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Metropolitan Washington Council of Governments

FY-2005 Development Program
for
TPB Travel Forecasting Models

DRAFT

June 30, 2005

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The Metropolitan Washington Council of Governments (COG) and the National Capital Region Transportation Planning Board (TPB).

COG serves as the regional planning organization for the Washington metropolitan area. COG works toward solutions to regional problems, especially those related to regional growth, transportation, housing, human services, and the environment. The TPB is the designated Metropolitan Planning Organization (MPO) for transportation for the Washington region. Members of the TPB include representatives of local governments; state transportation agencies; the Maryland and Virginia General Assemblies; the Washington Metropolitan Area Transit Authority; and non-voting members from the Metropolitan Washington Airports Authority and federal agencies.

Credits

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Abstract: This report describes work activities undertaken during FY-2005 supporting improved travel forecasting methods for the metropolitan Washington, D.C. region. This work represents a continuation of an ongoing models development plan that was formulated in FY-93 by the Travel Forecasting Subcommittee (TFS), a subcommittee of the TPB's Technical Committee.

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Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

This report documents technical work activities that have been undertaken to fulfill the FY-2005 COG/TPB work program in the area of Models Development (Unified Planning Work Program, or UPWP element III.C.) The Models Development program area functions to maintain and improve the travel forecasting methods applied by the TPB staff for regional and project planning studies. TPB presently uses a conventional four-step travel modeling process known as the Version 2.1D #50 model. The model is applied on microcomputer workstations using the TP+ software platform and is designed to operate on a 2,191 TAZ system. Four-step forecasting models are commonly used to support regional planning activities in most major metropolitan areas.

Implementing advanced modeling methods into practice presents some practical concerns. While the TPB requires acceptable procedures to serve regularly scheduled planning work during the year, there are inherent uncertainties about when specific modeling improvements will be ready for production use. The Models Development program is designed to manage uncertainty by including both short-range and long-range model improvement activities. The program is structured along five concurrent 'tracks' as listed below:

- **Track 1 – Application:** Short-term improvements made to the currently adopted travel model while more advanced models remain in development.   These improvements consist of, for example, updates to coefficients with newly collected data or building additional capabilities to the existing model structure.

- **Track 2 – Methods Development:** Longer-term improvements involving the incorporation of advanced forecasting methods that are not yet operational. Methods improvements may be associated with a structurally advanced 4-step model or a 'next generation' model. At some point the 'methods' model will replace the application model.

- **Track 3 – Research:** Keeping abreast of advanced travel forecasting theory that has not yet made its way into accepted transportation planning practice.

- **Track 4 - Data Collection:** Collecting travel information to serve the needs of the above tracks.

- **Track 5 - Maintenance:** Promoting guidance on the model application through information sharing, documentation and training.

The Models Development program has evolved along these five tracks since its inception in FY-1993. The multi-track approach allows for longer term improvements to proceed off-line while the application model is maintained, with minor refinements, to support immediate planning needs in the mean time. The longer-term improvements are brought into the application track only when deemed appropriate. The work program is formally reviewed and monitored by the TPB Travel Forecasting Subcommittee (TFS). The TFS is a subcommittee to the TPB Technical Committee and is comprised of representatives from state and local transportation agencies in the

Washington, D.C. region, and the Washington Metropolitan Area Transit Authority (WMATA). The TFS also encourages the participation of consultants working in the region and various public interest groups. The TFS meets on a bi-monthly schedule to keep subcommittee members apprised of the program's progress and to discuss technical issues associated with program activities. TFS members have a stake in monitoring models development activities as the regional travel model is commonly used (or adapted) to support a host of state and local planning studies.

Work activities associated with each track are mapped out over several fiscal years so that the necessary data is in place to serve short- and long-term improvement needs. Specific activities associated with each track are formulated by TPB staff based on recommendations of formal model reviews, emerging study needs, changes in federal guidance, and funding levels.

1.1 *FY-2005 Work Program Background*

The first TP+ based travel forecasting model used in production, known as the Version 2.1/TP+ Release C model, was released by the TPB during FY-2003[1]. The Version 2.1 model included several advanced features, including time of day traffic assignment procedures and explicit work and non-work mode choice models. During FY-2004, the Version 2.1 model was thoroughly reviewed by an expert panel appointed by the Transportation Research Board of the National Research Council[2]. The expert review process culminated in two letter reports transmitted to the TPB on September 8, 2003 and April 26, 2004. The first letter provided the panel's assessment of the Version 2.1 travel model specification and performance, and the post processor used to estimate mobile source emissions. The second letter provided the panel's comments on the future direction of the TPB's models development program, addressing the TPB's proposed future work program, data collection needs, and zone system grain. The recommendations that resulted from the expert review were heavily considered in formulating the Models Development program for the second half of FY-2004 and beyond. The following improvement areas were identified:

1) Improve Overall Performance – The panel felt that the model performance associated with daily highway link volumes and transit ridership should be improved.
2) Develop a Model of Commercial Travel - The panel suggested that commercial/business travel should be modeled explicitly instead of subsuming it within the non-home-based (NHB) trip purpose.
3) Improve Bus Speed Treatment – The panel suggested that the TPB should explicitly relate bus speeds to highway congestion as an alternative to the current method of preserving fixed speeds based on existing scheduled running times.
4) Minimize Adjustments – The panel advised that external adjustment factors, such as K-factors in trip distribution model, should be used sparingly and any remaining factors should be justified.

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[1] MWCOG, "COG/TPB Travel Forecasting Model / Version 2.1/TP+, Release C, Calibration Report," December 2002," December 2003

[2] The expert panel consisted of seven individuals, a chairman, two academic scholars, two consultants, and two MPO practitioners.

5) Incorporate the Mode Choice Model in the Speed Feedback Loop – The panel recommended that the mode choice process should be included inside the speed feedback loop, along with trip distribution, as an alternative to running the mode choice model once and bypassing the mode choice model during subsequent feedback loops.
6) Promote Travel Model / Mobile Emissions Model Consistency – The panel advised that greater consistency between the link volumes produced by the traffic assignment and the hourly volumes developed as part of the mobile emissions post processor should be established.

During the late FY-2004 through the first half of FY-2005, TPB staff began implementing as many of the above improvements as staff felt could be reasonably accomplished in the near term. The Version 2.1D Draft #50 model was a product of that effort. The key improvements consisted of revising the volume-delay function (VDF) function used in the equilibrium traffic assignment process which improved simulated link volume performance, the incorporation of the mode choice model into the speed feedback process, and a substantial reduction in the number of adjustment factors used in the model (K-factors in particular). A method for linking future bus speeds to highway congestion was also implemented. In addition, the mobile emissions post-processor was also improved to address the expert panel's concerns.

The activities documented in this report reflect the staff efforts to continue the implementation of the six improvement areas since the release of the 2.1 D Draft #50 model.

1.2 *FY-2005 Activities Described in This Report*

The quality of observed travel data and land use data have been the subject of discussion at several recent TFS meetings. During FY-2005, staff examined the impact of refining the traffic count data used to validate the travel model. Traffic count quality is obviously important as it relates to model performance issues as well as to the use of model adjustment factors. A discussion of this analysis is presented in Chapter 2.

Data collection to support the development of a commercial/business vehicle model began at the end of FY-2005 and will continue into early FY-2006. The survey sampling plan and a status report of the data collection effort are presented in Chapter 3. The data collection is not only important for developing a commercial vehicle model, slated for completion by the end of FY-2006, but will also be used to update the TPB's medium and heavy truck modeling process during FY-2007.

During FY-2005 TPB has established a continuing dialog with WMATA, local consultants engaged in transit project planning, and various transportation agencies to keep apprised of mode choice model work that has been in development. TPB plans to take advantage of the technical knowledge and methods developed as part of project planning work to begin implementing a nested logit mode choice model for the region during FY-2006. A status report of this project is presented in Chapter 4.

The Models Development work program has in recent years included a work element for investigating the development of an airport access model for the region. This element is included in the FY-2005 work program, but has been assigned a much lower priority given other more immediate recommendations that have emerged from the expert review. The existing airport modeling procedures are presented in Chapter 5. The current thinking about issues associated with a more elaborate airport access model is also included.

Staff is planning to update demographic models with 2000 CTPP information during FY-2006. Chapter 6 describes the demographic data that has been compiled in anticipation of updating the demographic models which are used to apportion total households among size, income, and vehicle availability groups.

Chapter 7 details staff activities that have been undertaken to keep abreast of best practices in the field. The activities include conference attendance and participation in two working groups with other MPOs. Finally, Chapter 8 describes the Models Development program elements that are anticipated for FY-2006 and beyond.

Chapter 2 Review of Observed Traffic Counts

The TRB review of the TPB's Version 2.1 C travel model placed emphasis on the subject of model performance, simulated link volume performance in particular. In response, TPB staff focused on this area in subsequent development work. The documented year 2000 performance of the currently adopted Version 2.1 D #50 travel model is notably improved in comparison with the prior Version 2.1 C model. The estimated-to-observed ratio of the overall daily screenline crossings declined from 1.17 to 1.08 and the percent root mean square error (RMSE) was reduced from 52% to 47%. The improvement in model performance was achieved essentially by adjusting model parameters and by refining inputs to the travel model. A more robust assessment of modeling performance should additionally take into consideration the quality of the observed data used to validate the model, in this case, the coded ground counts. Observed information is typically regarded as a 'given' and is rarely analyzed for accuracy, reliability, or consistency. Though commonly ignored, observed information is subject to various and significant sources of error that should be taken into account. It is the analyst's challenge to exercise good judgment in evaluating both the estimated and observed figures before adjusting the model.

During FY-2005 TPB staff had an opportunity to analyze traffic counts in detail and to investigate how the travel model performance changes as the traffic count quality is enhanced. It was determined that traffic count quality did affect modeling performance notably. The analysis also indicated that changes should be considered regarding how traffic count data are collected and how traffic counts are coded in the highway network.

This first section of this chapter addresses some background on the Highway Performance Monitoring System (HPMS) program from which traffic counts are obtained, and its connection to travel modeling practice. Next, a description of the HPMS information in the Washington region is presented. Finally, an overview of the traffic count analysis is described and conclusions are made.

2.1 *Highway Performance Monitoring System Background*

Traffic counts serve as the 'yardstick' for validating the regional travel model and for providing a quantitative basis for measuring performance. Regional highway networks generally include, at minimum, a daily directional count field as a dedicated network link attribute so that simulated link volumes can be easily compared and various performance summaries can be generated. The following types of performance metrics are typical of most regional travel models:

- Estimated-to-observed traffic volume ratios for all links with coded counts, and for links associated with screenlines
- Estimated-to-observed vehicle miles traveled (VMT) ratios by facility type, area type, and jurisdiction
- Coefficient of Determination (R^2) when observed traffic volumes are compared with estimates
- Percent Root Mean Square Error of link volumes, summarized for the entire system and by facility type

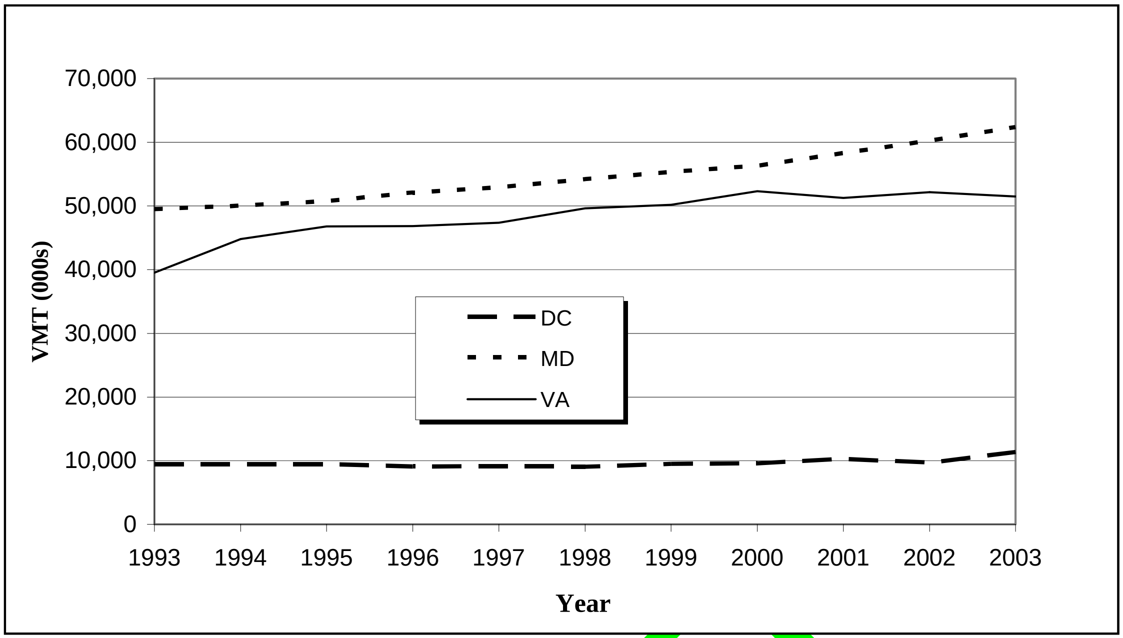
Given the increasing complexity of conventional travel models and the stringent modeling requirements associated with mobile emissions estimation procedures in non-attainment areas, there is an obvious need for more detailed traffic count data at the link level, for example, counts by time period and/or by vehicle type. Most metropolitan areas, including Washington, do not currently have regional traffic counts at this level of detail.

