Specifying, Estimating, and Validating a New Trip Generation Model:

A Case Study of Montgomery County, Maryland

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ABSTRACT

This paper discusses the development of an afternoon peak period trip generation model for both work and non-work trips. 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, so reframing the conventional schema of home-based and non-home-based trips. Prior to estimating the model, 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 under-reporting of the relatively short and less regular shopping trips. Normalization procedures are developed to ensure that all ends of a chained trip were properly accounted for.

INTRODUCTION

This paper discusses the procedures used to specify, estimate, and validate a trip generation model for both work and non-work trips. The model's temporal focus on the afternoon peak period (3:30 - 6:30 p.m.) was decided upon 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). A specific attempt in this paper is made to comprehensively account for travel by defining trip sequencing patterns. The modeling of chained trips also necessitates some redefinition of conventional normalization procedures, which are described later. By accounting for all modes in trip generation (driver, passenger, transit, walk, and bike), application of a comprehensive mode choice model which captures the dynamics of changing travel behavior is possible.

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 non-work trips). Moreover, the decennial Census reports transportation data only on commuter characteristics. However, recent literature brings out the growing importance of non-work trips and the need to correctly specify non-work 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, sensitive to some of the concerns raised against the conventional model applications (3). In the most recent version of the MCPD transportation planning model, TRAVEL/2, an attempt is made to account for interdependence among trips by looking at specific activities pursued at each trip end (4). 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 multi-modal gravity model formulation is used in trip distribution (5). 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 looks specifically at 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 a discussion of the data used for model estimation, the specific trips 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 of the trip purposes. The model is validated against the site based person Trip Generation Study.

DATA

Three primary data sources were used in this research. The 1987-88 Metropolitan Washington Council of Governments (MWCOG) Household Travel Survey was used for model estimation (6). The Montgomery County Planning Department's 1987 Census-Update allowed the correction for sampling bias in the survey (7). The Montgomery County Trip Generation Study conducted from 1986-88 provided a means to validate the model against site based trip generation rates (8).

Metropolitan Washington Household Travel Survey

The data on demographics and travel behavior is obtained from the 1987-88 Metropolitan Washington Council of Governments (MWCOG) 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 region were contacted by telephone and asked to record all trips made by members of their household for a pre-selected 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 done in two segments. The first segment was conducted between March and July, 1987; the second segment between March and July, 1988. The initial survey design was to collect 2,000 samples each in 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% 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. This survey data was used after correcting for sampling bias because of a non-representative sample, which is discussed below.

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.

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, utilizing 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 THE HOUSEHOLD TRAVEL SURVEY

The key data base used in estimating trip generation coefficients and rates was the 1987-88 MWCOG Household Travel Survey. However, as observed earlier, this survey, although rich in describing travel behavior, was based on a less than one percent sample in Montgomery County. As the county also conducts a Census-Update survey which is based on a five 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 under-representation of particular groups to properly replicate the observed population distribution as prerequisite to estimating true travel behavior from the survey. This section focuses on differences in some of the demographic variables between the two surveys and the rationale for calibrating the Household Travel Survey. Detailed methodology on calibrating the two data-sets is provided in (9).

To examine the differences between the two data-sets, a cross-tabulation (Table 2) was prepared displaying number of dwelling types (single family, town houses, apartments), by number of persons in households (1, 2, 3, and 4+), by sex 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 female headed households as they represent a growing proportion of the population and often occupy lower ranks in the household income distribution. Under-representation of households with a female head carries the implication of under-representing low-income households.

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:

1. Persons living in apartments are under-represented in the Household Travel Survey sample;

2. Persons living in single-family detached and single-family attached (townhouse) housing units, especially male-headed households, are over-represented in the Household Travel Survey; and

3. Female-headed households with two or more persons in town houses and three or more persons in single family detached homes are also under-represented in the Household Travel Survey.

A relatively simple procedure was developed to normalize some key variables (sex, 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 under-represented population segments. In 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 (10).

