**H+T INDEX**

The Center for Neighborhood Technology’s Housing + Transportation (H+T®) Affordability Index is an innovative tool that measures the true affordability of housing by calculating the transportation costs associated with a home’s location. Planners, lenders, and most consumers traditionally measure housing affordability as 30 percent or less of income. The H+T Index proposes expanding the definition of housing affordability to include transportation costs to better reflect the true cost of households’ location choices. Based on research in metro areas ranging from large cities with extensive transit to small metro areas with extremely limited transit options, CNT has found 15 percent of income to be an attainable goal for transportation affordability. By combining this 15 percent level with the 30 percent housing affordability standard, the H+T Index recommends a new view of affordability, one defined as combined housing and transportation costs consuming no more than 45 percent of household income.

The H+T Index was constructed to estimate three dependent variables (auto ownership, auto use, and transit use) as functions of 11 independent variables (median income, per capita income, average household size, average commuters per household, residential density, gross density, average block size, intersection density, transit connectivity, transit access shed, and employment access). To hone in on the built environment’s influence on transportation costs, the independent household variables (income, household size, and commuters per household) are set at fixed values to control for any variation they might cause. By establishing and running the model for a “typical household,” (one defined as earning the regional area median income, having the regional average household size, and having the regional average number of commuters per household) any variation observed in transportation costs is due to place and location, not household characteristics.

See below for detailed information on the H+T Index methods.

**Geographic Level and Data Availability**

The H+T Index was constructed at the Census block group level. The H+T Index currently covers the Metropolitan and Micropolitan Areas in the United States, or the Core Based Statistical Areas (CBSAs), as defined by the Office of Management and Budget (OMB). The 2009 American Community Survey 5-year estimates serve as the primary dataset, thereby dictating the use of the 953 CBSAs as defined in 2008.

However, due to data limitations, multiple CBSAs were excluded from the Index. Due to incompatible and insufficient data, all regions in Puerto Rico (13) were excluded. Also, in 19 counties in eight states, the Census identified geographic code and definition problems, making block groups within these counties unusable (http://www.census.gov/acs/www/data_documentation/2009_geography_release_notes/). This resulted in the exclusion of four CBSAs where no usable data were available.

Data availability due to data suppression also presented difficulties. Regions where necessary variables were available for less than 80 percent of the regional households were also excluded. This resulted in the exclusion of 59 CBSAs.
In total, 76 regions were excluded due to data limitations, bringing the total Index coverage from 953 to 877 regions.

**Housing Costs**

To calculate the H in the H+T Index, housing costs are derived directly from nationally available datasets. Median Selected Monthly Owner Costs and Median Gross Rent, both from the 2009 American Community Survey 5-year Estimates (ACS), are averaged and weighted by the ratio of owner- to renter-occupied housing units from the Tenure variable for every block group in the 877 CBSAs.

**Transportation Cost Model**

While housing costs are derived directly from ACS data, transportation costs, the T in the H+T Index, are modeled as three components of transportation behavior—auto ownership, auto use, and transit use—which are combined to estimate the cost of transportation.

**Basic Structure**

The household transportation model is based on a multidimensional regression analysis, in which formulae describe the relationships between three dependent variables (auto ownership, auto use, and transit use) and independent household and local environment variables. Neighborhood level (Census block group) data on household income (both median and per capita), household size, commuters per household, household density (both residential and gross), street connectivity (as measured using average block size and intersection density), transit access, and employment access were utilized as the independent or predictor variables.

To construct the regression equations, each predictor variable was tested separately: first to determine the distribution of the sample and second to test the strength of the relationship to the criterion variables. For this research, the regression analysis was conducted in a comprehensive way, thus ignoring the distinction between the local environment variables and the household variables in order to obtain the best fit possible from all of the independent variables. The predicted result from each model was multiplied by the appropriate price for each unit—autos, miles, and transit trips—to obtain the cost of that aspect of transportation. Total transportation costs were calculated as the sum of the three cost components as follows:

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

Where
- \(C\) = cost factor (i.e. dollars per mile)
- \(F\) = function of the independent variables (\(F_{AO}\) is auto ownership, \(F_{AU}\) is auto use, and \(F_{TU}\) is transit use)
INDEPENDENT VARIABLES: NEIGHBORHOOD CHARACTERISTICS
The 2009 American Community Survey 5-year estimates (ACS) at the block group level serve as the primary data source for the independent variables.

Household Density
Household density has been found to be one of the largest factors in explaining the variation in all three dependent variables. Various definitions of density have been constructed and tested, and the following two are utilized in the final transportation models.

Residential Density:
Residential Density represents household density of residential areas, in contrast to population density on land area. Total households are obtained at the block level from the 2010 US Census, and TIGER/Line files are used to define blocks. Blocks are selected on the criteria that gross density (households per land acre) must be greater than one. From these selected blocks, land acres are aggregated to calculate the total acres of residential blocks at the block group level. The count of households from the ACS is then scaled by the ratio of households in residential blocks to total households, and is then divided by the residential land area to calculate the block group level residential density.

