Specifying, Estimating, and Validating a New Trip Generation Model: Case Study in Montgomery County, Maryland

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The development of an afternoon peak-period trip-generation model for both work and nonwork trips is discussed. Three data sources are used in model development: a household travel survey, a census update survey, and a trip generation study. Seven one-direction trip purposes are defined, specifically accounting for stops made on the return trip from work to home. Trips are classified by origin and destination activities rather than by production and attraction, reframing the conventional schema of home-based and non-home-based trips. Before the model was estimated the household travel survey was demographically calibrated against the census update to minimize demographic bias. A model of home-end trip generation is estimated using the household travel survey as a cross-classification of the demographic factors of age and household size in addition to dwelling type. Non-home-end generation uses employment by type and population. The model was validated by comparison with a site-based trip generation study, which revealed an underreporting of the relatively short and less regular shopping trips. Normalization procedures were developed to ensure that all ends of a chained trip were properly accounted for.

This paper discusses the procedures used to specify, estimate, and validate a trip-generation model for both work and nonwork trips. The model's temporal focus is on the afternoon peak period (3:30 to 6:30 p.m.) because it is used, among other applications, for staging development to ensure adequate transportation facilities. Studies in Montgomery County, Maryland, have demonstrated that transportation capacity is more of a constraint during the afternoon peak period due to increased non-work travel (*1*). This paper attempts to comprehensively account for travel by defining trip sequencing patterns. Modeling chained trips also requires some redefinition of conventional normalization procedures, which are described later. By accounting for all modes in trip generation (driver, passenger, transit, walk, and bicycle), it is possible to apply a comprehensive mode choice model that captures the dynamics of changing travel behavior.

The development of an afternoon peak-period travel model has received scant attention in the transportation literature even though temporal clustering of daily trips is a well understood phenomenon. In addition, the models constructed by transportation analysts in most metropolitan planning organizations primarily emphasize the journey to work. The rationale for the attention given to the work trip is easy to understand. Although work trips account for only about one-quarter of total household trips, their priority rests on their fixed route, their regularity, and their length (work trip distances are longer on average than the distances of nonwork trips). Moreover, the decennial census reports transportation data only on commuter characteristics. However, recent literature brings out the growing importance of nonwork trips and the need to correctly specify nonwork purposes (*2*).

Ongoing efforts have been made by the Montgomery County Planning Department (MCPD) of the Maryland–National Capital Park and Planning Commission (MNCPPC) to develop a transportation planning model, covering metropolitan Washington and Baltimore, that is sensitive to some of the concerns raised against the conventional model applications (*3*). The most recent version of the MCPD transportation planning model, TRAVEL/2, attempts to account for interdependence among trips by looking at specific activities pursued at each trip end; this is discussed by Levinson and Kumar in another paper in this Record. The model framework is sensitive to changes in demographic structure and spatial organization. Peak-period trip distribution models are developed consistent with the trip purposes defined in trip generation. A multimodal gravity model formulation is used in trip distribution (*4*). The model adjusts travel demand in response to changes in transportation network supply and estimates traffic conditions prevailing during the afternoon peak hour. This paper examines how the trip generation component of the transportation planning model can better include changes in demographics and behavior to improve travel demand estimation.

As the subsequent steps in modeling travel demand are based on estimates derived from the trip-generation stage, the validity of the assumptions in the trip-generation analysis are crucial to the overall quality of the forecasts. After discussing the data used for model estimation, the specific trip purposes used in the study are defined by origin and destination activity. An attempt is made to explicitly account for stops made on the return trip from work, including a discussion of model normalization procedures. Trip-generation factors are estimated for each trip purpose. The model is validated against the site-based person Trip Generation Study.

DATA

Three primary data sources were used in this research. The 1987–1988 Metropolitan Washington Council of Governments (MWCOG) *Household Travel Survey* was used for model estimation (*5*). The Montgomery County Planning Depart-

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ment's *1987 Census-Update Survey* allowed the correction for sampling bias in the survey (*6*). The *Montgomery County Trip Generation Study* conducted from 1986 to 1988 provided a means to validate the model against site-based trip generation rates (*7*).

MWCOG Household Travel Survey

The data on demographics and travel behavior were obtained from the *1987–88 Household Travel Survey*. This was the first major regional travel survey conducted in the Washington area since 1968. More than 20,000 randomly selected households in the regions were contacted by telephone and asked to record all trips made by members of their household for a preselected weekday. Approximately 8,000 of these households, making 55,000 trips, completed and returned by mail the travel diaries sent to them. Up to three follow-up calls were made to each household to obtain completed travel diaries.