DEFINITION 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 where 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, while 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, since over the 24-hour 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 since the trips may not be balanced within the selected time 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 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), as 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 home-based other and from the non-home-based categories.

As an example, going from one shopping center to another will have on average shorter trip length then will going from work to pick up groceries on the way home. Both could be considered Non-Home Based in the conventional definitions. Analysis of trip length distributions for metropolitan Washington bears this out (11).

For these reasons, following the procedure for chained trips discussed below, the trip purposes shown in Table 3 were identified. Table 3 also displays person trip volumes for each of the trip purposes 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 Non-Home-Based.

Accounting for Chained Trips

A major problem in developing a PM trip generation model is accounting for chained trips, where a stop for a non-work 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 Metropolitan Washington Council of Governments Household Travel Survey indicates that during 1988 almost 30 percent of commuting trips during the PM peak period involved a stop for non-work activities (12). Though the intermediary stop is likely to be a pass-by trip on the way home, the possibility of a longer detour can not 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/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 non-work 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: a) work-to-home, or b) work-to-other-to-home.

Afternoon Home to Work Trips

The "home to work" trips identified in this classification deserve special mention. The nature of these work trips during 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 most accurate, and for non-work trips the rates developed for the non-home end (primarily retail) are assumed to be 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, since each trip interchange by definition must have two trip ends. There are several techniques for doing this, and depending upon 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.

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, intermediate zones respectively

p_i, q_j, r_k - trips generated in origin, destination, intermediate zones

p'_i, r'_k - adjusted trips generated in origin, intermediate zones

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 models using standard matrix balancing procedures, the “work to other” leg may go in one direction, while the “other to home” leg may go in any direction to which destinations are attracted. However, data from Metropolitan Washington suggest almost 75% of these stops are closer to home than to work (12). 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. While “home” and “work” are conventionally defined, “other” includes all trip ends other than home or work (retail, visit friends, recreation, etc.).

Home-End Trip Generation

For the “home” trip end, a separate person-based trip production estimating procedure is used for each of the trip purposes. 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+ persons per household), and person age. The single family household type includes both detached (houses) and attached (townhouses) 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 multi-family residence types.

The use of age as a variable was decided upon 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, prior to gentrification, often have older populations. While 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 sub-areas within Montgomery County. The more elderly population in the more urban areas of the county result 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, something that the age variable can capture.

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 in estimating trip rates for the work-end are Employment in Offices (OFFEMP), Retail (RETEMP), and Other (OTHEMP).

A standard form of the equation can be expressed as:

$$T_i = B_1 \times OFFEMP_i + B_2 \times RETEMP_i + B_3 \times OTHEMP_i$$

Where: T_i - Person trips attracted per worker in the ith zone

$OFFEMP_i$ - office employment in the ith zone

$RETEMP_i$ - retail employment in the ith zone

$OTHEMP_i$ - other employment in the ith zone

B_1, B_2, B_3 - model coefficients

A regression analysis was done for each of the trip purposes. Montgomery County was divided into 22 areas for this analysis. Base land use activity numbers for each of these policy areas was 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 done for each of the trip purposes.

MODEL VALIDATION

As noted above, the trip generation coefficients at the non-home end were initially estimated using the 1987/88 Metropolitan Washington Council of Governments Household Travel Survey. These results were compared with those obtained from the Montgomery County Trip Generation Study performed from 1986-88 by Douglas & Douglas for both office and retail trips. The work trips per office employee were almost identical between the two sources, while the retail rates were significantly higher in the Trip Generation Study.

Comparison with the Montgomery County Trip Generation Study revealed under-reporting 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. Under-reporting of retail trips in a cross-sectional survey is not very surprising. 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. Preliminary analysis of the Montgomery County Longitudinal Travel Panel

Survey, which asked respondents for detailed travel information, also brought out the nature of the under-reporting in the general purpose cross-sectional survey (9).

