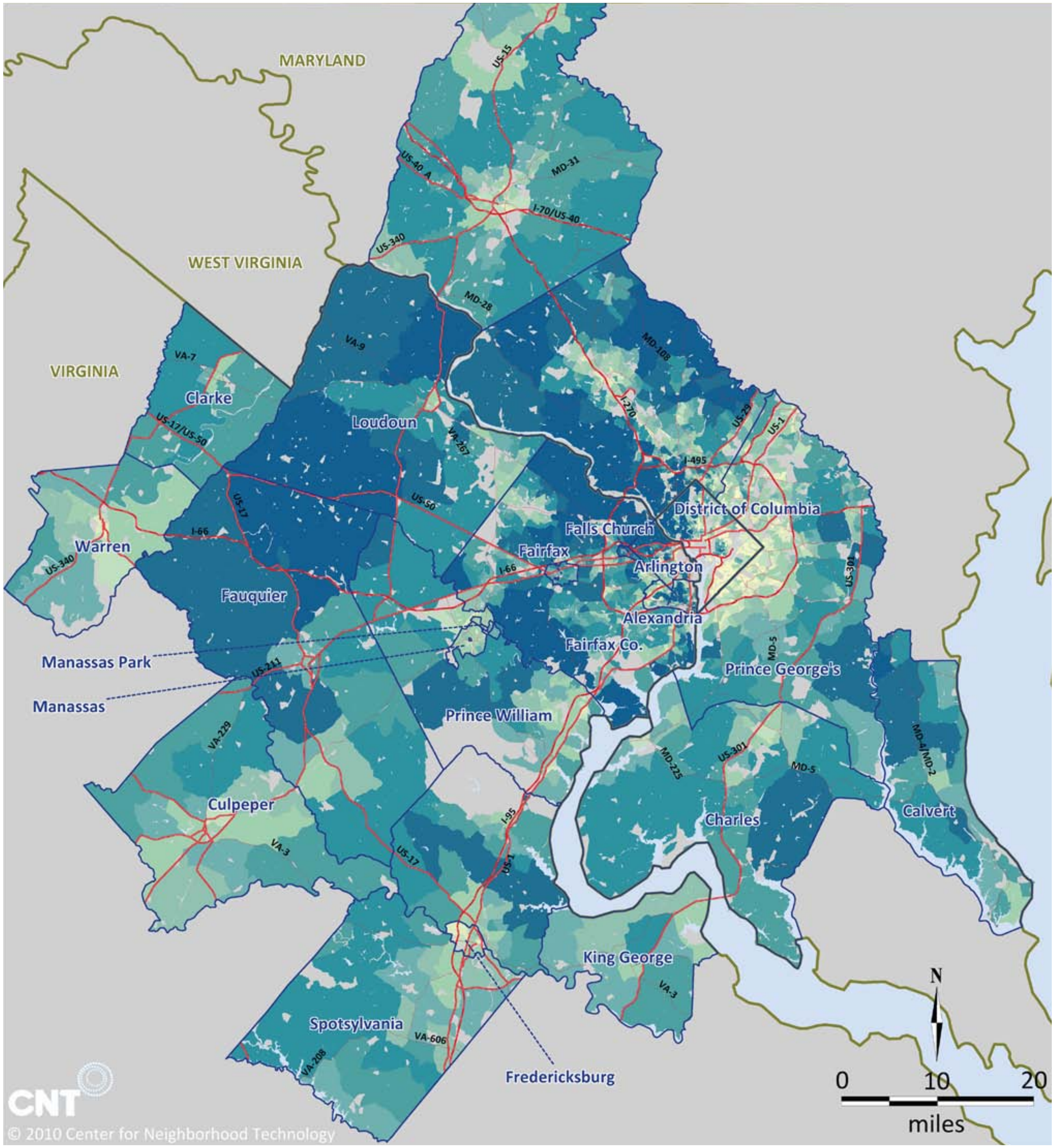
Combining the two costs, both housing and transportation (H+T), gives a much more complete picture of the costs associated with the location in which a household chooses to live. Considering these costs together provides a means to evaluate the tradeoffs households make—do the lower housing costs pursued far from the city center pay off? Do the lower transportation costs of centrally located neighborhoods offset higher housing costs?

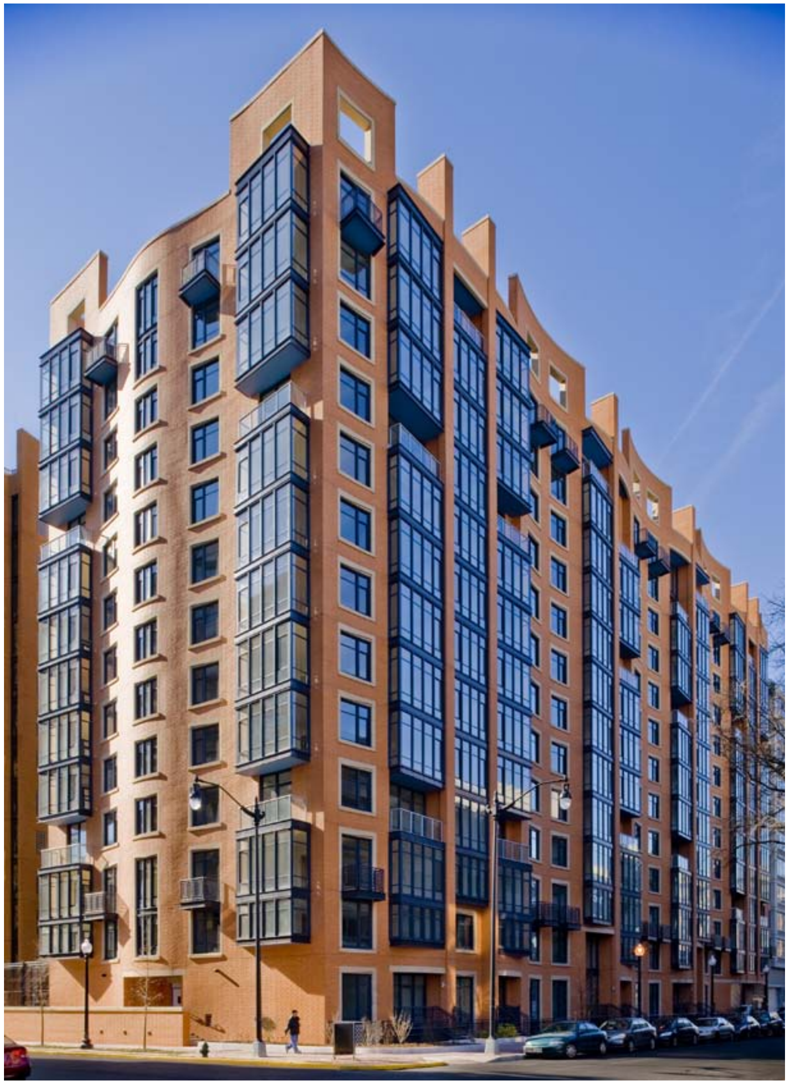
The areas in the northwest of the District and extending northwest into Montgomery and Fairfax counties where housing costs are high also have some of the highest H+T costs in the region. Here, housing costs are so high that they likely overwhelm any savings these households may experience from being in location-efficient areas with low transportation costs. However, in areas in the District of Columbia, Arlington County and Alexandria, low transportation costs help keep overall H+T costs low. The outlying counties that present some of the lowest housing costs in the region look much different when considered through the lens of combined H+T costs. High average transportation costs in these areas erode the perceived savings on housing, and these areas become some of the more expensive places to live in the region.

When considering H+T, looking at these combined costs as a percentage of AMI, as in figure 14, presents a useful metric—the burden experienced by typical households in the region. As previously mentioned, CNT has defined a goal for affordability as spending no more than 45% of income on the combined costs of H+T. Here, it becomes apparent that "affordable" housing in the farthest-reaching areas of the region is much less so when transportation costs are added. Average H+T burdens in Spotsylvania, Charles, and Calvert counties are largely

FIGURE 14
Average H+T costs as a percentage of AMI

- <30 %
- 30 to 33%
- 33 to 35%
- 35 to 40%
- 40 to 42%
- 42 to 45%
- 45 to 48%
- 48 to 55%
- 55 to 65%
- 65% +
- Insufficient Data





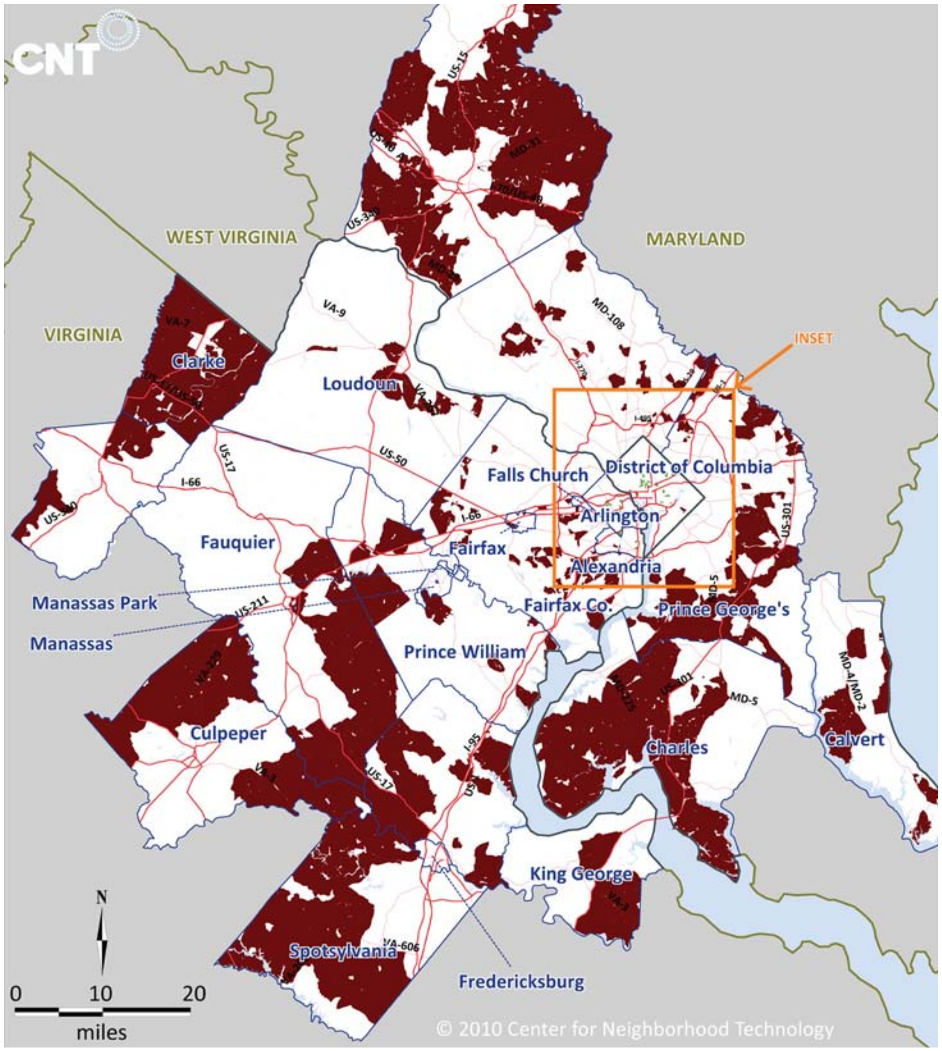
RESIDENTIAL DEVELOPMENT IN DOWNTOWN DC
Photo by Maxwell MacKenzie

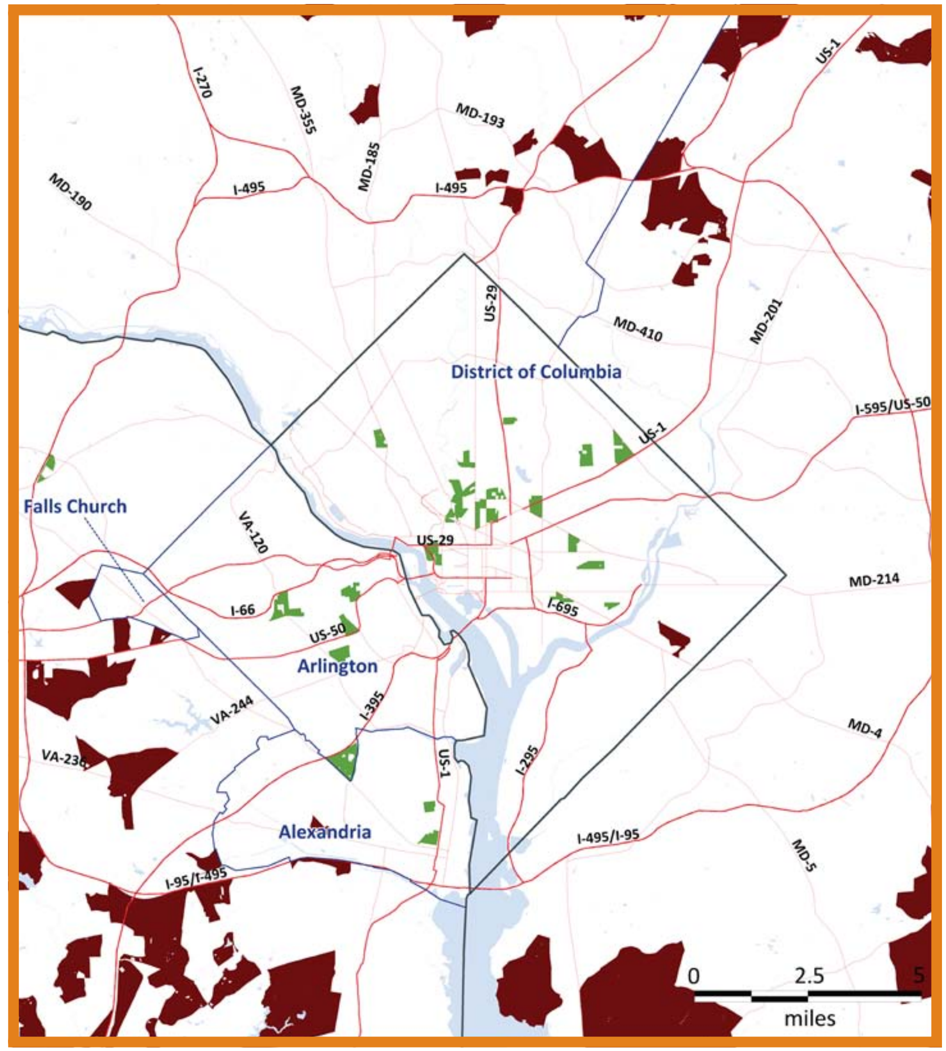
over 45% of AMI, and even exceed 55% of AMI in areas. Conversely, the District of Columbia, Prince George's County, Arlington County, and Alexandria present some of the most affordable areas in the region. Here, even where housing costs are relatively high, average H+T burdens are largely less than 45% of AMI.

As shown in earlier maps (figs. 1 and 2), in many areas, the average affordability changes when transportation costs are added to the affordability definition. The two maps below (fig. 15) highlight these places of change: areas highlighted in red represent neighborhoods where average housing costs are affordable for typical households (less than 30% of AMI) but the addition of transportation costs puts the average combined H+T costs out of an affordable range (greater than 45% of AMI). Zooming in on the District, Arlington, and Alexandria, the map on the right shows (highlighted in green) where the opposite is true: average housing costs are more than 30% of AMI, but average H+T costs are affordable (less than 45%) for households earning the AMI.

FIGURE 15
Changes in affordability
with new definition

- Housing costs < 30% of AMI
  H+T costs > 45% of AMI
- Housing costs > 30% of AMI
  H+T costs < 45% of AMI





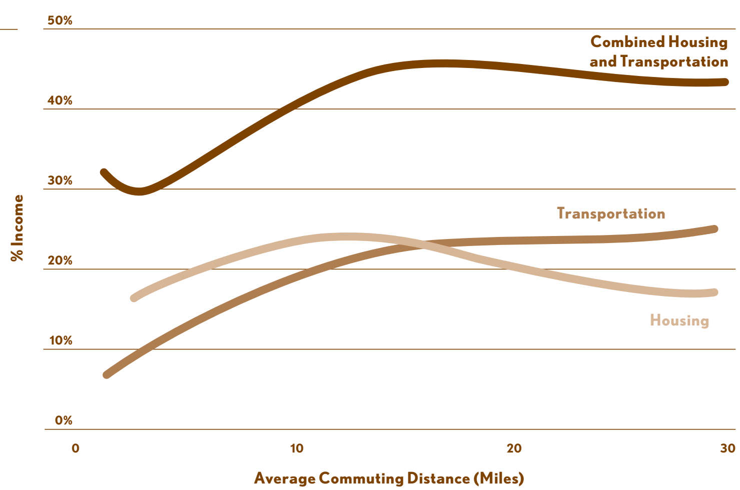
Impact of Varying Transportation Costs on Cost of Living

This analysis shows that, to have a more complete understanding of their cost of living, households must understand their transportation costs, and how these costs are intrinsically connected to location. Without full transparency of transportation costs, households can unexpectedly and unknowingly be putting themselves in a position of financial risk. By illuminating the full cost of location decisions, this work helps to put households in financial control.

Previous research on H+T costs in the greater Washington, DC, area illustrates just how significant a burden transportation costs can be. As figure 16 shows, at an average commute distance of approximately 15–18 miles, average household transportation costs can actually exceed housing costs. At an average cost of nearly $5,600 per year, auto ownership is, by and large, the most significant component of these transportation costs. Areas far from job centers, with low density and little access to goods, services, and transit, leave residents largely dependent on automobiles to meet their daily needs. On the other hand, location-efficient neighborhoods, or compact, mixed-use communities in which residents can walk, bike, or use transit, enable households to get by with fewer automobiles and therefore experience significantly lower transportation costs.

FIGURE 16
H+T cost burdens
by commute distance

Source: *Beltway Burden: The Combined Cost of Housing and Transportation in the Greater Washington, DC, Metropolitan Area, Urban Land Institute Terwilliger Center for Workforce Housing, 2009.*



Implications for Future Growth

Future growth must be planned strategically. By taking into consideration H+T and the factors that impact transportation costs, communities have the potential to grow in a way that is both more location efficient and more affordable for their residents. Communities can increase affordability by targeting growth in location-efficient areas where households are not auto dependent. At the same time, considering the factors that make for location-efficient areas and expanding these characteristics elsewhere can also increase the number of affordable areas.

The District of Columbia can and should serve as a good example of this. While average housing costs are quite high in much of the District and seemingly out of reach for many households, high location efficiency and low transportation costs can actually offset this expense in places, as seen through affordable H+T costs. Expanding the definition of housing affordability to include the transportation costs of a given location will also be helpful to those coming to the region from other areas. First and foremost, the results of this study will help households understand that there is more to housing affordability than "drive 'til you qualify." This study helps them understand that transportation costs have a significant impact on their budget and will enable them to consider a broader range of housing choices to better suit their needs. Second, it provides actual estimates of transportation costs by neighborhood and an understanding of the neighborhood characteristics that affect transportation costs the most.

Finally, this report, combined with the knowledge that transportation costs in auto-dependent neighborhoods will only worsen with rising energy prices, reemphasizes the point that location efficiency of urban walkable neighborhoods (like many in the District), does not just reduce household costs now. The location efficiency of these neighborhoods also provides economic resilience to those households that live in them, enabling them to better accumulate wealth or weather future adversity—from a temporary rise in household costs (e.g., to assist an aging parent) to a nationwide recession.

