Estimating Transportation Costs by Characteristics of Neighborhood and Household

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Since information on U.S. household expenditures was first collected, transport expenditures have risen from the sixth-highest share of household budgets, less than 2%, in 1917 to the second-highest share since the 1970s. This rise is linked to increased automobile purchase and automobile use and a relative decline in other costs, particularly food. Studies have also linked variations in the built environment to transport expenditures, but this influence cannot be tested by the federal Consumer Expenditure Survey since it is reported at the metropolitan level. Regional travel demand models recognize the dual influence of land use and household characteristics but do not include sufficient detail on the built environment of neighborhoods. Additionally, these models report travel time, distance, and frequency but not out-of-pocket household transportation expenditures. A study was launched to create a statistical model to predict household total annual transportation expenditures for each neighborhood in the largest metropolitan regions in the United States, controlling for the built environment and household size and income. The model specifies five independent variables—density, jobs access, neighborhood services, walkability, and transit connectivity. Model parameters were calibrated to measured vehicle ownership and transit use in the pilot region, Minneapolis–St. Paul, Minnesota, and to vehicle miles traveled by households at the block group level in the National Household Travel Survey. Statistically significant results confirm the influence of the built environment and regional accessibility on transport expenditures. Intended users are households, policy makers, and planners making location, design, and investment decisions.

This paper documents the development of a three-part model to predict a household's total transportation expenditures for a given household size and income at the neighborhood level for the largest regions in the United States. The three components predict how many automobiles a household will own, how many miles each automobile will be driven, and the number of annual transit trips the household will take. Prices for automobile ownership, automobile use, and transit use can then be applied to each output to obtain the total annual household transportation expenditure. The pilot model, based on Minneapolis–St. Paul, Minnesota, data in 2000, is documented here. In 2007, the model was adjusted and applied to 51 other regions (*1*).

Since the 1970s, U.S. expenditure surveys show that household transportation expenditures are a significant share of total household expenditures, second only to housing outlays (*2, 3*). Although the survey has documented fairly consistent shares for transportation, from 18% to 19% on average since 1985, the shares are not necessarily static. In 1920, for example, food costs were 41%, housing 27%, and transportation just 3%, whereas in 2005, food was 16%, housing 35%, and transportation ranged from 15% to 25%, depending on the size and income of the consumer unit, how many vehicles owned, how much spent on vehicle maintenance, how much transit purchased, and the region in which they lived. In the near future, transportation may increase drastically as costs rise more quickly than wages (*4, 5*); the cost of gasoline (*6*) and autos is rising along with the number of trips and trip lengths, whereas wages have remained flat or have declined.

Policies to reduce transportation costs for households have largely focused on lowering gas prices; however, creating transportation alternatives and the land uses and built environment that support them would be an additional and effective strategy for lowering total transportation costs since gasoline and motor oil are only 16% of total transportation expenditures (*2, 4*). Studies have shown that compact land use patterns, mixed uses, and other urban design elements that support better transit, walking, biking, and carsharing allow households to reduce automobile ownership, make fewer and shorter trips by auto, and increase their use of lower-cost nonautomobile modes. However, these studies often are limited to a small study area, employ specialized data sets, or raise additional empirical questions (*7*). Without a widely available, routinely updated measure of the actual transportation costs to households at the neighborhood level, policy makers and planners lack sufficient information to act on the broader set of recommendations to lower costs. Although information on gas prices and refinery capacity is readily available, reinforcing the emphasis on controlling gasoline prices, most households and planners do not have information on the true difference in transportation costs by neighborhood or town. Households may locate to minimize or manage their current and future commute times and distances (*8, 9*) but do not realize that a new location may necessitate purchase of an additional automobile or more driving for the growing number of daily nonwork trips.

Although researchers have been estimating demand for autos for at least 50 years (*10, 11*), demand rarely has been translated into a total end-user cost. Early demand models were developed to project the need for new roads, parking, automobile supply, and transit use, as well as to measure household well-being and a nation's standard of living. Current demand models that incorporate socioeconomic characteristics typically are created at the regional level and are based on

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an aggregate of transit analysis zones. These models and others estimate household costs by using travel time multiplied by a portion of the average hourly wage. The authors are not aware of other analyses across multiple regions that incorporate socioeconomic and built-environment characteristics at the neighborhood level for predicting household travel activity by mode to estimate total transportation expenditures.

RELATED STUDIES

Research topics related to this model's specification include the studies on household travel demand, travel and the built environment, urban economics, and location theory.

