INCORPORATING URBAN DESIGN VARIABLES IN METROPOLITAN PLANNING ORGANIZATIONS' TRAVEL DEMAND MODELS

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Metropolitan Planning Organizations (MPOs) find it difficult to address urban design issues in their work programs for both technical and policy reasons. Even though many MPOs have endorsed general land use policies to keep development from flood plains, protect open space and support transit oriented development, only a few MPOs have any real input into local land use and zoning decisions that affect urban design. The responsibility for zoning most often rests with municipal or other local officials. While these local officials may be members of or represented on MPO policy boards, their zoning and land use decisions are primarily driven by real estate market forces, constituents' interests, intergovernmental rivalries and funding availability[1].

Few MPOs have challenged this division of planning responsibilities. Metropolitan Planning Organizations have historically carried out regional transportation planning at a scale too gross to consider how the design of planned urban developments, residential subdivisions and office parks affects travel demand. In the socioeconomic and land use data files that MPOs use for transportation planning, these developments appear only as added employment, housing or population summarized within some geographic unit.

In northeastern Illinois, for example, the quarter square mile quarter-section is the principal geographic unit for assembling land use, population and employment transportation planning data. Within quarter-sections, activities can be separated by as much as a mile of right angle distance. Even though a quarter-section may have both retail employment and households, there is no way to determine whether stores and households are distributed throughout the quarter-section and located close to one another, or clustered in opposite corners of the quarter-section and separated by up to a mile of walking or driving distance.

The geographic level at which MPOs apply the travel demand models for regional planning and major investment studies is often even larger than the geographic level at which the socioeconomic and land use data are maintained. The number of analysis zones that can be used in travel demand models is more constrained by computing requirements than the number of geographic units in the land use and socioeconomic databases. Again considering northeastern Illinois as an example, the 16,300 plus quarter-sections that are used to maintain the primary transportation planning data are further aggregated to 1,900 to 2,000 analysis zones for regional trip distribution, mode choice and assignment. Most analysis zones are one square mile sections, but

[1] Robert T. Dunphy. "Transportation Oriented Development: Making a Difference." *Urban Land*, July, 1995.

they increase to four square mile zones in suburban counties, where much of the new development is taking place.

Forecasting urban design variables is extremely problematic for MPOs. Should these variables be part of the endorsed regional land use and socioeconomic forecast used for transportation planning or remain “wild card” variables that can be manipulated by modelers within the framework of a more general forecast? Should the values for future urban design variables be set through policy decisions, be the result of a technical forecasting process, extrapolated from existing values, or be allowed to range between reasonable maximum and minimum values for scenario testing?

Even if there were no technical problems in forecasting urban design variables, it would still be difficult for many MPOs to explicitly include these variables in their endorsed forecasts. Agreement on gross population and employment figures is easier to achieve than agreement on land use densities, land use mixes, multiple unit housing and similar variables that are more controversial. Local officials are also unlikely to willingly give up any of their prerogatives over zoning.

Reasons to Consider Urban Design Variables

There are emerging arguments for MPOs staff to take the relationship between urban design and travel demand more seriously. The air quality conformity requirements that MPOs face provide an incentive to include urban design variables. Those regions in non-attainment areas, and especially those regions classified as moderate and above ozone non-attainment areas, must find ways to reduce the growth in vehicle-miles of travel. Urban design is seen as one means to reduce personal automobile use, by locating activities so that nonmotorized and transit trips can be substituted for automobile trips.

In the northeastern Illinois region, and in many other regions, a loose confederation of public interest organizations are active in the MPO’s planning and project programming processes. These groups focus on improving the quality of life, reducing reliance on the automobile for personal travel, and promoting transit and pedestrian/bicycle usage. It is simply impossible for MPOs to ignore these groups’ interests, which all touch on urban design, due to their important role in the MPO planning process.

Transit interests have also keyed on the relationship between urban design and transit ridership because transit ridership depends on the types and densities of activities in the immediate vicinity of stations and bus stops. Transit proponents have also reversed the development (cause) and ridership (effect) relationship to argue that the availability of transit can influence location decisions, creating an urban environment that supports transit ridership. Both arguments undermine the certainty of transit ridership forecasts based upon a single forecast compiled in analysis zones larger than convenient transit access walking distances.

The technology associated with the maintenance, display and manipulation of demographic and land use data is rapidly changing within MPOs. This technology includes not only the Geographical Information Systems (GIS) software, but also government and private vendor databases for GIS applications, more efficient land use and demographic data collection, and data resources available through the Internet. This technology allows MPOs to maintain land use and socioeconomic data at much less aggregate geography than previously. A wide range of urban design variables - mix of housing types, running feet of sidewalk, distances between households and retailing, the number of households within an eighth of a mile of a bus stop - can be readily developed and then used as independent variables in travel demand models. Just as importantly, this technology can generate urban design variables - vacant or underutilized housing, distributions of population characteristics for households within transit comutersheds, land available for development - for use as independent variables in land use and demographic forecasting processes, as well as for the creation of alternative development scenarios.

Modeling Travel Demand Impacts of Urban Design

Those who argue that the travel demand models need to be responsive to urban design variables expect urban design to influence travel behavior in the following manner.

1. **Increase transit ridership by reducing the access/egress distances for transit**. This mode shift is achieved by increasing the densities around transit stations and bus stops, more efficient location of transit services relative to activities, and improving the pedestrian environment around stations and stops.

2. **Substitute nonmotorized trips for vehicle trips**. Urban design can increase nonmotorized travel by mixing activities so that trip productions and attractions are located within walking distances of one another. This means that some retail and service activities are located within reasonable walking or biking distances of residences. Another way to improve the pedestrian and bicycle environment is to make it easier to complete pedestrian and bicycle trips either by eliminating barriers to nonmotorized travel or by improving pedestrian and bicycle facilities.

3. **Shorten trip lengths**. It is argued that exclusionary zoning and market forces have tended to segregate activities and lengthen trips. Workers must live some distance from their place of employment because adequate or affordable housing is not available near their job sites. Shoppers have to travel to regional shopping centers for even the most ordinary purchases and services. Better urban design would locate activities linked as trip productions and attractions as closely together as possible.