The data collection for this survey was conducted in two segments. The first segment was conducted from March to July 1987, and the second segment was conducted from March to July 1988. The initial survey design was to collect 2,000 samples each for the District of Columbia, Maryland, and Virginia. Montgomery County and the city of Alexandria contracted with MWCOG to collect additional samples in their jurisdictions, resulting in just under 1 percent of Montgomery County residents being sampled. In 1988, the Maryland counties of Charles and Frederick were added to the survey and an additional 500 samples were collected for each of these jurisdictions. The number of completed samples from each of the jurisdictions is given in Table 1.

Household data from the MWCOG Round IV Cooperative Forecasts were used to expand the survey results to regional control totals. The survey data were adjusted to match regional household size and vehicle ownership characteristics using marginal weighting techniques. Because these survey data were a nonrepresentative sample, they were corrected for sampling bias.

Montgomery County Census-Update Survey

The Montgomery County Planning Department collects demographic and some basic travel data for Montgomery County every 4 years to supplement the decennial census data. The 1987 census update is based on a 5 percent sample and was conducted during April 1987. This survey updated information previously reported in the 1980 U.S. Census, providing information more specific to current planning issues in Montgomery County. About 22,000 survey forms were mailed to a carefully designed random sample of county households, and nearly 63 percent of the 13,900 recipients voluntarily sent back valid responses. Collected data were adjusted on the basis of known household and school enrollment distributions to provide reliable county information.

TABLE 1 Sample Size by Jurisdiction

Jurisdiction	No. of Completed Samples	Household Size (in '000)	Sample Size (%)
Washington, DC	1,952	250	0.78
Montgomery County, MD	1,827	280	0.65
Prince George's County, MD	992	263	0.38
Arlington County, VA	266	48	0.55
Alexandria City, VA	378	79	0.48
Fairfax County, VA	1,059	328	0.32
Loudoun County, VA	258	31	0.83
Prince William County, VA	288	89	0.32
Frederick County, MD	481		
Total	7,501	1,368	0.55

Montgomery County Trip Generation Study

Douglas & Douglas, Inc., assisted by Gorove/Slade Associates, Inc., and Dynamic Concepts for data collection, performed a comprehensive study of person and vehicle trip generation for several important land-use types for sites in Montgomery County, Maryland. The number of trips made to and from a total of 162 sites were surveyed, including 79 commercial office buildings, 59 residential sites, 15 shopping centers, and 9 fast food restaurants. Vehicle occupancy and walk in and out were separately observed from vehicle trips to obtain person trip rates. The study has produced a trip-generation data set based on a statistically reliable and randomly selected collection of development sites.

CORRECTING FOR BIAS IN HOUSEHOLD TRAVEL SURVEY

The key data base used to estimate trip-generation coefficients and rates was the *1987–88 Household Travel Survey*. However, as observed earlier, this survey, although rich in describing travel behavior, was based on a less than 1 percent sample in Montgomery County. Because the county also conducts a survey to update the census that is based on a 5 percent sample, it was possible to calibrate the household travel survey to the larger sample. The hypothesis of this exercise is that the household travel survey does not truly represent all segments of the population. Thus, there is a need to compensate for the underrepresentation of particular groups to properly replicate the observed population distribution as a prerequisite to estimating true travel behavior from the survey. This section focuses on the differences among some of the demographic variables between the two surveys and the rationale for calibrating the household travel survey. A detailed methodology on calibrating the two sets is provided by Kumar (*8*).

To examine the differences between the two sets, a cross-tabulation (Table 2) was prepared displaying the number of dwelling types (single family, townhouses, apartments), by the number of persons in the households (1, 2, 3, and 4 plus), by the gender of the household head, for both the MWCOG household travel survey and the MCPD census update samples. Though the definition of household head can never be specific, it is important to identify single-parent females who are heads of households, because they represent a growing proportion of the population and often occupy lower ranks in the household income distribution. Underrepresentation of households with a female head carries the implication of underrepresenting low-income households.