The primary data source of ‘observed’ average daily traffic counts is the HPMS. The HPMS is a national highway information system that serves one of many reporting requirements to the Federal Highway Administration (FHWA). The primary function of the HPMS is to assist Congress in determining the scope and size of the Federal-aid Highway Program and to determine Federal highway taxation. Data collection supporting the HPMS is administered on a state-by-state basis and addresses the size and composition of the highway system as well as the level of highway use. The regional VMT published in HPMS reports is especially important to travel forecasters in non-attainment areas, as Environmental Protection Agency (EPA) requirements mandate that base year modeled VMT should not only agree with HPMS figures, but also should ‘track’ with HPMS VMT figures over time.

The VMT published in HPMS reports is not based on a count of all highway sections of the state, but instead, is based on a comprehensive *sample* of observed traffic counts that represent the various Federal Aid Urbanized Area (FAUA) facility classifications. Considering that the sampled traffic counts must be expanded to arrive at the total universe of statewide VMT, the HPMS observed VMT figures are actually *estimated* observed figures. There are some important limitations that should be considered in the context of metropolitan area travel modeling, regarding the use of HPMS data. The HPMS system is intended to provide national information based on statewide sampling. In other words, the VMT is representative of highway facilities throughout each state, and is not necessarily representative of a specific metropolitan area. This issue is complicated in the Washington area given that regional VMT is the combination of independent estimates submitted by Maryland, Virginia, and the District of Columbia.

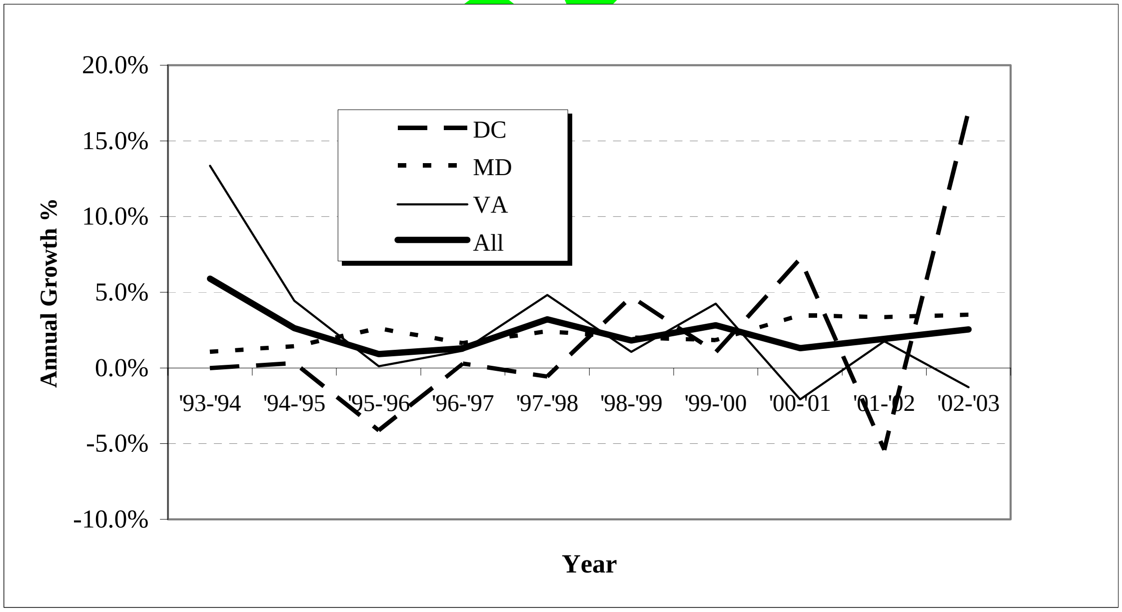
TPB staff recently compiled time series comparisons of published VMT for the Washington D.C. Metropolitan Statistical Area (MSA), as provided by Maryland, Virginia, and District of Columbia. Figure 2-1 shows the average daily VMT between 1993 and 2003, as published by HPMS sources. The figure indicates that VMT growth is more pronounced in Northern Virginia and suburban Maryland compared to that of the District of Columbia, reflecting the suburban growth that has taken place over the ten-year period. A closer examination of the annual VMT growth for the region and by state is shown on Figure 2-2. The figure shows that average growth rate in VMT for the entire MSA is generally around 2 to 3 percent. Further, the Maryland change rate appears constant over the decade, in contrast to the growth rates of Virginia and the District, which are shown to be more volatile and often moving in opposite directions. There is no clear reason why the growth rates are different even though the data reflects the same metropolitan area. The differences do suggest that there is some level of error in the traffic counts or in the traffic count expansion technique used to develop the aggregate VMT.

Figure 2-1 Daily VMT for the Washington MSA Over Time, by State



(Source: FHWA Highway Statistics, MDSHA Web site, VMT Information Provided to MWCOG by VDOT)

Figure 2-2 Annual Daily VMT Change for the Washington MSA, by State



(Source: FHWA Highway Statistics, MDSHA Web site, VMT Information Provided to MWCOG by VDOT)

2.2 *HPMS Data in the Washington Region*

The TPB obtains regional traffic count information from three transportation agencies, the District of Columbia Department of Transportation (DDOT), the Maryland State Highway Administration (MDSHA), and the Virginia Department of Transportation (VDOT). Daily traffic counts have historically been manually coded onto highway links using paper maps and traffic count books. More recently GIS aided procedures have been implemented to enable electronic coding. The traffic counts are coded by direction in the highway network, although the vast majority of published traffic counts are provided as non-directional, or two-way, figures (directionality is not of interest in developing daily vehicle miles of travel). The directional counts are computed by simply dividing the published two-way count by two.

The TPB codes average annual weekday traffic counts (AAWDT) into the network as the travel surveys used to calibrate models reflect weekday travel behavior. As of the year 2000, AAWDT counts are furnished by DDOT and VDOT, while average annual daily traffic (AADT) counts are provided by MDSHA. The conversion factor for adjusting AADT to AAWDT figures is currently 1.05.

The traffic counts are collected at either permanent count stations, where continuous traffic data is mechanically recorded throughout the year, or at more numerous program counting locations, where short-term (24-/48-hour) traffic counts are recorded with pneumatic tube systems. There are approximately 60 permanent counting stations and 1,500 program count locations in the Washington D.C. region. There are several levels of data adjustments once counts are collected. The 'raw' traffic counts commonly require manual adjustments to account for equipment failure or atypical conditions (weather, construction, or other events) that might have been detected during the collection period. Equipment failure possibilities pertain to both program and permanent counts. Data collection at program count locations rotates on a three-year cycle. This means that only one third of program counting locations are actually surveyed during any given year while counts assumed at the remaining locations are carried forward from previous years or are growth factored. To convert short-term traffic counts into annualized estimates at program counting locations, seasonal, monthly, and daily factors are computed from the statewide permanent counting data. It is important to recognize that adjustments developed with statewide data may not be representative of the metropolitan region. Given these considerations, the HPMS traffic 'counts' are in actuality annualized *estimates* of traffic flows that are subject to error as a result of numerous adjustments.

Another source of error pertains to how traffic counts are coded in the highway network. Model performance accuracy is dependent on how well traffic counts are coded with respect to centroid connection nodes. The exact location of arterial counts in many instances is not known and the placement of a given count is left to the judgment of the analyst. TPB has historically interpolated counts or coded a single observed count value on to several contiguous links in order to maximize the observed link coverage. These types of coding practices may contribute to error in the performance statistics.

Finally, TPB has historically reported performance statistics for the entire modeled area, which is comprised of jurisdictions that lie beyond the non-attainment area. The network grain outside of the non-attainment area is particularly coarse and is therefore more subject to 'lumpy' traffic assignment loadings. It is now recognized that the performance statistics should pertain to the non-attainment area, where the network grain is more accurate and where model results are of greatest relevance to the planning process.

2.3 *Relationship between Model Performance and Quality of Ground Counts*

TPB staff has recently revisited the year 2000 performance of the Version 2.1D #50 model using refined 'test sets' of observed data. The purpose of the analysis was to investigate how model performance was impacted by the quality of observed data. The model performance was originally assessed on the basis of 11,000 directional highway links containing observed counts throughout the modeled area (both inside and outside of the MSA). There were three test sets of observed data that where analyzed.

Test Set #1 - All permanent station and all program counting locations actually counted during the year 2000 or synthetically estimated from a prior year (2,953 directional links in the MSA and 3,595 directional links in the modeled area). This set of observed data represented moderate traffic count quality.

Test Set #2 - All permanent station and program counting locations that were actually counted during 2000 (1,194 directional links). This set of observed data represented improved traffic count quality compared with Test Set 1.

Test Set #3 – Only permanent count stations (68 directional links). This set of observed data represented the highest quality of traffic counts compared with Test Sets 1 and 2.

It is important to point out that all three test sets were constrained to locations within the MSA and were associated with specific count locations, and so links with interpolated counts and instances where the same count was used for multiple contiguous link segments were omitted from the analysis. Finally, a 1.05 factor for converting AADT counts in Maryland to AAWDT counts was assumed. Previously, a conversion factor of 1.10 was assumed.

The results of the analysis, shown on Table 2-1, indicate that the model performance does improve with the quality of the traffic count data. The percent root mean square error (RMSE) was found to improve from the original value of 47% to values of 45%, 40%, and 18% for Test Sets #1, 2 and 3, respectively. R-square values also show marked improvements with higher quality data.

Table 2-1 Comparison of Sample Size, % RMSE, and R-Square of Traffic Count Analysis Groups

Sample Description	Obs.	RMSE	%RMSE	R^2
V2.1D#50 Model Validation Performance	*11,004*	*8.01*	*47.21*	*0.84*
Permanent Station and Program Counts - Actual & Factored	2,953	7.12	44.89	0.89
Permanent and Actual Program Counts	1,194	5.80	40.33	0.92
Permanent Counting Stations	68	6.65	18.04	0.96

Estimated and observed scatter plots were also prepared to investigate possible biases that might exist for specific volume ranges. Figure 2-3 shows the scatter plot for the original validation data for the V2.1 D #50 model. The figure indicates a notable under-estimation of observed counts at the higher volume range, i.e., the linear regression line drops below the line of perfect agreement. The same plots corresponding to Test Sets 1, 2, and 3 are shown on Figure 2-4, Figure 2-5, and Figure 2-6 respectively. This bias is reduced substantially with the improved data. Finally, estimated and observed VMT and screenline summaries were prepared, using observed counts for the modeled region, i.e., 3,595 directional links. This corresponds to Test Set #1, but without the MSA constraint. The VMT summary is shown on Table 2-2, and the screenline performance is shown on Table 2-3. Maps showing screenline locations appear on Figure 2-7 and Figure 2-8. The performance shown at this level is comparable to the documented performance in the Version 2.1D #50 calibration report.

2.4 *Conclusions*

An in-depth discussion has been presented regarding technical issues relating to observed count data used to validate the TPB models. There are several sources of error that exist around observed counts collected to support the HPMS that should be acknowledged. An analysis to evaluate model performance when the quality of observed data is improved has shown that aggregate statistics such as the R-squared and %RMSE do improve when the traffic count quality is enhanced. Biases in the model detected earlier (i.e., the tendency to underestimate high volume facilities) is largely removed with higher quality counts.

Ground count coding practices should be changed. The previous practice of coding interpolated count values should be discontinued. Also coding a single count to multiple links should be discontinued, as well. These practices introduce error into the performance statistics.

The number of high quality counts (i.e., counts collected at permanent counting stations) is quite limited in the Washington region. The TPB should work with local agencies to develop counts from a metropolitan area sample frame as opposed to the statewide sampling that is currently the basis of traffic count sampling.