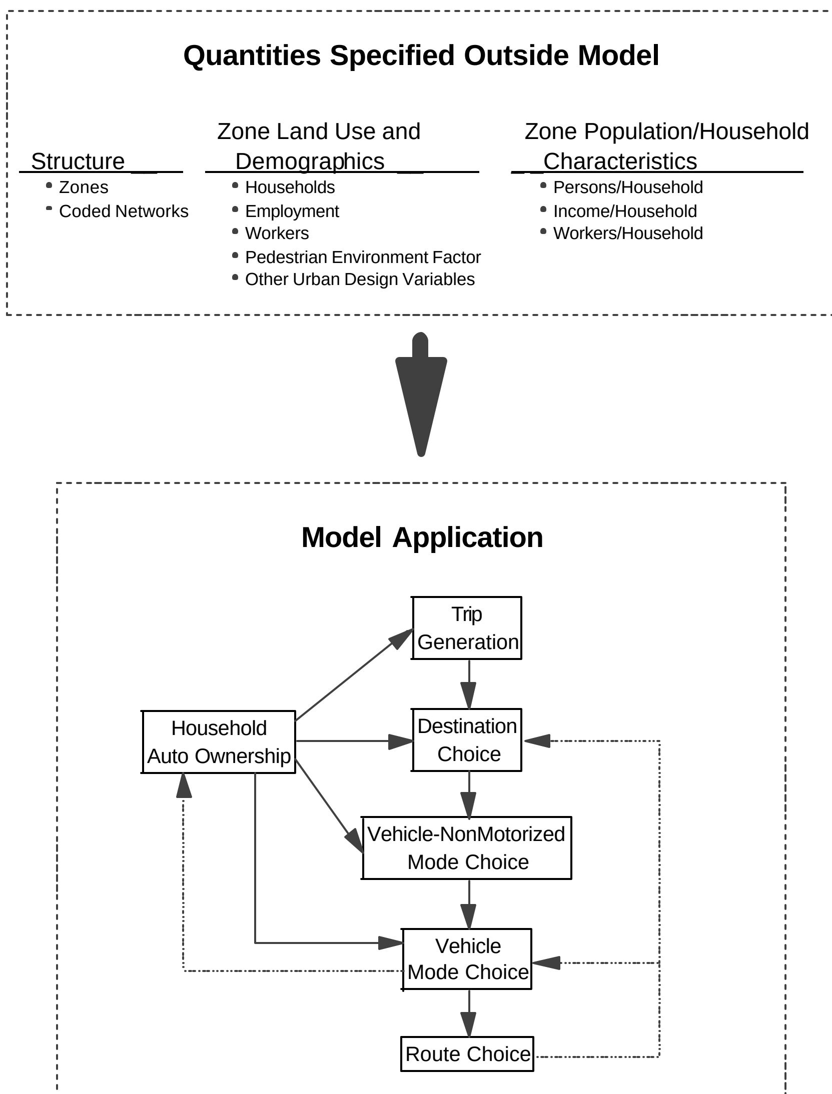
4. **Increase transit ridership by altering travel patterns**. In order to have enough transit ridership to support a major transit investment, enough riders and suitable destinations for them have to be located in the corridor served by the line. A mix of residential and employment at adequate densities must be located in a transit corridor to create travel patterns that can be well served by the corridor's transit service.

5. **Alter trip generation**. There is a general sense that urban design can affect the character of household travel. Household trip generation models that incorporate auto ownership usually indicate that vehicle trips are lower when auto ownership is less, although auto ownership is often a surrogate for household income. When total household trip generation is considered, including walk and bicycle trips, these

relationships are much weaker. If more shopping is located in residential areas will households substitute more frequent short home to shop trips for longer weekly trips to a shopping center? Are transit commuters more likely to take care of errands during the lunch hour than auto commuters, who carry our the same errands while traveling to and from work?

Figure 1 is a diagram showing the sequence of person travel demand models in the modeling process under development at CATS. For simplicity, some details that affect the application of the models, such as trip purpose and time of day, are omitted. The Figure 1 process is typical of the modeling approaches that several larger MPOs have in place or under development. The purpose of this diagram is to help identify where the travel demand impacts from urban design variables can be modeled.

Figure 1. State-of-the-Art Travel Demand Modeling Process



Quantities that are specified prior to the application of the models are listed in the top of Figure 1 under the headings model structure, zone level land use and demographic quantities, and zone level population/household characteristics. The sequence of model steps is shown beneath. It a slightly expanded version of the traditional four step modeling process. Trip generation includes both vehicle and nonmotorized trips. Destination choice is a more generic term for trip distribution, and it also includes nonmotorized as well as vehicle trips. An initial mode choice step allocates trips to vehicle and nonmotorized modes. The remaining vehicle trips are split into vehicle modes in the subsequent vehicle mode choice model. Route choice refers to the assignment of trips onto the coded networks. A household auto ownership model estimates levels of household auto ownership, which is an independent variable in trip generation, destination and mode choice. Feedback loops in the diagram are used to enter the auto dependency associated with a household's location into the household auto ownership model, and to feedback the increased travel times and costs associated with highway congestion.

Table 1 combines the anticipated impacts upon travel behavior from urban design with the Figure 1 travel demand models to show where these impacts are likely to be reproduced. The rightmost column lists alternative means of incorporating urban design impacts in the models, based on a brief review of the literature and the author's experience in peer group reviews of agency travel models. The next sections of this paper follow the organization of Table 1.