Technical Report

MORNING ON THE METRO
Photo by Chip Py

Introduction

Significance of Transportation Costs and the Lack of Transparency

Today, the real estate market knows how to incorporate the value of land into the price of the home—based on its location and proximity to jobs and amenities—but there is less clarity about how the accompanying transportation costs also contribute to the desirability of a location. In most cases, the very same features that make the land and home more attractive, and likely more expensive per square foot, also make the transportation costs lower. Being close to jobs and commuter transit options reduces the expenses associated with daily commuting. And being within walking distance of an urban or suburban downtown or neighborhood shopping district allows a family to replace some of their daily auto trips with more walking trips. Walking, bicycling, taking transit, or using car sharing instead of driving a private automobile reduces gasoline and auto maintenance costs, and may even allow a family to get by with one less automobile.

By contrast, places where single-family homes are more "affordable" or offer "more house for the money" are often found in outlying areas where land is cheaper. However, the lack of amenities and access to necessities common in these neighborhoods often results in households having transportation costs that are much higher and can often outweigh the savings on housing costs. In many of the areas where households "drive to qualify" for affordable housing, transportation costs can exceed 32% of household income, making it, at times, a greater burden than housing. Conversely, for some communities where households benefit from less automobile dependency, transportation can represent as little as 10% of median household income.[4]

4. High and low transportation expenditure percentages calculated from the 337 metropolitan areas presented on the H+T Affordability Index website (http://htaindex.cnt.org).

This information gap on location efficiency, which is measured here as the cost of transportation associated with each place, leads to unexpected financial burdens and time constraints for households, poor location decisions by developers, and missed and misplaced opportunities for municipalities. Furthermore, it leads to misinformed criticisms of the cost of building transit since these critiques do not fully account for the benefits or take into account the hidden costs associated with sprawl and auto dependency. Not only are the high costs of transportation hidden, but so are the low costs, and therefore so is the inherent value of more convenient in-town urban, inner-suburban, and other urbanizing locations. Consequently, many of these convenient but undervalued areas suffer from disinvestment and lack the ability to attract new investment and redevelopment.

Expanding the Definition of Affordability

From an affordability perspective, the lack of transparency in transportation costs puts households at significant financial risk. Traditionally, a home is deemed affordable if its costs consume no more than 30% of a household's income. This measure, however, ignores transportation costs—typically a household's second largest expenditure[5] —which are largely a function of the area in which a household chooses to locate. This report proposes expanding the definition of housing affordability to include transportation costs to better reflect the true cost of households' location choices. Based on data from 337 metro areas, ranging from large cities with extensive transit (such as the New York metro area) to small metro areas with extremely limited transit options (such as Fort Wayne, IN), CNT has found 15% of the Area Median Income (AMI) to be an attainable goal for transportation affordability. By combining this 15% level with the 30% housing affordability standard, this report recommends a **new view of affordability,** one defined as **H+T costs consuming no more than 45% of household income.**

5. Consumer Expenditure Survey from the Bureau of Labor Statistics, http://www.bls.gov/cex/home.htm

Considering housing and transportation costs in conjunction changes the picture of affordability significantly. Many areas in which low home prices make the area appear affordable are no longer so attractive when transportation costs are added to the equation. Conversely, areas in which housing prices may seem out of reach for many households can actually become more affordable when high levels of location efficiency allow households to experience significantly lower transportation costs.

The maps below present the ***two views of affordability***: the traditional definition showing where average housing costs are deemed affordable for households earning the AMI (indicated by the areas shaded in yellow in figure 17); and the new view in which affordability is defined as average H+T costs consuming no more than 45% of AMI (fig. 18).[6] Between the two maps, the shift in areas from yellow to blue represents the change in areas with average costs affordable to AMI-earning households when the measure of affordability is expanded to include transportation costs.

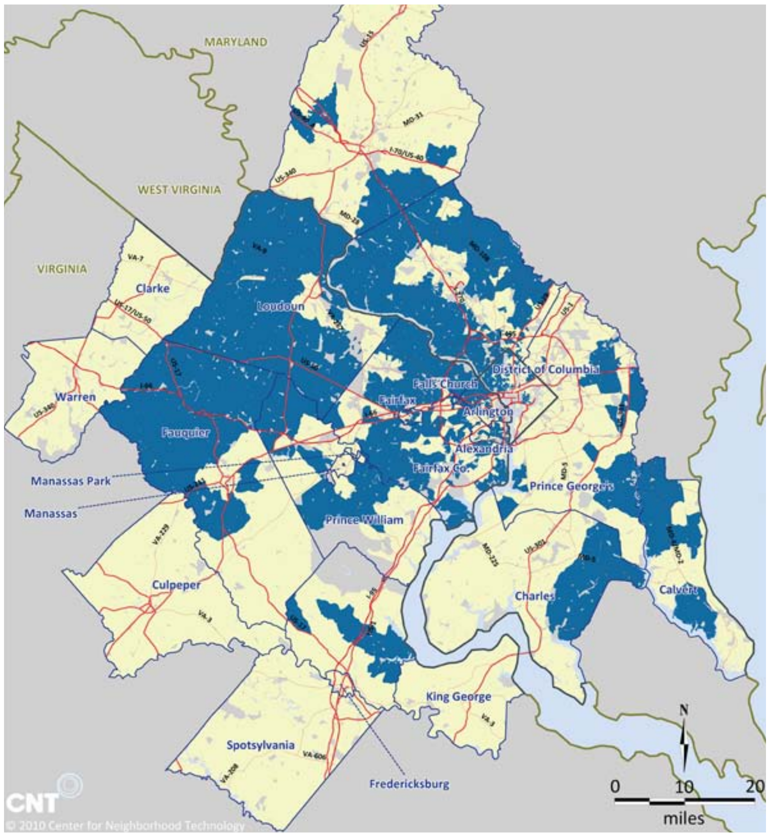


FIGURE 17
Traditional view of affordability: housing costs as a percentage of AMI

- <30%
- 30% +
- Insufficient Data

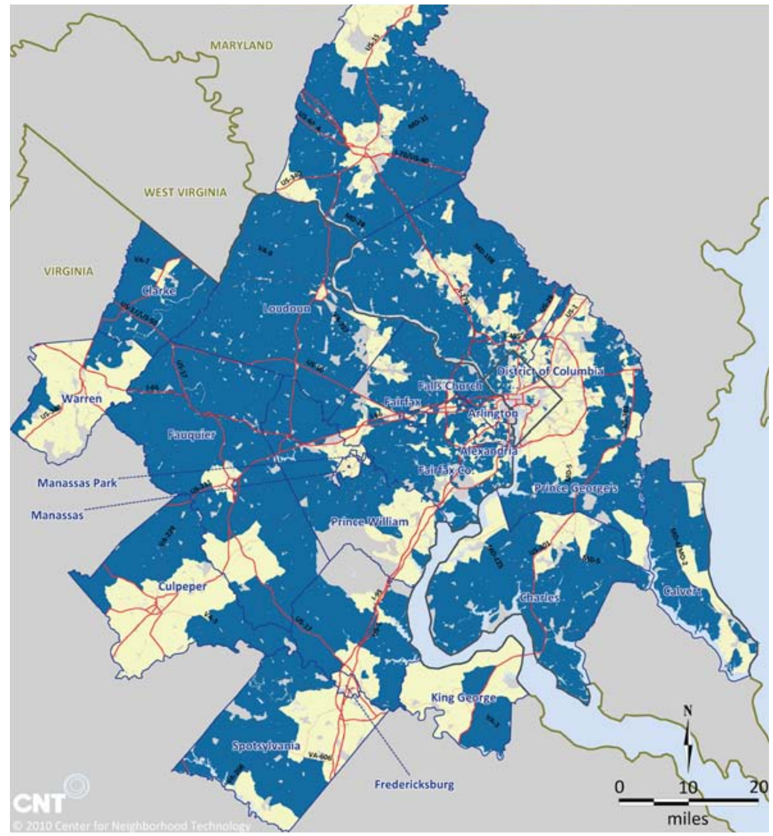


FIGURE 18
New view of affordability: H+T costs as a percentage of AMI

- <45%
- 45% +
- Insufficient Data

6. For the purposes of this research, a value of $87,623 has been utilized as AMI, representing the regional average of block group level household median incomes. Because this value was constructed as an average median for the study area, it differs from the HUD-defined AMI for a family of four.

Development of Body of Work: Applications to Date

The Center for Neighborhood Technology (CNT) has developed a unique tool, the Housing + Transportation (H+T®) Affordability Index, which has so far been applied to all 337 metro areas[7] in the United States. The key to creating true affordability in housing and transportation choices is recognizing the relationship between urban form, housing site selection, and transportation costs, and integrating this way of thinking into the choices and decisions of homebuyers, renters, elected officials, urban and transportation planners, employers, and developers.

The transportation cost model, which was created as part of this Index, was originally developed through an effort supported by the Brookings Institution's Metropolitan Policy Program's Urban Markets Initiative.[8] The methods for the transportation cost model draw from peer-reviewed location efficiency research findings on the factors that drive household transportation costs. CNT, a principal partner in the location efficiency research conducted in Chicago, Los Angeles, and San Francisco,[9] led this model's development. The model has been reviewed by practitioners at the Metropolitan Council in Minneapolis-St. Paul, fellows with the Brookings Institution, and other academics specializing in transportation modeling, household travel behavior, and community indicators from the University of Minnesota, Virginia Polytechnic, and Temple University, among others.

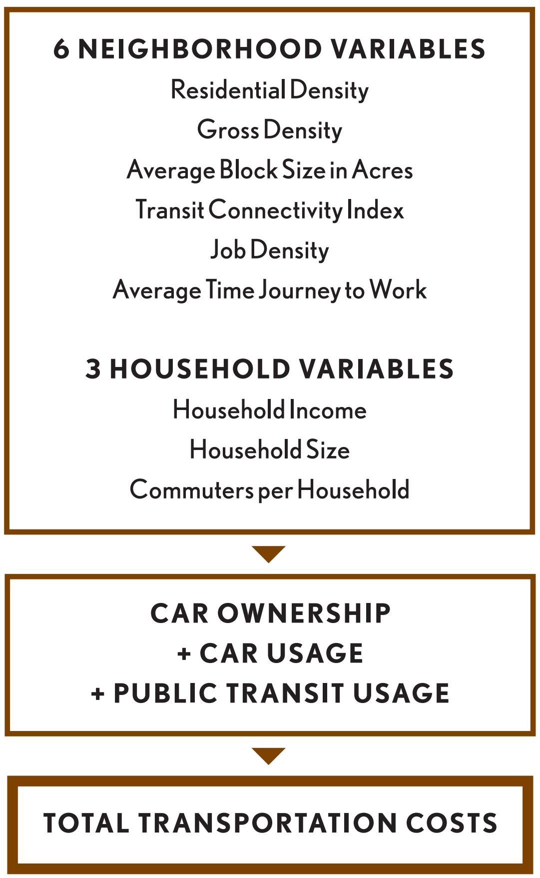
In April 2008, CNT launched a new interactive mapping website, http://cnt.htaindex.org, to serve as a visual tool illustrating the H+T Affordability Index. Here, users could examine any of the 52 metro areas initially covered and view maps of the variables involved in the transportation cost model, housing costs, and combined costs, down to the Census block group level.

In March 2010, the H+T Index was expanded through support from the Rockefeller Foundation. The Index, as a result of this work, now covers all 337 metro areas in the United States.

7. Metro areas analyzed include the Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas as utilized in the 2000 Census.
8. See http://www.brookings.edu/reports/2006/01_affordability_index.aspx
9. Holtzclaw, Clear, Dittmar, Goldstein and Haas (2002). "Location Efficiency: Neighborhood and Socioeconomic Characteristics Determine Auto Ownership and Use." *Transportation Planning and Technology*, Vol. 25.

The H+T Index

FIGURE 19
Transportation cost model



Methods

The transportation cost model (fig. 19),[10] the T in the H+T Index, uses six neighborhood characteristics (residential density, gross density, average block size, transit connectivity, job density, and average time for journey to work) and three household characteristics (income, size, and number of commuters) as independent variables. These variables predict three dependent variables—auto ownership, auto use, and public transit usage—that determine total transportation costs at a neighborhood level.

The transportation cost model is based on a multidimensional regression analysis, where formulae describe the relationships between the dependent variables and the independent household and local environment variables. To construct the regression equations, independent variables are fit one at a time, starting with the one that appears to have the strongest correlation with the given dependent variable. After the first independent variable is fit, the remaining independent variables are plotted with the resulting residual values. The independent variable that appears to have the strongest correlation with the residual values is added second. This process repeats for all independent variables, and only those that improve the fit are kept in the final formulae.

The resulting formulae ("the model") are then used to predict, at the Census block group level, average auto ownership (AO), average auto use (AU), and average transit use (TU). The predicted results from each model are multiplied by the appropriate price for each unit—autos, miles, and transit trips—to obtain the cost of that aspect of transportation. This is summarized as:

Household T Costs =

$$[C_{AO}{*}F_{AO}(X)] + [C_{AU}{*}F_{AU}(X)] + [C_{TU}{*}F_{TU}(X)]$$

Where $C \equiv$ cost factor (e.g., dollars per mile) and $F \equiv$ function of the independent variables,[11] X.

10. The methods for the transportation cost model, are explained more thoroughly in the Detailed Methods section.
11. Independent variables are explained more specifically in the Detailed Methods section.

Because the model was constructed to estimate the three dependent variables (auto ownership, auto use, and transit use) as functions of independent variables, any set of independent variables can be altered to see how the outputs are affected. As a way to focus on the built environment, the independent household variables (income, household size, and commuters per household) were set at fixed values. This controlled for any variation in the dependent variables that was a function of household characteristics, leaving the remaining variation a sole function of the built environment. In other words, by establishing and running the model for a "typical household," any variation observed in transportation costs is due to place and location, not household characteristics.

To define the values on which these three parameters were fixed (household income, household size, and commuters per household), block group level values were averaged for the full region study area ($87,623, 2.65, and 1.37 respectively). Therefore, for the purposes of this study, the reported "AMI" represents the regional average of block group level household median income values.[12]

CUSTOMIZING THE H+T INDEX FOR THE WASHINGTON, DC AREA

This project utilized the H+T Index developed by CNT and customized and recalibrated it to estimate housing and transportation costs in the Washington, DC, metropolitan area. Three main refinements were made to customize the Index for the DC area (see Detailed Methods for more detail).

Updated Data

The H+T Index has so far been developed to calculate combined housing and transportation costs using primarily 2000 US Census data. The data required to calculate H+T costs at the neighborhood level is currently only available at the Census block group level for the year 2000. The American Community Survey (ACS) data, while available for more recent years, is currently not available at the block group level. Therefore, a combination of the block group level 2000 Census data and the 2006–2008 American Community Survey data at the Public Use Microdata Area (PUMA) level was utilized, preserving the block group level variation while updating the data to the 2006–2008 time period.

Local Data

It has been found that the addition of detailed local datasets as independent variables can help improve the fit, and therefore accuracy, of the regression analyses. To further expand existing H+T work in the DC region, the regression analyses were refined through the use of detailed datasets (described below in the Development of Two Transportation Models section) obtained from local agencies and organizations along with national datasets to serve as independent variables in the customized transportation model.

Market Rate Housing Costs

Another significant aspect to the customization of the Index was the incorporation of market rate housing costs. The original Index utilizes Selected Monthly Owner Costs and Gross Rent, both from the US Census, to estimate housing costs. However, because Selected Monthly Owner Costs represent the average costs for all households with a mortgage, regardless of the age of the mortgage, these values can diminish recent housing trends. To capture more recent trends in the housing market, multiple listing service (MLS) sales data were utilized to calculate average ownership costs. Updated values (using the 2000 Census and the 2006–2008 ACS) for Gross Rent were utilized to capture renting costs.

12. The value of $87,623 utilized as AMI was constructed as an average median for the study area; this value thus differs from the HUD-defined AMI for a family of four.

DEVELOPMENT OF TWO TRANSPORTATION MODELS

As discussed above, it has been found that the addition of detailed local datasets as independent variables can help improve the fit, and therefore accuracy, of the regression analyses. However, because these data were obtained from various local agencies, geographic coverage of the datasets varied. Therefore, two separate sets of regression analyses were constructed: the General, Full Region model (the General Model) for the full study area,[13] fit utilizing the standard independent variables; and the Refined, Small Region model (the Refined Model) for a smaller geography,[14] refined through the incorporation of local datasets. The General Model is used throughout this report, while the Refined Model is only addressed when explicitly discussing the differences between the two models.

The primary local data collected for this research included land use data. Land use data, in the most accurate and detailed form available, was collected for all jurisdictions in the Refined Model study area. These data were incorporated in various independent variables, including a refined measure of residential density, land use diversity measures, and in more robust measures of transit access.

Residential Density

In the original H+T Index, as well as in the General Model, residential density is calculated considering total households in residential blocks. Using Census data and block boundaries, blocks are deemed "residential" only when containing at least one household per acre. The count of households and the total land acreage contained within these residential blocks are then aggregated to the Census block groups, at which level residential density is calculated. However, the incorporation of land use data enabled a more refined means by which to define residential land, and therefore, a more accurate measure of residential density. Using the local land use data for the Refined Model, any land use classification that could contain housing (e.g., mixed use) was identified as residential, and the acreage was aggregated to the block group level. Total households in a block group, divided by this measure of residential acres, produced the estimated value for block group refined residential density.

Land Use Diversity

A significant development in this research was the incorporation of a measure of land use diversity. It has been found that the level of land use mix, or diversity, shows a significant correlation with auto ownership, auto use, and transit use. To test this, various measures of land use diversity were constructed and tested.

Utilizing the local land use data, three basic forms of land use diversity measures were considered: percentage residential; Herfindahl-Hirschman indices; and entropy indices.[15] These measures were considered both directly within each block group as well as using a gravity measure to compensate for diverse land uses that are nearby but not directly in the given block group.

DC OP's Transit Network Analysis

Another measure utilizing these local land use data, here to evaluate transit accessibility, was provided and modeled by the DC Office of Planning (OP). A transit network analysis model has been developed to model the distance that can be traveled in 30 minutes through walking and transit. Using this model in conjunction with the land use data, OP estimated the total acreage of each land use type accessible by transit and walking from the center of each block group in the Small Region study area. These modeled results were utilized to create two distinct measures of accessibility: the total acreage of each land use type as well as the sum of all accessible types; and of the total accessible acreage, the fraction of each land use type.

13. The General Model's 23-jurisdiction study area comprises the District of Columbia; Calvert, Charles, Frederick, Montgomery, and Prince George's counties, MD; Arlington, Clarke, Culpeper, Fairfax, Fauquier, King George, Loudoun, Prince William, Spotsylvania, Stafford, and Warren counties, VA; and the cities of Alexandria, Fairfax, Falls Church, Fredericksburg, Manassas, and Manassas Park, VA.

14. The Refined Model's 8-jurisdiction study area comprises the District of Columbia; Montgomery and Prince George's counties, MD; Arlington and Fairfax counties, VA; and the cities of Alexandria, Fairfax, and Falls Church, VA. Jurisdictions were chosen based on the geographic extent of DC's transit network analysis.

15. Song and Rodriguez, 2004. "The Measurement of the Level of Mixed Land Use: A Synthetic Approach." *Carolina Transportation Program White Paper Series*. From http://planningandactivity.unc.edu/RP3.htm

The independent variables tested in developing the Refined Model are explained in greater depth in the Detailed Methods. As with the overall regression methods, the measures that correlated best and provided the greatest marginal improvement to the overall fits were included.