Early on, as researchers attempted to project automobile ownership 30 years out, a debate began on what more strongly influenced a household's transportation needs, specifically the need to travel by automobile. Some researchers noted that low-income households would have lower automobile ownership, because of where they typically lived (central cities with transit) as well as their need to purchase other necessities (*12*). Others argued that even low-income households would eventually have increased automobile ownership as automobiles became an economic necessity for workers (*10*). Continued suburban development, real increases in income, and the availability of lower-priced used cars would also increase automobile ownership (*10, 12*). Thus, there was early agreement that three sets of variables had influence: socioeconomic; built environment and land use patterns; and automobile supply and costs. Which had the most influence was debatable.

As the 20th century progressed, demand for autos greatly increased as generally expected and as predicted. Specifically, the movement to the suburbs by jobs and households increased the need for automobile ownership since suburban land form does not support dense transit service. The housing ownership opportunities often provided greater value for the same or lower price, but automobile ownership and use came with a high price tag.

More recent studies on the built environment and travel demand show the actual relationship among density, income, jobs, neighborhood amenities, and other factors that cause a household to shift travel modes from transit to auto and to increase the number of automobiles owned, trips made, and miles driven (*13, 14*). A team of researchers in 1999, including two authors of this study, translated such a relationship into a method to value neighborhoods by household transportation expenditures, called location efficiency. This measure was converted into a location efficient value, which prompted Fannie Mae to invest $100 million in an underwriting experiment called the Location Efficient Mortgage (*14*). Eventually, other similar mortgages were developed on the same premise, including Smart Commute, Take the T Home, and the Freddie Mac–backed walk-to-work mortgage (*15*). The adoption of these mortgages signifies the housing market's acceptance of the notion that household income and size as well as the built environment influence transportation expenditures. However, the location efficiency study was limited to three regions, San Francisco and Los Angeles, California, and Chicago, Illinois, (because of intensive and proprietary data requirements), and therefore the results could not be widely used by consumers or planners beyond mortgages in those three areas.

It is important to note that this study builds on the location efficiency study but uses different and generally more accessible data and results in modestly different yet statistically acceptable output. The research team is using this transportation cost model as an input to the Housing + Transportation Affordability Index, a project supported by the Brookings Institution's Urban Markets Initiative (*16*).

In a 2001 synthesis of approximately 50 empirical studies on the influence of land use on transportation choice, Ewing and Cervero identified several studies that found significant relationships between travel patterns, including trip lengths, trip frequencies, and trip modes, and the design of the built environment, transportation networks, land use pattern, and transit availability, when controlling for socioeconomic characteristics (*13*).

In 2006, Zhang's study on how travelers make their travel choices, in particular, how one formulates the mode choice set and makes a final choice, confirmed "the choice-enabling role of land use in reducing automobile dependence" and shows that street connectivity, population and job density, automobile availability, and transit supply also matter for whether a household is automobile dependent (*17*). The relationship noted between automobile availability and automobile dependence is considered a habituation effect. Once households have an automobile and use it for some trips, some households—although not all—may begin to rely on it for every trip, even if other modes are available.

Despite the repeated findings in this significant body of literature, some studies still identify self-selection as the main reason households in certain built environments use transit, walk, or bike. Specifically, these studies claim that higher transit ridership in transit-oriented developments is a result of self-selection and not the built environment, that is, households choose to live near transit in order to take transit, and therefore household preference, not the design, pedestrian orientation, or other factors of the neighborhood, increases transit use among those who live near transit (*18, 19*). However, a survey of 1,600 households in Boston, Massachusetts and Atlanta, Georgia, designed to test whether the self-selection bias was sufficient cause to dismiss the effect of urban form on travel behavior showed there was significant latent demand for more areas in which the urban form could support preferred travel patterns, for example, to walk or take transit to work and other destinations (*20*). The study showed that urban form and household preference affect travel behavior and that a greater number of households would self-select to take advantage of integrated land use and transportation, but there are not enough of these types of neighborhoods in most regions. Hence, a household's current choice of neighborhood is not necessarily its stated preference for that neighborhood type if there are few choices. Some households adopt an automobile-oriented lifestyle for lack of other choices, not because of preference. Handy and Mokhtarian also found that attitudes may predominate when using transit but that over time the neighborhood design may influence attitudes (*21*). The same authors, by using a survey of households in Austin, found that self-selection influenced whether walking was within an individual's mode choice set but that neighborhood design influenced the frequency of walking (*22*).

CONCEPTUAL FRAMEWORK

The household transportation cost model comprises three separate multiple regression equations. Each model combines several built-environment and socioeconomic variables, with various weights, to predict the three separate criterion variables that sum to total transportation costs: automobile ownership, automobile use in annual household miles, and annual household transit use.