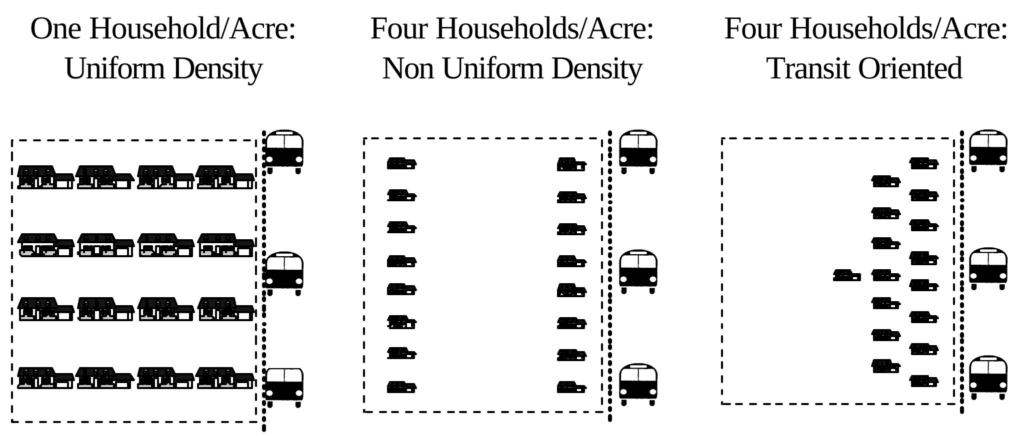
Table 1. Linkages Between Urban Design and Travel Demand Models

Impacts from Urban Design	Models Affected	Means of Representation
Transit Access/Egress Distances	1. Vehicle Mode Choice 2. Vehicle-Nonmotorized Mode Choice	1. Reduced Zone Sizes in Transit Service Areas 2. Network Coding and Locations of Zone Centroids 3. Market Segmentation of Households/Population and Employment by Distance from Transit 4. Pedestrian Environment Factor
Nonmotorized Travel	1. Vehicle-Nonmotorized Mode Choice 2. Trip Generation 3. Auto Ownership	1. Include Nonmotorized Trips in Trip Generation 2. Pedestrian Environment Factor 3. Other Urban Design Variables
Trip Lengths and Travel Patterns	1. Destination Choice	1. Use Generalized Cost Logsum That Reflects Nonmotorized and Transit Zone to Zone Costs 2. Representation of Transit Access/Egress Impedances
Trip Generation	1. Trip Generation 2. Auto Ownership	1. Pedestrian Environment Factor 2. Other Urban Design Variables

Representation of Transit Access/Egress in Mode Choice

To understand the importance of the access/egress component of transit utility, one only has to realize that over estimating the distance from home to transit service by a half mile increases the transit trip time by an additional ten minutes of out-of-vehicle walking time, which is generally valued more than in-vehicle time. Figure 2 illustrates why the average zone transit access/egress characteristics used in the travel demand models are often insensitive to alternative urban designs.

Figure 2. Transit Access Distance and Local Land Use Organization



Households	640	640	640
Area/Household	One Acre	Quarter-Acre	Quarter-Acre
Average Transit Access Distance	0.63 miles	0.63 miles	0.24 miles
Households < 0.5 Miles From Transit	220	320	640

This figure shows three different development patterns for 640 households in a one square mile zone. Bus service is available along the east side of the zone at three stops spaced one-half mile apart. The first development alternative features a perfectly uniform density of households on one acre parcels. The second alternative increases the density of households to four per acre and locates them on the east and west sides of the zone, as if the households were oriented to north-south arterial streets bordering the zone. In the last land use development pattern, the density is again four households per acre, but the households are oriented to the east side of the zone where transit service is available.

Two measures of transit accessibility are listed in the table beneath the three land development alternatives, the average distance from all the zone's households to transit service and the number of households within one-half mile of a bus stop. The three alternatives feature quite different transit accessibility. Every household in the transit oriented development pattern is within one-half mile of a bus stop, while the other development scenarios have households located further than one-half mile from transit service. Average transit access distances for the two non-transit oriented scenarios are more than double that of the transit oriented scenario. The 0.41 mile difference between the uniform density and transit oriented average transit access distances equals roughly eight minutes of extra walking time.

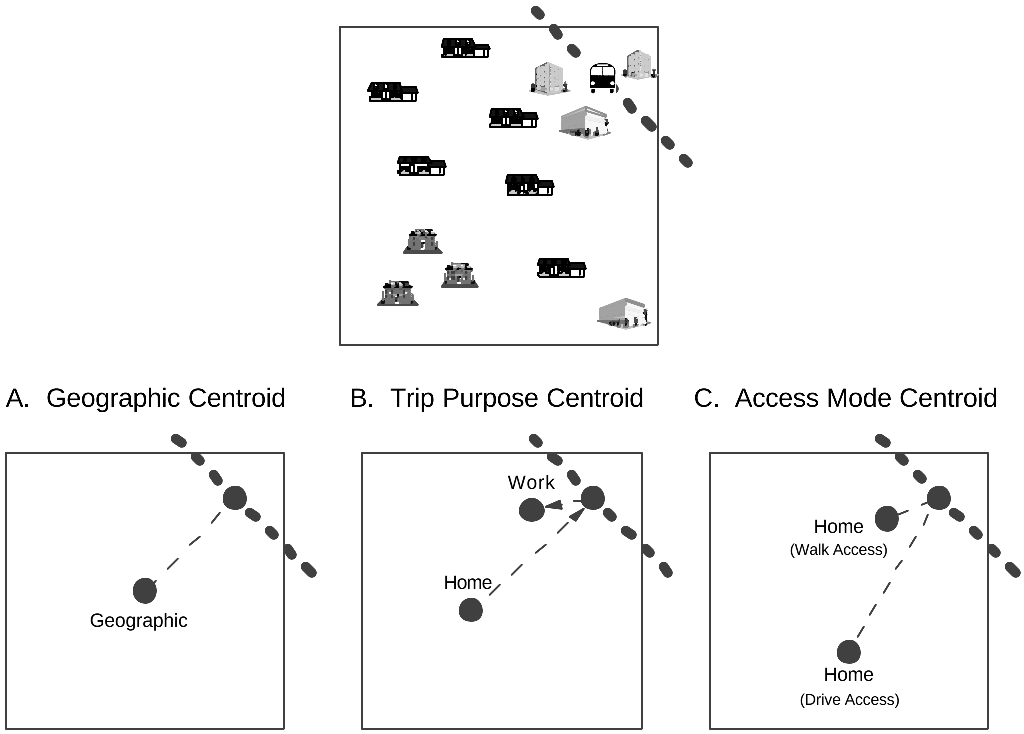
Urban design attributes can be introduced into transit access/egress utilities by changing the way transit access/egress characteristics are measured. Placing smaller zones around transit stations permits access/egress times and distances to be measured more accurately. Zones with reasonable walk to transit access can be distinguished from zones without walk access. Pro-transit urban design policies can then direct new development to walk access zones. Unfortunately, this approach rapidly increases the number of zones in any region with a reasonable amount of transit service. Reducing the zone sizes around rail transit and commuter rail stations in northeastern Illinois from one square mile to quarter-sections would add more than five hundred additional zones.