Transportation Model Findings

INDEPENDENT VARIABLES' SIGNIFICANCE

As discussed above, the three dependent variables used to measure transportation costs are autos per household, percent transit use for journey to work, and vehicle miles traveled. Independent variables were used to explain the variation observed in these dependent variables. As discussed in the Methods section, independent variables were fit one at a time, starting with the one that appeared to have the strongest correlation with the given dependent variable. After the first independent variable was fit, the remaining independent variables were plotted with the resulting residual values. The independent variable that appeared to have the strongest correlation with the residual values was added second. This process was repeated with all independent variables, and only those that improved the fit were kept in the final fit.

However, many of the independent variables are strongly correlated with each other. As planners tend to locate dense residential zones near dense commercial zones, retail locates near concentrations of people, and transit best serves dense areas, it is difficult to isolate the impacts of just one independent variable. Therefore, as additional variables were incorporated in the analysis, the marginal improvements to the fit diminished. To test the significance of each independent variable in explaining each dependent variable, a regression analysis was constructed fitting each independent variable with each dependent variable, one at a time. This analysis provided a clearer picture of the most significant determinants of each dependent variable, and therefore, overall transportation costs.

BICYCLIST CROSSING
Photo by Cesar Lujan

The following section shows maps (figs. 20–24) of the modeled outputs controlled for the "AMI-earning household" (when all appropriate independent variables were included), tables of the independent variables' significance in explaining each dependent variable (tables 3–7), and the overall R-squared values obtained in each regression analysis. Results are shown from both the General Model and the Refined Model.

In the following tables (tables 3–7), the tan rows indicate the household characteristics which are fixed and controlled for in the final model runs (the "AMI-earning household"). The dots indicate the independent variables used in the final fit of the regression analyses, and the "total variation described" is for the final fit of the model.

TABLE 3
Independent variable significance, autos per household, General Model

General Model Full Region		Autos per Household R-SQUARED
Residential Density	•	**0.62**
Transit Connectivity Index	•	**0.58**
Gross Density	•	**0.58**
Median Income	•	**0.52**
Job Gravity	•	**0.47**
Average Household Size	•	**0.39**
Average Block Size	•	**0.36**
Average Commuters per HH	•	**0.36**
Average Journey to Work: Transit		**0.23**
Average Journey to Work: Non-transit		**0.14**
Average Journey to Work		**0.06**
Total Variation Described		**0.89**

Tan rows indicate the household characteristics that are fixed and controlled for in the final model runs (the "AMI-earning household"). The dots indicate the independent variables used in the final fit of the regression analyses.

Table 3, showing the significance of each independent variable in the autos per household regression analysis, indicates that residential density explained the greatest variation (62%) as observed in autos per household. However, as previously mentioned, because the independent variables are so highly correlated with each other, this variation is not likely due to density alone. Areas with high residential density attract businesses, bringing jobs, amenities and services to the area, as well as transit service. All of these factors likely contribute to the significant correlation between residential density and autos per household.

In this study area, gross density explained only slightly less (58%). In the General Model, the Transit Connectivity Index was found to be the second largest determinant of autos per household. Household Income, while ultimately controlled for in the final model run (as represented in the mapped autos per household in figure 20), explained 52% of the variation seen in autos per household.

The final autos per household model (incorporating the independent variables labeled with dots) was fit to explain 89% of the variation observed. Interestingly, while it might be assumed that household characteristics play the largest role in determining how many automobiles a household will own, it is shown here that both density and transit access were more significant than any household variable.

FIGURE 20 (RIGHT)
Average autos per household, as modeled for the AMI-earning household, General Model

- <1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 1.9
- 1.9 to 2.0
- 2.0 to 2.1
- 2.1 to 2.2
- 2.2 to 2.3
- 2.3 to 2.5
- 2.5 +
- Insufficient Data

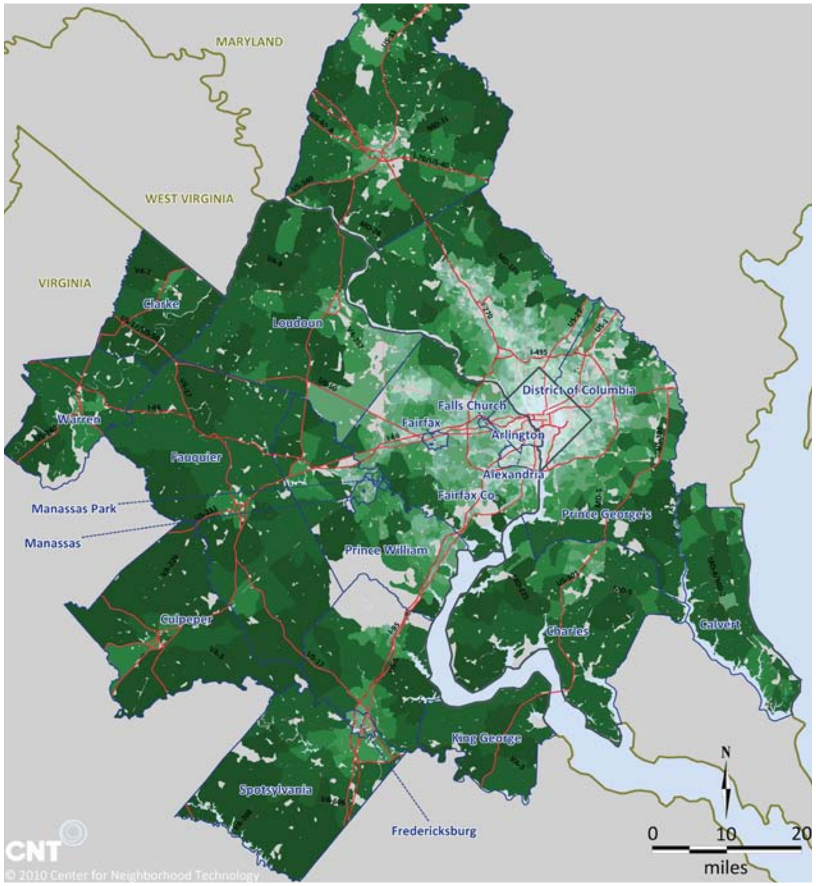


FIGURE 21
Average autos per household, as modeled for the AMI-earning household, Refined Model

- <1.4
- 1.4 to 1.6
- 1.6 to 1.7
- 1.7 to 1.8
- 1.8 to 1.9
- 1.9 to 2.0
- 2.0 to 2.1
- 2.1 to 2.2
- 2.2 to 2.3
- 2.3 +
- Insufficient Data

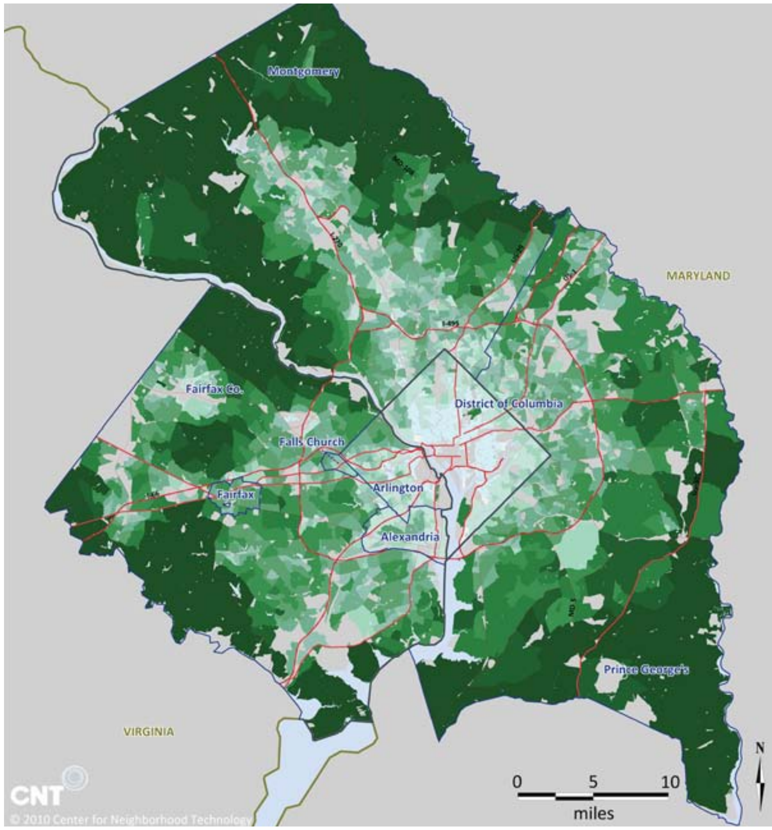


Table 4, like table 3, shows the significance of each independent variable in explaining the variation observed in autos per household, but in this case for the Refined Model. Notable here is the significant role that the land use data played. Residential density, as defined simply using Census blocks, obtained an R-squared value of 67%. However, when this measure was refined through the incorporation of land use data, the R-squared value increased to 71%. The other measures utilizing land use data incorporated here include the gravity Herfindahl-Hirschman 4 measure (representing land use diversity), explaining 33% of the variation in autos per household; the sum of total acres as measured in OP's transit network analysis, with an R-squared value of 32%; and the fraction of commercial acres from the transit network analysis, with an R-squared value of 26%.

TABLE 4
Independent variable significance, autos per household, Refined Model

Refined Model Small Region		Autos per Household R-SQUARED
Residential Density (using land use data)	•	**0.71**
Residential Density		**0.67**
Median Income	•	**0.60**
Transit Connectivity Index	•	**0.58**
Gross Density (using land use data)		**0.57**
Gross Density		**0.56**
Job Gravity	•	**0.43**
Average Commuters per HH	•	**0.37**
Average Household Size	•	**0.35**
Gravity Herfindahl-Hirschman 4	•	**0.33**
Sum of Total Acres from Transit Network Analysis	•	**0.32**
Average Block Size		**0.29**
Fraction Commercial Acres from Transit Network Analysis	•	**0.26**
Average Journey to Work: Transit		**0.19**
Average Journey to Work: Non-Transit		**0.06**
Average Journey to Work		**0.03**
Total Variation Described		**0.90**

Tan rows indicate the household characteristics that are fixed and controlled for in the final model runs (the "AMI-earning household"). The dots indicate the independent variables used in the final fit of the regression analyses.

TABLE 5
Independent variable significance, percentage transit for journey to work, General Model

General Model Full Region		Percent Transit for Journey to Work R-SQUARED
Transit Connectivity Index	•	**0.60**
Job Gravity	•	**0.49**
Gross Density		**0.38**
Residential Density	•	**0.35**
Average Block Size		**0.34**
Average Journey to Work: Transit	•	**0.32**
Median Income	•	**0.27**
Average Commuters per HH	•	**0.19**
Average Household Size		**0.15**
Average Journey to Work: Non-Transit	•	**0.08**
Average Journey to Work	•	**0.01**
Total Variation Described		**0.75**

Tan rows indicate the household characteristics that are fixed and controlled for in the final model runs (the "AMI-earning household"). The dots indicate the independent variables used in the final fit of the regression analyses.

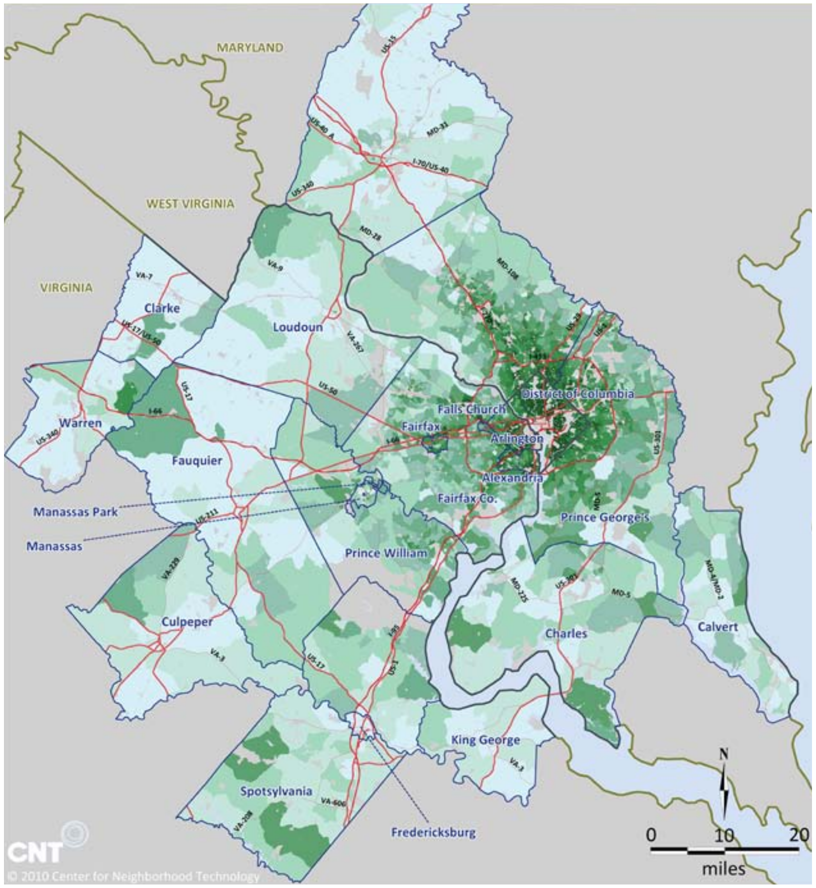
Together, the independent variables in the autos per household Refined Model explained 90% of the variation observed. When compared to the General Model, this indicates that while the incorporation of land use data identified significant independent variables, these variables were so highly correlated with the other independent variables that there was only a modest marginal improvement in the overall model fit.

Table 5 shows the significance of each independent variable with respect to transit use for journey to work for the General Model. Here, built environment factors showed significantly more influence than household characteristics. Transit access, with an R-squared value of 60%, showed the greatest significance, with job access (49%) and density (38% for gross and 35% for residential) making up the largest determinants.

The final fit, considering the independent variables in conjunction, had an R-squared value of 75%.

FIGURE 22
Average percentage journey to work by transit, as modeled for the AMI-earning household, General Model

- < 1 %
- 1 to 4%
- 4 to 7%
- 7 to 9%
- 9 to 11%
- 11 to 14%
- 14 to 18%
- 18 to 24%
- 24 to 33%
- 33 % +
- Insufficient Data



As seen in table 6, for transit journey to work in the Refined Model, transit access was again the most significant independent variable, with an R-squared value of 52%. It is interesting to note that in the Refined Model, median income was a more significant determinant, explaining 38% of the variation observed in transit use, than in the General Model, where only 27% was explained by income.

Transit use in the Refined Model, considering the independent variables together, had an R-squared value of 74%, a value slightly lower than that obtained in the General Model. While this difference is so slight that it is not likely explained by any real phenomenon, it is interesting to note that the refinements using land use data did not actually improve the fit of the model here.

TABLE 6
Independent variable significance, percentage transit for journey to work, Refined Model

Refined Model Small Region		Percent Transit for Journey to Work R-SQUARED
Transit Connectivity Index	•	0.52
Median Income	•	0.38
Residential Density		0.38
Residential Density (using land use data)	•	0.36
Job Gravity	•	0.35
Gross Density (using land use data)	•	0.33
Gross Density		0.33
Sum of Total Acres from Transit Network Analysis	•	0.32
Average Block Size		0.28
Gravity Herfindahl-Hirschman 4	•	0.23
Average Journey to Work: Transit	•	0.20
Fraction Commercial Acres from Transit Network Analysis	•	0.20
Average Commuters per HH		0.19
Average Household Size	•	0.14
Average Journey to Work:Non-Transit	•	0.05
Average Journey to Work	•	0.04
Total Variation Described		0.74

Tan rows indicate the household characteristics that are fixed and controlled for in the final model runs (the "AMI-earning household"). The dots indicate the independent variables used in the final fit of the regression analyses.

FIGURE 23
Average percentage journey to work by transit, as modeled for the AMI-earning household, Refined Model

- < 1 %
- 1 to 4%
- 4 to 7%
- 7 to 9%
- 9 to 11%
- 11 to 14%
- 14 to 18%
- 18 to 24%
- 24 to 33%
- 33 % +
- Insufficient Data

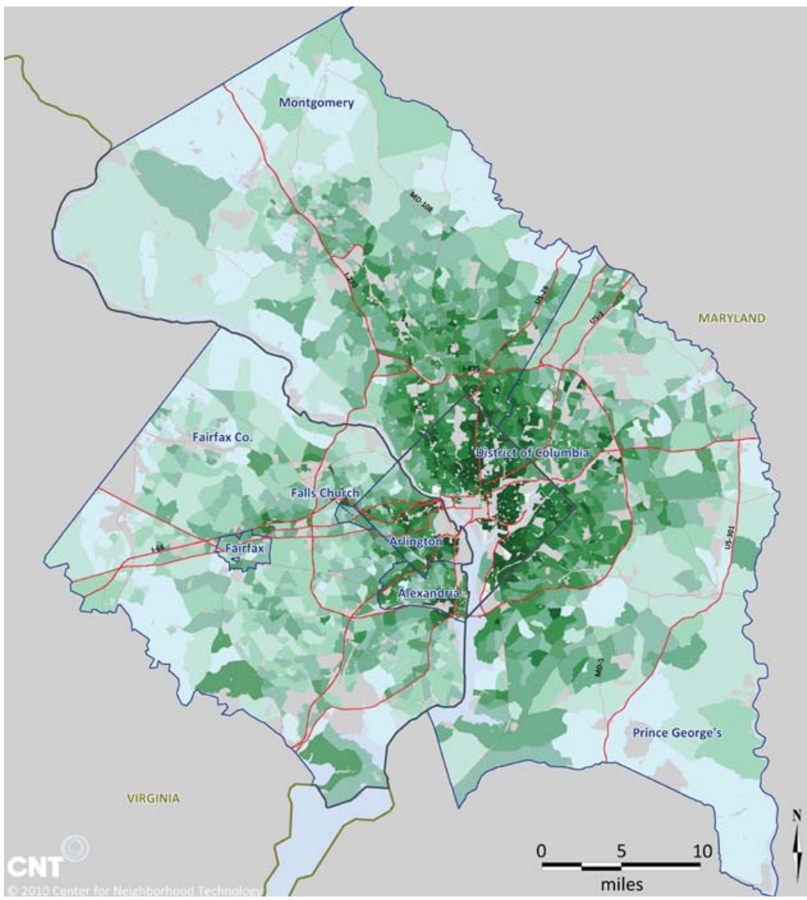


TABLE 7
Independent variable significance, vehicle miles traveled, Massachusetts model

Massachusetts Model		VMT R-SQUARED
Gross Density	•	**0.67**
Residential Density	•	**0.58**
Average Block Size	•	**0.58**
Job Gravity	•	**0.55**
Transit Connectivity Index	•	**0.55**
Median Income	•	**0.28**
Average Commuters per HH	•	**0.23**
Average Household Size	•	**0.22**
Per Capita Income	•	**0.21**
Average Journey to Work Time	•	**0.05**
Total Variation Described		**0.84**

Tan rows indicate the household characteristics that are fixed and controlled for in the final model runs (the "AMI-earning household"). The dots indicate the independent variables used in the final fit of the regression analyses.