Finally, the performance statistics generated from the travel model should be reported for the MSA area as opposed to the larger modeled area which includes jurisdictions outside of the non-attainment area. The performance in the outer jurisdictions is subject to coarse network coding, and moreover, modeling performance in the outer areas are not relevant to the TPB air quality planning area. The purpose in coding networks into these outer jurisdictions is to improve the performance of the modeling process within the MSA.

Figure 2-3 Validation E/O Scatter Plots

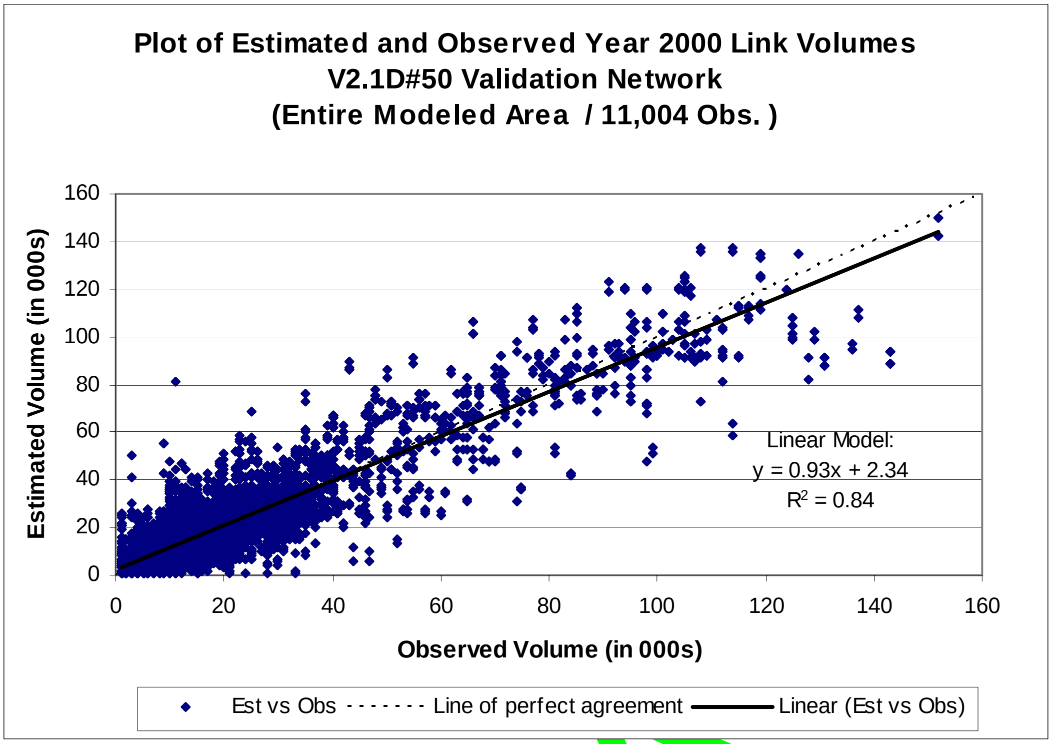


Figure 2-4 Permanent /Actual & Factored Program Counts

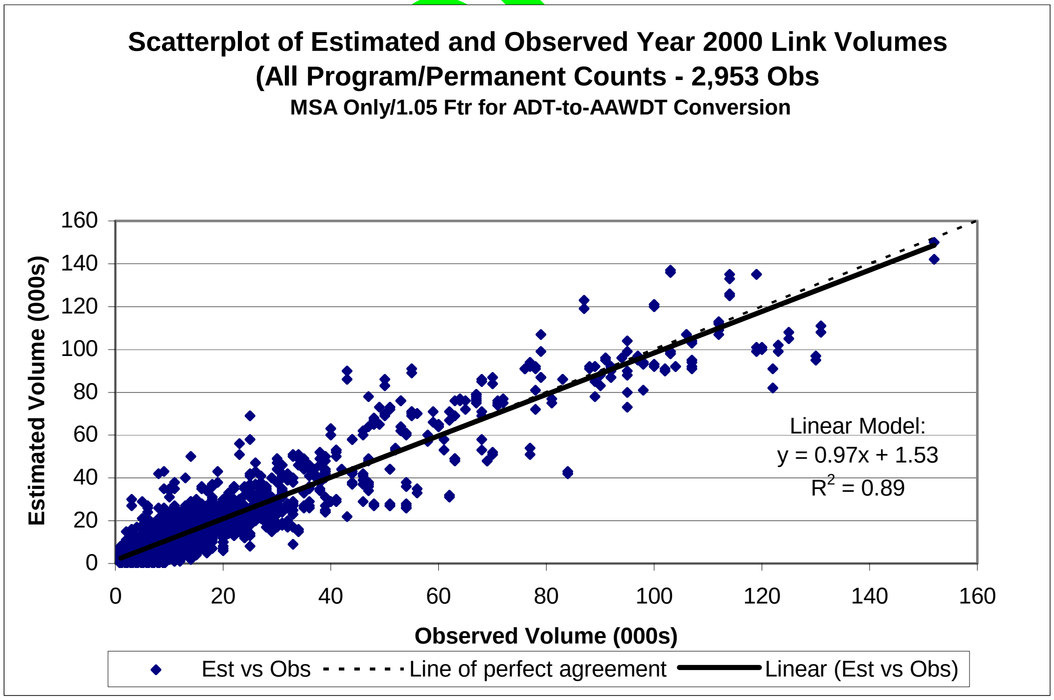


Figure 2-5 Permanent /Actual Program Counts

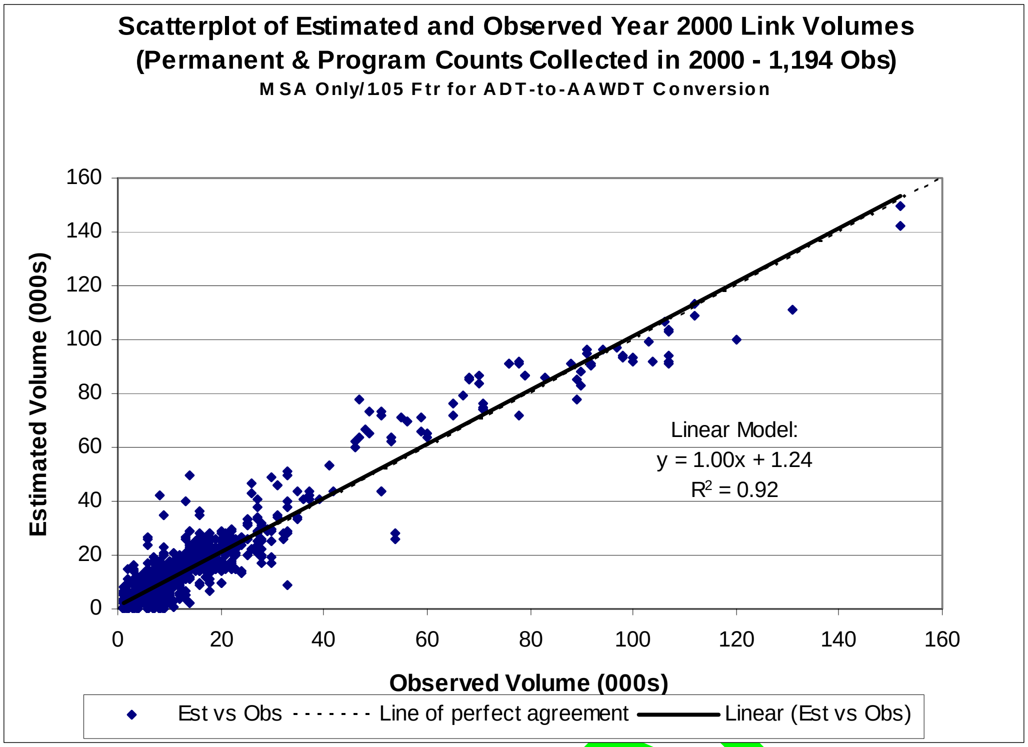


Figure 2-6 Permanent Count Stations – 68 Observations

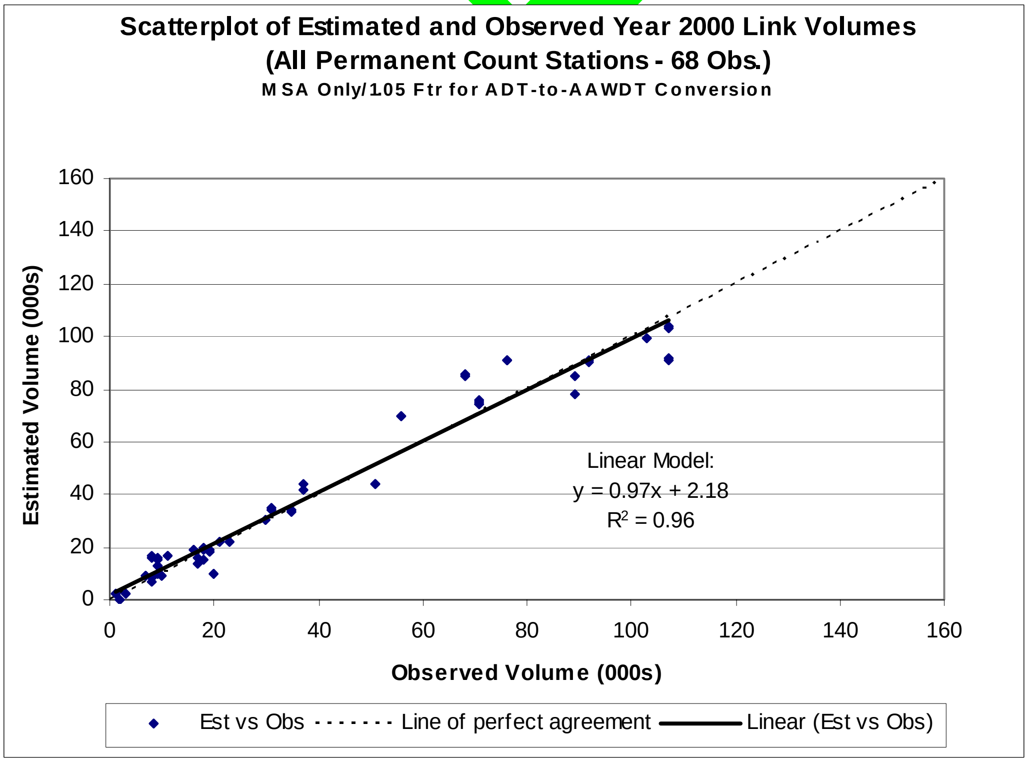


Table 2-2 2000 Estimated and Observed VMT (in thousands) by Jurisdiction V2.1 D #50 Model Performance 3,595 Observations

Jurisdiction	Estimated	Observed	Ratio
District of Columbia	2,476	2,152	1.15
Montgomery	7,200	6,850	1.05
Prince George's	8,078	7,984	1.01
Arlington	796	863	0.92
Alexandria	134	90	1.49
Fairfax	7,955	7,646	1.04
Loudoun	1,004	923	1.09
Prince William	2,221	2,184	1.02
Frederick	3,421	3,106	1.10
COG Member Jurisdictions Subtotal:	*33,285*	*31,798*	*1.05*
Howard	4,363	4,018	1.09
Anne Arundel	6,049	5,327	1.14
Charles	748	1,136	0.66
1,478 Zone Cordon Subtotal	*44,445*	*42,279*	*1.05*
Carroll	1,127	1,013	1.11
Calvert	594	748	0.79
St. Mary's	704	710	0.99
King George	274	254	1.08
Fredericksburg	114	238	0.48
Stafford	1,189	1,059	1.12
Spotsylvania	940	959	0.98
Fauquier	1,089	1,106	0.98
Clarke	133	104	1.28
Jefferson	0	0	0.00
Outer Counties Subtotal	*6,164*	*6,191*	*1.00*
Expanded Cordon Total	**50,609**	**48,470**	**1.04**

(Thousands)	**MSA Summary**		
			Est/Obs
	Estimated	**Observed**	**Ratio**
DC	**2,476**	**2,152**	**1.15**
MD	**20,041**	**19,824**	**1.01**
VA	**13,299**	**12,765**	**1.04**
Total MSA	**35,816**	**34,741**	**1.03**

The table reflects highway links with coded ground counts.
Source: cgv21d_50\2000_with_Revised_Counts\Revise_Cnts.rpt **6/3/2005**
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Table 2-3 2000 Estimated and Observed Screenline Volumes (in thousands) V2.1 D #50 Model performance