There were two major considerations in the choice of data for the models:

1. Selecting a set of built environment and socioeconomic predictor variables supported in the literature as having an influence on household travel activity and

2. Identifying data sets that are available at a small geographic scale from nationally available sources that are updated on a regular basis, such as the U.S. decennial census.

The purpose of the second data source constraint was to produce a model that could be made available in most major metropolitan areas at a low cost. For example, data included in the decennial census are universally available at a fine resolution. While the cost, time, and scale benefits were clear from use of these types of publicly available data sets, there were necessary constraints because of the few transportation-related questions posed in the survey, such as the local quality of the pedestrian environment or whether households shopped at neighborhood services. Therefore, the model is much like most social science models that attempt to predict human behavior—it provides a reliable prediction for the typical or mean household in each census block group within a reasonable range, but it cannot accurately predict travel behavior for all households. In particular, model accuracy declines in block groups with fewer households and a less intensely built environment. In these neighborhoods, the socioeconomic variables have a stronger influence and there is greater variability in the three predicted outputs. Generally, households do not act in completely predictable ways. They do not always locate to minimize current work trips (*23, 24*) or to locate in the ideal neighborhood but instead often choose the best house they can afford (*8, 9, 25, 26*). Nor do households always buy vehicles because of economic necessity, and some will have more than the model predicts. Mode choice may be based on preference, rather than convenience or cost, and miles traveled may be greater if households choose shops and services farther from their homes, even if the data show there are several closer. Increasingly complex polycentric regions make household travel even more difficult to predict as housing and jobs disperse. Finally, certain exogenous factors, such as the quality of school districts, the presence of a natural feature, high crime rates, or the ability to telecommute, may also influence household travel activity, but these are not directly captured through this model.

After testing of several variables and model configurations, the final model includes variables that address both mode choice set for a household in a given location and the actual mode choice decisions throughout a year (*17*).

Within the model, choice-set formation is represented by variables that describe the neighborhood characteristics of a household's primary location and the choices that might be available—residential density, job density, regional proximity to all jobs, average block size (as a proxy for the pedestrian environment), transit connectivity, and nearby services. The socioeconomic characteristics of household size and income also influence the choices available and the choice-set formation. Income often affects where people live, which in turn is related to what choices are available in their neighborhood. Income also influences transit use: higher-income households use transit at lower rates overall (*27*), and lower-income households are more likely to locate near transit because of the higher cost of driving relative to their incomes. Household size affects the mode choice set and mode decisions because it increases the number of travelers and destinations within a household, and therefore the choices available and the number of trips by various modes (*17*).

Additional socioeconomic variables that influence travel behavior have been noted in other studies, such as number of workers per household, but tests show these additional variables were closely associated with household income and size. Whereas adding the number of workers to the model could, for instance, distinguish if a two-person household is a two-worker household or is a single worker and child, which might influence automobile ownership, the income variable tends to reflect the number of workers per household. The higher income associated with two workers will likely influence how many automobiles the model predicts. Where income does not compensate for other socioeconomic variables not included in the model, the land use variables may determine the mode choice set and mode choice.

METHODOLOGY AND DATA

Data

The model uses several data sources. Table 1 describes the source for each dependent and independent variable, respectively, and how each is used in the model. The variables in the tables describe the analysis for the pilot Minneapolis–St. Paul metropolitan area.

The variables at the smaller of the two geographies, either block group or tract, depending on availability, were gathered by using a geographic information system (GIS) for aggregation and spatial analysis. For employment center data from the Census Transportation Planning Package, the tract level was used since block group and travel analysis zone data were available for only some counties. SPSS was used for statistical analysis.

Variables

The variables within the model are transformed from their original format to varying degrees. In particular, employment centers, transit connectivity index, and vehicle miles traveled require additional explanation beyond the information in Table 1.

Employment Centers and Regional Accessibility

To identify the employment centers, GIS is used to identify clusters of jobs in contiguous census tracts that meet two thresholds: at least seven jobs per acre and at least 5,000 jobs. The centers are defined from a center point, and the outer boundaries are established when the adjacent tracts drop below the density threshold.

Two measures of access to employment are used within the model: the distance to the nearest large employment center from a household location, and the pull or attraction of all employment by census tract within the region, for example, the likelihood of where a household member will be employed. This second measure is calculated by the gravity model, the sum of the ratio of the number of employees within all census tracts in the region over the distance to that tract squared. The two measures are weighted separately in the final regression equation.