Transit access/egress quantities in mode choice models are frequently scaled directly from the coded transit network. Adjusting the location of zone centroids according to the trip purposes and choice structure in the mode choice model allows more accurate estimation of transit access/egress characteristics. Different rationales for locating zone centroids are illustrated in Figure 3.

The top diagram in this figure shows the distribution of activities in a zone served by a transit station in the upper right corner. A zone centroid and one or more access links are depicted in the lower three diagrams, which show different approaches for locating zone centroids within the zone. The simplest choice is the geographic center of the zone. Centroid locations can also be weighted by different purpose trip ends, illustrated in the second example by a home centroid and a work centroid. Average distance from households to the station are likely to be different than the average distance from the station to employment. In

A similar approach can be used to locate centroids by transit access mode. In the last example, the walk to station access link distance is measured using centroid coordinates that are weighted by all households within reasonable walking distance of the transit station. The auto to station access link distance is based on centroid coordinates weighted by the remaining households in the zone that are located beyond comfortable walking distance from the station.

Figure 3. Urban Design and Zone Centroid Location



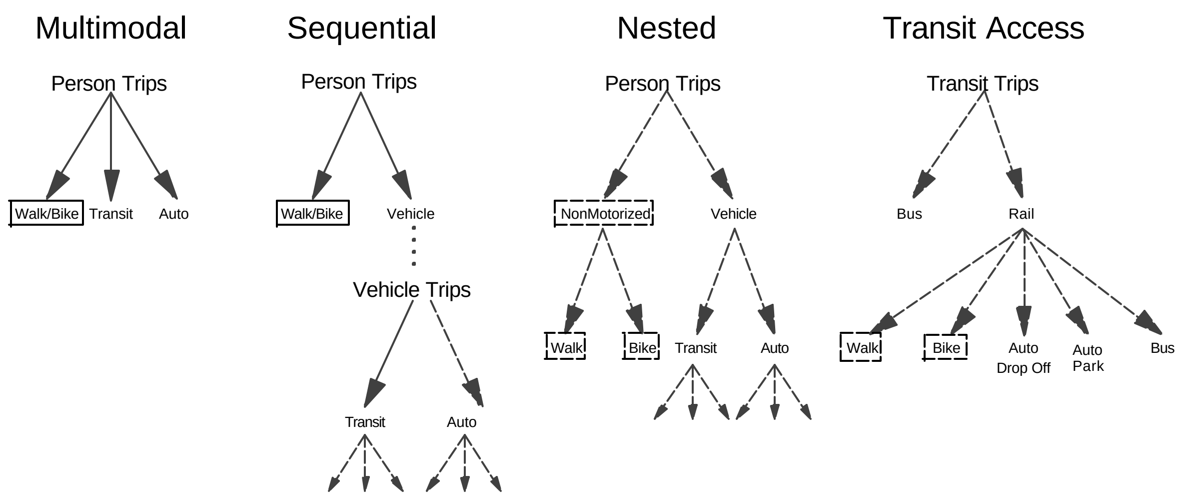
Transit access/egress characteristics for mode choice can be entered into the mode choice model as vectors of network independent zone characteristics and do not have to be traced from the coded transit network. There is no major difference in the calculations that are required, however. Households at the block level, for example, can be used to locate a home centroid for a zone, or they can be combined with transit network coordinates to directly estimate average home to transit distances in the zone.

Estimating transit access/egress characteristics is, without doubt, a good GIS application. If sidewalk information is available as a coverage in the GIS, walking distances to stops and stations can even be measured along a sidewalk network. Block coverages for GIS and block level data for population and households are available from the census. Population and household densities can, therefore, be determined by fairly small geographic units in areas that have reasonable transit service. In northeastern Illinois, the Illinois Department of Employment Securities provides an address file of nearly all employment by Standard Industrial Code, which can be located to blocks.

Nonmotorized-Vehicle Mode Choice Models With Urban Design Variables

A few MPOs have developed mode choice models that include nonmotorized modes as an alternative to vehicle modes. All of these are logit mode choice models, but different model structures have been employed. Figure 4 illustrates several mode choice model structures that have nonmotorized alternatives. Regardless of the structure of the mode choice model, including nonmotorized modes in mode choice requires an estimate of the utility associated with walking and bicycling.

Figure 4. Alternative Mode Choice Models With Nonmotorized Modes



A sequential nonmotorized-vehicle mode choice model was used in the Portland, Oregon, LUTRAQ project[2]. Trips are first split into nonmotorized and vehicle trips, followed by a subsequent split of vehicle trips into different vehicle modes. The reference utility associated with the nonmotorized choice is zero, while the vehicle utility includes independent variables that measure employment densities at the attraction end of the trip, as well as a pedestrian environment factor. Model variables and coefficients for vehicular utilities are listed in Table 2.

The pedestrian environment factor used in the Portland model has four components. These are: (1) sidewalk availability; (2) ease of street crossing; (3) connectivity of the street/sidewalk system, and; (4) terrain. Every zone is given a score between one and three for each of these four components, resulting in a combined pedestrian environment factor for each zone that ranges between four and twelve. The employment variables depend upon the type of trip, but are similar in that all three employment variables measure the amount of employment within one mile of the attraction zone.

Table 2. Vehicle Utility Equations in the LUTRAQ Study

Variable	Home Based Work	Home Based Other	Nonhome Based Work	Nonhome Based
Trip Distance	0.705	0.686	1.998	0.717
Household Car Ownership		-2.205		

2 Cambridge Systematics, Inc.; S. H. Putnam Associates; Calthorpe Associates; Parsons, Brinckerhoff, Quade and Douglas, Inc. *Making the Land Use, Transportation and Air Quality Connection: Volume 4: Model Modifications.* 1000 Friends of Oregon, November, 1992.