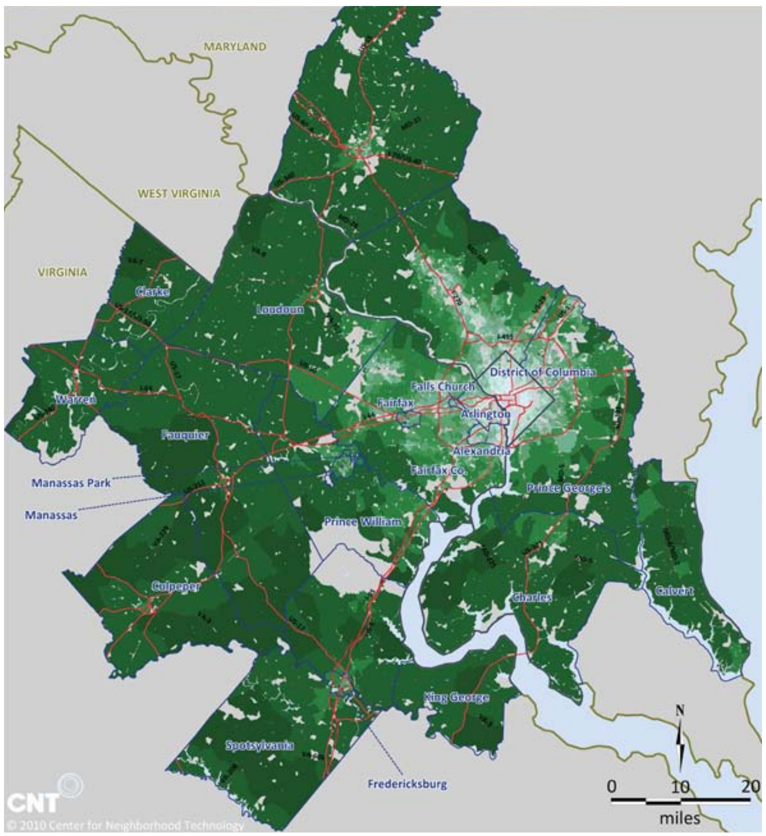


FIGURE 24
Average annual vehicle miles traveled, as modeled for the AMI-earning household, Massachusetts model

- <14,100
- 14,100 to 15,900
- 15,900 to 17,300
- 17,300 to 18,500
- 18,500 to 19,800
- 19,800 to 21,300
- 21,300 to 22,700
- 22,700 to 26,100
- 26,100 to 34,800
- 34,800 +
- Insufficient Data

As discussed in the Detailed Methods, the best measured data for vehicle use—odometer readings—have only been obtained for the state of Massachusetts. Thus the model was fit, and the independent variable significance could only be tested, for Massachusetts. In turn, the values in table 7 do not directly represent the greater DC area. But for the purposes of this research, it is assumed that the correlation and trends hold true outside of Massachusetts.

Here, similar to the percent journey to work by transit model, built environment factors showed a much stronger significance in explaining vehicle miles traveled than did household characteristics. While gross density, residential density, average block size, job access, and transit access each explained more than 50% of the variation observed, household income, commuters per household, and household size each explained less than 30% of the variation.

Largely a function of the built environment, an R-squared value of 84% was obtained in the final model of vehicle miles traveled.

DIFFERENCES BETWEEN THE TWO MODELS

As shown in table 4, the incorporation of land use data provided for a better fit of autos per household overall, and therefore created a more accurate model. Access to mixed land uses, both in the land diversity measures and transit network analyses, proved to be significantly correlated with both auto ownership and transit use. However, the marginal improvement between the two models indicated that these variables are so highly correlated with the other neighborhood characteristics (e.g., density, job access, block size) that in conjunction, their impact had largely been accounted for.

It is interesting to note that the measure of residential density that incorporated land use data to define residential acres provided a significantly greater fit than residential density without land use data. However, because the land use data utilized were not uniform or detailed in all jurisdictions, this led to some anomalous results.

For example, in figure 25, showing transportation costs from the Refined Model, the area around the Crystal City Metro station is modeled to have significantly higher transportation costs than the surrounding area. It was found that the model actually overpredicted auto ownership in this area. Upon further inspection into the cause of this overestimate, it was determined that the residential density measure utilizing the land use data (as shown in figure 26) had values of zero in this area, causing the model to predict high auto ownership. The cause of this was the fact that this area was identified as commercial in the land use data, but from the Census, it was determined that there were a small number of households located here. Having households in an area with zero residential acres caused the residential density value to be zero, and therefore, reduced the accuracy of the model.

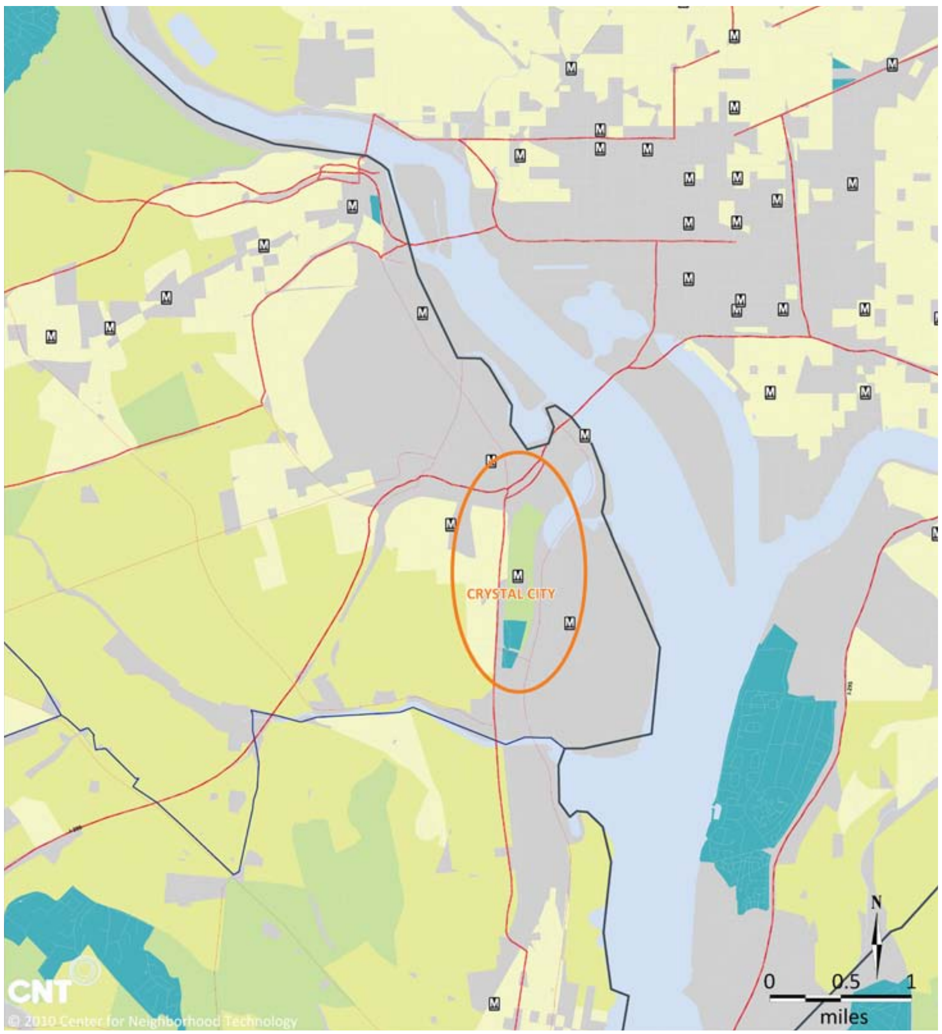
Therefore, while the addition of land use data only marginally improved the fit of the model, this could largely be a function of anomalous results such as these. With more detailed and consistent land use data, there is the potential that a refined measure of residential density and measures of access to mixed land uses could more significantly improve the accuracy of estimating auto ownership and transit use.

FIGURE 25
Average monthly transportation costs, Refined Model

- < $975
- $975 to $1,150
- $1,150 to $1,250
- $1,250 to $1,500
- $1,500 +
- Insufficient Data

FIGURE 26
Residential density using land use data, households per residential acre

- 0
- < 20
- 20 to 100
- 100 to 780
- 780 +
- Insufficient Data



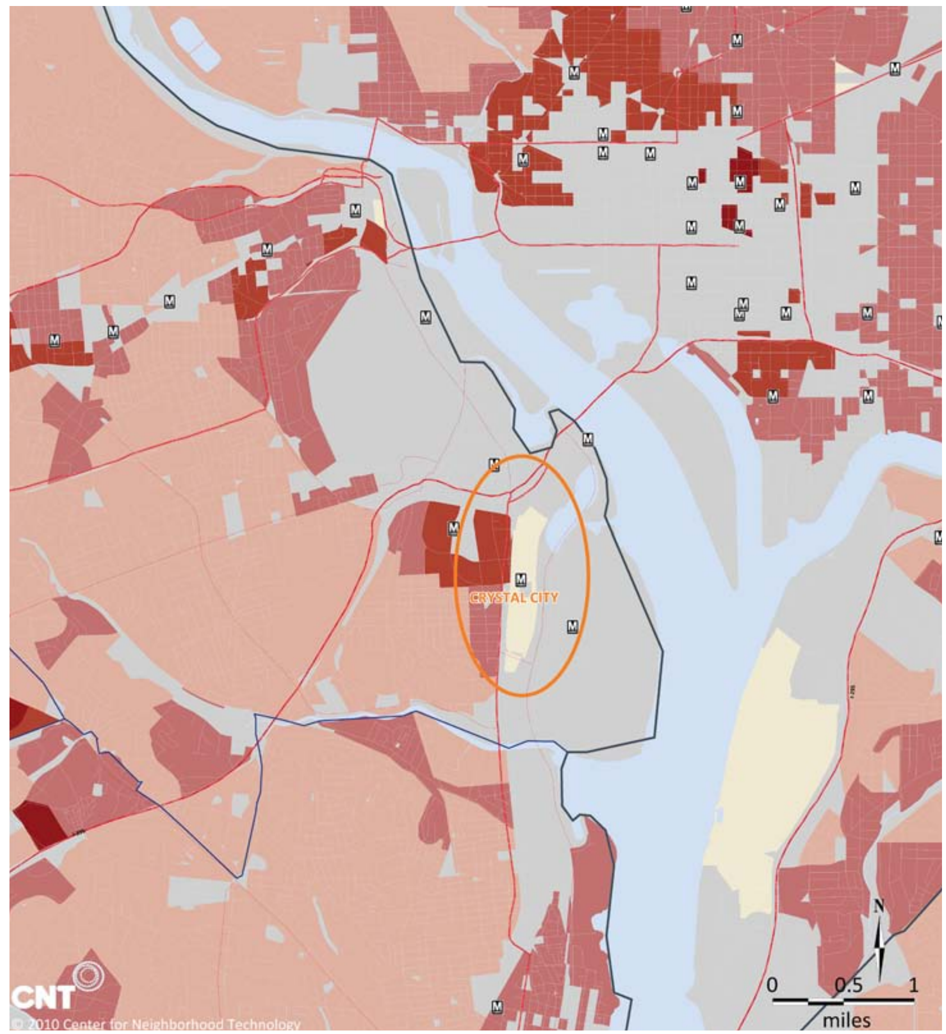
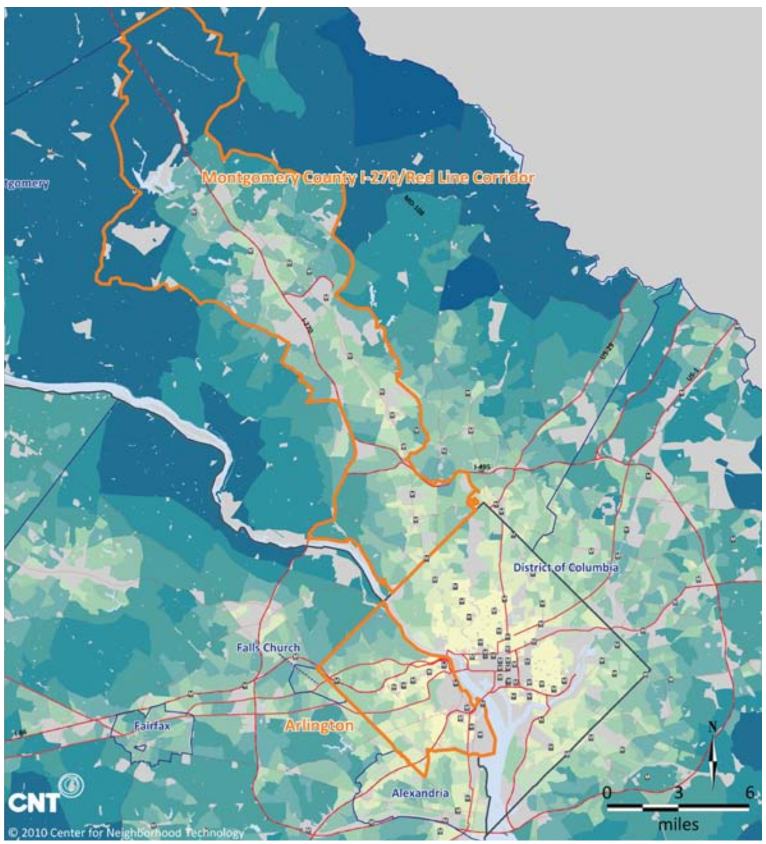


TABLE 8
Comparative statistics in Montgomery and Arlington counties

	Montgomery County I-270/Red Line Corridor	Arlington County	Full Region
Average Monthly Transportation Costs	$1,177	$975	$1,246
Average Residential Density (HHs/Res. Acre)	4.2	7.6	3.9
Average Gross Density (HHs/Land Acre)	1.9	5.8	0.5
Average Block Size (Acres)	22.4	8.4	75.5
Average Transit Connectivity Index	1,199	3,529	1,420
Average Job Access (Gravity Index)	51,754	120,881	54,052
Average Time for Journey to Work (Mins.)	31.1	26.2	33.1

FIGURE 27
Average monthly transportation costs, as modeled for the AMI-earning household

- < $920
- $920 to $1,020
- $1,020 to $1,100
- $1,100 to $1,170
- $1,170 to $1,230
- $1,230 to $1,280
- $1,280 to $1,370
- $1,370 to $1,500
- $1,500 to $1,770
- $1,770 +
- Insufficient Data



DETERMINING FACTORS: WHAT DRIVES TRANSPORTATION COSTS?

Focusing on the General Model, the built environment or neighborhood characteristics were found to be the most significant determinants of transportation costs. Because auto ownership costs typically make up the largest component of overall transportation costs, it can be assumed that residential density is the most significant factor in determining transportation costs. Transit access, as measured by the Transit Connectivity Index, job access, gross density, average block size, and average time for journey to work proved to be the most important factors after residential density.

Table 8 and the following series of seven maps (figs. 27–33) highlight this with an example comparing the Montgomery County I-270/Red Line corridor with Arlington County. While Montgomery County has been effective at focusing development along the I-270/Red Line corridor and protecting the surrounding farmland, average transportation costs are higher than they are in Arlington County.

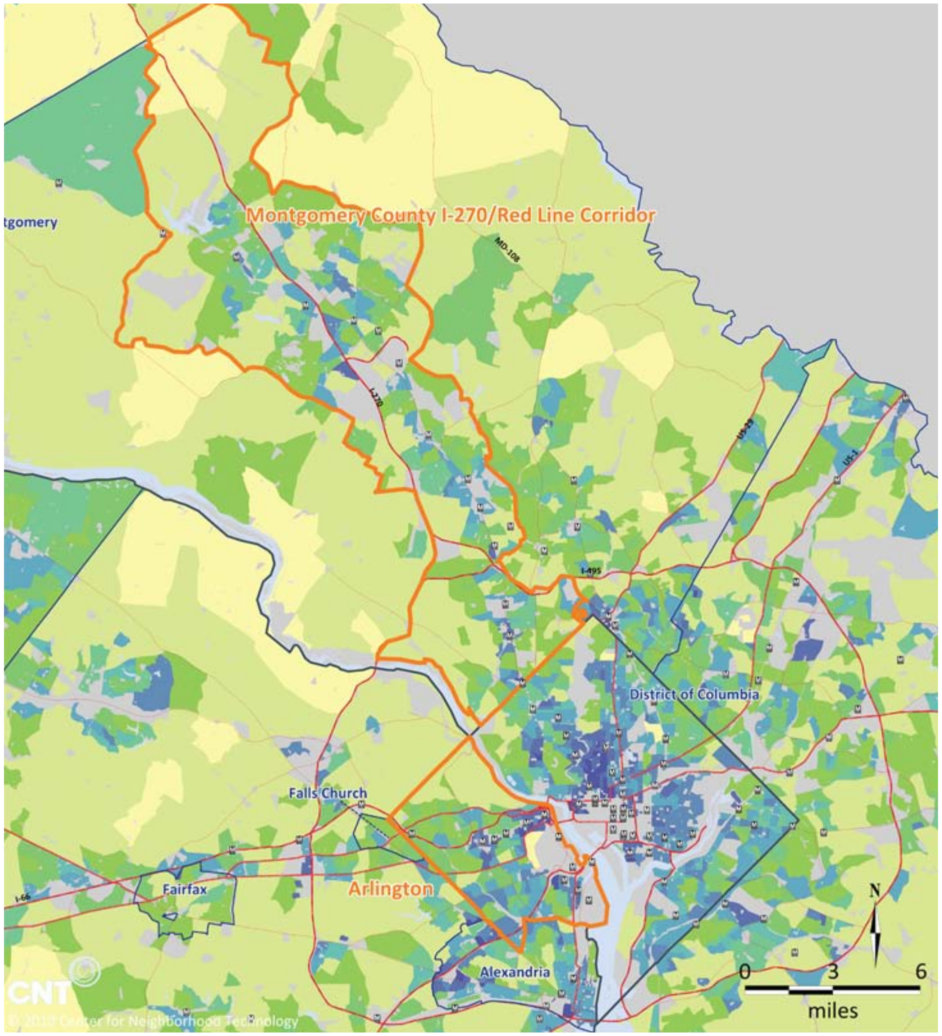
In aggregate, the comparative examples of the Montgomery County I-270/Red Line corridor and Arlington County show the importance of all six highlighted neighborhood characteristics on transportation costs. However, considering the maps provides an added level of detail. For example, areas can be identified where residential density is nearly the same in Arlington and in the I-270/Red Line corridor, yet the transportation costs in Arlington are lower. Even in areas where transit access is lower in Arlington, transportation costs are still lower. Focusing on such areas reveals the significance of the other neighborhood characteristics. The one measure consistently higher in Arlington than in the I-270/Red Line corridor is Job Access, indicating its likely importance in the difference in transportation costs between the two areas.