Gross Density:
Gross Density is calculated as total households (from the ACS) divided by total land acres (as calculated using TIGER/Line files).

Street Connectivity and Walkability
Measures of street connectivity have been found to be good proxies for pedestrian friendliness and walkability. Greater connectivity created from numerous streets and intersections creates smaller blocks and tends to lead to more frequent walking and biking trips, as well as shorter average trips. While other factors clearly have an impact on the pedestrian environment (e.g., crime), two measures of street connectivity have been found to be important drivers of auto ownership, auto use, and transit use.

Average Block Size:
Census TIGER/Line files are used to calculate average block size (in acres) as the total block group land area divided by the number of blocks within the block group.

Intersection Density:
To determine intersection density, Census TIGER/Line files are used to identify every street intersection. All streets in the TIGER/Line files are included (e.g., alleys, interstates, etc.). For each block group, the sum of all intersections (including those on the borders) is calculated and divided by the total land area of the block group.
Transit Access
Transit access is measured through General Transit Feed Specification (GTFS) data collected and created by CNT. In addition to the publicly available GTFS data provided by a small number of transit agencies, CNT has created GTFS structured datasets utilizing online transit maps and schedules. In many cases, CNT has directly contacted transit agencies to obtain more specific information on stop locations and schedules. All GTFS data is merged into a proprietary dataset known as AllTransit™. AllTransit is an online tool that facilitates the collection, normalization, aggregation, and analysis of GTFS data to determine fixed-route transit service. To date, CNT has compiled station and stop data for bus, rail, and ferry service for more than 75 percent of all metropolitan and micropolitan areas in the country.

Transit Connectivity Index:
The Transit Connectivity Index (TCI) is a measure of transit access that CNT has developed specifically for use in this household transportation cost model.

To calculate this measure, a buffer was constructed around each transit access point (¼ mile radius for bus stops and ½ mile radius for rail stations and all other access points). Next, five concentric annuli were constructed, each with the width of the initial buffer. These six access areas were then assigned a service frequency value (total trips per week) for the transit access point they surround.

Next, at the block group level, six access values were calculated. These were calculated as:

\[
\frac{\text{land area of the access area intersecting the block group} \times \text{service frequency value} \times \text{weighting multiplier}}{\text{total block group land area}}
\]

The weighting multiplier identified in the above equation is calculated using regression analysis. Measured values of autos per household and percent journey to work by transit were each regressed against the six access values as defined above to obtain the optimal weighting multiplier for each. Therefore, two weighting multipliers are identified for each access area (one from the autos per household regression and one from the percent journey to work by transit regression). The rounded average of the two is used, and the six access values are summed for each block group in the final TCI calculation.

Transit Access Shed:
The Transit Access Shed is defined as the optimal accessible area from any block group within 30 minutes by public transportation scaled by the frequency of service. This measure was derived from the GTFS schedules discussed above. For each transit stop, all stops that can be reached within 30 minutes were identified. One transfer within 600 meters of a stop was allowed, and all transfers were padded with 10 minutes of walking and/or waiting. The stops reachable within 30 minutes were all based on the minimum travel time between the two stops, allowing the inclusion of more distant stops that are reachable within 30 minutes via express service. For each origination stop, a quarter mile buffer was created around the destination stops. Based on the location of the originating stop, the access shed was then aggregated for each stop to the block group and multiplied by the frequency of service (trips per week). Finally, the accessible area was derived and called the Transit Access Shed.
Employment Access Index

Employment numbers are calculated using OnTheMap Version 5 which provides Local Employment Dynamics (LED) data at the Census block level. These data are currently unavailable in New Hampshire, Massachusetts, and the District of Columbia. CNT created an alternative dataset for these areas using 2000 Census tract level data from the Census Transportation Planning Package (CTPP), scaled to 2007 using county level employment estimates from the Bureau of Labor Statistics (BLS). Utilizing a constant share method, the tract level variation from the 2000 CTPP data is preserved, while the 2007 county level BLS data enables updating to the appropriate time period. The estimates for New Hampshire, Massachusetts, and the District of Columbia are then combined with the more compressive LED data available for all other states.

The Employment Access Index was determined using a gravity model, which considered both the quantity of and distance to all employment 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 allows us to examine 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 gives a better measure of job opportunity, and thus a better understanding of job access than a simple employment density measure.

The Employment Access Index is 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 blocks, \( p_i \) is the number of jobs in the \( i^{th} \) Census block, and \( r_i \) is the distance (in miles) from the center of the given Census block group to the center or the \( i^{th} \) Census block.

Because it was not feasible to include all jobs nationally in the calculation of employment access, jobs within 63 mile radius of a given block group were included. This cutoff was used as it represents the 90th percentile of commute distances nationally in the LED data.
**INDEPENDENT VARIABLES: HOUSEHOLD CHARACTERISTICS**

The 2009 American Community Survey 5-year estimates (ACS) at the block group level serve as the primary data source for the independent variables pertaining to household characteristics.