TABLE 2 Number of Households by Gender of Household Head, Size, and Dwelling Type

Household Size		Dwelling Type: Single Family	Town-House	Multi-Family
Male household head				
1	C-U	4512	2587	10300
	COG	6386	4250	10756
	% Diff.	41.5%	64.3%	4.4%
2	C-U	38084	8818	15381
	COG	47744	13390	1151
	% Diff.	25.4%	51.8%	-92.5%
3	C-U	24684	6309	5522
	COG	34296	8282	4017
	% Diff.	38.9%	31.3%	-27.3%
4+	C-U	46009	7998	4882
	COG	70938	10602	2473
	% Diff.	54.2%	32.6%	-49.3%
Female Household head				
1	C-U	8637	3706	23050
	COG	9082	5065	19512
	% Diff.	5.2%	36.7%	-15.3%
2	C-U	9506	4622	10315
	COG	10748	2763	4814
	% Diff.	13.1%	-40.2%	-53.3%
3	C-U	5415	1672	3747
	COG	3185	1396	1749
	% Diff.	-41.2%	-16.5%	-53.3%
4+	C-U	4777	1429	1078
	COG	3875	746	351
	% Diff.	-18.9%	-47.8%	-67.4%

Note: C-U: MCPD Census Update Survey, 1987
COG: 1987/88 MWCOG Household Travel Survey

The percentage difference between the household travel survey and the census update is displayed in the third row of each classification type in Table 2. Three observations can be made from this table:

- Persons living in apartments are underrepresented in the household travel survey sample;
- Persons living in single-family detached and single-family attached (townhouse) housing units, especially male-headed households, are overrepresented in the household travel survey; and
- Female-headed households with two or more persons in townhouses and three or more persons in single-family detached homes are also underrepresented in the household travel survey.

A relatively simple procedure was developed to normalize some key variables (gender, household size, and dwelling type) in the household travel survey with the census update. The expectation is that using a richer data base as a benchmark to calibrate a household travel survey will better represent travel behavior of underrepresented population segments. In the absence of better information on travel behavior, it is difficult to calculate confidence limits of the calibrated data sets. It is hoped that with the availability of a detailed longitudinal travel panel survey currently being undertaken by the Montgomery County Planning Department, some of the data problems can be resolved (*9*).

DEFINITIONS OF TRIP PURPOSE

Conventional Definition of Trip Purpose

As a matter of convention, two categories of trip purpose are defined: home-based and non-home-based (NHB) trips. A home-based trip is any trip in which one end of the trip is at home—that is, it may have either started or ended at home. The home-based trips are typically further classified into home-based work (HBW), home-based shop (HBS), and home-based other (HBO) trips. For the HBW trip, the zone of production is the home end of the trip, whereas the zone of attraction is the work end of the trip. Thus, a trip from home to work in the morning and a return trip from work to home in the afternoon will be characterized by two productions from home and two attractions to work. The origin and destination are not considered synonymous with production and attraction. This scheme of trip accounting may work consistently if the model is used to calibrate daily travel demand, because over the 24-hr period, almost every trip originating from home returns to home later in the day.

Revised Definition of Trip Purpose

For developing a model to estimate travel during a part of the day, however, each trip end has to be explicitly accounted for because the trips may not be balanced within the selected period. A trip here is defined as a one-way movement. Thus, the HBW trip in the morning is almost always a home-to-work trip, with home as the origin and the workplace as the destination. In the afternoon, it is usually a work-to-home trip, with workplace as the origin and home as the destination. Similarly, the HBO trip may involve going shopping and returning home.

There are two primary reasons to classify trip only by one-way movements: (a) if the concern is with travel during a specific time period, it is important to classify trips by origin and destination (rather than as productions and attractions), because the return trip may not be performed within the same time period; and (b) trip-length distributions for the two legs of a chained trip are different from both the traditional HBO and from the NHB categories.

For example, going from one shopping center to another will have an average shorter trip length than going from work to pick up groceries on the way home. Both could be considered NHB in the conventional definitions. An analysis of trip-length distributions for metropolitan Washington demonstrates this (*10*).

For these reasons, following the procedure for chained trips discussed later, the trip purposes shown in Table 3 were identified. Table 3 also presents person trip volumes for each trip purpose during the afternoon peak period. Only about 29 percent of the trips are direct work to home. It is interesting to observe that almost 12 percent of the trips involve stopping on the way, which conventionally would be considered NHB.