Person trip generation rates for the non-home end of non-work 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 as 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 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: (1) integrating several survey data sets and using a benchmark data set to validate model results, and (2) 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 non-work 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 the three factors of age, household size, and dwelling type to determine trip generation. Other factors affecting trip making behavior for both work and non-work trips such as income and accessibility will be used in further refinements of the model as better data becomes available. Efforts are currently underway in Montgomery County to collect this 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.

ACKNOWLEDGEMENTS

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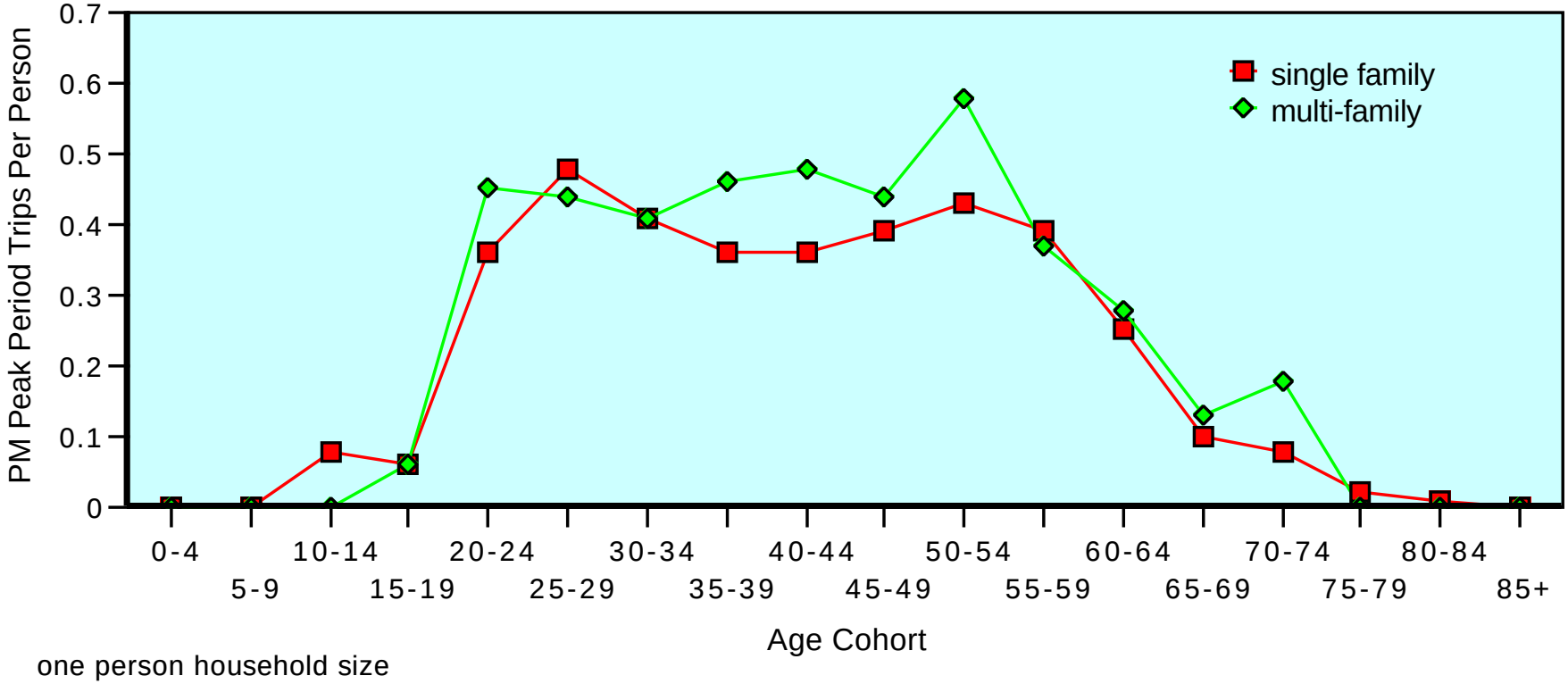
Life Cycle Trip Generation

Work to Home Trips



one person household size

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

Table 2:
Number of Households by Sex of the Household Head, by 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

Table 3:
PM Peak Period Person Trips By Purpose

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

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

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