Screenline No.	Screenline Location	Estimated Volume	Observed Volume	Est./Obs.
1	Ring 1, Virginia	641	641	1.00
2	Ring 1, DC	820	678	1.21
3	Ring 3, Virginia	707	648	1.09
4	Ring 3, DC	972	868	1.12
5	Beltway, Virginia	1139	906	1.26
6	Beltway, Maryland	1513	1442	1.05
7	Ring 5, Virginia	1039	1116	0.93
8	Ring 5, Maryland	1385	1244	1.11
9	Ring 7, Virginia	786	716	1.10
10	Eastern Loudoun Co.	351	302	1.16
11	US 15, Loudoun / Pr. William Co.	177	148	1.20
12	Central Montgomery Co. Radial	386	386	1.00
13	Eastern Montgomery Co. Radial	315	304	1.04
14	NE. Pr.Geo. Co. Radial	306	298	1.03
15	Central Pr.George's Co. Radial	282	286	0.99
16	Southern Pr.George's Co. Radial	237	204	1.16
17	Southern Fairfax / Pr. Wm. Radial	404	360	1.12
18	Central Fairfax Co. Radial	698	658	1.06
19	VA Route 7 Radial	525	466	1.13
20	Beltway & 'Inner' Potomac River Crossings	1042	962	1.08
22	Central Mtg./P.G. Radial	1263	1136	1.11
23	NE Montgomery Co. Radial	180	144	1.25
24	Montgomery / Pr.Geo. Co. border	379	380	1.00
25	Montgomery/ Frederick Co. border	107	88	1.22
26	Montgomery / Howard Co. border	379	330	1.15
27	Pr.Geo. / Anne Arundel Co. Border	330	306	1.08
28	Charles / Pr.Geo. Co. Border	147	162	0.91
	Inner Screenline Subtotal	*16,510*	*15,179*	*1.09*
31	Frederick / Carroll Co. Border	134	80	1.68
32	Western Loudoun Co. Border	114	64	1.78
33	'Outer' Southwestern Circumferential	315	226	1.39
34	'Outer' Southeastern Circumferential	109	98	1.11
35	South of Baltimore City	910	856	1.06
36	'Outer' Northwestern Radial	93	40	2.33
37	'Outer' Western Circumferential	38	32	1.19
38	'Outer' I-95 (South) Radial	178	174	1.02
	Outer Screenline Subtotal	*1,891*	*1,570*	*1.20*
	Grand Total	**18,401**	**16,749**	**1.10**

Notes:

- The estimated figures reflect highway links with coded ground counts only.
- The estimated link volumes that have been rounded to thousands as the observed volumes are coded in thousands.
- Source: cgv21d_50\2000_with_Revised_Counts\Revise_Cnts.rpt **6/3/2005**

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Figure 2-7 Screenline Locations Map 1 of 2

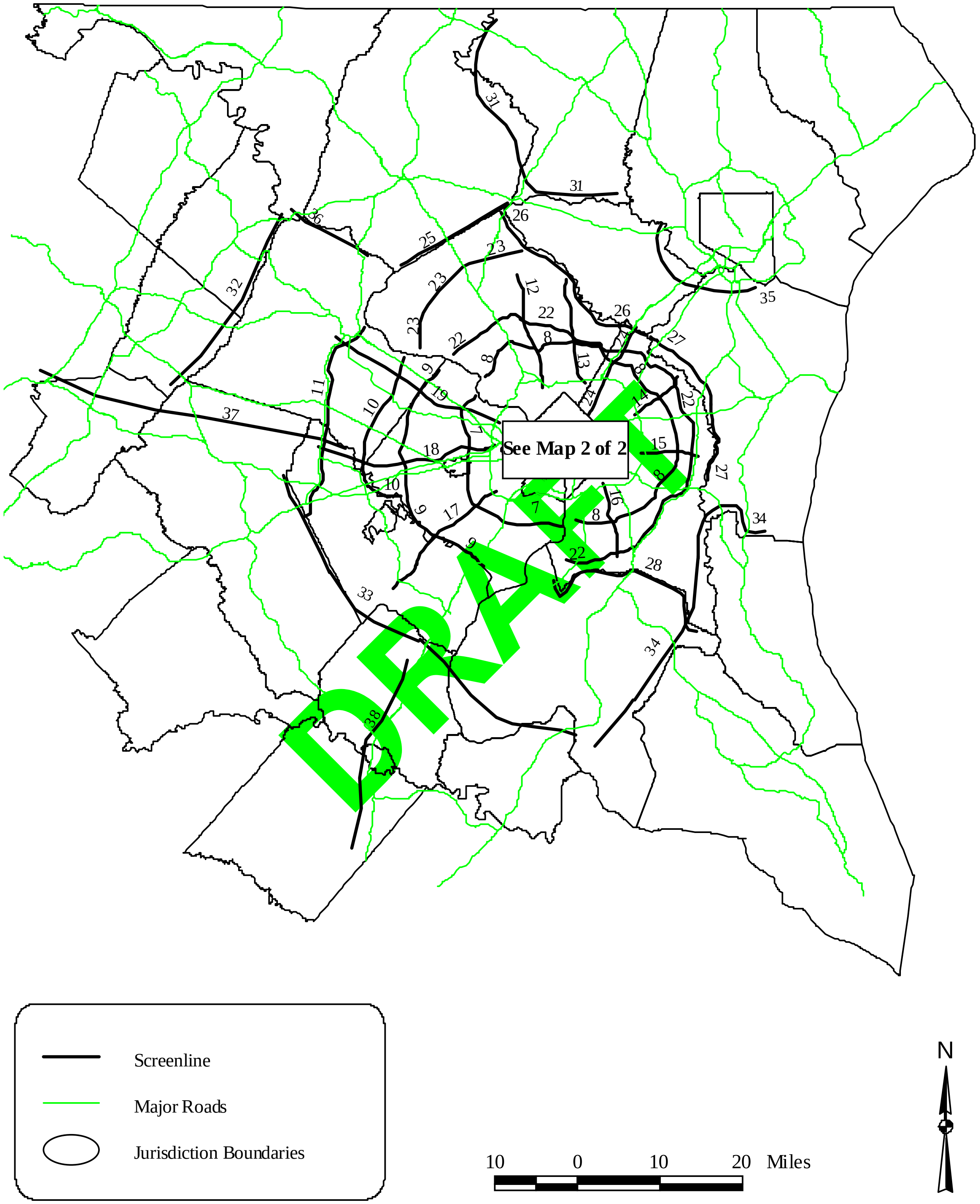
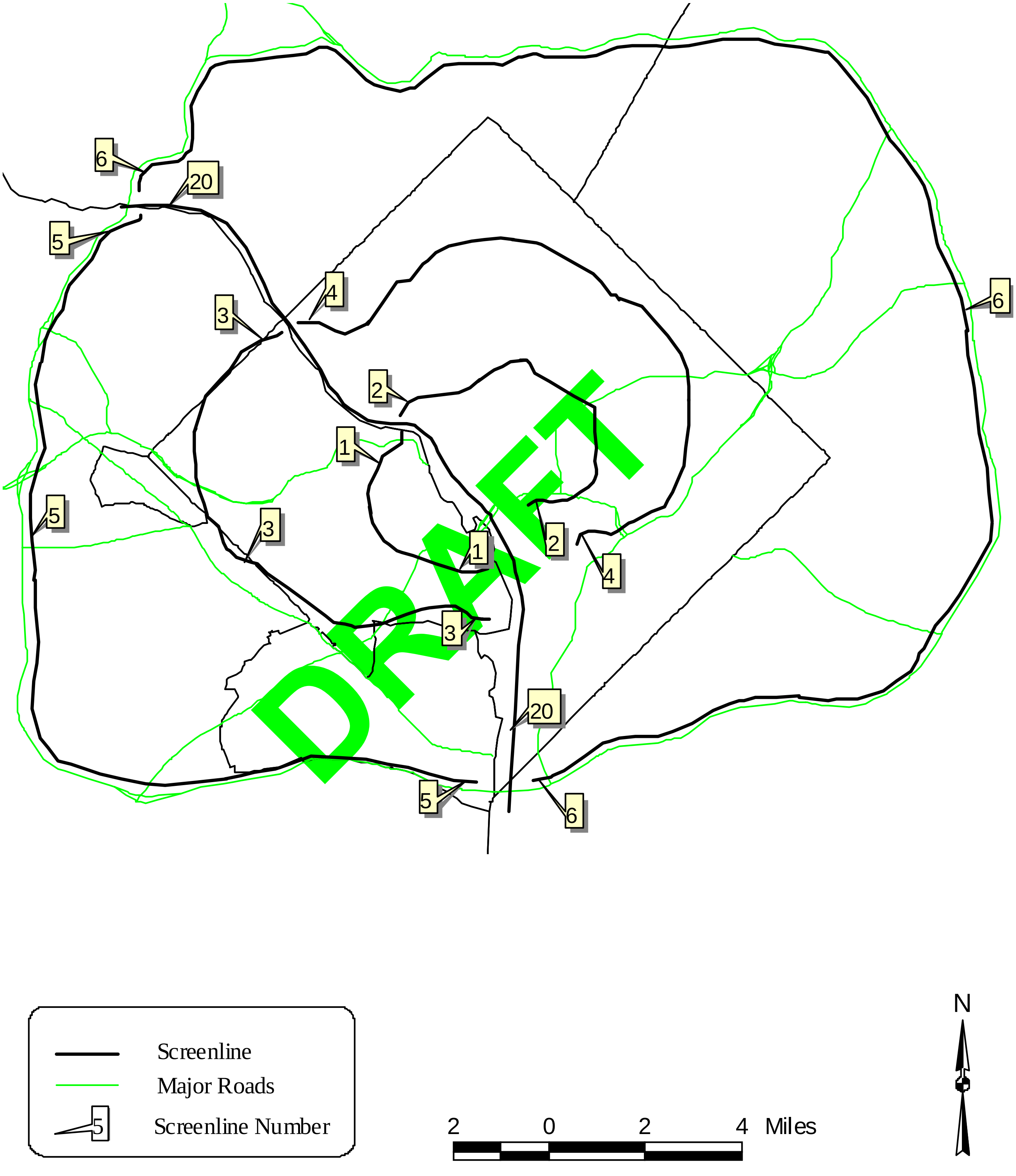


Figure 2-8 Screenline Locations Map 2 of 2



Chapter 3 Status of Commercial Vehicle Model Development

The ability to model commercial and business travel is a key near-term element in the Models Development program. This travel market is not well understood, but is, nonetheless, important to account for in the travel forecasting process. Commercial travel is currently ‘folded into’ the Non-Home-Based trip purpose in the current Version 2.1 D #50 travel model. This is not desirable because commercial person travel is presumably quite dissimilar from residential NHB travel in many respects. It is generally accepted, for example, that commercial travel should not be included with NHB person trips that are input to the mode choice process.

One of the important lessons learned by the TPB in recent years is that collecting regional origin-destination (O-D) information on trucks and commercial vehicles is very difficult given that numerous institutional and practical obstacles exist when attempting to obtain data from private businesses. It has become clear that alternative methods for modeling these types of markets should be explored. William Allen has been retained to support the TPB in developing a commercial vehicle model. Mr. Allen has advanced an innovative technique for explicitly modeling commercial travel in a way that can be easily integrated with the existing travel demand model. He has had success in implementing the technique in other areas. At the present time data collection activities are underway to support the technique in the Washington region.

This chapter briefly describes Mr. Allen’s approach for modeling commercial travel and describes the status of the data collection activities as of June 30, 2005. It is anticipated that the commercial model development will be completed by the end of FY-2006.

3.1 *The Commercial Vehicle Modeling Approach*

Mr. Allen’s approach for modeling commercial travel differs from the traditional approach where O-D survey data is used to statistically estimate trip generation and trip distribution parameters. Instead, the selected calibration approach is one that ‘works backward’ from commercial vehicle link volumes to a zone-to-zone matrix of commercial vehicle trips.

The calibration approach will involve the development of an “observed” commercial trip table that is synthesized from commercial vehicle counts on network links. Technical procedures for developing observed trip tables in this fashion are commonly available. Mr. Allen has developed what he refers to as an ‘adaptable assignment’ technique to create an observed trip table from link counts. The observed vehicle trip table is compared to a simulated trip matrix resulting from an initial model that consists of ‘borrowed’ trip generation and distribution parameters from other urban areas. The comparison ultimately leads to the third, and final, component of the commercial model- a ‘delta’ O-D matrix that is used to adjustment the initial simulated trip table so that the observed O-D pattern is closely replicated.