Accounting for Chained Trips

A major problem in developing an afternoon trip-generation model is accounting for chained trips, where a stop for a nonwork activity is introduced on the journey from work to home to satisfy daily needs. Travelers more frequently stop to shop, eat, or visit friends on their way home from work than on their way to work. An analysis of the MWCOG household travel survey indicates that during 1988 almost 30 percent of commuting trips during the afternoon peak period involved a stop for nonwork activities (*11*). Though the intermediary stop is likely to be a pass-by trip on the way home, the possibility of a longer detour cannot be overlooked. Among other things, such trip "linkages" are a function of life-cycle stage (for example, households with children are more likely to make pick-up and drop-off stops). This makes it useful to consider household trip generation as a function of age of the trip maker.

To properly analyze afternoon travel behavior, it was necessary to distinguish complex chained trips from the simpler single-purpose trips. The trip records in the household travel survey identify trip purpose at both origin and destination ends. For example, a trip from home to work is identified with home as the origin purpose and work as the destination purpose. This information was used to link commuting trips with intermediary stops for nonwork purposes

In the afternoon, the most significant chained trip is on the journey from work to home. For trips with work as the origin purpose and destination purpose other than home, the destination purpose was matched with the origin purpose of the subsequent trip. This procedure was repeated until home was reached as a destination. All intermediary trips were considered to be linked trips on the return journey from work.

For simplicity, the model was estimated assuming only one stop. Multiple intermediary stops were combined with the other-to-other category for trip generation and distribution. Thus a commuting trip during the afternoon period can be identified as either work-to-home or work-to-other-to-home.

TABLE 3 Afternoon Peak-Period Person Trips by Purpose (*5*)

Trip Purpose	Trip Volumes	%
Unchained Work Trips		
1. Work-to-Home	768,246	28.9
Chained Work Trips		
2. Work-to-Other	329,409	12.4
3. Other-to-Home	307,384	11.6
Sub-Total	636,793	23.9
Afternoon Home to Work Trips		
4. Home-to-Work	50,668	1.9
Nonwork Trips		
5. Home-to-Other	409,742	15.4
6. Other-to-Home	535,648	20.1
7. Other-to-Other	258,120	9.7
Sub-Total	1,203,510	45.3
TOTAL PERSON TRIPS	2,659,217	100.0

Source: 1987/88 Metropolitian Washington Council of Governments Household Travel Survey

Afternoon Home-to-Work Trips

The home-to-work trips identified in this classification deserve special mention. The nature of these work trips during the afternoon with home as the origin is very different from commuting trips as commonly understood, warranting their separate classification. The home-to-work trips during the afternoon peak period are more likely to be associated with part-time and service workers with a very different trip distribution and mode choice as compared to the regular morning commuters. This particular trip purpose is expected to become more important in future years, particularly with changing life styles and demographics.

NORMALIZATION PROCEDURES

For work trips, the rates developed for the home end are assumed to be the most accurate, and for nonwork trips the rates developed for the non-home end (primarily retail) are assumed to be the most accurate. After the number of trips originating in or destined for a given traffic zone is computed, it is necessary to assure that the total number of trip origins equals the total number of trip destinations, because each trip interchange by definition must have two trip ends. There are several techniques for doing this, and depending on which data are considered more accurate, different results might be obtained. For the trip purposes, one trip end is fixed, and the second trip end is adjusted. Or in the case of chained trips, one of the three trip ends may be fixed, and the other two adjusted. Table 4 highlights the normalization assumptions used in model application.

TABLE 4 Normalization Assumptions

Trip Purpose	Origin	Destination
Unchained Work Trips		
Work-to-Home	Adjusted	Fixed
Chained Work Trips		
Work-to-Other	Adjusted	Adjusted
Other-to-Home	Adjusted	Fixed
Afternoon Home to Work Trips		
Home-to-Work	Fixed	Adjusted
Nonwork Trips		
Home-to-Other	Adjusted	Fixed
Other-to-Home	Fixed	Adjusted
Other-to-Other	Fixed	Adjusted

The basic equation for normalization is as follows:

$$p_i = p_i \frac{\sum_{j=1}^{J} q_j}{\sum_{i=1}^{I} p_i}$$

For chained trip purposes, normalization requires two equations:

$$p_i' = p_i \frac{\sum_{k=1}^{K} r_k'}{\sum_{i=1}^{I} p_i}$$

$$r_k' = r_k \frac{\sum_{j=1}^{J} q_j}{\sum_{k=1}^{K} r_k}$$

where

i, j, k = origin, destination, and intermediate zones, respectively;
p_i, q_j, r_k = trips generated in origin, destination, and intermediate zones, respectively; and
p_i, r_k = adjusted trips generated in origin and intermediate zones, respectively.