FIGURE 28
Residential density
households per residential acre

- < 1
- 1 to 3
- 3 to 4
- 4 to 5
- 5 to 6
- 6 to 7
- 7 to 12
- 12 to 20
- 20 to 36
- 36 +
- Insufficient Data

FIGURE 29
Gross density
households per land acre

- < 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 5
- 5 to 7
- 7 to 10
- 10 to 15
- 15 to 27
- 27 +
- Insufficient Data



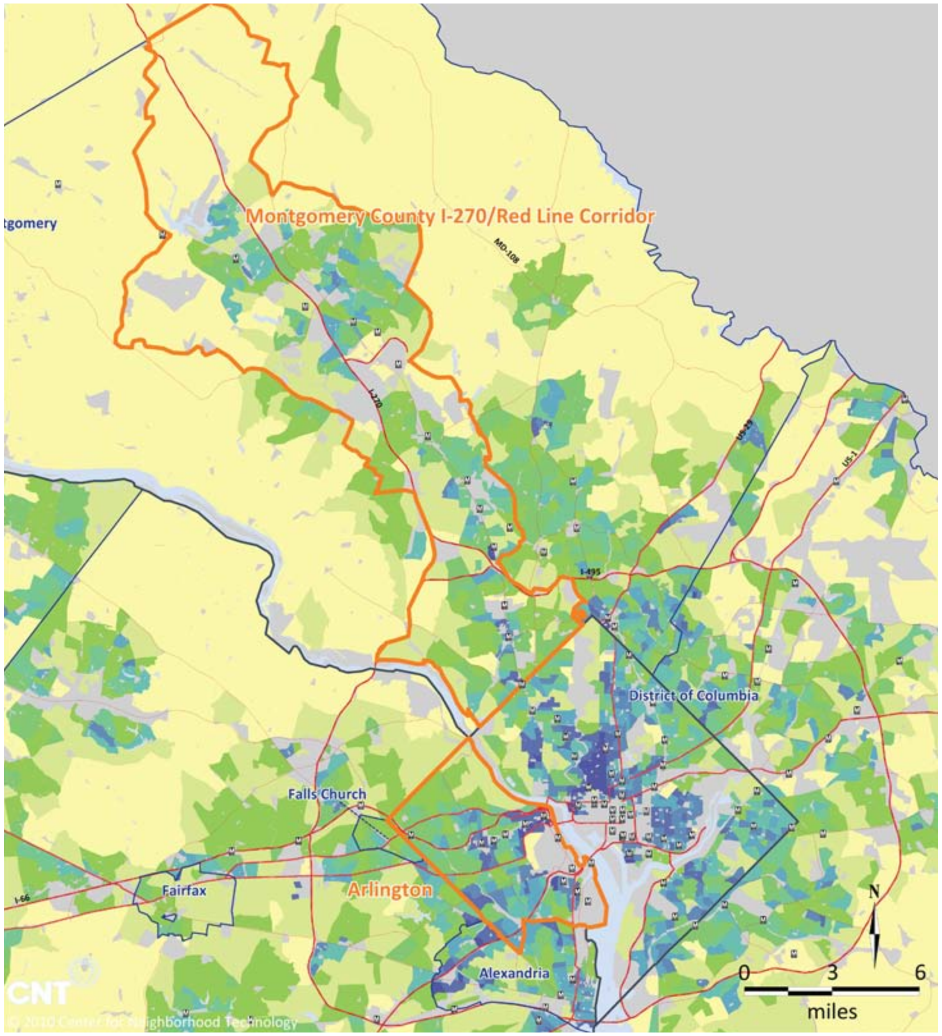


FIGURE 30
Average block size in acres

- < 10
- 10 to 20
- 20 to 30
- 30 to 50
- 50 to 80
- 80 to 150
- 150 to 250
- 250 to 390
- 390 to 800
- 800 +
- Insufficient Data

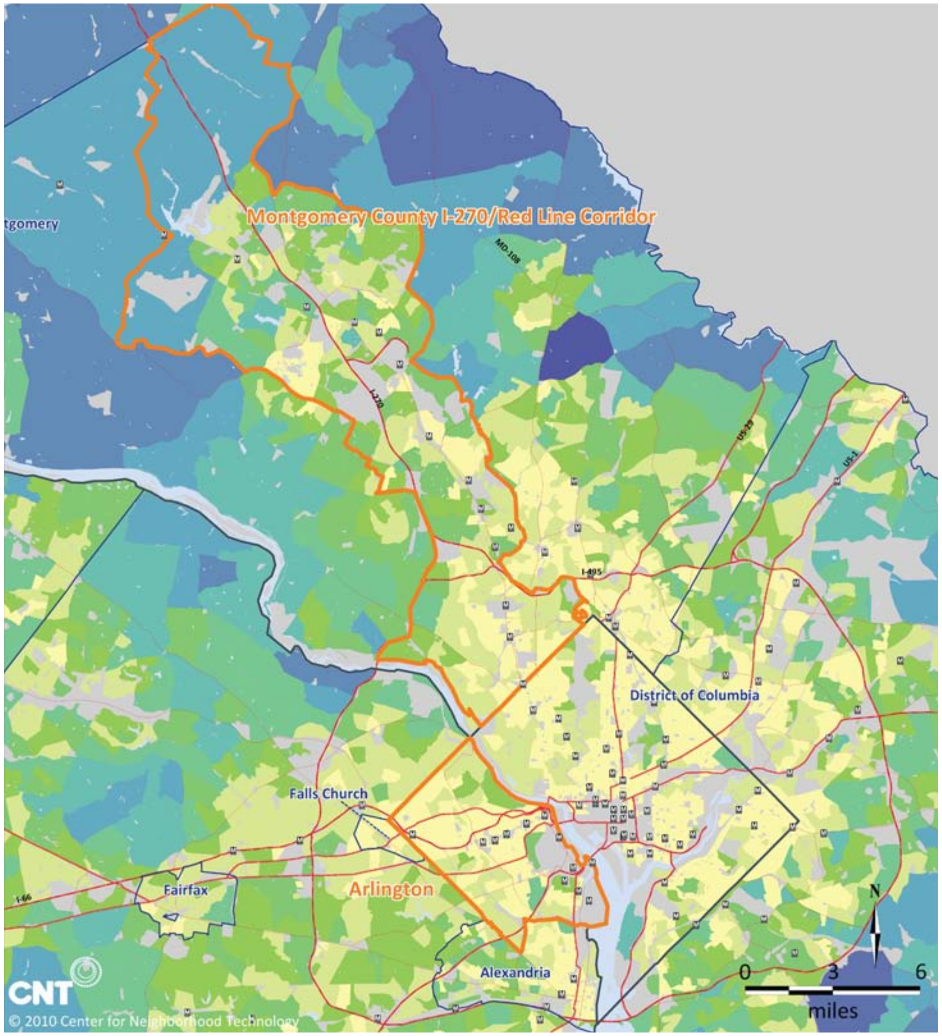


FIGURE 31
Transit Connectivity Index

- Low
- Moderate
- High
- Insufficient Data

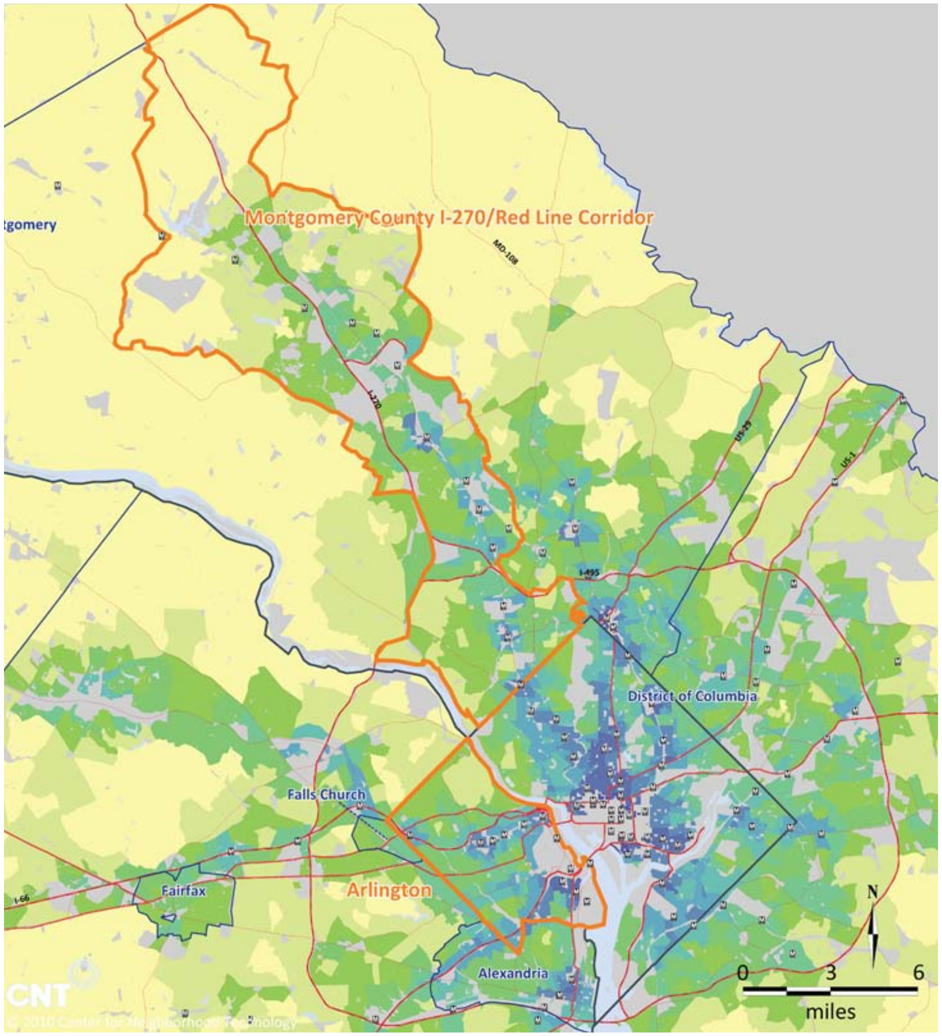
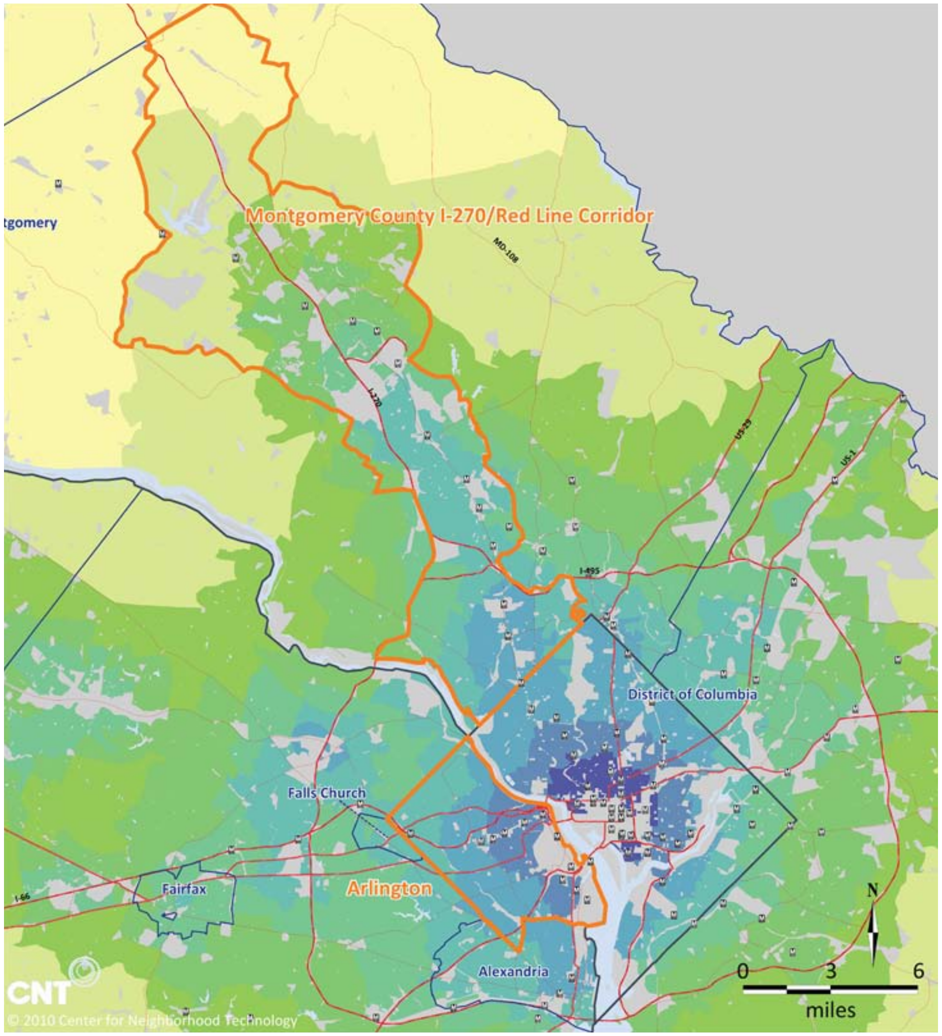


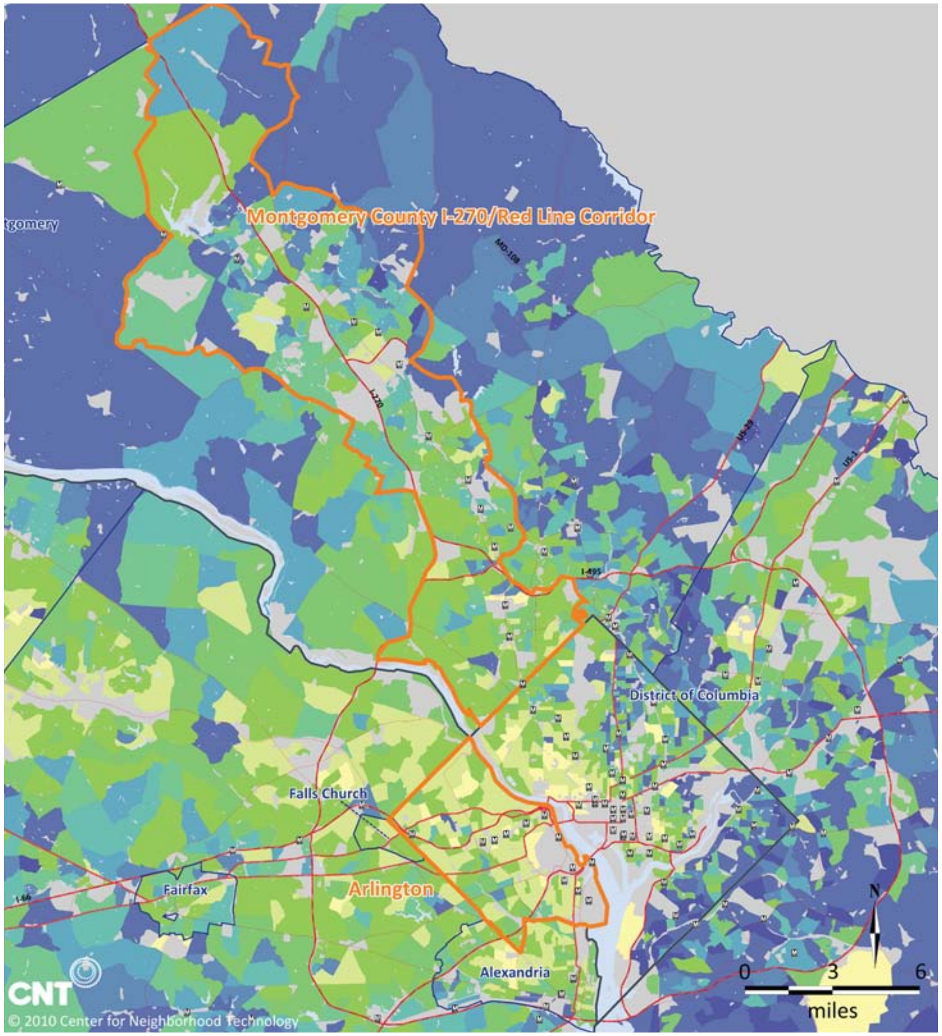
FIGURE 32
Job access

- Low
- Moderate
- High
- Insufficient Data

FIGURE 33
Average time for journey to work in minutes

- <22
- 22 to 26
- 26 to 29
- 29 to 31
- 31 to 32
- 32 to 33
- 33 to 34
- 34 to 35
- 35 to 41
- 41 +
- Insufficient Data





Model Outputs and Results

DISCUSSION OF COSTS

The following three maps show the average costs throughout the region: average monthly housing costs (fig. 34); average monthly transportation costs (fig. 35); and average monthly H+T costs combined (fig. 36).

Housing Costs

As the DC area is known for having a strong housing market, it is not surprising that average monthly housing costs are high throughout the region. These costs are highest, averaging over $5,200 monthly, in the northwest areas of the District and spreading northwest into Fairfax and Montgomery counties. Costs are lowest in the eastern portion of the District where average monthly costs less than $1,200 can be found. Also, the farthest reaching areas of the region, such as Warren and Culpeper counties, contain areas with average monthly housing costs in the less than $1,200 range.

Transportation Costs

Transportation costs, however, present a near mirror image to housing costs. Average transportation costs are lowest in the District of Columbia, where households have convenient access to jobs and amenities. Households here, on average, own fewer cars and drive them less because they are largely able to walk, bike, and use transit to meet their daily needs. Areas of compact, mixed-use development outside of the District, such as in Arlington and Fairfax counties, the I-270/Red Line corridor extending out through Montgomery County, in the center of Frederick County, and in Fredericksburg, also have development patterns that enable their residents to have lower transportation costs.

Average transportation costs are highest in the dispersed, auto dependent areas of the region. Residents in the furthest reaching counties of the region, such as Clarke, Warren, Calvert, and Charles, must rely on automobiles and drive long distances, creating high transportation expenditures.

H+T Costs

Combining the two costs, both housing and transportation, gives a much more complete picture of the costs associated with the location a household chooses. The areas in the northwest of the District and extending northwest into Montgomery and Fairfax counties, where housing costs are high, also have some of the highest H+T costs in the region. Here, housing costs are so high that they likely overwhelm any savings these households may experience from being in location-efficient areas with low transportation costs. However, in areas in the District of Columbia, Arlington County, and Alexandria, low transportation costs help keep overall H+T costs low. The outlying counties that present some of the lowest housing costs in the region look much different when considered through the lens of combined H+T costs. High average transportation costs in these areas erode the perceived savings on housing, and these areas become some of the more expensive places to live in the region.