Thus, in application, the commercial vehicle model will consist of an initial model and a ‘delta’ matrix that is applied to the initial trip table. The ‘delta’ matrix is assumed to remain constant over time. Mr. Allen’s technique lacks behavioral underpinnings, but the approach is appealing to the TPB because it is cost effective, practical, and relatively straight forward to implement once the observed data is in place.

3.2 *Status of the Data Collection*

In December 2004, a data collection plan for collecting commercial vehicle counts was presented to the Travel Forecasting Subcommittee in anticipation of a spring/summer survey period. The plan consisted of 177 survey locations for collecting both commercial vehicle counts, as well as medium and heavy truck counts (which will support future model development work beyond FY-2006). Data collection was planned to occur on a directional basis for a six-hour duration, from 10:00 AM until 4:00 PM.[3] The 177 locations were selected on the basis of area type and facility type classifications that are presently considered in the Version 2.1 D#50 travel model.

Data collection began during May of 2005 and is still in progress. As of June 30, 2005, 116 of the planned 177 count locations have been surveyed (66%). Given constraints in time and budget, it is unlikely that all of the planned 177 locations will be surveyed. A revised sampling plan consisting of 130 locations has been devised to ensure that an adequate number of observations will be collected in each area type/facility type class. The original and revised plan is shown in Table 3-1 .

Table 3-1 Original and Revised Sampling Plan for the Commercial Vehicle Survey

Original Target Sample	Freeway/1	Arterial/2	Collector/3	Total
Urban/1	9	37	24	70
Suburban/2	11	30	24	65
Exurban/3	6	19	17	42
Total	26	86	65	177

Revised Sample	Freeway/1	Arterial/2	Collector/3	Total
Urban/1	7	27	18	51
Suburban/2	8	22	18	48
Exurban/3	4	14	12	31
Total	19	63	48	130

3.3 *Next Steps*

In FY-2006 data collection will be completed and data analysis and cleaning activities will follow. The work on the commercial vehicle model is anticipated to occur during the balance of the fiscal year. As part of this work, TPB will need to revisit and adjust the NHB trip generation process so that commercial vehicles are not ‘double-counted’ in the travel model.

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[3] This period of the day was found to be representative of the commercial vehicle traffic occurring during a 24-hour day. See Sharma, Satish; Luo, Zongfan; and Liu, Guo Xin. (2002) “Short-Period Counts with a Focus on Truck Traffic Estimation.” In ITE Journal, November 2002.

Chapter 4 Status of Nested Logit Mode Choice Model Implementation

4.1 *Background on logit models*

A mode choice model is used to estimate the share of person trips made by each travel mode. Many mode choice models include only motorized travel modes, such as auto driver, auto passenger, and transit. More advanced mode choice models include non-motorized modes, such as walk and bike. Some mode choice models include the transit sub-modes (e.g., bus or rail) and/or mode of access to transit (e.g., walk, drive, kiss-and-ride). The most common mode choice variables are travel time, travel cost, household or individual income, number of workers in the household, and household auto ownership level. Most mode choice models are applied after trip distribution and before trip assignment, at the zone-to-zone trip interchange level. Separate models are usually developed for each trip purpose. In the past, methods such as diversion curves and regression models were used to estimate mode split. The current state of the practice is the logit model, which is a discrete choice model, usually estimated with disaggregate (person-trip level) data. Binary logit models allow for two outcomes or choices. Multinomial logit (MNL) allow for three or more choices. The multinomial logit formulation is shown below:

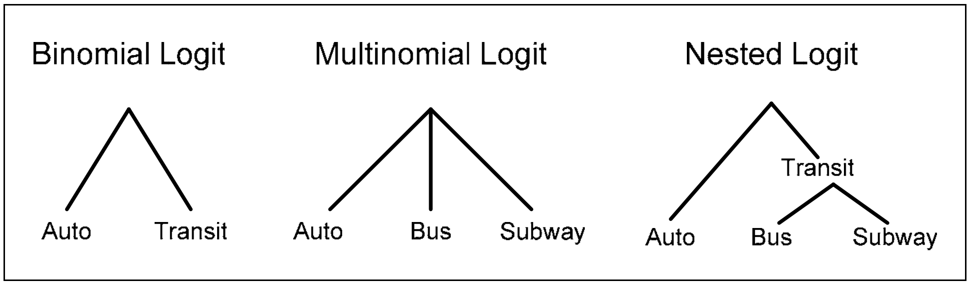
$$P_m = \frac{\exp(U_m)}{\sum_{l=1}^{N} \exp(U_l)}$$

where:

P_m is the probability of choosing mode m;
U_m is the traveler's utility for the mode m;
N represents the set of available modes.

Nested logit (NL) is a third type of logit model that is an enhancement of multinomial logit. Nested logit allows one to group choices that have similar attributes. Each grouping is called a nest. This nesting can lead to improved model performance, as will be discussed in the next section. Schematics of the three logit models can be found in Figure 4-1.

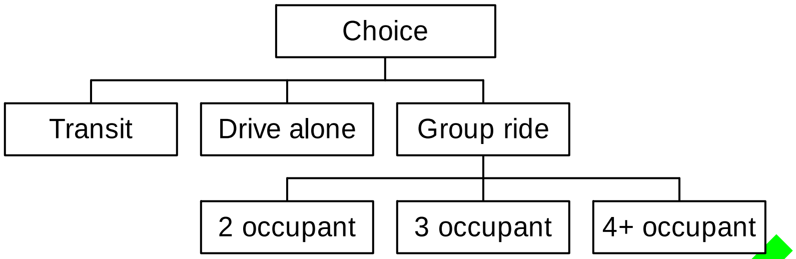
Figure 4-1 Types of logit models



Ref: logit_bin_mnl.vsd

The current TPB mode choice model has a structure that is a variant of the standard MNL: *sequential* multinomial logit (SMNL), as shown in Figure 4-2. The model is made up of two sub-models. The main mode choice model allocates person trips among transit, drive alone, and group ride (carpool) modes. The carpool occupancy model allocates group ride person trips among 2-person carpool, 3-person carpool, and 4+person carpool modes. Graphically, this model appears to be a nested logit model, but it is not, since the two sub-models were estimated separately. When the structure of the COG/TPB mode choice model was originally developed, in the early 1980s, it was difficult to find software that could estimate NL models, so sequential MNL was often used. Now, software products such as Alogit and LIMDEP allow one to estimate NL models.

Figure 4-2 TPB mode choice model structure (Version 2.1D #50)



The classic procedure for estimating any logit model is to use a statistical estimation technique, such as maximum likelihood estimation, to calculate the values of the coefficients that are most consistent with the observed data. When estimating nested logit model, in particular, the first step is to a series of candidate MNL models. Next, one selects the best MNL model and estimates various nesting structures. Each nest of a nested logit model has a nesting coefficient, also known as a gamma coefficient or theta parameter, whose value should lie between 0 and 1.0. If the nesting coefficient is greater than 1.0, then the model is rejected due to an illogical nesting coefficient value. If the nesting coefficient equals 1.0, the NL model is functionally equivalent to the MNL model. In a t-test for a nesting coefficient, the null hypothesis is that the value equals 1.0. By contrast, for other model coefficients, the null hypothesis is usually that the coefficient equals 0.0. More discussion about estimation/calibration techniques can be found in the section describing the AECOM mode choice model.

4.2 *Rationale for moving toward a nested logit model*

Moving to a nested logit mode choice model carries both benefits and risks. The main benefits include:

- More consistent with best practice.
- More advanced choice theory, allowing:
  - Greater ability to model corridors where there are competing transit modes.
  - Better potential for accurate transit assignments, especially if the nesting structure is detailed enough to include transit sub-mode and/or transit mode of access.

IIA property of MNL models: Multinomial logit models exhibit a property known as the “independence of irrelevant alternatives” or IIA property. This property can be viewed as both a strength and a weakness. It is a strength because it allows one to add a new mode that did not exist during model estimation. It can be a weakness, however, in the way in which the new mode draws share from the existing modes. Specifically, if a new mode is added, it will draw from the present modes in proportion to their existing shares. The most common example of how the IIA property can be a liability is known as the “red bus, blue bus paradox.” According to this paradox, suppose that, initially, there are two modes in a city: auto and red bus. Suppose further that each mode has the same utility. Since they have the same utility, they would also have the same predicted mode share: 50% auto and 50% red bus. Now suppose that half of the red buses are painted blue. An MNL model would predict that the mode share would be equally split (i.e., 33% auto, 33% red bus, and 33% blue bus), since the new mode would draw from the present modes in proportion to their existing shares. The correct answer, of course, is that the bus service, no matter what its color, should continue to have a 50% share. A nested logit model would get around this problem by placing the auto and bus modes in their own nests. When a new bus mode was added, it would take market share from the other bus service in the nest, but not from the auto, which is in its own nest.

Despite the benefits, moving to a nested logit model also carries a number of risks. First, there is a concern that existing data sets might not be up to the task of model estimation, calibration, and validation. This is particularly a concern as the nesting structure becomes more complex. Second, after the model is calibrated, new computer programs will need to be written to apply the model in application. These mode choice application programs are typically very long and complex. The program for applying current TPB mode choice model, COGMC.EXE, is written in Fortran, is thousands of lines long, and is typically maintained by a consultant (except for minor updates, which can be done in house). There is also a debate whether to write these programs in a compiled language, such as Fortran, or an interpreted/scripting language, such as TP+ scripting language. A compiled language will run faster, but it can also be more opaque, since the executable file cannot be opened up in a text editor and examined (By contrast, the pre-compiled version of the program, known as the source code, is human readable, but in some cases, the person or agency who developed the program may choose not to share the source code with others). By contrast, scripting languages run slower, may only be run on a computer that has the relevant interpreter (e.g., to run a TP+ script, you have to own TP+), but it is impossible to hide the details in an executable file and the scripts are generally simpler and easier to understand their compiled-program counterparts.

4.3 *Recent developments*

4.3.1 Emergence of FTA Summit model

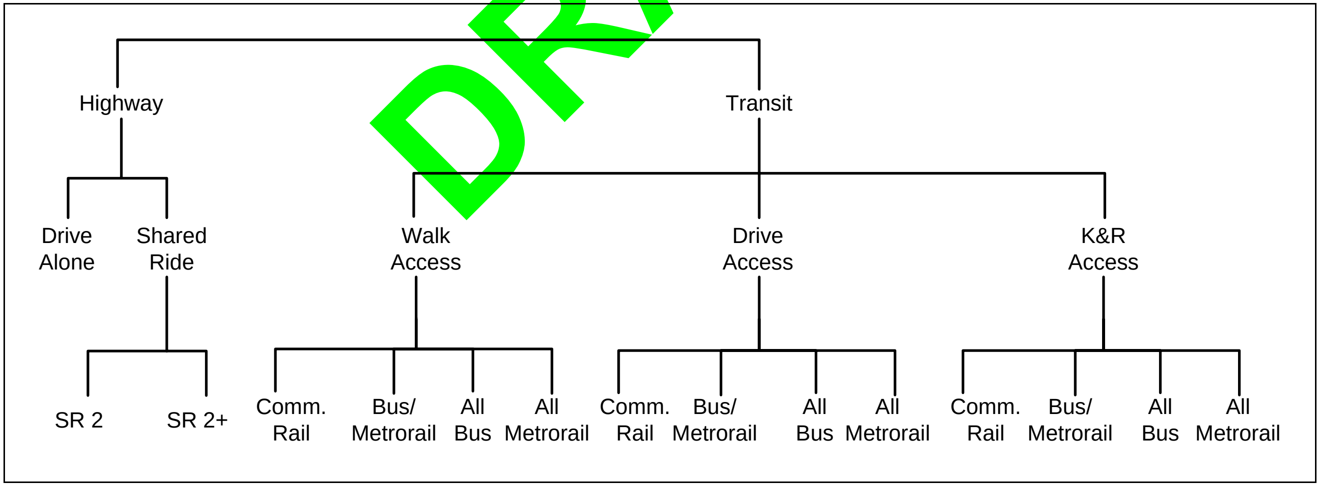
Perhaps the single largest consideration of mode choice modeling work in the U.S. today is the ability to pass muster with regard to the newly developed FTA SUMMIT model. SUMMIT is a program that is used to analyze mode choice model output files, typically a “base” and “build” alternative. SUMMIT enables various benefit measures to be calculated in tabular and graphical form for very detailed sub-markets. The detailed relative analysis offered by SUMMIT has revealed a host of problems associated with mode choice model specifications, network coding, and traffic assignments. TPB is aware of developmental work being undertaken by FTA and will strive to take advantage of knowledge gained as the SUMMIT model is developed. TPB is one of several MPOs taking part in an FTA working group, known as Working Group on Travel Forecasting for New Starts Projects. See Chapter 7, Review of Best Practices, for more on this working group.