Transit Connectivity Index

Bus data, but not rail—since Minneapolis–St. Paul did not have rail at the time of the 2000 census—were used to calculate the frequency and extent of transit for a given block group. This calculation is referred to as the transit connectivity index (TCI) and represents the quality of fixed-route bus and rail transit service where available. Quality of transit is based on access, intensity and frequency of transit service in a given census block group. Access is captured by a 0.25-mi buffer around each bus route. Intensity is based on the number of routes and trains that serve the census block group. Frequency

TABLE 1 Dependent and Independent Socioeconomic and Local Environment Variables

Dependent	Source	Purpose
Socioeconomic Variables		
Household income by tenure	U.S. Census 2000, SF3, table HCT12, census tract	Associated with mode choice preference, relative travel cost, travel activity (*27*), and workers per household.
Household size	U.S. Census 2000, SF1, table P17, block group	Associated with transportation activity, workers per household.
Built Environment and Land Use Pattern Variables		
Households per residential acre	Total households: table P15 from US census 2000, SF1, block level Residential block acres: block acreage from US census TIGER/Line for blocks with at least one housing unit	Represents household density of residential areas in contrast to population density on total land area. Density influences parking availability and costs, corresponds to the number of neighborhood commercial services, influences transit availability, and nonwork travel distance.
Households per total acre	U.S. Census 2000, SF 1, table P15, block group Total households divided by the total block group area in acres	Represents population density. The delta between residential density and total density may indicate the mix of other uses, as well as open or undeveloped space. Density is associated with parking availability and costs, the number of neighborhood commercial services, transit service levels and transit use, and often the age of development and therefore the land use pattern.
Average block size (acres)	Average is calculated in GIS using census TIGER/Line Total block group area divided by the number of census blocks within that block group	Represents street connectivity and pedestrian friendliness, which influences travel mode and distances traveled. Where there is greater connectivity, from more streets and intersections, there is generally a higher use of transit, walking, and biking. Trips also tend to be shorter, although more frequent.
Transit connectivity index (TCI)	CTOD National TOD Database derived from NTAD 2003 and transit agency files (*28*); local bus route files and the 1995 FTA bus route GIS database	Represents the quality, quantity, and extent of the transit routes within walking distance of the census block group. The frequency, proximity, and connectivity of transit influence the formation of a household's mode choice set and mode decisions. (Note: Data do not include bus stops.)
Distance to, and size of, nearest employment center, 5,000+ employees	U.S. Census transportation planning package (CTPP) 2000 total employees per census tract	Represents distance a worker may travel to work and their possible mode choice. The greater the distance to an employment center, the less likely a worker will commute by transit. However, the size and density of a center, in addition to distance, also influences mode choice. Distance, size, and density are represented in the model (*17, 29*).
Regional job density and access	CTPP 2000	Represents the accessibility to the number of all jobs and most destinations within the region from a household's location using a gravity model. High regional accessibility reduces annual vehicle miles and vehicle hours traveled (*13, 19, 30, 31*).
Access to amenities (density of service workers)	CTPP 2000, table 2. Service-sector jobs per square mile were proportionally estimated to each tract	Represents a measure of local accessibility to services, which influences frequency, distance, and mode choice for nonwork trips (*19, 32*).
Average auto ownership by tenure and average income of the block group	U.S. Census 2000 SF3 block group data: aggregate number of vehicles by tenure (H46)/households by tenure (HCT12)	Represents average auto ownership per household at the block group level by tenure in the regression model to fit auto ownership to the socioeconomic (household income and size) and built environment characteristics within the block group.
Annual vehicle miles traveled per household by auto	2001 National Household Travel Survey records at the block group level	Actual vehicle miles traveled per year per auto for a household at the block group level is used to calibrate the model to predict annual vehicle miles traveled per household given local environment and socioeconomic characteristics. Total miles per household are used to calibrate the model, but the output assigns miles to each vehicle within a household based on FHWA research on VMT per household in multiple vehicle households.
Average daily transit trips per household	U.S. Census 2000, SF3 means of transportation to work, fraction of total trips by transit 2001 FTA Transit revenue database: total revenue for Minneapolis–St. Paul	An estimate of the number of transit trips per household—based on the share of workers that use transit for work (US Census), which was then used to estimate the share of transit revenue collected in that block group—is used to calibrate the model to predict annual transit trips per household given local environment and socioeconomic characteristics.