1 = If Household Owns Car 0 = No Vehicle				
Low Worker Car Ownership 1 = Household Has Less Than One Car/Worker 0 = Otherwise	-0.954	-0.600		
High Worker Car Ownership 1 = Household Has One or More Cars/Worker 0 = Otherwise	0.408			
Total Employment Within One Mile of Attraction Zone	-0.0000191		-0.0000205	
Retail Employment Within One Mile of Attraction Zone		-0.000135		0.000778
Nonretail Employment Within One Mile of Attraction Zone				-0.000142
Pedestrian Environment Factor	-0.0632	-0.0620	-0.178	-0.167
Bias Constant	1.717	2.697	3.718	3.597

The Sacramento Area Council of Governments[3] developed a set of multimodal logit mode choice models that have walking and bicycle submodes. Independent variables in these models include a pedestrian environment factor identical to the LUTRAQ variable and employment within one mile of the attraction zone. A variable called "partner density," measures both the density of households at the home production zone and density of employment at the work attraction zone in the shared ride mode utility. It is calculated as the log of the number of households within one mile of the home zone times the log of employment within one mile of the work zone.

A variable similar to the LUTRAQ pedestrian environment factor was developed by the Maryland National Capital Parks and Planning Commission[4,5]. This variable appears in the walk/bike transit access utility in a nested mode choice model for home to work trips. It is an index that measures the pedestrian and bicycle environment and includes the factors listed in Table 3. The index ranges from zero to one, with higher values indicating more pedestrian/bicycle friendly environments.

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3 DKS Associates. *Sacramento Area Travel Demand Model: Mode Choice Submodel*. Working Paper 2, Sacramento Area Council of Governments, July, 1993.

4 M. Replogle. *MNCPPC 1988 Logit Mode Choice Model for Home to Work Trips*. Maryland National Parks and Planning Commission, April, 1991.

5 Cambridge Systematics, Inc. with Barton-Aschman Associates. *Short-Term Travel Model Improvements*. Final Report, Travel Model Improvement Program, Technology Sharing Program, U.S. Department of Transportation, October, 1994, p. 3-3.

Table 3. MNCPPC Walk/Bike Index Factors

Factor	Weight
Sidewalks	
No Sidewalks	.00
Discontinuous, Narrow Sidewalks	.05
Narrow Sidewalks Along All Major Streets	.15
Adequate Sidewalks Along All Major Streets	.25
Adequate Sidewalks Along Most Streets With Some Off-Street Paths	.35
Pedestrian District With Sidewalks Everywhere, Pedestrian Streets and Auto Restraints	.45
Land Use Mix	
Homogeneous Land Use Within Easy Walking Distance	.00
Some Walk Accessible Lunch Time Service Retail in Employment Centers	.10
Mixed Land Use at Moderate Density	.20
Mixed Land Use at High Density	.25
Building Setbacks	
Mostly Setback Sprawled Campus Style	.00
Mixed Campus Style But Clustered With Bus Stops Within Walking Distance	.05
Few or No Building Setbacks From Streets With Transit	.10
Transit Stop Conditions	
No Shelters	.00
Some Bus Stop Shelters	.05
Widely Available Bus Stop Shelters	.10
Bicycle Infrastructure	
Little or None	.00
Some Cycle Paths or Routes	.05
Many Cycle Paths, Lanes, or Routes Forming Network	.10

Several vehicle-nonmotorized mode choice models have been calibrated for northeastern Illinois for home to work, home to nonwork, home to transit and non-home trips[6]. The motorized alternative has a reference utility of zero in these models. Variables in the utility for nonmotorized modes' and calibration coefficients are in Table 4.

Table 4. Variables and Coefficients for Nonmotorized Modes' Utility in CATS' Models

	Trip Categories			
	Home to Work	Home to Transit	Home to Nonwork	Nonhome
X+Y Distance	-1.25	-2.02	-1.49	-1.83
Vehicles per Worker in Household 1 = More Than One Car/Worker 0 = Less Than One Car/Worker	-1.43			
Vehicles per Adult		-1.72	-3.45	
Trip Pedestrian Environment	0.039	0.041	0.016	0.081

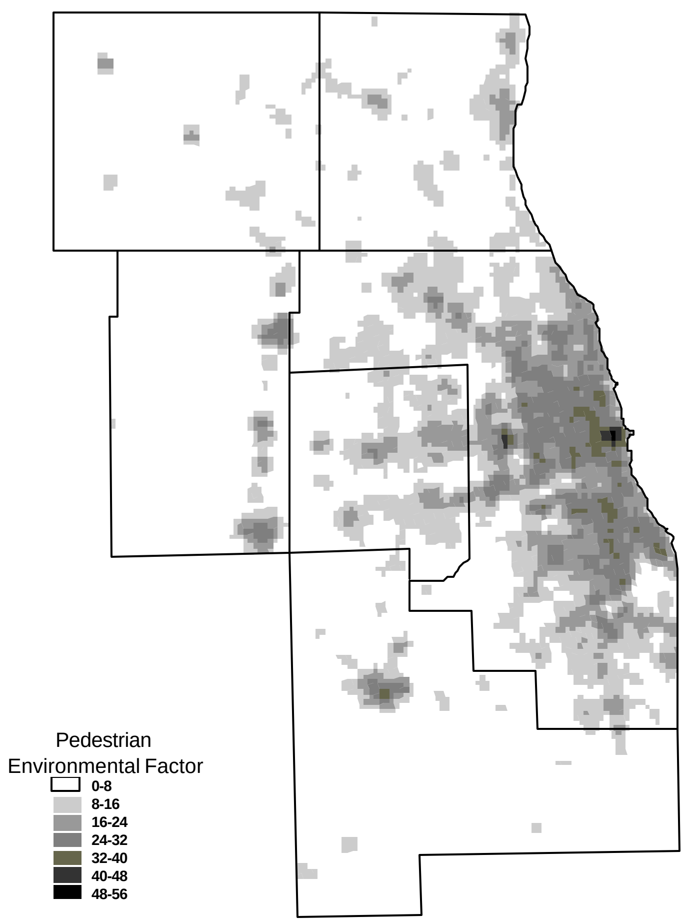
[6] Ronald Eash. "Enhancing Public Transportation and Nonmotorized Modes' Performance in the Regional Transportation Planning Models." *Proceedings, Metropolitan Conference on Public Transportation Research*, University of Illinois at Chicago, June, 1996.