FIGURE 34
Average monthly housing costs

- < $1,200
- $1,200 to $1,400
- $1,400 to $1,500
- $1,500 to $1,600
- $1,600 to $1,900
- $1,900 to $2,200
- $2,200 to $2,700
- $2,700 to $3,600
- $3,600 to $5,200
- $5,200 +
- Insufficient Data

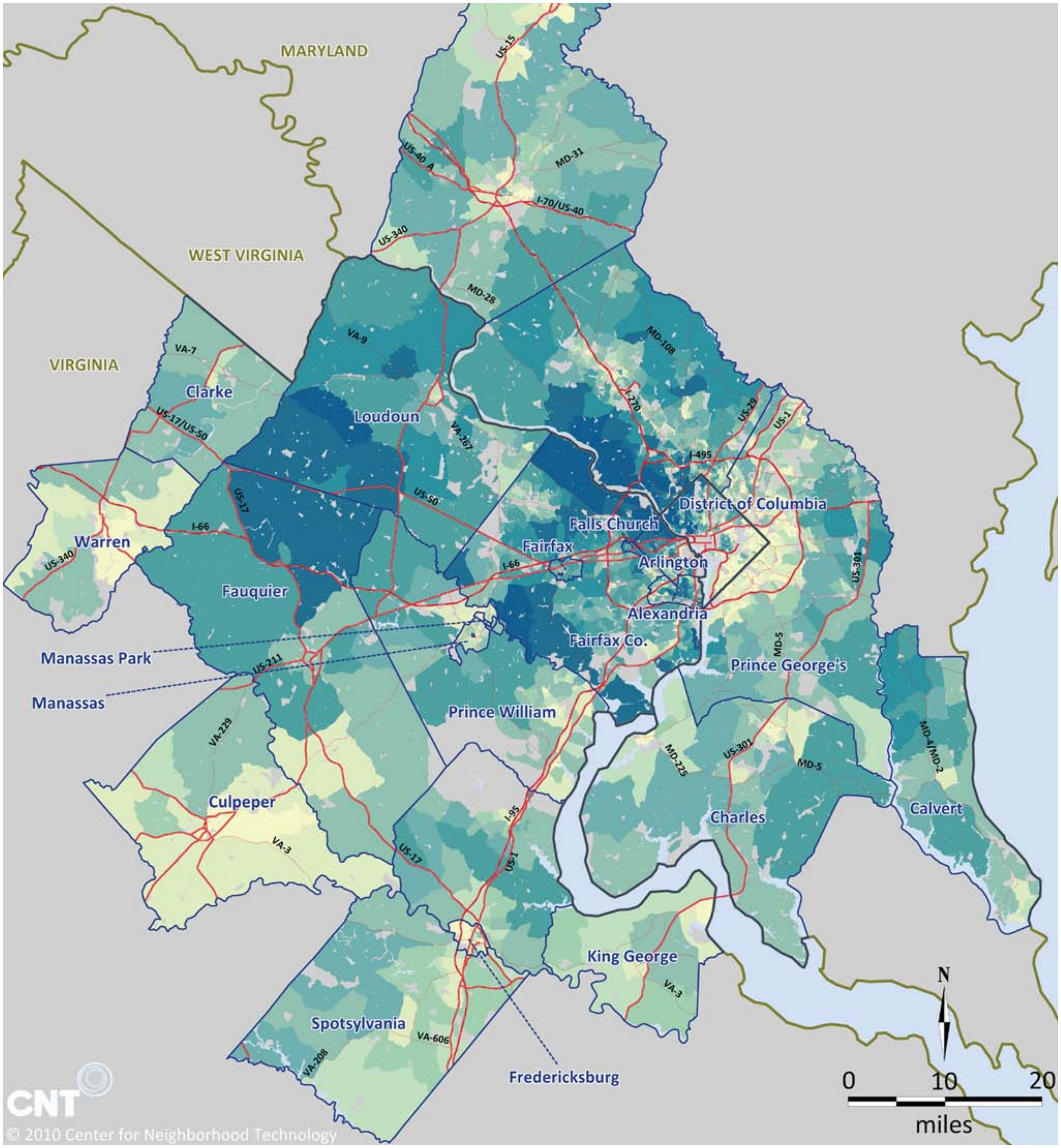


FIGURE 35
Average monthly transportation costs, as modeled for the AMI-earning household

- < $920
- $920 to $1,020
- $1,020 to $1,100
- $1,100 to $1,170
- $1,170 to $1,230
- $1,230 to $1,280
- $1,280 to $1,370
- $1,370 to $1,500
- $1,500 to $1,770
- $1,770 +
- Insufficient Data

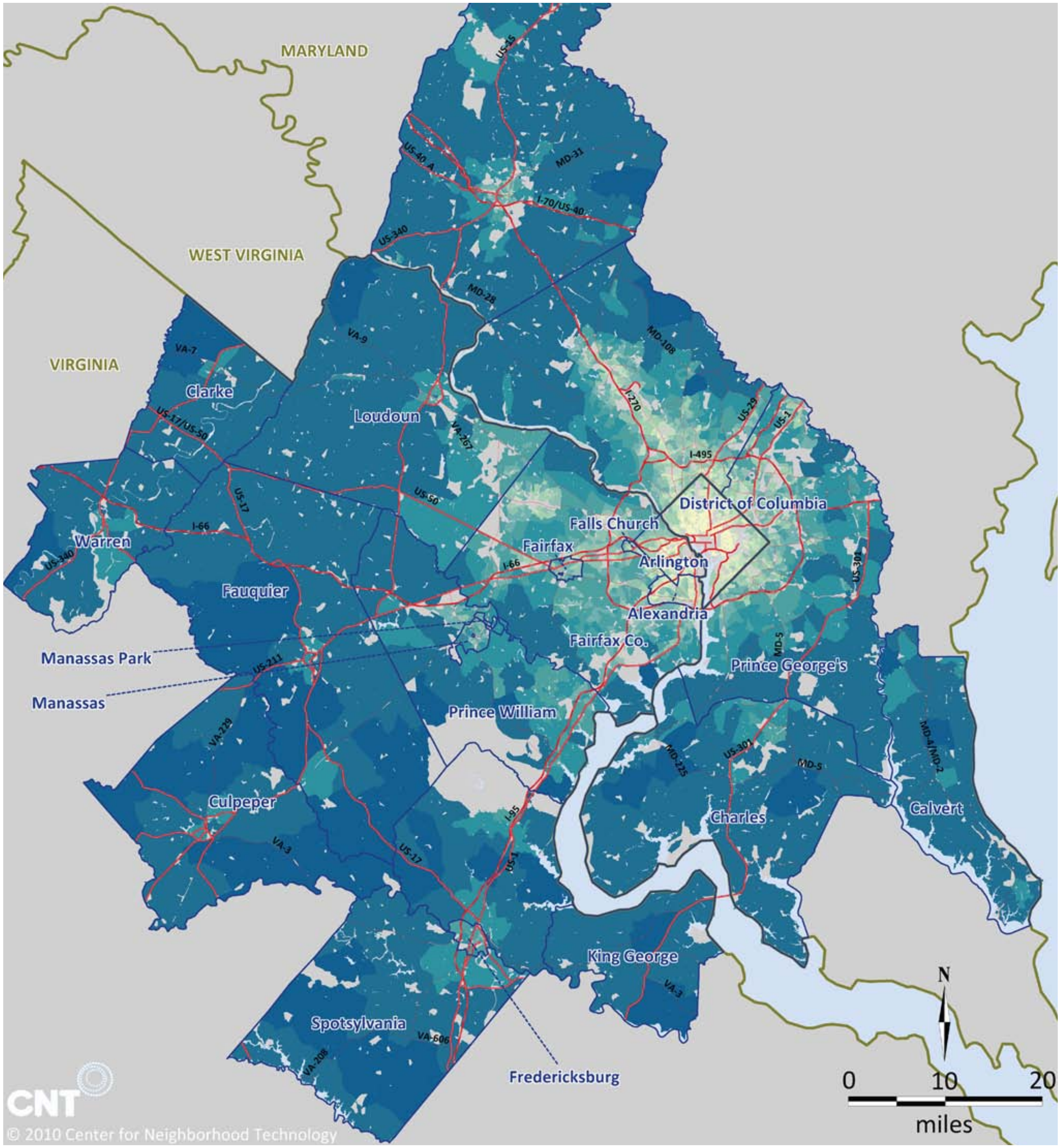
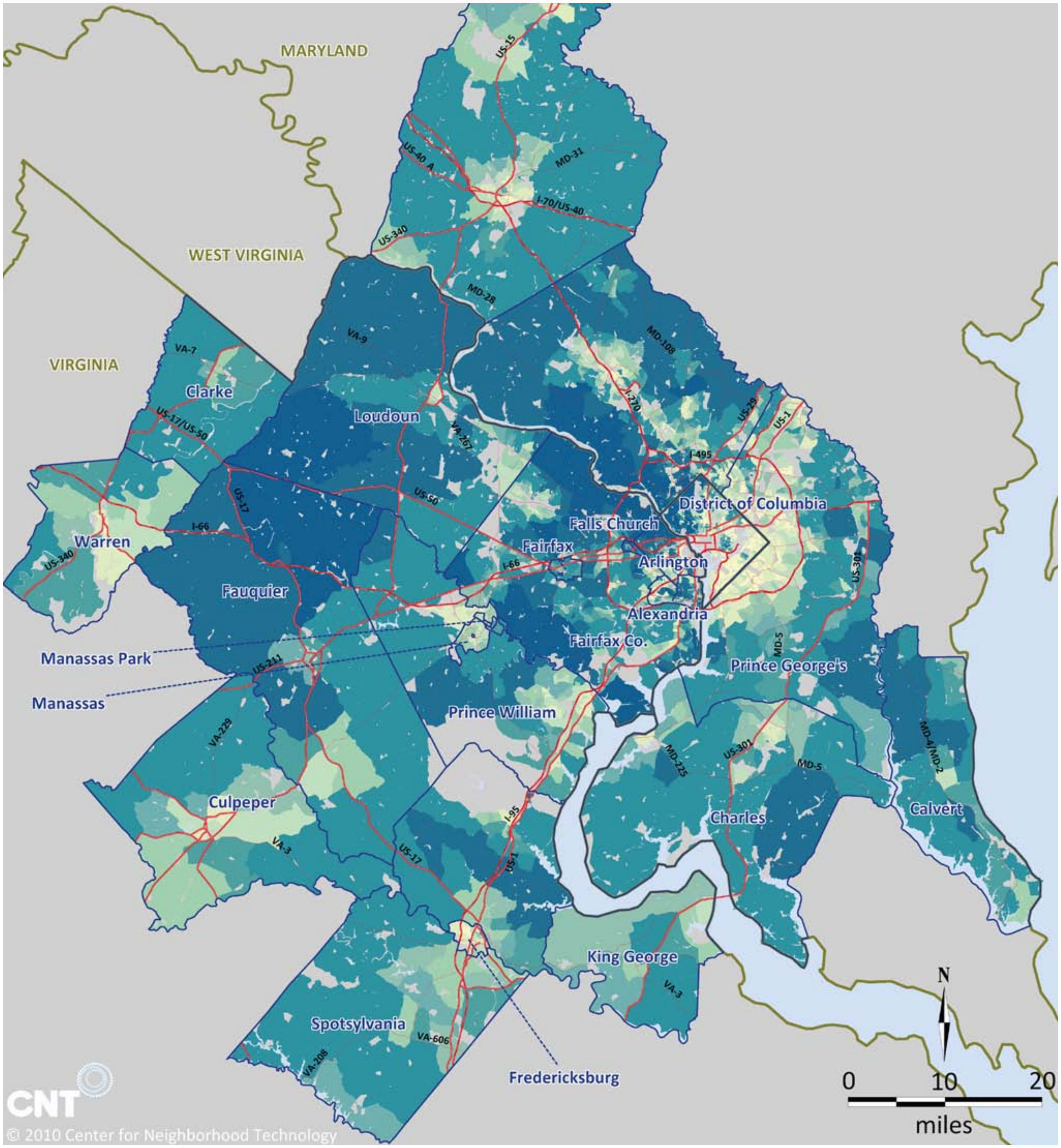


FIGURE 36
Average monthly H+T costs, with transportation costs modeled for the AMI-earning household

- <$2,300
- $2,300 to $2,600
- $2,600 to $2,800
- $2,800 to $3,000
- $3,000 to $3,100
- $3,100 to $3,200
- $3,200 to $3,300
- $3,300 to $4,000
- $4,000 to $5,400
- $5,400 +
- Insufficient Data



DISCUSSION OF AFFORDABILITY

The following three maps show the average costs throughout the region as a percentage of AMI,[16] or the burden experienced by the typical household: average housing burden (fig. 37), average transportation burden (fig. 38), and average H+T burden (fig. 39).

Housing Burden

Using the standard measure of "affordability" defined as housing costs consuming no more than 30% of income, average housing costs throughout much of the inner region (i.e., the District, Montgomery and Arlington counties, Alexandria, and Fairfax County) are largely out of reach for the typical household. Average costs easily exceed 40% of AMI through much of this area. Counties farther from the District, such as Frederick, Clark, Warren, Culpeper, King George, and Charles present a much different picture of housing affordability. In these areas, average housing costs are, by and large, affordable for the typical household.

Transportation Burden

Transportation burdens, again, present a very different picture than housing burdens. The inner areas of the region have average transportation costs that rarely consume more than 20% of AMI. In many areas here, especially in the District, average transportation costs can consume less than 15% of AMI. However, the outer counties described above as providing the most affordable housing options also present the least affordable transportation costs. Areas in Clarke, Culpeper, and Spotsylvania counties, for example, present average transportation costs that can consume more than 24% of AMI.

H+T Burden

As a means to weigh these tradeoffs, such as low housing costs and high transportation costs, average H+T costs as a percentage of AMI enables a more complete understanding of affordability. Through this lens, it becomes apparent that "affordable" housing in the farthest reaches of the region is much less so when transportation costs are considered. Average H+T burdens in Spotsylvania, Charles, and Calvert counties are largely over 45% of AMI, and even exceed 55% of AMI in areas. Conversely, the District of Columbia, Prince George's and Arlington counties, and Alexandria present some of the most affordable areas in the region. Here, even where housing costs are relatively high, average H+T burdens are largely less than 45% of AMI, a threshold established by CNT as affordable.

16. A value of $87,623 has been utilized as AMI, representing the regional average of block group level household median incomes.

FIGURE 37
Average housing costs as a percentage of AMI

- <25 %
- 25 to 30%
- 30 to 35%
- 35 to 40%
- 40 % +
- Insufficient Data

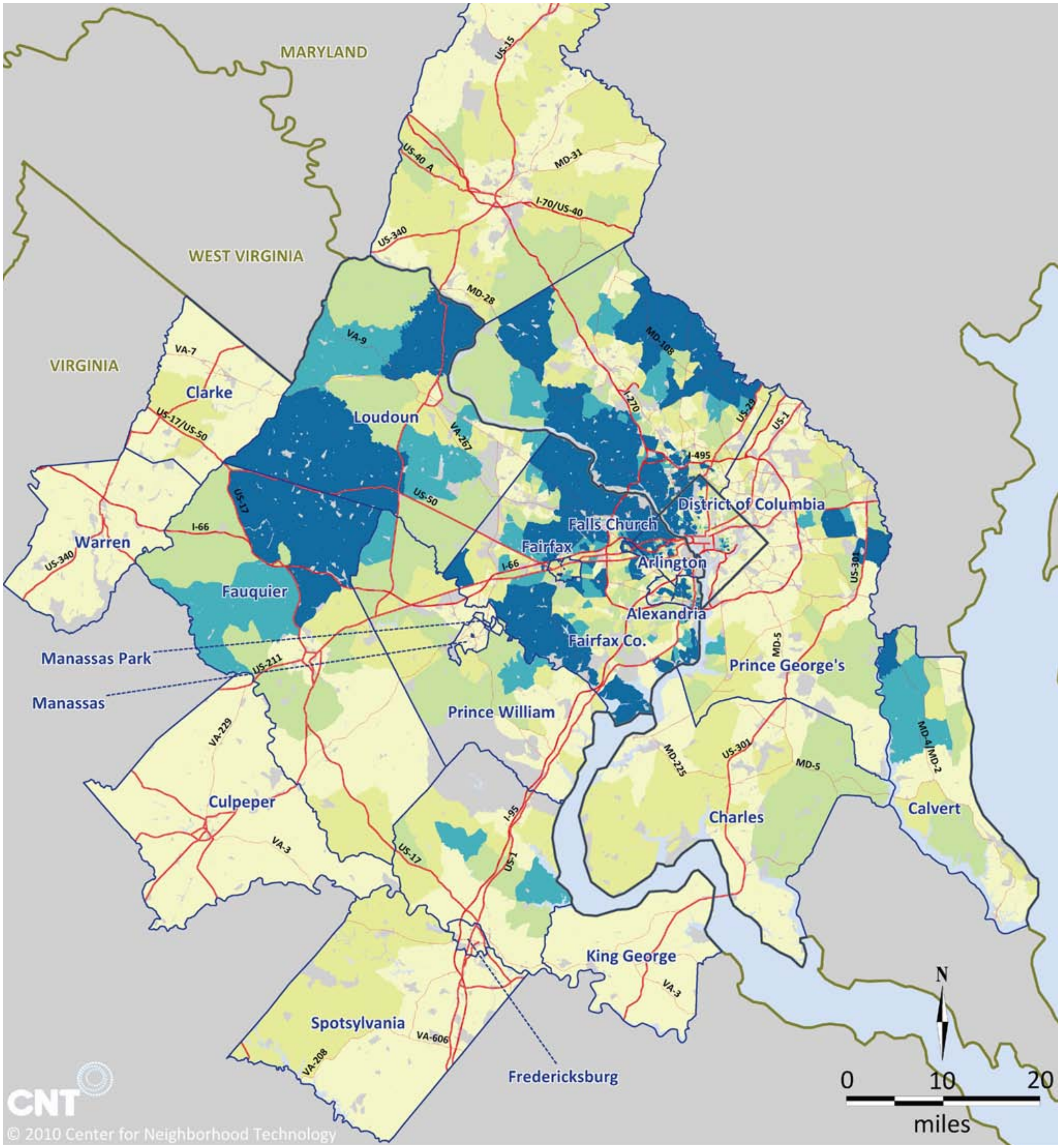


FIGURE 38
Average transportation costs as a percentage of AMI

- <15 %
- 15 to 18%
- 18 to 20%
- 20 to 24%
- 24 % +
- Insufficient Data

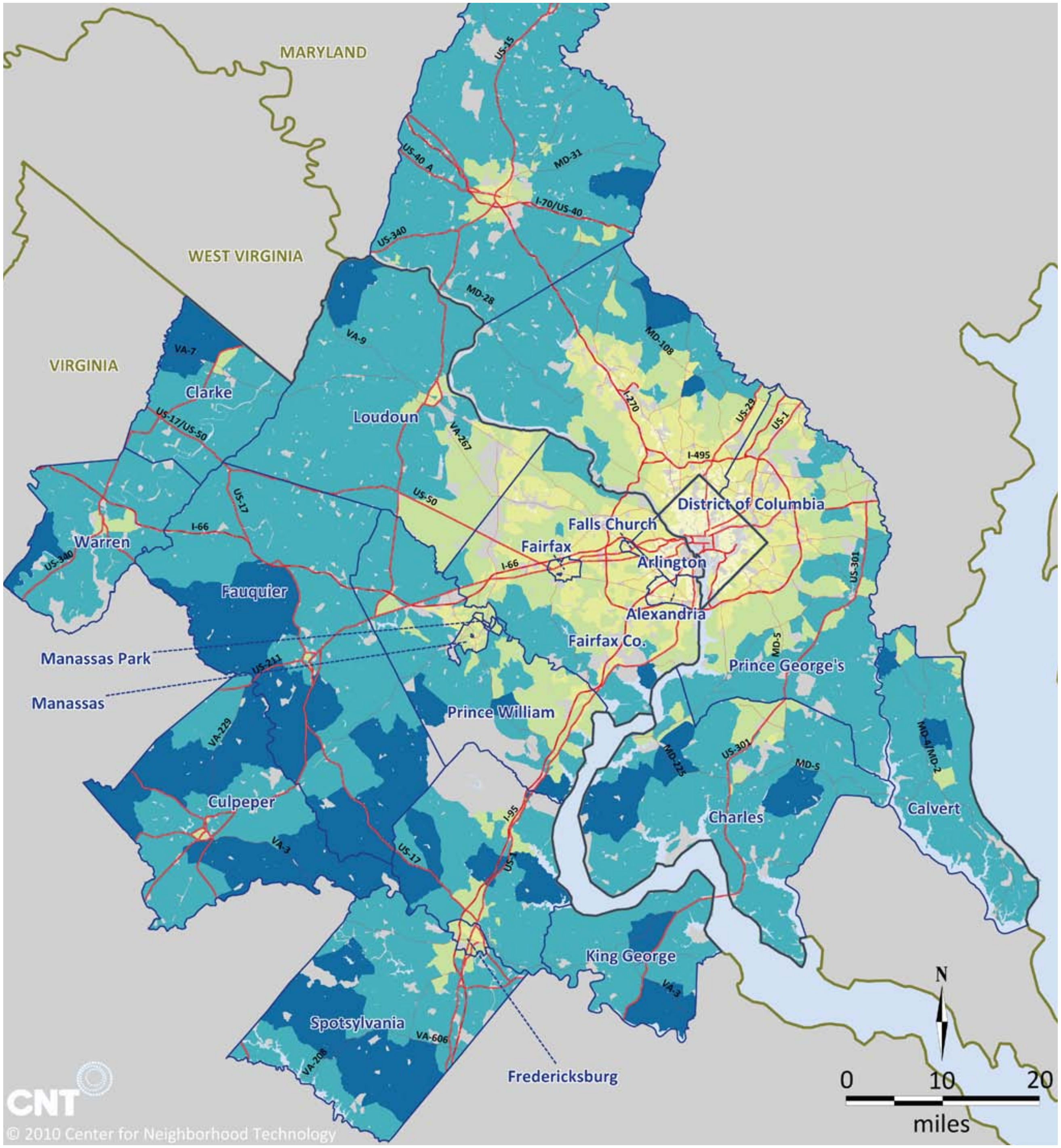
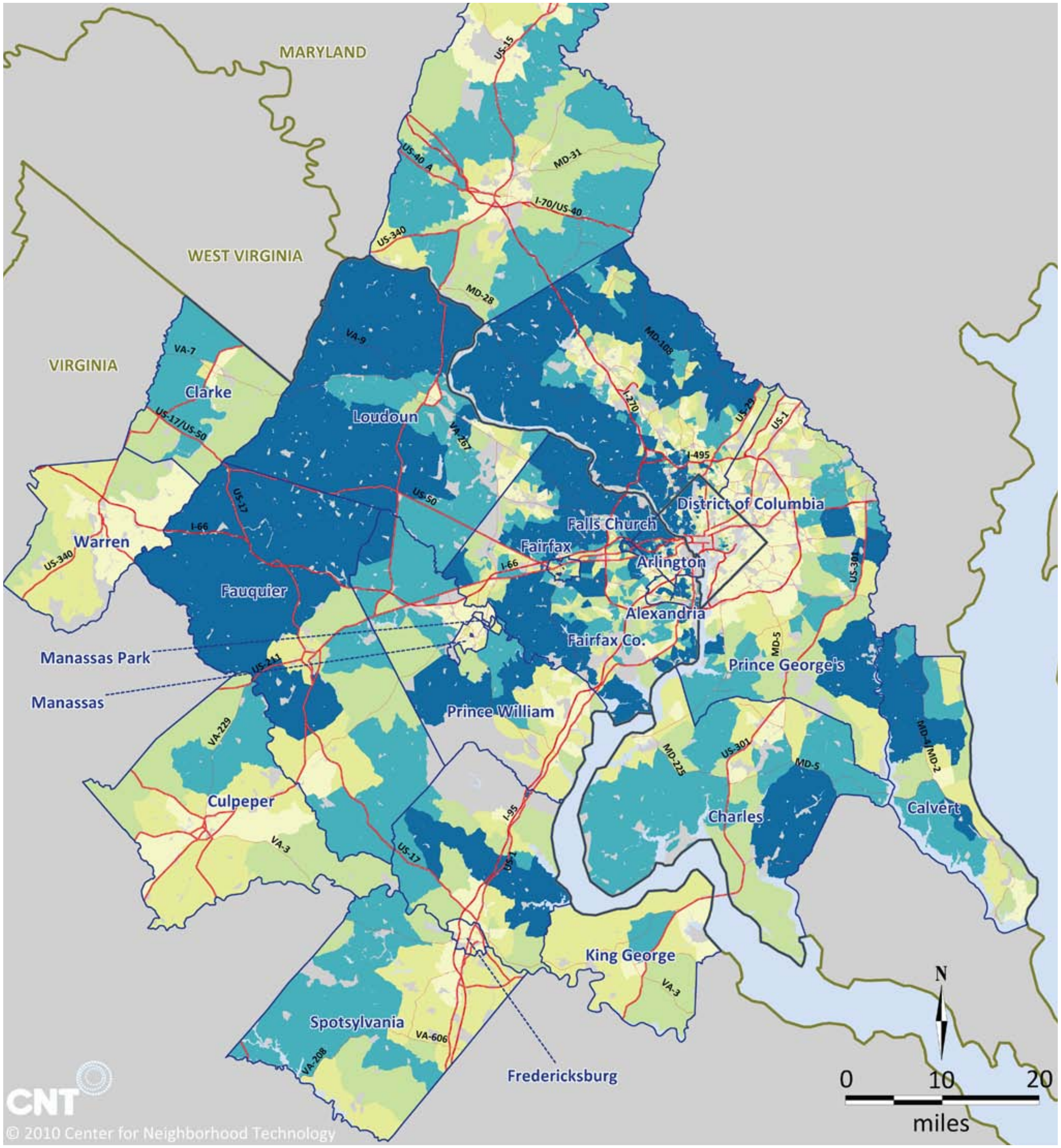