NOTE: the model would benefit from information on discounted transfers versus full fairs and information on transit trips per household each day. Currently, transit trips are estimated based on share of transit users for work commute and total transit trips in region. Regional transit trips are distributed to the block groups based on the share of workers commuting by transit in that block group. CTOD = Center for Transit-Oriented Development, TOD = transit-oriented development, NTAD = National Transportation Atlas Database.

is the sum of total weekly trips for all routes in both directions within the buffered area. This combined measure results in an index:

$$\text{TCI} = \frac{\sum \left[\begin{array}{c} (\text{0.25-mi buffer area intersecting block group}) \\ \times (\text{route total weekly trips}) \end{array} \right]}{\text{total census block group area}}$$

Other studies that have constructed similar indexes were referenced to develop the TCI formula. The quality of the 1995 FTA Bus Routes Database data was checked by comparing them to the local bus transit data from MetroGIS in the twin cities region. Although the MetroGIS data were more recent and detailed, the difference was not statistically significant.

Vehicle Miles Traveled

The National Household Travel Survey (NHTS) collects data on vehicle ownership and vehicle miles traveled (VMT) per automobile for individual households. The survey is reported at the county level, but the data set includes seven characteristics for the block group and surrounding tract, including percent of rental units, household and population density, county, and state. These seven characteristics were used to match the block groups in the survey with the census block groups for the entire United States. Of the 69,817 households in the NHTS sample, 8,912 were unambiguously matched to a census block group, and 6,840 household records had complete income and VMT data. Of these records, 92 were in the Minneapolis–St. Paul area, and the distribution of the sample in this region was similar to the national sample of 6,840 records.

VMT for each automobile in a household were summed to obtain a total VMT per household. This is used as the criterion variable in the regression model to predict household VMT. Although the other two components of the model exclusively used Minneapolis–St. Paul data, the similarity of the reported VMT in the 92 Minneapolis–St. Paul records to the national records makes this a valid use of the national data. The study was limited to this data set because of the lack of any other source of neighborhood household VMT data for this region or others.

Model Specification

To construct the regression equation, 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. In the original research, the final three multiple regression equations incorporate two-stage models to fit first the local environment effects (X_{le}) and then the household effects (X_{hh}) while holding the local environment variables constant. However, for this paper, the regression analysis was conducted in a more comprehensive way, ignoring the distinction between the environment variables and the household variables to get the best fit possible from all the independent variables. The three models are summed to derive the total (T) household costs for automobile ownership (AO), automobile use (AU), and transit (PT) as follows:

$$\text{household } T \text{ costs} = [C_{AO} * F_{AO}(X)] + [C_{AU} * F_{AU}(X)] + [C_{PT} * F_{PT}(X)]$$

where C is cost factor (i.e., dollars per mile) and F is function of the independent variables.

The predicted result from each model is multiplied by the appropriate price for each unit—autos, miles, and transit trips—to obtain the cost of that aspect of transportation. For instance, the predicted autos per household are multiplied by the annual cost to own the average vehicle. The cost used may be adjusted by region, household income, or an average of the fleet of vehicles according to a source such as the *Complete Car Cost Guide* (*33*) and the *Transportation Data Energy Book* (*34*). However, this paper does not cover the detailed pricing aspect because the paper's purpose is to predict the variables. A user of the model's output can apply the appropriate costs as prices change for automobiles, maintenance, gasoline, and transit. For a more detailed explanation of costs used in the full Housing and Transportation Affordability Index, see the white paper by Haas et al. (*35*).

Table 2 provides the coefficients and standard error for the variables used in each of the three models and the R-squared for each of the models.

Automobile Ownership Model

In the Minneapolis–St. Paul metropolitan statistical area, according to the 2000 U.S. census, the average household automobile ownership is 1.74 with a standard deviation of 0.42. The distribution follows the normal curve, so a standard multiple regression model was used:

$$\begin{aligned} \text{autos/hh} = {} & \text{auto\_hh\_b} * (\text{DR}^{\text{auto\_hh\_c}}) \\ & * (1 - \exp(\text{auto\_hh\_f} * [(\text{HINCOME}/100{,}000)^{\text{auto\_hh\_e}}])) \\ & * [(\text{JTOTAL}/10{,}000)^{\text{auto\_hh\_t}}] \\ & * [\exp(\text{TCI} * \text{auto\_hh\_g}/1{,}000)] \\ & * (\text{HSIZE}^{\text{auto\_hh\_k}}) \\ & * (\text{REC}^{\text{auto\_hh\_r}}) \end{aligned}$$

Automobile Use Model—Annual VMT

The VMT per automobile from the NHTS is used as the dependent variable in a regression equation with two local environment variables, households per acre and average block size; socioeconomic variables, household income and size; and automobile ownership. Automobile ownership is added to this equation because independent variables tests clearly show that the miles driven per household were most dependent on number of automobiles per household. This regression model was run by using the 6,840 block groups in the NHTS sample rather than the 2,007 block groups in the Minneapolis–St. Paul area. The VMT for a given block is estimated by applying the VMT of similar blocks from the national sample, where similarity is based on the variables in the regression.