Bias	-0.66	1.73	0.98	-1.59

The signs on the calibrated model coefficients appear correct. Longer distances reduce the utility of the nonmotorized choice. Higher household vehicle ownership should make nonmotorized travel options less attractive. Improved walking and biking conditions, measured by the trip pedestrian environmental factor, increase the utility of the nonmotorized alternative.

The pedestrian environment factor is a zone level measure of the walking and biking environment. It is the number of census blocks in a quarter-section, and it is a surrogate variable that replaces a survey of pedestrian and bicycle facilities. Figure 5 is a map showing quarter-section Pedestrian Environment Factors (PEFs).

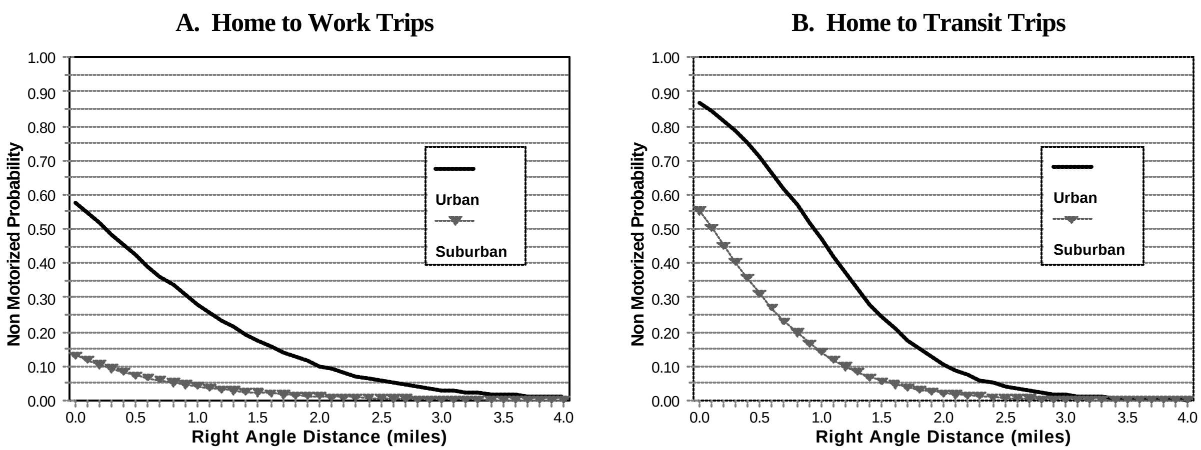
Figure 5. Pedestrian Environment Factors



Highest PEFs are located in the central area, where a one-sixteenth of a mile street grid produces the maximum PEF of sixty-four. A city neighborhood with streets in a one-eighth by one-sixteenth mile pattern has a PEF of thirty-two. Established suburban areas have PEFs ranging from ten to twenty, while newer suburban areas without regular street patterns may have PEFs of five or less. For the mode choice models, the PEFs are averaged over the quarter-sections in the rectangle formed by the trip's origin and destination.

Some model results are shown in Figure 6 to evaluate whether the models' variables seem appropriate. The probability that trips of different lengths are by walk/bike modes is shown for typical suburban and urban households' trips. On the left is home to work trips, on the right, home to transit trips. The urban household used in these mode choice calculations has one auto shared by two drivers, while in the suburban household every driving adult has a vehicle. Average trip PEFs are twenty-five for urban areas with a good pedestrian walking and bike environment and five for suburban areas that are less well suited for nonmotorized travel.

Figure 6. Predicted Nonmotorized Mode Share for Typical Households



A different urban design variable that could be used in mode choice modeling was developed for a study of suburban centers[7]. It is a land use entropy type variable that measures the mix of activities in an area. In the referenced study, it is defined as:

$$\text{Land Use Entropy} = -\sum_{i} LU_i * \log_{10}(LU_i).$$

In this equation, LU_i is the proportion of floor space in one of four land use categories, office, retail, housing and other. This entropy measure ranges from zero when only one land use activity is present in the zone to 0.60 when an equal amount of floor space is allocated to the four activities.

The Impact of Urban Design on Household Vehicle Ownership

An alternate way to introduce urban design variables into mode choice models is through household car ownership, which often appears as an independent variable affecting mode choice.

[7] Robert Cervero. America's Suburban Centers: *A Study of the Land Use-Transportation Link*. Final Report, Technology Sharing Program, U. S. Department of Transportation, January, 1988. p. 57.

In the LUTRAQ study, the previously discussed Portland pedestrian environment factor was included in an enhanced household vehicle ownership model.

The Portland household auto ownership model is a logit discrete choice model, where each choice is a level of household auto ownership. The utility of a household auto ownership level is calculated in much the same way that mode choice utilities are calculated in a logit mode choice model. In the original Portland model, household auto ownership utility was a function of household size, workers in the household, household income level, and the number of employees within thirty minutes of transit travel time of the household. The enhanced household auto ownership model has a revised income variable and includes the PEF variable.

Table 5 is reproduced from the, *Model Modifications* LUTRAQ report[8]. It compares the original household vehicle ownership model and the enhanced model with survey data. Higher auto ownership levels are clearly associated with lower PEFs and the PEF variable consistently improves the fit of the model to survey data.

Table 5. LUTRAQ Auto Ownership Model Results

		Percent of Households		
PEF	Cars	Survey	Original	Enhanced
0 to 5	0	1.5%	2.4%	1.7%
	1	24.2%	26.2%	24.1%
	2	48.3%	47.4%	49.4%
	3+	25.9%	24.0%	24.7%
6	0	2.4%	2.6%	2.4%
	1	23.8%	26.7%	26.0%
	2	50.9%	46.3%	46.7%
	3+	22.8%	24.3%	24.9%
7 to 9	0	7.3%	6.8%	6.8%
	1	36.6%	35.1%	35.6%
	2	40.9%	41.3%	41.1%
	3+	15.2%	16.9%	16.6%
10 to 12	0	12.7%	11.5%	12.8%
	1	38.8%	38.2%	39.0%
	2	36.5%	37.4%	36.0%
	3+	12.0%	13.0%	12.2%

The CATS household auto ownership model is a logit model similar to the Portland model. In the CATS model, the utility of household vehicle ownership depends on the pedestrian environment, which is measured by the number of census blocks in the quarter-section and auto work trip mode share. For calibration, the auto mode share is calculated from the census journey to work data, although in planning applications it would likely come from the mode choice model. It is the number of workers driving, sharing a ride or taking a taxi divided by the total number of workers.