4.3.2 AECOM mode choice model developed for WMATA

In 2004 and 2005, AECOM Consult developed a new nested logit mode choice model for use in two light rail project planning studies it was conducting in Arlington, Virginia and Washington, D.C. for the Washington Metropolitan Area Transit Authority (WMATA). The starting point for the AECOM mode choice model was the TPB mode choice model (Version 2.1D #50). However the AECOM model is fundamentally different from the TPB model in a number of ways. First, the AECOM model is a deep nested model that explicitly includes transit mode of access as part of its nesting structure. Specifically, as shown in Figure 4-3, the model has 15 choices, comprised of:

- Three auto modes (drive alone, shared ride 2, and shared ride 3+ persons)
- Four transit modes
    - Metrorail only
    - Bus only
    - Bus and Metrorail
    - Commuter rail
- Three access modes to transit
    - Walk-access
    - Drive-access (park)
    - Kiss-and-ride access (drop off passenger)

Figure 4-3 AECOM mode choice model structure



Ref: NestedChoice_Struct2.vsd

This contrasts to the TPB mode choice model which has only five choices: transit, drive alone, shared ride 2, shared ride 3, and shared ride 4+ person. In the first implementation of the Version 2 model (using MINUTP) in 2001, there was a transit sub-mode choice model and transit mode of arrival model (TPB 2001, Chapter 9). The sub-mode model was used to apportion total transit trips among "bus-only" (including commuter rail) and Metrorail-related trips. The mode of arrival (MOA) model was then used to apportion Metrorail trips among access mode (walk, bus, auto passenger, and auto driver) and Metrorail station. When the

Version 2 model was converted from MINUTP to TP+ in July 2002, these two models were not re-estimated, and, thus have not been a part of the regional travel model since that time.

In the AECOM model, home-based shop (HBS) and home-based other (HBO) have been combined into one purpose, called home-based other (HBO). Consequently, there are six different mode choice models:

- HBW peak
- HBW off-peak
- HBO peak
- HBO off-peak
- NHB peak
- NHB off-peak

A second major difference between the TPB and AECOM models is that the AECOM mode choice model is operated in a post-processing mode, i.e., it is run directly after running the TPB travel model. By contrast, the TPB mode choice model is run within the speed feedback loop, which is used to feed congested link speeds from the traffic assignment back to both trip distribution and mode choice. The speed feedback loop is run six times, so the TPB mode choice model is run six times for each transportation network alternative analyzed. For each of the six times that trip distribution is run, a revised person trip table is created. However, the Federal Transit Administration (FTA) has indicated that projects being reviewed for New Starts funding,[4] should use fixed trip tables. AECOM's solution to this dilemma was to create a post-process mode choice model, i.e., one that is run after the TPB travel demand model (including its six loops of speed feedback) is run.

Transit access coding

A third major difference between the TPB and AECOM models is that AECOM made several changes to transit access coding and path building. The changes were in five main areas: 1) the station database; 2) sidewalk links and zonal walk links; 3) zonal auto access links; 4) station links; and 5) zonal percent walk to transit. Updates to the station database, also known as the consolidated station file, include:

- Expanded the mode code to cover more types of transit (M = Metrorail; C = commuter rail; L = light rail; N = BRT/street car; B = Bus)
- Added an access distance code for park-and-ride lots. This code aids in determining the number, extent, and directionality of PNR links generated for each park-and-ride lot.
- Added fields for parking cost and capacity, both of which are used in to determine the time that is coded on parking-node to station node transfer links.
- Added a field for shadow prices at parking lots. This is not currently used, but could be incorporated at a future time.

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[4] The Federal Transit Administration's (FTA) discretionary New Starts program is the federal government's primary financial resource for supporting locally-planned, implemented, and operated transit "guideway" capital investments, e.g., light rail, heavy rail, commuter rail, and bus rapid transit.

Sidewalk links and zonal walk links: A sidewalk network was created throughout the region. This was done by converting all highway links suitable for walking into sidewalks, using the link characteristics from the highway network and a typical walking speed. According to AECOM:

> Links for which walking was inappropriate, such as freeways, parkways, and outer suburban major arterials, were eliminated from the list. In order to reduce the size of the link file by eliminating irrelevant links, links which were geocoded to be part of a zone with zero walk access to transit were also eliminated. Some additional links were added during the same process when the centroid connectors were reviewed, to represent sidewalks on links which would otherwise be eliminated, such as Memorial Bridge, or to reflect trails or other connections which would be needed to reflect access opportunities correctly.

AECOM developed a revised procedure for generating zonal walk links, also known as walk-access-to-transit links. In this procedure, access links are generated from each centroid to all nodes within a maximum walk distance, set equal to the square root of the zonal area, times 0.75. The actual calculated distance and computed walk time is placed on each link, up to a maximum of one mile. No walk links are generated where the percent walk to transit is zero. After the automated procedure (walkacc.for) is run results are viewed graphically in Viper and, based on judgment, some walk-access links are added or deleted.

Zonal auto access links: Zonal auto access links are developed using an automated program (autoacc3.for). Separate connectors are generated for park-and-ride (PNR) lots and kiss-and-ride (KNR) lots. These links are a function of:

- The orientation toward downtown;
- A backtracking penalty and Potomac crossing barriers (except Loudoun County to MARC);
- Link distance is a function of station type (terminal versus line station) and mode;
- Highway skims;
- Manually specified overrides

Station links: Station links are walk transfer links that connect stations with sidewalks, bus service, or park-and-ride lots. These links are generated from data maintained in the consolidated station file. For PNR-to-station links, the time on the link is a function of the parking capacity and parking cost.

Zonal percent walk to transit: A new procedure was developed to estimate the zonal walk percentages to transit. The GIS procedure (ArcMap 9) starts by generating four sets of node buffers around transit stop nodes:

- Percent within 0.5 miles of any transit stop node;
- Percent within 0.5 miles of Metrorail;
- Percent within 1.0 miles of any transit stop node;
- Percent within 1.0 miles of Metrorail;

The four node buffer layers are overlaid on a zone boundary layer. These four sets of percentages were used as inputs for the process of pathbuilding by transit sub-mode. In the end, a single percent walk to transit value is developed for each zone, using the following formula:

$$\text{pctwalk} = \frac{\text{zonal area within walking distance}}{\text{total zonal area}} \equiv \frac{100\%\ \text{short walk area} + 25\%\ \text{long walk area}}{\text{total zonal area}}$$

Transit path building

Twenty-four separate transit paths are built:

- Three modes of access to transit
  - Walk
  - Drive and park (PNR driver)
  - Ride to transit (drop off/pick up or ride with a PNR driver)
- Four transit modes
  - Metrorail only
  - Bus only
  - Bus and Metrorail used in combination
  - Commuter rail (alone and in combination with bus and/or Metrorail)
- Two time periods
  - AM peak
  - Midday

Transit run times are based on the same procedures as used in the Version 2.1D #50 travel model. Run times are controlled with the RT variable, which corresponds to the run time found in current bus schedules. Output bus in-vehicle time skims are adjusted, using the TPB bus speed model, to account for congestion effects. Path weights have been made consistent with those used in the mode choice model. Specifically, the weight on drive access time is 1.5 times the in-vehicle time. The weight on walk-access time is 2.0 times in-vehicle time. The weight on other out-of-vehicle time is 2.5 times in-vehicle time. Maximum path time has been set to 360 weighted minutes. There is no weighting of transit sub-modes, i.e., the weight for in-vehicle time on all transit modes is set to 1.0. It is assumed that there is a two-minute transfer penalty (treated as part of out-of-vehicle travel time in path and mode choice) for all transit, except for Metrorail-to-Metrorail transfers.

Variables and coefficient values used in mode choice model

The AECOM mode choice model has about the same number of variables as the TPB mode choice model. Unlike the TPB model, it lacks a land-use mix variable. The relevant variables and their corresponding coefficient estimates are shown in Table 4-1.

Table 4-1 AECOM mode choice model: Variables and coefficient values

	Trip Purpose		
Variable	**HBW**	**HBO**	**NHB**
In-vehicle time (IVTT)	-0.02128	-0.02322	-0.02860
Auto access time	-0.03192	-0.03483	-0.04290
Other out-of-vehicle time	-0.05320	-0.05805	-0.07150
Cost - Income group 1	-0.00185	-0.00202	-0.00994
Cost - Income group 2	-0.00092	-0.00101	-0.00994
Cost - Income group 3	-0.00059	-0.00065	-0.00994
Cost - Income group 4	-0.00044	-0.00048	-0.00994
Boarding penalty	-0.05320	-0.05805	-0.07150
Walk time	-0.04256	-0.04644	-0.05720
Constants	**HBW**	**HBO**	**NHB**
INC1	2.00000	2.00000	--
INC2	0.00000	0.00000	--
INC3	0.00000	0.00000	--
INC4	-2.00000	-2.00000	--

Ref: aecom_wmata_mc_coeffs.xls

<u>Calibration: Statistical estimation with disaggregate data versus direct aggregate calibration</u>

The classic way to estimate and calibrate a discrete choice logit mode choice model is with a statistical estimation technique applied to disaggregate (person-trip level) data. Typical steps include:

1) Specify the model, i.e., choose variables and their functional form in the utility equations.
2) Estimate the coefficient values using disaggregate data and a statistical estimation technique, such as maximum likelihood estimation. Typically one would use a software package such as Alogit, LIMDEP, or BIOGEME.
3) Perform a disaggregate calibration/validation of the model, using a hold-out sample from the disaggregate data used to estimate the model.
4) Perform an aggregate calibration/validation of the model, where the model is actually applied to aggregate zone-to-zone person trip flows. In this step, alternative-specific constants would be adjusted until the model matches observed data.

An alternate approach is to use a direct aggregate calibration, skipping the disaggregate statistical estimation altogether. Typical steps include:

1) Specify the model, i.e., choose variables and their functional form in the utility equations.
2) Borrow the coefficient values from another study or set their values, based on professional judgment or agency guidelines.
3) Perform an aggregate calibration/validation. In this step, alternative-specific constants and/or any other coefficient values are adjusted until the model matches observed data.

Although the classical technique is more theoretically pure, it has some disadvantages that are causing many in the field to move to the alternate approach. The first disadvantage of the classical approach is that it is very difficult to develop the estimation data set. Each record of the data set would include the characteristics of the chosen mode, as well as the characteristics of the unchosen, but available modes. If you are modeling 15 modes, you need 15 sets of level-of-service data (such as walk access time, drive access time, initial wait time, transfer wait time, in-vehicle travel time, fare, auto operating cost). In theory, these variables should be for the individual traveler, not simply zone-to-zone averages. In reality, it is hard to get such disaggregate information and compromises are often made. These compromises can cause a flawed estimation and flawed coefficient estimates. Furthermore, estimation data sets are often too small to support the detailed nesting structure of the model. A second disadvantage with the classical estimation technique is that, sometimes, when developing a model, one is required or strongly encouraged to use certain rules of thumb, that may or may not be borne out by the available observed data. For example, according to the Federal Transit Administration (FTA), the coefficient on in-vehicle travel time (IVTT) should range between -0.3 and -0.2 (based on historical evidence from a variety of studies). Suppose now that an individual performs a classical estimation and obtains a coefficient of -0.35 on IVTT. Does this mean that people in the region in question behave differently that those in other regions or does it mean that the estimation data set had a flaw in it? With the alternate approach to model calibration, one can set initial coefficient values by fiat, using a priori assumptions (e.g., that the ratio of out-of-vehicle time to in-vehicle time should be between 2 and 3), then, one can adjust the model, by adjusting coefficients or alternative-specific constants, until the model replicates observed data.

AECOM used the alternative (direct aggregate) calibration approach for their model. Table 4-1 shows the variables used and the calibrated coefficient values. In this case, the IVTT coefficients were borrowed from an earlier regional travel model. The auto access time coefficients are simply 1.5 * IVTT. The other out-of-vehicle time coefficients and the boarding penalty coefficients are 2.5 * IVTT. The walk time coefficients are 2 * IVTT. The cost coefficients are based on the value of time at 1/3 the wage rate, by income group.