$$\begin{aligned} \text{VMT/hh} = {} & \text{vmt\_hh\_n} * \exp(\text{VCLHH}^{\text{vmt\_hh\_a}}) \\ & * (1 - \exp[\text{vmt\_hh\_f p } (\text{D}^{\text{vmt\_hh\_e}})]) \\ & * (\text{BLKSIZE}^{\text{vmt\_hh\_c}}) \\ & * \exp[(\text{HINCOME}/100{,}000)^{\text{vmt\_hh\_g}}] \\ & * \exp(\text{HSIZE}^{\text{vmt\_hh\_i}}) \end{aligned}$$

TABLE 2 Multiple Regression Correlation Results

Variable	Coefficient	Value	Standard Error
Auto Ownership			
Constant	auto_hh_b	1.541	0.034
Residential density (DR)	auto_hh_c	−0.028	0.003
Average household income (HINCOME)	auto_hh_e	1.141	0.037
	auto_hh_f	−4.508	0.232
Total jobs/mi² (JTOTAL)	auto_hh_t	−0.022	0.006
Transit connectivity index (TCI)	auto_hh_g	−0.021	0.003
Average household size (HSIZE)	auto_hh_k	0.322	0.015
Distance to nearest large EC (REC)	auto_hh_r	0.013	0.005
Summary Statistics	$R^2 = .845$		
Auto Use			
Constant	vmt_hh_n	638.900	19.763
Vehicles per household (VCLHH)	vmt_hh_a	0.487	0.007
Density (D)	vmt_hh_e	−0.542	0.211
	vmt_hh_f	−11.246	8.026
Average block size (BLKSIZE)	vmt_hh_c	0.045	0.006
HINCOME	vmt_hh_g	0.219	0.019
HSIZE	vmt_hh_i	0.212	0.011
Summary statistics	$R^2 = .381$		
Transit Use			
Constant	transit_j2w_a	14.104	1.663
DR	transit_j2w_b	0.188	0.027
mi² JTOTAL	transit_j2w_t	0.272	0.036
TCI	transit_j2w_g	0.237	0.020
HSIZE	transit_j2w_k	0.253	0.019
HINCOME	transit_j2w_e	0.536	0.034
Summary statistics	$R^2 = .626$		

Transit Use Model—Annual Transit Trips per Household

The distribution for transit trips is binomial and peaked at zero. The best fit for this came from a simple regression rather than the more complex least-squares fit. The following formula estimates the fraction of workers taking transit to work:

$$\text{transit mode share} = (\text{transit\_j2w\_a}/10{,}000) * \left[(\text{DR})^{\text{transit\_j2w\_b}}\right] * \left([(\text{JTOTAL}/10{,}000)]^{\text{transit\_j2w\_t}}\right) * \left[(\text{TCI})^{\text{transit\_j2w\_g}}\right] * (\exp[(\text{HSIZE} * \text{transit\_j2w\_k})]) * (\exp[1/(\text{HINCOME}/100{,}000) + \text{transit\_j2w\_e}])$$

The predicted share of workers in a block group commuting by transit is then translated into transit use per household by using the FTA transit database for 2001, which reports total transit trips purchased from Metro Transit. To obtain total transit trips for a household, the share of the population in a block group commuting by transit is applied to the total transit trips and then proportioned to the households:

$$\text{trips/household} = \alpha * \text{transit mode share}$$

where α is total regional transit trips/Σ(transit mode share* households).

This results in a distribution of transit trips per household with a mean of 2.4 daily one-way transit trips per household and a standard deviation of 2.88. This is a large standard deviation, and therefore this model does not as accurately predict transit trips as it does automobile ownership and VMT. However, for the significant share of households in the region that do not use transit, the transit costs are not overestimated. For heavier transit users, the model may over- or underpredict transit costs in some neighborhoods by up to $700 a year. It is also difficult to price the average transit trip because of discounted fares for transfers and monthly passes and higher fares for peak hour and express buses. However, annual predicted costs for transit in neighborhoods with high transit use were similar to what routine transit users report for annual transit expenditures in the Consumer Expenditure Survey.

The combination of predictor variables in the preceding equations are statistically significant and predict approximately two-thirds of the variation. The results are best at higher-density places and taper off in exurban places, in part because of fewer cases in these areas against which to model, and the diminished influence of the built environment and increased influence of household characteristics. When the built-environment variables are less intense, for example, lower densities, fewer services, less transit, and larger blocks, a household's mode choice set is often limited to the automobile, and household travel behavior becomes less predictable.