Obviously, with this formulation, there is no guarantee of directionality for chained trips. Treating the different legs of the trips by using separate trip matrices prevents explicit tracking of specific trips. Thus, in a gravity-type distribution model using standard matrix balancing procedures, the work-to-other leg may go in one direction, and the other-to-home leg may go in any direction to which destinations are attracted. However, data from MWCOG suggest that almost 75 percent of these stops are closer to home than to work (*11*). Therefore, even if the direction is different, the other-to-home trip is shorter than the work-to-other.

MODEL ESTIMATION

For the estimation of trip-generation factors, three primary trip ends are defined: work, home, and other. Although "home" and "work" are conventionally defined, "other" includes all trip ends other than home or work (e.g., retail, visit friends, recreation).

Home-End Trip Generation

For the home trip end, a separate person-based trip production estimating procedure is used for each trip purpose. The dependent variable is trips per person. The independent variables are dwelling type (single or multiple family), household size (1, 2, 3, 4, or 5 plus persons per household), and person age. The single-family household type includes both detached (house) and attached (townhouse) structures. A cross-classification scheme based on household size, dwelling type, and age is developed to determine trips per person by purpose. Figure 1 shows a typical example of how trips vary by age, in this case for work to home trips, for three-person households in both single-family and multiple-family residence types.

The use of age as a variable was decided on to avoid area-specific trip-generation factors. One of the key reasons for different trip-generation rates in different areas is the age of the population. Older neighborhoods, before gentrification, often have older populations. Although the demographic model used as input to this trip generation model is exogenous to transportation variables, it does reflect changing age structure resulting from varying births, deaths, and working age population. The demographic model outputs are in 5-year age cohorts for over 20 subareas within Montgomery County. The more elderly population in the more urban areas of the county results in different trip generation than do young families starting out in the newer suburbs. As areas age, their trip-making characteristics can be expected to change. The age variable can capture this change.

Non-Home-End Trip Generation

The trip-generation rates for both work and "other" trip ends were developed using ordinary least squares (OLS), relating trips to employment by type and population characteristics. The variables used to estimate trip rates for the work-end are employment in offices (OFFEMP), retail (RETEMP), and other (OTHEMP).

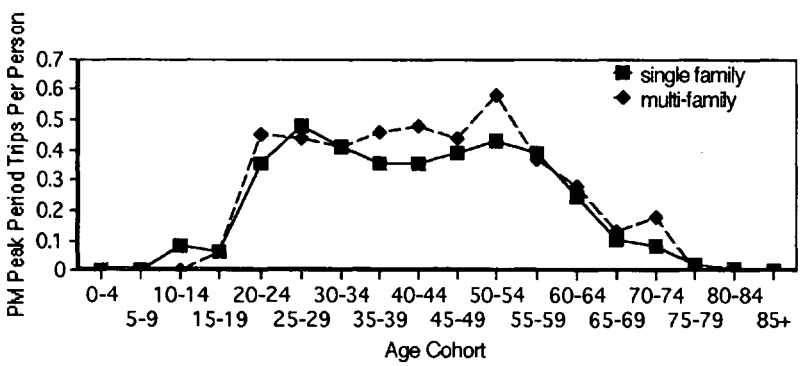

FIGURE 1 Life cycle trip generation—work to home trips, one-person household size.

A standard form of the equation can be expressed as:

$$T_i = B_1 \times \text{OFFEMP}_i + B_2 \times \text{RETEMP}_i + B_3 \times \text{OTHEMP}_i$$

where

T_i = person trips attracted per worker in ith zone,
OFFEMP_i = office employment in ith zone,
RETEMP_i = retail employment in ith zone,
OTHEMP_i = other employment in ith zone, and
B_1, B_2, B_3 = model coefficients.

A regression analysis was conducted for each trip purpose. Montgomery County was divided into 22 areas for this analysis. Base land-use activity numbers for each policy area were obtained from the county's tax assessors file by the MCPD. The results are displayed in Table 5; the significance of each variable is reported in the t-statistic. It may be noted that the intercept term of the regression equations was forced to pass through origin so that the coefficient would represent the number of trips per person. For other trip ends, both retail employment and demographic factors are used. As with the work end, regression analysis was conducted for each trip purpose.