The model was calibrated for the year 2002, using the following data:

- 2002 land use and networks
- Control data
    - 2002 published transit boarding data (by operator)
    - 2002 Metrorail Survey
- Other data
    - 2000 Regional Bus Survey
    - 2000 Census Journey-to-Work data
    - 2003 Surveys of selected DC bus routes

In AECOM’s initial calibration work, a model was specified that had trip-end production and attraction variables, but these proved to be problematic, since the resultant model had large and unstable constant values, and the model did not validate well in some markets. Consequently, a revised calibration approach was followed that made use of the following market segments:

- Production areas
    - DC
    - MD Urban
    - MD Suburban
    - VA Urban
    - VA Suburban

- Attraction areas
    - DC Core
    - VA Core
    - Other DC and MD/VA Urban
    - MD/VA Suburban

Thus, there were 5 x 4 = 20 geographical market segments. Each market segment and mode has a nesting constant, so there are 20 x 15 = 300 nesting constants per mode choice model (There are six mode choice models: HBW PK, HBW OP, HBO PK, HBO OP, NHB PK, NHB OP).

4.4 *Work plan for implementing a nested logit model*

TPB staff is currently developing a work plan for moving to a nested logit mode choice model. At the request of TPB staff, AECOM Consult has prepared guidance, which TPB staff will incorporate into the final work plan. The remainder of this chapter will summarize some of the key points made in the AECOM guidance and provide some initial insights into TPB plans at this point in time.

Some steps depend on the outcome of preceding steps. For example, one needs to decide which path building software to use: TRNBUILD, which is part of TP+, or PUBLIC TRANSPORT (PT), which is part of Cube Voyager. Both packages come from the same vendor, Citilabs, and TPB has licenses for using both packages. However, there are technical issues relating to the choice of one over the other.

AECOM has identified several issues that should be decided early on in the process. Table 4-2 contains a list of these questions/issues and the initial TPB staff comments. AECOM notes that these decisions should be made with input from various stakeholders. As indicated in Table 4-2, one of the critical first decisions is whether to use the existing transit path building software (TRNBUILD) or to move to the newer PUBLIC TRANSPORT, or PT. PT is being pushed by the vendor, Citilabs, but it is not known if there are any examples of large MPOs in the U.S. using PT. Cube Voyager’s PT has a number of advantages, as indicated in the AECOM proposed work plan:

- Ability to display path building on screen to facilitate coding and error checking
- Ability to incorporate fares in path building
- Ability to compute different waiting time functions
- Ability to build multiple paths between centroids

The last item could also be a disadvantage, since it can make it harder to develop separate paths for each transit sub-mode, which is a feature of both the AECOM model and many other large-scale travel models. The software does have the capability to control the extent of multi-path path building, but this feature should be tested to make sure it works. Another limitation of PT is that there is no direct way to eliminate a mode or sub-mode from path building. Citilabs has promised to add this feature in the future. Another limitation of PT is that, because it uses a tree builder rather than a vine builder like TRNBUILD, different paths can be built during various stages of the model, which can lead to inconsistencies between paths and skims. This last issue can cause uncertain results when used in modeling that feeds into the FTA Summit user benefits process. According to AECOM, Citilabs plans to fix these issues in Version 4.0, which is supposed to be released in about six weeks (September 2005). Thus, a true exploration into path differences between TRNBUILD and PT may need to wait until the new version of PT is ready.

Table 4-2 Issues to be addressed early on regarding development of a nested logit mode choice model

Issue	**Current view of TPB staff**
Which path building software to use: TRNBUILD, which is part of TP+, or PUBLIC TRANSPORT (PT), which is part of Cube Voyager?	After the new version of PT is available (ca. Sept. 2005), convert a base-year network to PT and conduct path building tests. Choose one package.
Should the design of the system work toward eliminating all stand-alone programs and conversion of the entire model to Cube "native" software or should a more eclectic approach be undertaken?	The goal is to convert as many of the existing Fortran programs into TP+ or Cube Voyager scripting language. The first priority will be on the mode choice application program. Since the scripts will be slower, tests need to be conducted to make sure that total model run time is still acceptable.
Should further research be undertaken to improve the estimation of highway speeds within the model system?	Yes. Some time should be spent investigating if changes in the way the highway assignment process is conducted (e.g., number of speed feedback loops, iterations, assignment algorithms) will improve model performance.
Should transit auto access trips be assigned to the highway network? Although nominally a "last step" consideration, in reality inclusion of transit access trips in the highway assignment can have a notable impact on highway volumes, speed estimation, and feedback processes.	No decision has been made.
Should model development and estimation be undertaken with available data resources, possibly augmented by limited review and recoding, or should any significant additional data collection activities be undertaken and model implementation schedules be adjusted based on the scheduling of the receipt of new data sources?	A first-cut nested logit mode should be developed with existing data sets. In the future, a new NL model can be calibrated with new data and/or smaller zone sizes.

Here are the current working assumptions for conducting the nested logit work:

- Most of the models development work will be conducted with TPB staff, using consultants for help where needed.
- Use the existing (2,191) zone system. It is assumed that, in two to three years, a finer grained zone system will be developed. At that time a new nested logit model would be developed.
- Start with AECOM mode choice model structure and coefficient values.
- Highway assignment: Discontinue use of integer processing and bucket rounding. Move to real numbers with two decimal places.

- Market segmentation for mode choice: Switch from the current auto ownership (three categories) to method used by the AECOM model: household income (four categories).

Table 4-3 list some of the other technical issues that will need to be addressed. For example, on the issue of application code, we will need to have a program that will apply the new model. We could use the application code developed by AECOM for the WMATA work: AEMS (AECOM Mode Split). AEMS is a general purpose utility program, written in Fortran, for applying and calibrating logit mode choice models. It allows one to specify all aspects of a logit mode choice model: the branching structure of the model, whether to use MNL or NL, the form of the utility equations, the coefficient values, alternative-specific constants, and nesting coefficients. It also includes automated calibration features. Alternatively, we could write or have written for us our own new Fortran program. Or, we could write a script, either in TP+ MATRIX or in Cube Voyager PT script. A compiled Fortran program will run much faster than any interpreted script. AECOM is recommending that TPB staff use AEMS, at least for the model calibration phase. In the view of TPB staff, some of the drawbacks to using AEMS include:

- No access to source code, so it is not possible to view the internal workings of the program: “Since the program is also designed to work with other software packages, including TransCAD, EMME/2, and Tranplan, program maintenance and particularly compilation is very complicated. For this reason, AECOM management is not willing to turn over the source code to MWCOG.”
- It is unlikely that there is a user’s guide, so TPB staff would need some training from AECOM staff to learn how to use AEMS.

Table 4-3 Other technical issues needing addressing

Choices that need to be made	Current view of TPB staff
Application code: 1) Use AEMS, 2) Write a new Fortran program, 3) Use scripting language, TP+ MATRIX, 4) Use scripting language, Cube Voyager PT	Undecided
Highway assignment: 1) Stick with current process: 6 speed feedback loops, 20 iterations for UE traffic assignment 2) Use fewer speed feedback loops and more user equilibrium iterations	Conduct tests to see if there is a better arrangement.
Should auto access trips to transit be assigned to the highway network? Currently, they are not.	Undecided
How many of the changes to transit access coding should we adopt?	Undecided
Transit speeds: Should we continue to use the existing bus speed model or move to a more refined model where bus speeds are directly related to highway speeds. Right now the relationship is more distant.	Undecided
Transit speeds: Is there a way to use RT (run time) coding for some transit routes, say rail, and network-derived run times for buses?	Undecided

Another issue of interest is highway assignment. AECOM has recommended that TPB get away from integer bucket rounding of trip tables used in highway assignment, and TPB staff agrees with this recommendation. AECOM has also suggested that there may be an unnecessarily high number of speed feedback loops (currently six). AECOM has suggested that it might be beneficial to lower the number of speed feedback loops and raise the number of iterations used in each application of the user equilibrium highway assignment. TPB staff feels that this is an area that would be worth investigating with some sensitivity tests. Several other technical issues remain undecided, such as whether auto access trips to transit be assigned to the highway network, or which of the AECOM transit access coding enhancements should be added into the TPB model.

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Chapter 5 Status of Airport Access Model

One of the goals of the TPB models development program has been to improve the representation of so-called “special generators.” A “special generator” is a site, facility, or area that has unique trip making characteristics that are different from those represented in the standard trip production and attraction models used in the regional travel forecasting model. Examples of special generators include airports, military bases, universities, tourist attractions, and major shopping centers. This chapter focuses on commercial airports as special generators and their treatment in the region travel model, Version 2.1D #50.

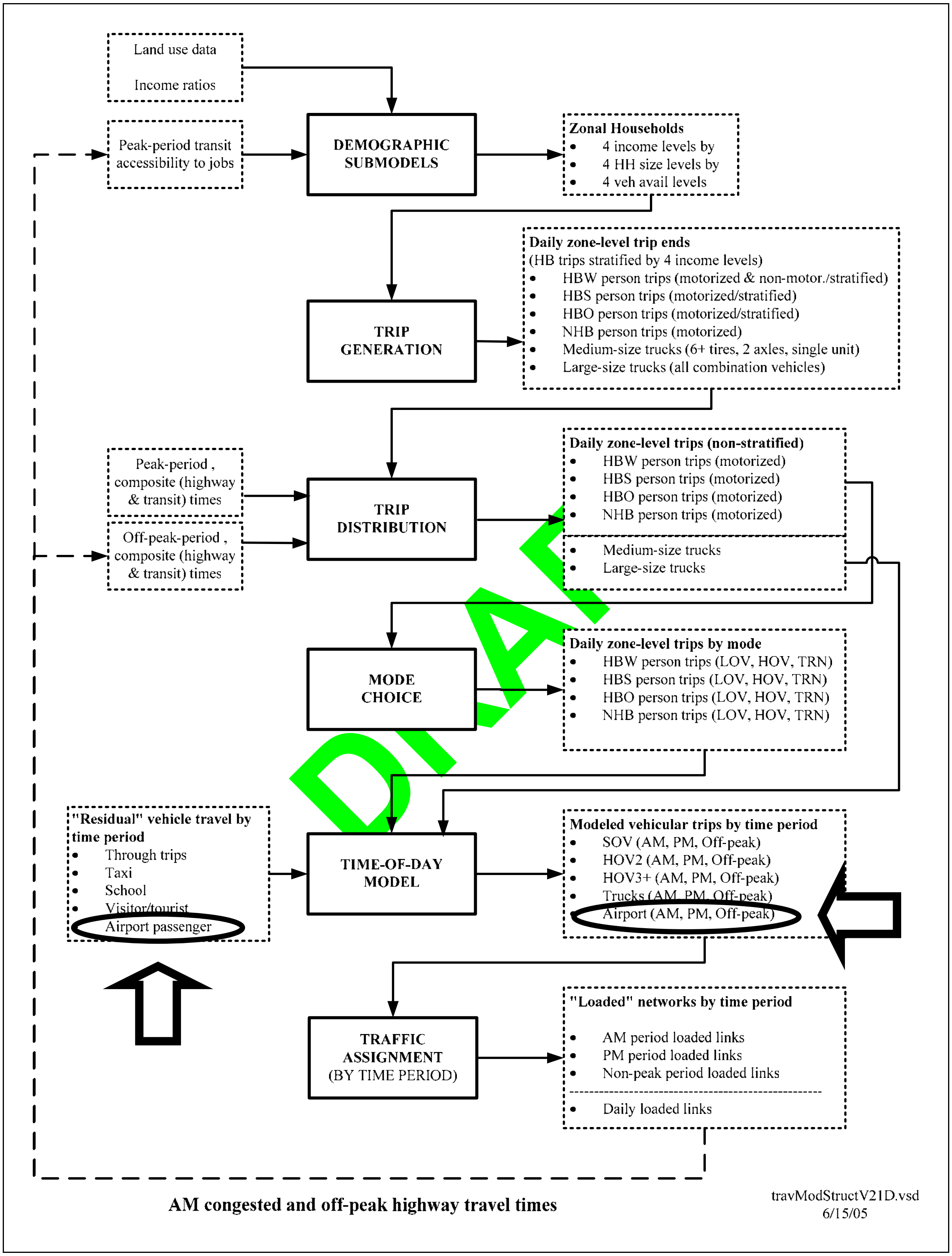
Airport ground access travel in the Washington area is very complex. The region is served by three commercial airports, and there are many ground access modes of travel to each airport. The region’s three commercial airports are Ronald Reagan Washington National Airport (DCA), Washington Dulles International Airport (IAD), and Baltimore/Washington International Airport (BWI). Travel modes can be divided into private modes (such as private auto, rental car, walk, bike) and public modes (such as mass transit and paratransit). Paratransit represents a middle ground between the flexibility of private transportation and the fixed-route, fixed-schedule nature of mass transit. Two of the three airports are well served by rail transit (National and BWI) and there are plans to extend rail to Dulles. The transit networks developed to support the regional travel demand model usually include (fixed-route) mass transit, but not paratransit modes. Similarly, the walk and bicycle modes are usually only represented in a limited way (e.g. as access modes to transit) in the travel demand forecasting model.