FIGURE 39
Average H+T costs as
a percentage of AMI

- < 40 %
- 40 to 45%
- 45 to 48%
- 48 to 55%
- 55 % +
- Insufficient Data



Location Efficiency and Concluding Remarks

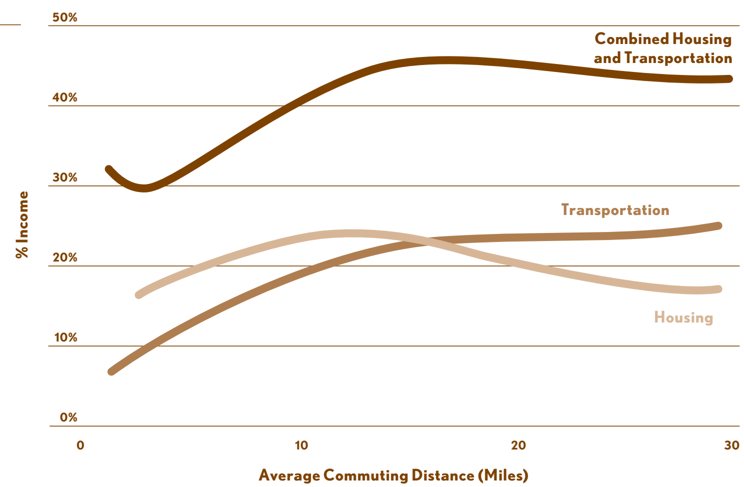


FIGURE 40
H+T cost burdens by commute distance

Source: *Beltway Burden: The Combined Cost of Housing and Transportation in the Greater Washington, DC, Metropolitan Area*

Impact of Varying Transportation Costs on the Cost of Living

This analysis shows that, to have a more complete understanding of their cost of living, households must understand their transportation costs and how these costs are intrinsically connected to location. Without full transparency of transportation costs, households can unexpectedly and unknowingly be putting themselves in a position of financial risk. By illuminating the full cost of location decisions, this work helps to put households in financial control.

Previous research on H+T costs in the greater Washington, DC, area[17] illustrates just how significant a burden transportation costs can be. As figure 40 shows, at an average commute distance of approximately 15–18 miles, average household transportation costs can actually exceed housing costs. At an average cost of nearly $5,600 per year, auto ownership is, by and large, the most significant component of these transportation costs. Areas far from job centers, with low density and little access to goods, services, or transit, leave residents largely dependent on automobiles to meet their daily needs. On the other hand, location-efficient neighborhoods, or compact, mixed-use communities in which residents can walk, bike, or use transit, enable households to get by with fewer automobiles and therefore experience significantly lower transportation costs.

17. *Beltway Burden: The Combined Cost of Housing and Transportation in the Greater Washington, DC, Metropolitan Area*, Urban Land Institute Terwilliger Center for Workforce Housing, 2009.

Implications for Future Growth

Future growth must be planned strategically. By taking into consideration H+T and the factors that impact transportation costs, communities have the potential to grow in a way that is both more location efficient and more affordable for their residents. Communities can increase affordability by targeting growth in location-efficient areas where households are not auto dependent. At the same time, considering the factors that make for location-efficient areas and expanding these characteristics elsewhere can also increase the number of affordable areas.

The District of Columbia can and should serve as a good example of this. While average housing costs are quite high in much of the District, and seemingly out of reach for many households, high location efficiency and low transportation costs can actually offset this expense in places, in terms of H+T costs. Expanding the definition of housing affordability to include the transportation costs of a given location will also be helpful to those coming to the region from other areas. First and foremost, the results of this study will help households understand that there is more to housing affordability than "drive 'til you qualify." This study helps them understand that transportation costs have a significant impact on their budget and will enable them to consider a broader range of housing choices to better suit their needs. Second, it provides actual estimates of transportation costs by neighborhood and an understanding of the neighborhood characteristics that affect transportation costs the most.

Finally, this report, combined with the knowledge that transportation costs in auto-dependent neighborhoods will only worsen with rising energy prices, reemphasizes the point that location efficiency of urban walkable neighborhoods (like many in the District), does not just reduce household costs now. The location efficiency of these neighborhoods also provides economic resilience to those households that live in them, enabling them to better accumulate wealth or weather future adversity—from a temporary rise in household costs (e.g., to assist an aging parent) to a nationwide recession.

14TH STREET
Photo by DC Office of Planning

Detailed Methods

14TH AND HARVARD
Photo by Mr. T in DC

Customizing the H+T Index for the Greater DC Area

This project utilized the H+T Index developed by CNT, and customized and recalibrated it to estimate housing and transportation costs in the Washington, DC metropolitan area. Calculations were done at the block group level using 2006–2008 American Community Survey (ACS) Public Use Microdata Area (PUMA) data in conjunction with 2000 US Census data.

Local Data

CNT's original H+T Index was developed to utilize nationally available datasets with the intention of covering metropolitan areas across the county. However, in previous work focusing on one area, it has been found that the addition of detailed local datasets as independent variables can help improve the fit, and therefore accuracy, of the regression analyses. To further expand existing H+T work in the DC region, the regression analyses were refined through the use of detailed datasets (described below) obtained from local agencies and organizations, along with national datasets, to serve as independent variables in the customized transportation model. Specifically, detailed land use data were incorporated, both to refine the measurement of residential density as well as to create a land-use diversity measure; more robust measures of transit access were also tested and incorporated.

Updated Data

The H+T Index has so far been developed to calculate combined housing and transportation costs using primarily 2000 US Census data. The data required to calculate H+T costs at the neighborhood level is currently only available at the Census block group level for the year 2000. The ACS data, while available in more recent years, is currently not available at the block group level. Therefore, a combination of the block group-level 2000 Census data and the 2006–2008 ACS data at the PUMA level was utilized.

To preserve the block group level analysis with the best available current data at the PUMA level, a constant-share ratio extrapolation method was utilized. Smith, Tayman and Swanson explain that "the smaller area's share of the larger area's population is held constant at some historical level. . . . A projection of the smaller area can then be made by applying this share to the projection of the larger area" (2002, p.177).[18] Specifically, variables at the PUMA level were assumed to maintain the same block group composition between 2000 and 2006–2008. In other words, if the population in a block group made up 5% of the population of the PUMA in 2000, it was assumed that the population of the same block group made up 5% of the population of the same PUMA in 2006–2008. Algebraically, this is equivalent to calculating the percent change for each PUMA between 2000 and 2006–2008 and multiplying each 2000 block group by the appropriate PUMA percent change to estimate the 2006–2008 value.

Market Rate Housing Costs

Another significant aspect to the customization of the Index was the incorporation of market rate housing costs. The original Index utilizes Selected Monthly Owner Costs and Gross Rent, both from the US Census, to estimate housing costs. However, because Selected Monthly Owner Costs represent the average costs for all households with a mortgage, regardless of the age of the mortgage, these values can diminish recent housing trends.

To capture more recent trends in the housing market, multiple listing service (MLS) sales data were utilized to calculate average ownership costs for each census tract for which data were available.

Updated values (using the 2000 Census and the 2006–2008 ACS) for Gross Rent were utilized to capture renting costs.

RENTER COSTS

American Community Survey 3-Year Estimates 2006–2008:

Gross Rent—Universe: Renter-occupied housing units; used to define count of renter-occupied housing units with cash rent.

Aggregate Gross Rent—Universe: Renter-occupied housing units paying cash rent

Average gross rent is calculated for every PUMA necessary to cover the study area. Seven PUMAs had no data available for Gross Rent, and therefore no count of renter-occupied housing units paying cash rent, even though an aggregate value was available in Aggregate Gross Rent. Therefore, a weighted average ratio of renter-occupied housing units with cash rent to total renter-occupied housing units was obtained by state from the PUMAs for which the data were available. This ratio was then applied in the seven PUMAs without data to estimate the count of renter-occupied housing units paying cash rent from the total count of renter-occupied housing units.

Census 2000 SF3:

Gross Rent—Universe: Specified renter-occupied housing units; used to define count of specified renter-occupied housing units with cash rent.

Aggregate Gross Rent—Universe: Specified renter-occupied housing units paying cash rent

Average gross rent was calculated for every block group necessary to have equal coverage to the PUMAs utilized. These block group level values were then aggregated through weighted averages to the PUMA geographies.

PUMA level values for Average Gross Rent 2000 and Average Gross Rent 2006–2008 were then compared and percent changes were calculated for each PUMA. Every block group was then assigned a percent change value from the PUMA it is contained within, and the Average Gross Rent 2000 values were scaled up to 2006–2008 using this change.

18. Smith, Tayman and Swanson. 2002. *State and Local Population Projections: Methodology and Analysis.* Kluwer Academic/ Plenum Publishers, New York.

OWNERSHIP COSTS

Ownership costs were estimated using MLS sales data, both for average monthly mortgage payments and property tax payments. First, sales point data were geocoded and located in Census tracts, and tracts were filtered requiring a minimum sample size of five sales in the 2006–2008 time period (as to be consistent with the transportation model). Average sale prices were calculated for every Census tract that met this criterion. Average sales prices were converted to monthly mortgage payments by assuming a 20% down payment and 6% interest rate. Because property tax data had more limited availability, monthly property taxes and average home prices were compared at the jurisdiction level to estimate the tax rate. This rate was then applied to the individual Census tract average home prices to calculate the average property tax payments. Average monthly mortgage payments were summed with average property taxes, and each block group was estimated to have the average monthly ownership costs of the tract containing it.

WEIGHTED AVERAGE HOUSING COSTS

Using the ownership and renter costs detailed above, weighted average housing costs were calculated for each Census block group as:

$$\frac{(\text{Avg. Costs}_{\text{Owners}} \text{ x } \text{Owners}_{\text{Occupied Housing Units}}) + (\text{Avg. Costs}_{\text{Renters}} \text{ x } \text{Renters}_{\text{Occupied Housing Units}})}{\text{Owners}_{\text{Occupied Housing Units}} + \text{Renters}_{\text{Occupied Housing Units}}}$$

Transportation Model Development

General Structure

Household transportation costs, while defined in many different ways, are typically composed of auto ownership costs, auto usage costs, and public transit costs. The Bureau of Labor Statistics, in their Consumer Expenditure Survey Annual Expenditure tables, present total transportation costs as composed of vehicle purchases, gasoline, motor oil, finance charges, maintenance, repairs, insurance, rentals, leases, licenses and other charges, and public transportation. In their annual *Your Driving Costs* reports, AAA uses a proprietary methodological process to compile the annual cost of auto ownership. Their ownership costs are composed of fuel, maintenance, tires, insurance, license, registration and taxes, depreciation, and finance charges. The Federal Highway Administration (FHWA), citing Intellichoice's *The Complete Car Cost Guide and Complete Small Truck Guide,* reports figures on the cost of owning and operating automobiles, vans and light trucks. These estimates are based on the annual average costs over five years, assuming 70,000 miles driven, and include depreciation, insurance, financing, fuel cost, maintenance, state fees, and repairs.

The transportation model developed for the H+T Index has been constructed to estimate auto ownership per household, vehicle miles traveled per household, and public transit use, to which cost components are multiplied.

Auto ownership costs, for the purposes of this research, were defined as depreciation, finance charges, insurance, license, registration, and taxes (state fees). These costs were chosen as ownership costs, as they are deemed largely fixed (i.e., less determined by use), and therefore a result of simply owning an automobile.

Auto use costs, for the purposes of this research, were defined as gas, maintenance, and repairs. These costs were chosen as use costs as they are largely variable and determined primarily by the level of use of the automobile.

It should be noted that the study does not include parking costs as part of either auto ownership or use, due to the variation in cost by location and a lack of data that makes accurate classification impossible. For instance, parking in dense urban areas, for both residents and commuters driving in from the suburbs, can cost up to $300 per month. In the case of residents parking, this would be classified as an ownership cost; in the case of commuters parking, it would be classified as a use cost.

Transit costs factor the average cost of transit use per household using a regional average price as derived from the National Transit Database (details follow in Cost Components section).

To develop the model, a non-linear regression analysis was conducted for each of the three dependent variables in which the set of independent variables was tested to determine their significance in describing the variation observed in each dependent variable. A set of formulae was then created equating the appropriate variables.

As an example, a histogram of the block group level autos per household for the District (as derived from the 2000 US Census), with frequency representing the count of block groups, shows the mean value and distribution of the data (fig. 41). This shows that block group average values for autos per household range from approximately 0.1 to 2.3, with a mean value of 0.96 autos per household in DC.

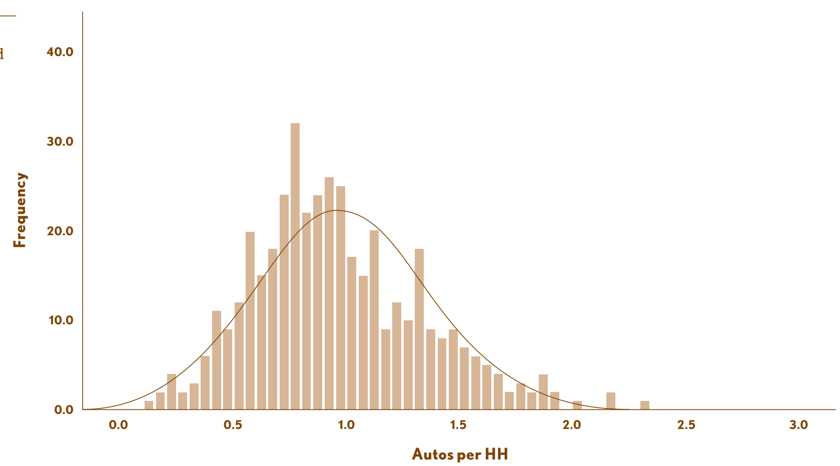


FIGURE 41
Histogram of autos per household by census block group in DC (2000 US census)

Mean = .96114546
Std. Dev. = .378763385
N = 422

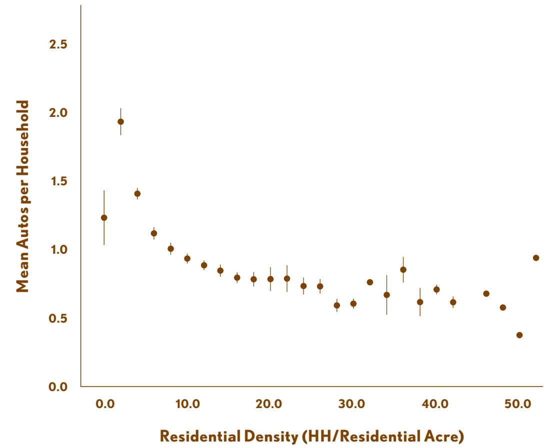


FIGURE 42
Average autos per household plotted relative to residential density

To explain the variation in average autos per household, the correlation of several independent variables were tested. Figure 42 shows the relationship between average autos per household and residential density as an example. A regression was run to fit a curve describing the relationship between the dependent (autos per household) and independent (residential density) variables. In a perfect regression (one in which all variation has been described), the modeled data perfectly replicate the measured data. To assess the goodness of fit, residual values (measured data minus modeled data) were considered. If all of the variation has been described, the plot of residual values versus the independent variable will be flat (fig. 43). An ANOVA (analysis of variance) indicated that an R-squared value of 0.437 was achieved in this example, meaning that 43.7% of the variation observed in auto per household can be described by residential density (table 9).

This example indicated that some variation persisted and that the dependent variable of autos per household was not solely a function of the independent variable of residential density. Therefore, this process was repeated and additional independent variables were tested and incorporated into the fit. The model was expanded until the addition of new independent variables no longer significantly improved the R-squared value.