Model Results

To obtain the estimated household transportation costs for a given block group, the models can use any combination of income or household size. To estimate the affordability to households in their current location, the models would use the existing average income and size in each block group as the socioeconomic inputs. To determine where a household of a given income could afford to live, given each neighborhood's associated transportation costs, the models would use a single income, for example, 80% of the area median income. The two maps in Figure 1 show these two different uses of the model. The map on the left estimates expenditures for the median-income household in each block group, and the map on the right displays what a moderate-income household would spend in all block groups. The results indicate that households in the lightest areas of the region are paying $600 per month or less, whereas households in the darkest areas are or would pay $1,120 or more per month.

Table 3 shows the specific model output in four neighborhood types plus the seven-county average for three different income levels and household sizes. The four neighborhoods represent an exurban community, Farmington; an older middle-ring suburb, Fridley; and two city neighborhoods, Midway in St. Paul and Seward in Minneapolis. Running the model for the same three sample households across four neighborhoods shows how both the built environment and household characteristics affect transportation demand and the associated costs.

The neighborhood characteristics in Midway and Seward include smaller block sizes, making them more walkable; a greater number of services within the neighborhood, making nonwork trips accessible by multiple modes and at shorter distances; greater residential densities, which supports more local services and job opportunities; higher levels of transit connectivity, making transit more attractive and usable; and closer proximity to major centers of employment, making the commute trip shorter and more likely doable by transit. In Farmington, the block sizes are more than 40 acres, making them unwalkable for short trips, and the job density is very low so there are few nonresidential uses or jobs in most neighborhoods. The nearest employment center is more than 10 mi away, and the transit connectivity is close to zero. These neighborhood differences explain why the model predicts a three-person household earning $54,304 a year will own 2.19 vehicles and take no transit in Farmington but own 1.09 and 1.43 vehicles in Seward and Midway, respectively and take from 18 to 156 transit trips a year.

The prices used to construct the costs in Table 3 are as follows. For automobile ownership and usage, prices are based on FHWA 2001 figures published in *Complete Car Cost Guide* (*33*) and *Complete Small Truck Guide* (*36*). FHWA factors into the ownership costs depreciation, insurance, financing, and state fees. FHWA automobile use costs include fuel, maintenance, fuel tax, and repairs. FHWA then

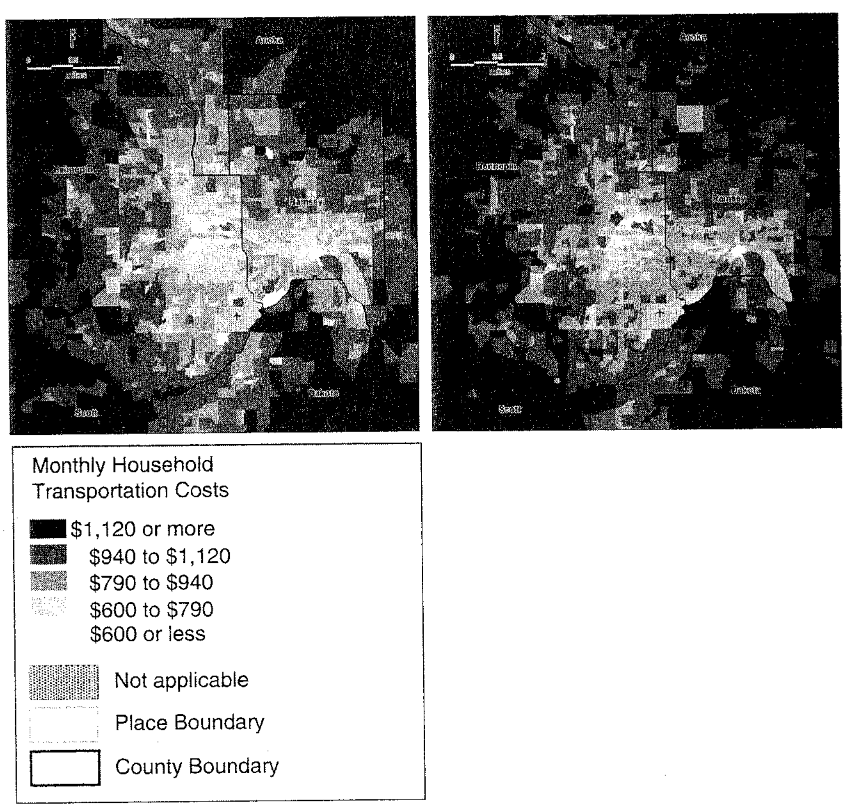

FIGURE 1 Modeled monthly total household transportation costs for (*left*) average income in each census block group and (*right*) households earning 80% of area median income.