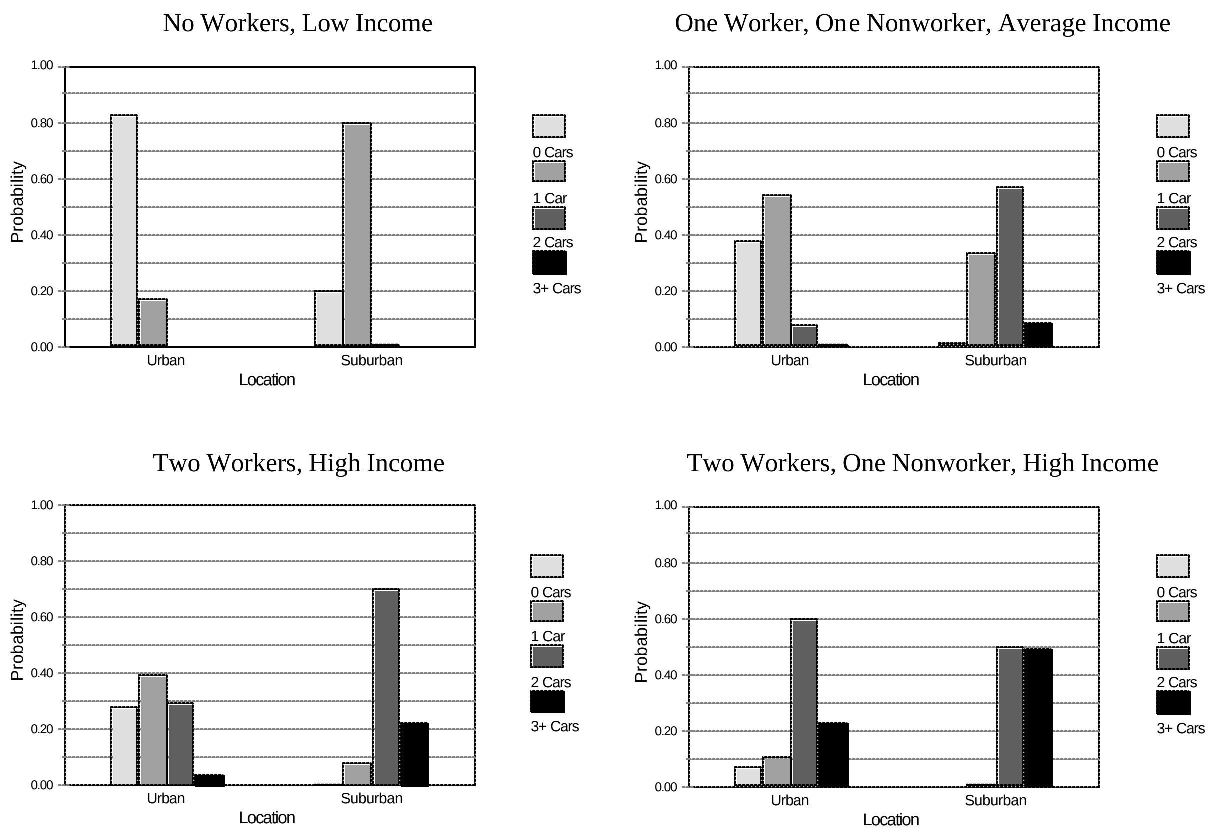
Figure 7 illustrates the behavior of the model for some typical households. These households feature different numbers of workers and nonworking adults and income levels. The distinction between urban and suburban locations is created by different pedestrian environmental factors and auto mode shares. The urban household vehicle ownership examples assume an auto work trip mode share of forty percent and a PEF of twenty-five. Suburban households are located in areas with a ninety percent auto mode share and a PEF of five.

8 Loc. cit. p. 14.

Influencing Destination Choice With Urban Design Variables

Most trip distribution models involve matrix balancing. These models have common inputs, an initial matrix to be balanced, trip productions at origin zones, and trip attractions at destination zones. The matrix to be balanced can be an existing trip table (growth factor methods), some function of zone to zone travel impedances (gravity models), the trip attractions between origin zone and destination zone (opportunity models), or the probability of an origin zone's trip selecting a destination zone (destination choice models). After the matrix balancing is completed, the models output a balanced matrix and the origin and destination zone weights that are required to balance the matrix. The balanced output matrix is a trip table whose row and column sums equal zone trip productions and attractions.

Figure 7. Predicted Vehicle Ownership for Typical Households



Even today, the vast majority of trip distribution models employed by MPOs distribute vehicle trips using travel impedances based upon highway travel times. This approach clearly has to change if alternative urban designs are to have some impact upon trip distribution. Strategies to increase nonmotorized travel cannot be reflected in trip tables, since only vehicle trips are distributed. Further, one can adjust land use to locate more trip productions and attractions in zones that have transit service, but there is no reason to expect these trip productions and attractions to link together into trips that can be served by transit when zone to zone impedances in the model are only highway based.

There is a fairly well established approach for using the composite impedance from a mode choice model in a gravity type distribution model[9]. If the mode choice model is a nested model than even changes in transit access will affect trip distribution when this composite impedance is used in the distribution model. For example, improved walk access to transit increases the logsum transit access variable that is part of the overall transit utility. This makes transit a more attractive choice than previously, which reduces the logsum transit and highway composite impedance used in distribution. Distributed trip interchanges between the zone with the improved transit access and all zones that can be reached by transit would then increase, essentially increasing the overall market for transit.

If vehicular and nonmotorized trips are distributed, the zone to zone composite impedance used for distribution has to measure the difficulty of travel by nonmotorized, as well as vehicular modes. This means a mode choice model that includes nonmotorized travel has to be calibrated before the distribution model is calibrated. Assumptions and network coding that affect intrazonal impedances become especially important when nonmotorized trips are distributed, since many walking trips will not escape the origin zone.