FIGURE 43
Residual values versus independent residential density variable

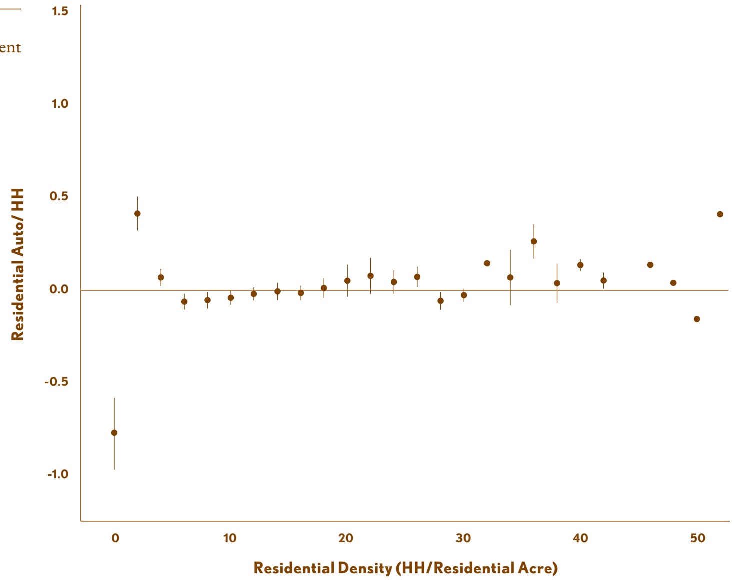


TABLE 9
Analysis of variance between measured and modeled data for autos per household, as fit for residential density

Source	Sum of Squares	df	Mean Squares
Regression	**416.241**	**3**	**138.747**
Residual	**34.000**	**419**	**.081**
Uncorrected Total	**450.241**	**422**	
Corrected Total	**60.397**	**421**	

ANOVA[A]
Dependent Variable: Autos per HH
a. R-squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .437

Dependent Variables—Measured Data

AUTOS PER HOUSEHOLD

For the dependent variable of auto ownership, the regression analysis was fit using measured data on auto ownership obtained from the 2000 US Census and the 2006–2008 American Community Survey. As described above, the constant share method was applied to the two datasets to estimate block group level values representing 2006–2008. Aggregate Number of Vehicles Available by Tenure defined the total number of vehicles, and Tenure defined the universe of Occupied Housing Units. Average vehicles per occupied housing unit were calculated.

AUTO USE

Auto use was measured as vehicle miles traveled (VMT) per automobile. In order to determine the amount that households drive their autos, odometer readings were utilized. Data were obtained for one region of the country, the optimum formula was determined using the independent variables in that region, and these formulae were then applied to the study area. Odometer readings for the time period of 2005–2007 were obtained from the Massachusetts Department of Transportation for the entire state at a 250-meter grid cell level. A similar dataset for the greater Chicago area was analyzed at the zip code level and compared with the Massachusetts dataset resulting in similar relationships with the independent variables. Due to the geographic scale of the Massachusetts dataset, the regression analysis was fit using these data.

PUBLIC TRANSIT USE

Because no direct measure of transit use was available at the block group level, a proxy was utilized for the measured data representing the dependent variable of transit use. Again from the 2000 US Census and the 2006–2008 American Community Survey, Means of Transportation to Work was used to calculate a percentage of commuters utilizing public transit.

Independent Variables

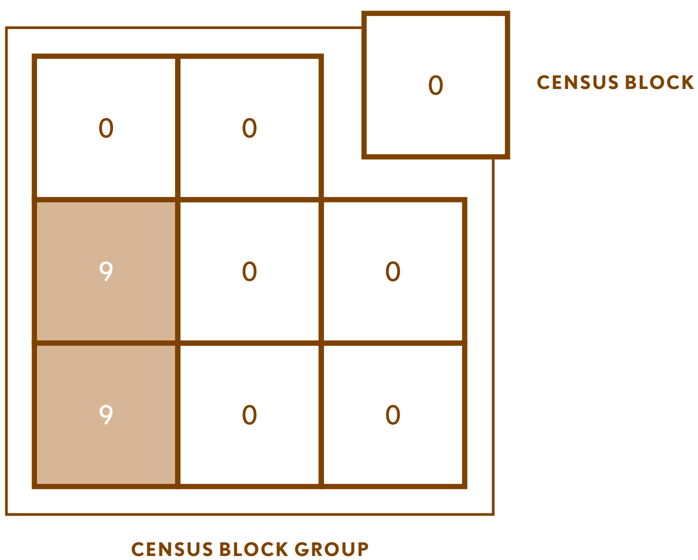
Literature and previous research revealed many potential independent variables significant in explaining the variation observed in auto ownership, auto use, and public transit use. The following variables representing both neighborhood and household characteristics were tested and utilized where appropriate. Independent variables were fit one at a time, starting with the one that appeared to have the strongest correlation with the given dependent variable. After the first independent variable was fit, the remaining independent variables were plotted with the resulting residual values. The independent variable that appeared to have the strongest correlation with the residual values was added second. This process was repeated with all independent variables, and only those that improved the fit were kept in the final fit.

As discussed above, it has been found that the addition of detailed local datasets as independent variables can help improve the fit, and therefore accuracy, of the regression analyses. However, because these data were obtained from various local agencies, geographic coverage of the datasets varied. Therefore, two separate sets of regression analyses needed to be constructed: The General, Full Region model (the General Model) for the full study area,[19] fit utilizing the standard independent variables; and the Refined, Small Region Model (the Refined Model) for a smaller geography,[20] refined through the incorporation of the local datasets. The General Model is used throughout this report, while the Refined Model is only addressed when explicitly discussing the differences between the two models.

FIGURE 44
Calculating gross and residential density at the block group level

GROSS DENSITY
2 UNITS/ACRE

RESIDENTIAL DENSITY
9 UNITS/ACRE



RESIDENTIAL DENSITY

Residential density represents household density of residential areas, in contrast to population density on land area. Our research has shown that by isolating residential land, residential density correlates more strongly with the dependent variables than a gross density measure of households per total land acres. As one method to identify and isolate residential land, total households were obtained at the Census block level. Only blocks that contain at least one household per land acre were deemed residential. To calculate residential density at the block group level, total households and land acres of these selected residential blocks were aggregated to the block group, at which level households were divided by total residential acres (figure 44 illustrates this graphically).

RESIDENTIAL DENSITY WITH LAND USE DATA

Another method of calculating residential density was accomplished through the use of detailed land use data. Land use data, in the most accurate and detailed form available, was collected for all jurisdictions in the Refined Model study area (see table 10). Any land use classification that could contain housing (e.g., mixed use) was identified as residential, and the acreage was aggregated to the block group level. Total households in a block group, divided by this measure of residential acreage, estimated the block group residential density value.

19. The General Model's 23-jurisdiction study area comprises the District of Columbia; Calvert, Charles, Frederick, Montgomery, and Prince George's counties, MD; Arlington, Clarke, Culpeper, Fairfax, Fauquier, King George, Loudoun, Prince William, Spotsylvania, Stafford, and Warren counties, VA; and the cities of Alexandria, Fairfax, Falls Church, Fredericksburg, Manassas, and Manassas Park, VA.

20. The Refined Model's 8-jurisdiction study area comprises the District of Columbia; Montgomery and Prince George's counties, MD; Arlington and Fairfax counties, VA; and the cities of Alexandria, Fairfax, and Falls Church, VA. Jurisdictions were chosen based on the geographic extent of DC's transit network analysis.

TABLE 10
Land use data collected and type

Name	Type	State	Land Use Data
District of Columbia		**DC**	**Tax Record/Parcel and Land Use**
Montgomery	**County**	**MD**	**Land Use**
Prince George's	**County**	**MD**	**Land Use**
Arlington	**County**	**VA**	**Parcel Data and Zoning**
Fairfax	**County**	**VA**	**Land Use**
Alexandria	**City**	**VA**	**Parcel**
Fairfax	**City**	**VA**	**Zoning**
Falls Church	**City**	**VA**	**Land Use**

This method of defining residential acreage, and therefore residential density, was tested only in the Refined Model regression analyses.

GROSS DENSITY

While residential density has been found to correlate more strongly with the dependent variables, gross density (total households divided by total land acres) also correlates and has been found to improve the fit above and beyond residential density alone.

LAND USE DIVERSITY

A significant development in this research was the incorporation of land use data, both in defining residential acres as described above, but also in developing a measure of land use diversity. Other research has shown that the level of land use mix or diversity shows a significant correlation with auto ownership, auto use, and transit use. Increasing land use mix allows residents in neighborhoods to have more transportation choice in how they meet their daily needs.[21] There has been some work to show that having more diverse land use in a neighborhood manifests itself in reduced driving and auto ownership.[22] These assumptions were tested by examining some measures of land use diversity,[23] and by examining which measures best correlated with auto ownership, auto usage, and transit usage. To test this, various measures of land use diversity were constructed and tested.

To construct these measures, general land use types were first identified and consolidated between the various land-use datasets obtained from local agencies (see table 10). Thirteen general land use types were identified, as shown in table 11. These types were defined with the necessity that every land use classification provided in the original datasets must be classified into one of the thirteen types. Each dataset had its own version of unidentified land, which therefore required the creation of four classifications that were not used in the land use

TABLE 11
Land-use categories

	General Land Use Classification	Description
1	**Residential**	Residential land
2	**Commercial**	Commercial land, including mixed use when defined
3	**Industrial**	Industrial land
4	**Institutional**	Institutional land—universities, hospitals, government agencies, etc.
5	**Agriculture**	Agricultural land when defined
6	**Park**	Parks
7	**Water**	Open water
8	**TCU**	Transportation, communication and utilities
9	**Open**	Open land—forests, beaches, other non-park open space
10	**Other**	These three categories were defined by the different data providers; we assume these are undefined, and keep them as separate categories
11	**Unknown**	
12	**NA**	
13	**Acres left over**	Calculated land area in Census block groups that is not defined

21. Evaluating Transportation Land Use Impacts: http://www.vtpi.org/landuse.pdf
22. For some examples see the article "Land Use Impacts on Transport, How Land Use Patterns Affect Travel Behavior" in the TDM Encyclopedia http://www.vtpi.org/tdm/tdm20.htm#_Toc119886791
23. Robert Cervero, et al (2004), *Transit-Oriented Development in the United States: Experience, Challenges, and Prospects*, Transit Cooperative Research Program, Transportation Research Board (http://gulliver.trb.org/publications/tcrp/tcrp_rpt_102.pdf).

diversity measures: other, unknown, NA, and acres left over. Each land-use dataset was modified to fit within this structure.

Utilizing these thirteen land use types, three basic forms of land-use diversity measures were considered: percent residential, Herfindahl-Hirschman indices, and entropy indices.[24] These measures were considered both directly within each block group as well as using a gravity measure to diminish the modifiable areal unit problem (or MAUP).[25] The definition of gravity, for the purposes of this study, is:

$$G \equiv \sum_{i=1}^{n} \frac{p_i}{r_i^2}$$

Where G is the gravity measure itself, n is the total number of measurements, P_i is the statistic (e.g., acres of residential land), and r_i is the distance from the given Census block group to the center of the grid cell. For this study we used a grid cell of 250m by 250m and measured the land use within each cell.

The measures shown in table 12 were calculated and tested, both as raw number values within the block groups, as well as by using a gravity measure as stated above. The definitions of the land use classifications as they pertain to Levels 2, 3, 4 and 6 of both the Herfindahl-Hirschman indices and the entropy indices are defined in table 13. As with the overall regression methods, the measures that correlated best and provided the greatest marginal improvement to the overall fits were included.

These methods of defining land use diversity were tested only in the Refined Model regression analyses.

TABLE 12
Land-use diversity measures

Measure	Elements
Percent Residential	Residential
HH 2	Residential, Non-residential
HH 3	Residential, Employment, Non-residential-employment
HH 4	Residential, Employment, Park, Not-intense
HH 6	Residential, Commercial, Industrial, Institutional park, Not-intense
Entropy 2	Residential, Non-residential
Entropy 3	Residential, Employment, Non-residential-employment
Entropy 4	Residential, Employment, Park, Not-intense
Entropy 6	Residential, Commercial, Industrial, Institutional park, Not-intense

AVERAGE BLOCK SIZE

The average block size in an area was used to represent street connectivity and pedestrian friendliness, which influences travel mode and distance traveled. Greater connectivity, from more streets and intersections, creates smaller blocks, and tends to lead to more frequent walking and biking trips, as well as shorter average trips. Census TIGER/Line files were utilized to calculate average block size (in acres) as the total block group area divided by the number of Census blocks within the block group. This measure is similar to intersection density, another commonly used indicator of walkability.

TRANSIT CONNECTIVITY INDEX

The significance of transit service levels were measured through the use of the Transit Connectivity Index (TCI), an index developed by CNT. The availability of local datasets is critical for this transit measure. In previous iterations of the transportation model, data have not been available to incorporate all regional bus routes and the frequency of service in the DC area. These data were obtained for

24. Yan Song and Daniel A. Rodriguez, "The Measurement of the Level of Mixed Land Use: A Synthetic Approach." From: http://planningandactivity.unc.edu/RP3.htm
25. Ibid.

TABLE 13
Definition of land-use grouping

	General Land Use Classification	Level 2	Level 3	Level 4	Level 6
1	**Residential**	Residential	Residential	Residential	Residential
2	**Commercial**	Non-Residential	Employment	Employment	Commercial
3	**Industrial**				Industrial
4	**Institutional**				Institutional
5	**Agriculture**		Non-Residential-Employment	Not-Intense	Not-Intense
6	**Park**			Park	Park
7	**Water**			Not-Intense	Not-Intense
8	**TCU**				
9	**Open**				
10	**Other**				
11	**Unknown**				
12	**NA**				
13	**Acres left over**				

use in this study. In the TCI, transit service levels were calculated as the number of bus routes and train stations within walking distance (¼ mile and ½ mile, respectively) for households in a given block group scaled by the frequency of service. The index value therefore represents the average rides per week available to households in a given block group.

DC OP'S TRANSIT NETWORK ANALYSIS

Another measure by which to evaluate transit accessibility was provided and modeled by the DC Office of Planning (OP). A transit network analysis model was developed to model the distance that can be traveled in 30 minutes through walking and transit. Using this model in conjunction with the land use classifications (see table 11), OP estimated the total acreage of each land use type accessible by transit and walking from the center of each block group in the study area.

These modeled results were utilized to create two distinct measures of accessibility: the total acreage of each land use type as well as the sum of all types accessible; and, of the total acreage accessible, the fraction of each land use type. Again, as with the land use diversity measures, the transit network analysis measures that correlated best and provided the greatest marginal improvement to the overall fits were included.

These methods of measuring transit access, as provided by the DC Office of Planning, were only tested and incorporated in the Refined Model regression analyses.

EMPLOYMENT ACCESS

Proximity to regional employment was determined using a gravity model, which considered both the quantity of and distance to all such destinations, relative to any given block group. Using an inverse-square law, an employment index was calculated by summing the total number of jobs divided by the square of the distance to those jobs. This quantity allowed examination of both the existence of jobs and the accessibility of these jobs for a given census block group. Because a gravity model enables consideration of jobs both directly and not directly in a given block group, the employment access index gave a better measure of job opportunity, and thus a better understanding of job access than a simple employment density measure.

To calculate the employment access index, data pertaining to the locations of all jobs in a region were obtained from the 2000 Census Transportation Planning Products (CTPP). The index was calculated as:

$$E \equiv \sum_{i=1}^{n} \frac{p_i}{r_i^2}$$

Where E is the employment access for a given Census block group, n is the total number of census tracts in the region, P_i is the number of jobs in the ith Census tract, and r_i is the distance (in miles) from the center of the given census block group to the center of the ith Census tract.

AVERAGE JOURNEY TO WORK TIME

Average journey to work time was calculated using the Census Bureau series Aggregate Travel Time to Work (in minutes) by Travel Time to Work by Means of Transportation to Work, and Means of Transportation to Work, to define the universe of Workers 16 Years and Over Who Did Not Work at Home, again from the 2000 US Census and the 2006–2008 ACS. Average journey to work time was calculated at the block group level in minutes.

MEDIAN HOUSEHOLD INCOME

Median household income was obtained from the 2000 US Census and the 2006–2008 ACS.

AVERAGE HOUSEHOLD SIZE

Average household size was obtained from the 2000 US Census and the 2006–2008 ACS. Total Population in Occupied Housing Units by Tenure was utilized in conjunction with Tenure, which was used to define the universe of occupied housing units.

AVERAGE COMMUTERS PER HOUSEHOLD

Average commuters per household was calculated using the figures for Total Workers 16 Years and Over Who Do Not Work at Home from Means of Transportation to Work, and Tenure to define occupied housing units. Because Means of Transportation to Work includes workers not living in occupied housing units (i.e., those living in group quarters), the ratio of Total Population in Occupied Housing Units to Total Population was used to scale the count of commuters to better represent those living in households. Again, all data were obtained from the 2000 US Census and the 2006–2008 ACS.

CONTROLLING FOR HOUSEHOLD VARIATION

Because the model was constructed to estimate the three dependent variables (auto ownership, auto use, and transit use) as functions of independent variables, any set of independent variables can be altered to see how the outputs are affected. As a way to focus on the built environment, the independent household variables (income, household size, and commuters per household) were set at fixed values. This controlled for any variation in the dependent variables that was a function of household characteristics, leaving the remaining variation a sole function of the built environment. In other words, by establishing and running the model for a "typical household," any variation observed in transportation costs is due to place and location, not household characteristics.

To define the values on which these three parameters were fixed (household income, household size, and commuters per household), block group level values were averaged for the full region study area ($87,623, 2.65, and 1.37 respectively). Therefore, for the purposes of this study, the reported "AMI" represents the regional average of block group level household median income values.

Cost Components

As discussed above, the predicted results from each model were multiplied by the appropriate price for each unit—autos, miles, and transit trips—to obtain the cost of that aspect of transportation. This is summarized as follows:

$$\text{Household T Costs} = [C_{AO}{*}F_{AO}(X)] + [C_{AU}{*}F_{AU}(X)] + [C_{TU}{*}F_{TU}(X)]$$

Where $C \equiv$ cost factor (e.g., dollars per mile) and $F \equiv$ function of the independent variables, X.

AUTO OWNERSHIP COSTS

Year	Ownership Costs
2006	$5,569
2007	$5,648
2008	$5,576
Average	**$5,598**

TABLE 14
AAA *Your Driving Costs*: average annual ownership costs

AUTO USE COSTS

TABLE 15
AAA *Your Driving Costs*: average annual operating costs (minus gasoline costs) in cents per mile

Year	Maintenance	Tires	Total
2006	**4.9¢**	**0.7¢**	**5.6¢**
2007	**4.9¢**	**0.7¢**	**5.6¢**
2008	**4.57¢**	**0.72¢**	**5.29¢**
Average			**5.50¢**

TABLE 16
EIA: Central Atlantic (PADD 1B) regular all formulations retail gasoline prices (MG_RT_1B)

Year	Gasoline Cost per Gallon
2006	**261.8¢**
2007	**279.0¢**
2008	**327.1¢**
Average	**289.3¢**
Assumed Fuel Efficiency 20.3 mpg	**14.25¢ per mile**
Total 2006–08 Average Operating Costs	**19.75¢ per mile**

TRANSIT USE COSTS

To identify transit use costs, the National Transit Database (NTD) was used to identify the total farebox revenue from transit agencies. The total revenue for all agencies serving the DC region was aggregated to the urbanized area, as that is the geography that the NTD uses to report its data. The urbanized area was brought into GIS and the data were proportionally summed to the study area included in this analysis. The proportion of the total transit commuters in the urbanized area was used to estimate the total transit revenue within the urbanized area. Once that amount was assigned to the urbanized area, the total revenue was divided by the total transit commuters to come up with an average fare per transit commuter. Thus, the total expenditure for transit for all the households in the urbanized area is equal to the farebox revenue for all of the transit agencies that serve the region.

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