TABLE 3 Model Results: Transport Use and Costs

			Results in Four Neighborhoods with Different Built Environment Characteristics Compared with the Region Average				
Example Household	Income	Size	Farmington (exurban)	Fridley (suburb)	Midway (city)	Seward (city)	Region Avg. (7 counties)
30% AMI	$17,000	1					
Autos/HH			1.49	1.17	0.97	0.74	1.19
VMT-year			18,481	14,590	12,183	9,523	14,853
Transit trips/year			7.6	48.6	144.2	298.2	70.7
Total annual cost			$9,242	$7,340	$6,363	$5,322	$7,522
80% AMI	$43,470	3					
Autos/HH			2.10	1.64	1.36	1.04	1.67
VMT-year			26,706	21,083	17,605	13,762	21,464
Transit trips/year			0.0	0.0	19.4	158.8	16.2
Total annual cost			$13,023	$10,200	$8,545	$6,889	$10,421
104% AMI	$54,304	3					
Autos/HH			2.19	1.71	1.43	1.09	1.74
VMT/year			28,005	22,109	18,461	14,431	22,508
Transit trips/year			0.0	0.0	17.9	155.7	15.7
Total annual cost			$13,625	$10,671	$8,934	$7,182	$10,900

estimates the annual ownership and use costs by type and age of vehicle. This analysis takes a weighted average of these two costs across the fleet of vehicles. The end result is the ownership costs for a vehicle are estimated at $5,068 and the usage costs are 9 cents per mile. These costs are averages and therefore can either over- or underestimate the true costs of automobile ownership and usage in some cases. Likewise, when households own more than one vehicle, the second or third vehicle is not always used as much as the first. This would tend to overestimate the usage costs associated with owning additional vehicles. Additional research will develop typical prices based on household incomes and update the prices each year.

CONCLUSIONS

As a composite index of the quality of the built environment, this transportation cost model provides an estimate, controlling for a household's size and income, of how the built environment will influence a household's transportation demand in a particular neighborhood. According to this model, the combination of these factors explains approximately two-thirds of the variation in household travel activity. The other third may be a factor of household preferences and other characteristics, such as the number and age of children, or additional factors of the built environment, such as crime, weather, pedestrian environment, and school quality. Hence, both the demand for transportation (socioeconomic) and the supply of destinations and transportation (built environment) influence automobile ownership, automobile use, and transit use.

Increasing gas prices have raised the profile of transportation costs for households, businesses, employers, and, more recently, the home mortgage industry. Stories of households unable to afford their homes and commutes show the need to more accurately predict and report the cost of transportation at a small geographic scale. By reporting the results from this type of model, households would have more complete information when selecting their housing locations and when making their travel choices. Microeconomic researchers have shown the validity of the theory of information asymmetry in explaining apparently subrational behavior and in designing systems that can correct for this. A rich field of research opportunity is suggested by the findings (*29, 30, 37, 38*).

Beyond reporting the results to the general public, this model and other studies indicate that both types of variable, supply and demand, should be used in travel demand forecasts and traffic impact studies to predict travel volume and behaviors and to design more efficient transportation systems, including setting appropriate parking requirements. Providing this information could help to increase the supply of efficient, mixed-use places, since putting a price tag on the transportation costs in each neighborhood may influence developers about where and how they build and design their developments. Planners might change zoning and design codes, and states and regions might direct development to existing areas served by transit. Creating situations that reduce automobile ownership and automobile use and increase transit use would help to moderate travel demand, which would benefit regions with congested roads and would benefit the environment and humans through reduced automobile emissions. Employers could consider the model results for office locations, to reduce absenteeism and tardiness. Neither current federal law nor any state or local jurisdiction screens transportation investments for their direct cost-of-living impact, although several jurisdictions are considering doing so. This type of policy could also be considered for inclusion in the next federal surface transportation statute.

Finally, this model is still in the early stages. Studies may have been missed that would question some of the variables used or not used, or how they were modeled. Therefore, additional work is underway to refine the model. For instance, the Longitudinal Employment and Household Dynamics database, which links census data from the long form to individual employer information, will be used to represent employment and local services. To increase the sample size and recognize the influence of varying transit system sizes and other regional differences, a metropolitan typology has been developed with model parameters for each of six metro types. The influence of workers per household will also be retested. Even with these deficiencies, the built-environment variables used in this model are successful in explaining some of the variation in the reported differences in household automobile ownership and transit use in the census at the block level, regardless of household size and income. Further research should look for other ways to explain the reasons for the differences in autos owned, transit used, and VMT. This research would either further verify or refute this study's findings. Studies with better sources of data available on transit use at the neighborhood level and VMT would be of particular interest.

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