**Household Income**
Median Income:
Median household income is obtained directly from the ACS.

Per Capita Income:
Per capita income was calculated as median household income divided by average household size.

**Average Household Size**
Average household size was calculated using Total Population in Occupied Housing Units by Tenure and Tenure to define the universe of Occupied Housing Units.

**Average Commuters per Household**
Average commuters per household was calculated using the 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.

**DEPENDENT VARIABLES**

**Auto Ownership**
For the dependent variable of auto ownership, the regression analysis was fit using measured data on auto ownership obtained from the ACS. 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 at the block group level.

**Auto Use**
For the dependent variable of auto use, the regression analysis was fit using measured data representing the total amount that households drive their autos, or vehicle miles traveled (VMT) per automobile. In order to determine the amount that households drive their autos, odometer readings were used. Odometer readings for 2005 through 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 findings. Due to the finer geographic scale of the Massachusetts dataset, the regression analysis is fit using these data.

**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. From the ACS, Means of Transportation to Work was used to calculate a percent of commuters utilizing public transit.
**Regression Analysis**

A rational function, a ratio of third order polynomials, was utilized as the functional form to regress each dependent variable:

\[
R(x) = \frac{a_1 x + a_2 x^2 + a_3 x^3}{1 + a_4 x + a_5 x^2 + a_6 x^3}
\]

Because the GTFS data used to calculate the independent variables of transit access were not available in all regions, two regressions were fit and two models constructed for each dependent variable: one for regions with transit data (669 regions) and one for all regions excluding transit data to be used in regions without data available (208 regions).

Due to small samples sizes in the ACS, many block groups have missing data for various variables. The regressions were fit only where all independent and the given dependent variable were available. The models were ultimately run everywhere all independent variables were available.

For the vehicle miles traveled regressions, due to limitations in measured data, the analyses were only conducted for the state of Massachusetts. The resulting coefficients or models were then run for all regions in the country.

**Transportation Cost Calculation**

As discussed, the transportation model in the H+T® Affordability Index estimates three components of travel behavior: auto ownership, auto use, and transit use. To calculate total transportation costs, each of these modeled outputs is multiplied by a cost per unit (e.g., cost per mile) and then summed to provide average values for each block group.

**Auto Ownership Costs**

The 2007 edition of the America Automobile Association’s (AAA) Your Driving Costs report serves as the basis for the auto ownership cost component. AAA reports an average ownership cost per year composed of full-coverage insurance, license, registration and taxes, depreciation, and finance charges.

**Auto Use Costs**

The 2007 Your Driving Costs report also serves as the basis for the auto use cost component. AAA reports an average operating cost per mile (composed of gas, maintenance, and tires). The gas component of AAA’s operating costs is subtracted and replaced with regional fuel costs from the Energy Information Administration (EIA) to account for regional variation in gas prices.

**Transit Use Costs**

The 2007 National Transit Database (NTD) served as the source for transit cost data. Specifically, directly operated and purchased transportation revenue were used (demand response revenue was not factored into this analysis). The transit revenue was assigned to each of the transit agencies where GTFS data were collected. The allocation of transit revenue to the metropolitan level was then based on the percentage of each transit agencies’ bus and rail stations within the primary versus surrounding metropolitan areas. For example, if a transit agency had a total of 500 bus stops and
425 of those stops were located in the primary metropolitan area and 75 stops extended into a neighboring metropolitan area, the primary metropolitan area received 85 percent of the transit revenue and the neighboring metropolitan area received 15 percent. The allocation of the transit revenue was then applied to the block group level based on the percentage of transit commutes and household commuter counts within each block group from the ACS, to estimate the average household transit costs.

There were a number of metropolitan areas for which GTFS data were not available and/or there was no revenue listed in the NTD. In these cases, the national transit cost average from the allocation calculation described in the previous paragraph was used for these metropolitan areas. The average transit costs were then allocated to the block group level based on the percentage of transit commutes and household commuter counts. The end result was an average household transit cost at the block group level.

**CONSTRUCTING AN INDEX**

Because the H+T Index 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 controls for any variation in the dependent variables that is 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,” (one defined as earning the regional area median income, having the regional average household size, and having the regional average number of commuters per household) any variation observed in transportation costs is due to place and location, not household characteristics.

**MODEL FINDINGS**

As discussed above, a rational function, a ratio of third order polynomials, was utilized as the functional form to regress each dependent variable:

\[ R(x) = \frac{a_1 \times x + a_2 \times x^2 + a_3 \times x^3}{1 + a_4 \times x + a_5 \times x^2 + a_6 \times x^3} \]

Each independent variable was normalized by a factor of 10 to eliminate very large and small values, and Table 1 below shows the coefficients, normalization values, and resulting R-squared values from each of the six regression analyses.
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<th>Autos per Household Coefficient Value (fit without transit data)</th>
<th>Percent Transit Commutes Coefficient Value (fit including transit data)</th>
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