Urban design variables can be incorporated into destination choice models more readily than gravity type trip distribution models. A logit model is used to estimate the probability of choosing from among competing destinations. The utility associated with a destination zone can include variables measuring the socioeconomic characteristics of the traveler, zone to zone travel impedances and destination zone attributes, including urban design variables comparable to those used in mode choice.

Relaxation of the two constraints usually placed upon trip distribution—that row and column totals from the resulting trip table match trip attractions and trip productions—allows the model to assist in matching land use with transportation accessibility. For this application, the distribution model is iterated only a couple of times instead of attempting to fully balance the initial matrix. Comparing intermediate matrix row and column totals against zone trip productions and attractions helps identify those zones that are either over or under developed relative to their accessibility. This is roughly equivalent to examining the zone weights required to balance the matrix.

Household Trip Generation's Sensitivity to Urban Design Variables

Several tests were carried out to evaluate the sensitivity of the CATS household trip generation model to the household environment variables in the agency's auto ownership model. These sensitivity tests only show how the model responds when these variables change, and should not be interpreted as policy testing. The 1990 base household trip generation was pivoted by decreasing the auto work trip mode share and/or increasing the pedestrian environmental factor ten

[9] Cambridge Systematics, Inc. with Barton-Aschman Associates, Inc. "Advanced Travel Demand Forecasting." Course Notes, NHI Course Number 15254, May, 1996.

percent for all households in the region. Both these changes act in the household vehicle ownership model to decrease the number of cars available in a household.

Table 6 summarizes the results of these sensitivity tests. Perhaps the most surprising result is that the number of trips generated by households is fairly insensitive to these two variables. Total household trip generation (motorized plus nonmotorized trips) does decline with reduced household vehicle ownership, but this relationship is much weaker than the relationship between vehicular trip generation and vehicle ownership.

Some changes in household trip making due to lower vehicle ownership levels are still apparent. Trips by workers tend to change less than trips by nonworkers in the household. The implication is that a nonworking adult makes use of "excess" vehicles in the household not required for work trips. Trips between workplaces decline somewhat more than other trips made by workers because private auto is most often used by workers, such as salespersons, who travel between work locations. Shopping trips from work made by workers are nearly constant, while other shopping trips from home decrease.

Table 6. Sensitivity of CATS Household Trip Generation to Work Trip Auto Mode Share and Pedestrian Environment

	Trips Produced by Households (1000s)						
Trip Purpose	1990 Base	-10% Auto Mode Share		+10% Pedestrian Environment Factor		-10% Auto Mode Share and +10% PEF	
Worker							
Home to Work	6,276	6,267	-0.1%	6,269	-0.1%	6,260	-0.3%
Home to Shop	1,256	1,250	-0.5%	1,251	-0.4%	1,245	-0.9%
Home to Other	3,026	3,014	-0.4%	3,015	-0.4%	3,003	-0.8%
Work to Shop	350	351	0.3%	350	0.0%	350	0.0%
Work to Other	1,307	1,298	-0.7%	1,300	-0.5%	1,291	-1.2%
Work to Work	931	914	-1.8%	919	-1.3%	901	-3.2%
Nonhome/Work	1,085	1,079	-0.6%	1,080	-0.5%	1,073	-1.1%
Nonworker							
Home to Shop	1,345	1,319	-1.9%	1,325	-1.5%	1,300	-3.3%
Home to Other	2,846	2,813	-1.2%	2,825	-0.7%	2,791	-1.9%
Nonhome	1,076	1,047	-2.7%	1,055	-2.0%	1,026	-4.6%
Child							
Home to Nonhome	591	587	-0.7%	587	-0.7%	582	-1.5%
Total	20,090	19,941	-0.7%	19,976	-0.6%	19,824	-1.3%

Simulation Models

This last section briefly looks at trip simulation as an alternative to the conventional four step travel demand models. Trip simulation offers an advantageous framework for considering the impacts of urban design variables upon travel behavior since it reduces the need to average model input variables across analysis zones. One of the features of the TRANSIMS framework is its simulation of individual travelers between trip origins and destinations, rather than between zone centroids[10].

[10] C. Barrett, K. Berkbigler, L. Smith, V. Loose, R. Beckman, J. Davis, D. Roberts, and M. Williams. *An Operational Description of TRANSIMS*. Los Alamos National Laboratory, June, 1995.

The CATS mode choice model is a simulation model that was originally developed in the 1970s[11]. Figure 8 summarizes the essential logic of the model. There are three major nested logic loops in the model, incremented by origin zone, destination zone and person trip. Four sets of calculations are completed for each person trip: (1) auto operating costs based on average travel speed and distance traveled; (2) transit access and egress costs and times to be combined with the transit line-haul data input into the model; (3) non-CBD auto parking costs and walking times at the beginning and end of the trip, and; (4) CBD parking costs and destination walk time when the destination zone is a CBD zone

The transit access-egress and CBD parking submodels are Monte Carlo simulations that generally work in the same fashion. They obtain an access-egress characteristic for a trip, such as distance from home to a rail station, by randomly sampling a distribution of the access-egress characteristics. For the distance between home and a rail station, the frequency distribution of station access distances weighted by all households in a zone is sampled.

Access-egress times and costs for auto and transit are combined with the modal line-haul times and costs and entered into a logistic equation, which calculates the probability that the trip is by transit. Since trips between the same two zones can have different access-egress characteristics, the transit mode choice probability can vary for each trip between the same pair of zones, just as it does in the real world for individuals traveling between the same two zones. A trip is then assigned to either transit or highways using another Monte Carlo simulation. Transit and auto trips are finally accumulated for the interchange.

This variability in zone transit access-egress time and cost corresponds to the distribution of trip origins and destinations within zones. Simulating access-egress characteristics in this way gets around the theoretical problem of using zone level average access times and costs, which can be unrepresentative of the actual conditions faced by transit users. It also provides a convenient means of representing different spatial relationships between activities by varying the distributions of transit access/egress characteristics.

[11] Yehuda Gur, Elizabeth Lowe, Anant Vyas, and Eugene Ryan. "Urban Modal Split Modeling Using Monte Carlo Simulation." Chicago Area Transportation Study, 1973.

Figure 8. CATS Mode Choice Model's Logic