MODEL VALIDATION

As noted above, the trip-generation coefficients at the nonhome end were initially estimated using the *1987–88 Household Travel Survey*. These results were compared with those obtained from the *Montgomery County Trip Generation Study* performed from 1986 to 1988 by Douglas & Douglas, Inc., for both office and retail trips. The work trips per office employee were almost identical between the two sources, whereas the retail rates were significantly higher in the trip generation study.

A comparison with the trip generation study revealed underreporting of trips at the "other" end. The household travel survey estimated about one "other" trip per retail employee. The trip generation study, which contained the square footage by site for retail centers (which was multiplied by estimates of employees per square foot), gave estimates of five "other" trips per retail employee. Underreporting of retail trips in a cross-sectional survey is not unusual. People are more likely to accurately report work trips because of their regularity. Retail trips, on the other hand, may involve short trips or trips from one retail center to another and are therefore more likely to be missed. A preliminary analysis of the Montgomery County longitudinal travel panel survey, which asked respondents for detailed travel information, also brought out the nature of the underreporting in the general-purpose cross-sectional survey (*8*).

Person trip generation rates for the nonhome end of nonwork trips were used from the trip generation study to correct the model. However it is not possible to obtain trip-purpose by trip-ends from this study because it is site based. For instance, a trip leaving a retail site may be going home (other to home) or to another retail center (other to other). The

TABLE 5 Trip Coefficients by Purpose (Afternoon Peak Period)

Trip Purpose	Variable	Trip Coeff.	T-Stat.	Adj. Coeff.
Unchained Work Trips				
	OFFEMP	0.50	22.42	0.50
Work-to-Home (Origin end)	OTHEMP	0.36	3.95	0.35
	RETEMP	0.09	0.47	0.10
Chained Work Trips				
	OFFEMP	0.19	20.08	0.19
Work-to-Other (Origin end)	OTHEMP	0.16	4.02	0.16
	RETEMP	0.01	0.14	0.01
Work-to-Other (Destination end)	POP	0.03	3.20	0.03
& Other-to-Home (Origin end)	RETEMP	0.56	6.04	0.56
Afternoon Home to Work Trips				
	OFFEMP	0.00		0.00
Home-to-Work (Destination end)	OTHEMP	0.01	0.80	0.01
	RETEMP	0.14	1.99	0.14
Nonwork Trips				
Home-to-Other (Destination end)	RETEMP	0.22	1.83	1.10
	POP	0.10	7.49	0.10
Other-to-Home (Origin end)	RETEMP	0.22	1.93	1.10
	POP	0.14	10.52	0.14
Other-to-Other (Both ends)	RETEMP	0.20	4.41	3.20
	POP	0.05	10.75	0.05

Note: Trip coefficients at the home end are calculated by a cross-classification scheme based on household size, dwelling type, and age. Detailed tables can be obtained from the authors on request

distribution among different trip purposes was assumed similar to that obtained from the household travel survey. Table 5 shows the RETEMP coefficients from the household travel survey before and after adjustment using the trip generation study.

CONCLUSIONS

This paper covers two important applications: (a) integrating several survey data sets and using a benchmark data set to validate model results and (b) specifying an afternoon peak-period trip-end trip-generation model in an attempt to better replicate travel demand and capture the intermediate stops that characterize many of the trips from work to home. Related research indicates that chained work trips are a significant component of afternoon travel. Simplifying these trips, or misclassifying them, would clearly lead to an misreporting of total travel. Classification of chained work trips, such as work-to-shop-to-home as nonwork trips or non-home-based trips will result in a misspecification of the model.

The person-based afternoon peak-period trip-generation model estimated uses three factors—age, household size, and dwelling type—to determine trip generation. Other factors affecting trip-making behavior for both work and nonwork trips, such as income and accessibility, will be used in further refinements of the model as better data become available. Efforts are under way in Montgomery County to collect these data as part of the ongoing longitudinal travel panel survey. Changing behavior over time, such as the increase in female labor force participation, has also altered trip generation. Any future attempt to validate this model's output against historical data needs to account for this changing behavior.

Transportation planning models are becoming increasingly important because of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. Major decisions are being affected by the outputs of transportation planning models. Trip generation, as the first stage in travel demand estimation, is extremely important in the final outcome of model results.

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