5.1 *Treatment of airport access trips in the TPB travel model*

Trips produced by or attracted to airports can be modeled in a number of different ways. Ideally, for a region with more than one commercial airport, one would have both an “airport choice” model and an “airport ground access” model. The airport choice model would predict the share of trips to each commercial airport. The airport ground access model would predict ground access travel mode (e.g., auto, transit, taxi, and limousine) for persons traveling to and from the airport. However, the Version 2.1D #50 model includes neither of these two models, due to the difficulty of estimating these types of models. Instead, a series of year-specific trip tables were developed, representing airport passenger auto driver trips on an average weekday. The first such trip table was for 1998 and was developed from COG’s 1998 Air Passenger Survey (COG/TPB 2001). Trip tables corresponding to the years 2000, 2005, 2010, 2015, 2020, and 2025 were later developed, using growth factors and a Fratar process (COG/TPB 2004, Technical appendix to memo). Lastly, a 2030 trip table was developed (COG/TPB 2004).

The current travel model, known as Version 2.1D #50, is a six-step travel model (See Figure 5-1). Airport passenger auto driver trips, along with other types of “residual” travel, are added into the model stream at step 5, the time-of-day model, just before the traffic assignment step. The airport passenger auto driver trips represent auto driver trips of air passengers headed to or from the three commercial airports (National, Dulles, and BWI) on an average weekday.

Figure 5-1 Structure of the COG/TPB travel model, Version 2.1D



5.2 *Recent developments at COG/TPB*

Work is currently in progress to update the air passenger auto driver trip tables, as part of the airport system planning work that goes on at COG/TPB. Some of the proposed revisions include:

- Moving the base year from 1998 to 2000, i.e., using the COG/TPB 2000 Air Passenger Survey; Forecast years include 2005, 2010, 2015, 2020, 2025, and 2030.
- Moving from three categories (resident home-based, resident non-home-based, and non-resident) to four categories (resident home-based, resident non-home-based, non-resident home-based, and non-resident non-home-based); Home-based trips are weighted to households and Non-home-based trips are weighted to employment.
- Moving from 83 aviation analysis zones (AAZs) to 160 AAZs.

The mode designations are the same as the previous work: auto, transit, airport transit and other. This new work is ongoing and has not yet been documented.

5.3 *Recent research by academia*

In the last two years, some interesting research work has been done regarding airport modeling in the San Francisco Bay area. The San Francisco Bay area was chosen because it has three commercial airports -- San Francisco International (SFO), Oakland International (OAK), and San Jose Municipal (SJC) -- and has good choice data available from air passenger surveys. The work is documented in two papers, by Hess and Polak (2004) and by Hess (2004). Motivation for the recent work was twofold. First, the authors felt that air passengers do not simply make a choice of airport, but, in fact, make a three-way choice of airport, airline, and access mode. Nonetheless, the majority of the past research was limited to only one or two of the choice dimensions. Second, the authors note that most of the past research made use of overly aggregated data for the air transportation and ground transportation level-of-service information. This latest work set out to address both these issues.

The first paper (Hess & Polak 2004) focused on developing the estimation data set and estimating a series of discrete choice models, both MNL and NL, segmented by resident status and trip purpose. Resident status was either “resident” or “visitor” (non-resident). Trip purpose was defined as “business” or “leisure,” where the latter can be divided into “holiday” (vacation) and “visiting friends and relatives” (VFR). A series of likelihood-ratio tests was used to assess the impact of using separate models by resident status and trip purpose or a common model. The tests showed strong differences between residents and visitors ($122.235 \sim \chi^2_{16}$), as well as between business trips and leisure ($241.57 \sim \chi^2_{21}$). In many other studies, holiday trips are combined with visiting friends and relatives to form one group of leisure trips. Several tests were conducted by Hess & Polak to assess the adequateness of such grouping. In the case of resident trips, the test revealed no significant differences between holiday trips and VFR trips ($18.629 \sim \chi^2_{20}$). However, in the case of visitors, the differences were very significant ($105.183 \sim \chi^2_{20}$). Thus, it was decided to develop MNL and NL models for six separate groups of travelers, dividing the population into resident and visitors, and dividing the trips into business, holiday, and VFR trips.

There were three primary data sources used to compile the estimation data set:

- Air passenger survey data:
  1995 Airline Passenger Survey conducted by the Metropolitan Transportation Commission (MTC)
- Air travel level-of-service data:
  BACK Aviation Solutions (includes info. on average fares paid on a given route)
- Ground access level-of-service data:
  Origin-destination travel time and cost matrices for the 1,099 TAZ network from MTC

In this first paper, it was found that flight frequency and in-vehicle access time had a significant overall impact on the choice of airport, while factors such as fare and aircraft size had a significant effect in only some population subgroups. The analysis also highlighted the need to use separate models for resident and non-resident travelers. As for model structure, the research showed that use of nested logit leads to significant improvements in model fit over the use of multinomial logit, although these improvements do not necessarily translate into significant advantages in prediction performance, which is already good for the MNL models used as a base. The authors think that this could suggest that an appropriate specification of utility is more important than the use of an adequate nesting structure.

In the second paper (Hess 2004), a model was developed for resident business travelers that included the three-way choice of airport, airline, and access mode. The analysis confirmed some of the results from earlier research showing the high explanatory power of the access time and flight frequency attributes. Furthermore, the analysis repeated the results of Windle and Dresner (1995), showing a significant effect of past experience on current choices. The author noted that it was not possible to estimate a significant impact of fare, which had also been found to be the case by earlier work done by other researchers.

5.4 *Next steps*

The last time a major review of airport choice models was conducted by TPB staff was in 2003, in the FY-2003 models development report (COG/TPB 2003). At that time, eight different planning agencies were contacted in seven different cities (two agencies were in New York). The cities contacted are listed below, with the number of commercial airports in each city listed in parentheses after the city name:

- Atlanta (1)
- Boston (1)
- Portland, Oregon (1)
- Chicago (2)
- New York (3)
- San Francisco (3)
- Los Angeles (6)

Table 5-1 lists the names of the commercial airports in each city and the date(s) of the most recent air passenger surveys. Table 5-2 summarizes the type of airport choice model used in each city.

Table 5-1 Summary of commercial airports and air passenger surveys: Contacted cities vs. Washington, D.C.

City	Commercial Airports	Date of Most Recent Air Pax. Survey
Atlanta	Hartsfield (ATL)	2000
Boston	Logan (BOS)	1999
Chicago	O'Hare (ORD) Midway (MDW)	1997 (ORD)
Los Angeles	Los Angeles (LAX) Ontario (ONT) John Wayne (SNA) Burbank (BUR) Long Beach (LGB) Palm Springs (PSP)	2000/2001 (LAX and ONT) Also 1993
New York	John F. Kennedy (JFK) Newark (EWR) LaGuardia (LGA)	1992/1993
Portland, Oregon	Portland Int'l (PDX)	1996
San Francisco	San Francisco (SFO) Oakland (OAK) San José (SJC)	2001 Also 1975, 1980, 1985, 1990, 1995
Washington, D.C.	Baltimore-Washington (BWI) Dulles (IAD) National (DCA)	2002 Also 1981/1982, 1987, 1992, 1998, 2000

Source: COG/TPB 2003

Table 5-2 Summary of airport models used by various planning agencies: Contacted cities vs. Washington, D.C.

City	Planning Agency	Airport Model(s)
Atlanta	ARC	1) Zonal allocation of O&Ds, 2) Ground access mode choice model
Boston	Boston MPO, CTPS	Airport ground access mode choice model*
Chicago	CATS	None
Los Angeles	SCAG	RADAM. MNL model that allocates current and forecast air passenger and cargo demand
New York	NYMTC	None
New York	PANYNJ	Econometric model for forecasting the number of passengers at the three airports
Portland, Oregon	Portland Metro	1) Zonal allocation of origins, 2) Ground access mode choice model
San Francisco	MTC	Airport choice model and airport ground access model
Washington, D.C.	MWCOG	No formal model. Resident air passenger trips are part of HBO and NHB. Non-resident air passenger trips are kept as separate trip table that is used in traffic assignment, but not in TG, TD, or MC.

* Unable to obtain information on this model.
Source: COG/TPB 2003

The recommendations from the 2003 report are reproduced below:

> At this time, it would seem the most useful models for COG/TPB to emulate would be those of ARC, Metro/Port of Portland, and MTC. All three of these model relied on having an air passenger survey as one of the primary data inputs for the calibration file. MTC's model was built without having information about airfare ticket prices (since it was not asked in their 1985 and 1990 surveys). Similarly, TPB's latest air passenger surveys also lack a question about ticket prices. In order to develop the necessary calibration file, TPB will probably need to purchase flight frequency data for the three commercial airports from a vendor such as OAG. It should be noted that airport choice and ground access models are quite complex. Many times, the most complex task in model estimation is not the estimation at all, but rather the development of the

> calibration/estimation data set. Nonetheless, model estimation can be more involved than that typically needed for regular mode choice models. For example, for Portland's ground access mode choice model, relied on a combination of both revealed preference data and stated preference data, and needed special estimation procedures that may not be part of the tool kit of many MPO modelers. It is recommended that TPB staff begin development of a calibration file which makes provision for the features of the model structures in Atlanta, San Francisco, and Portland.

Unfortunately, in the two years following that recommendation, sufficient resources could not be made available to proceed with any model calibration work (either data set creation and/or model estimation), due to other priorities in the work program. Instead, limited resources were used to keep abreast of developments in this area. Given the difficulty of developing these airport choice models and the resource requirements involved, it does not seem realistic to expect that one of these models will be estimated for the Washington, D.C. area in the coming fiscal year. Nonetheless, TPB will commit to keep abreast of developments in the field of airport choice modeling, both within the academic field and amongst other MPOs, with the hopes that, in the future, resources will be made available for development of a full-scale airport choice model.

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Chapter 6 CTPP 2000 Summary Tables for Re-estimation/ Validation of Demographic Sub-Models

This chapter documents tabulations that have been extracted from the Census Transportation Planning Package 2000 (CTPP 2000). These data files will be used to update the V2.1 D # 50 three demographic sub models: the income sub-model, the household size sub-model and the vehicles' ownership sub-model. While jurisdiction summaries are provided in this chapter, the final product of this work includes the same information summarized at the finer Census Tract level, which is required to re-estimate the sub-models. All extracted information was tailored to reflect the exact geographic coverage of the MWCOG expanded cordon area.

The CTPP 2000 is a collection of summary tables that were generated from both the 2000 Census short and long forms. The tables contain information about population and household characteristics, worker characteristics and characteristics of journey-to-work. The CTPP package consists of two elements (Urban and State) and is organized along three dimensions:

1. The Part: Part 1, (121 tables) deals with the residence end. Part 2 (68 tables) deals with work end. Part 3, (14 tables) deals with the flow between home and work.
2. The Universe: That is the factor used to expand the survey sample. It could be the number of all persons, all households, all workers, all household workers or all housing units. The universe for Part 3 is the number of all workers traveling from residence to work place.
3. The Geography: state, county, place, Minor Civil Division (MCD), Census Tract, Census Block or TAZ (as specified by MPOs). The geography for all tabulations presented in this chapter is the county and census tract levels, comprising the area of the expanded cordon.

6.1 *CTPP 2000 Data Sources*

The following three sources of CTPP data were used to extract all tabulations included in this chapter:

1. The CTPP Access Tool (CAT), together with CD's including data by state. Data for the expanded cordon jurisdictions are available from 3 CD's covering DC, Maryland, Virginia and West Virginia.
2. U.S. Census Bureau – American Fact-Finder Web site (http://factfinder.census.gov/)
3. The BTS – TRANSTATS Web site. (http://www.transtats.bts.gov/).

6.2 *Application of the CTPP Data*

The CTPP data provides rich information on the demographics and work trip characteristics of metropolitan regions. The CTPP includes information on reported work trip characteristics, the origin and destination, departure time, car occupancy, trip length, and choice of commuting mode, which can be used to inform the regional travel demand model. The CTPP data is useful for modeling the non-motorized travel models which typically suffer from lack of a reasonable sample size at small level of geographic areas. Last, but not least, the census data has been considered by many users as the standard by which many other surveys are designed, compared and expanded.

6.3 *Limitations of the CTPP Data*

Despite the large sample of the CTPP data, there are some limitations on its use in travel models. First, CTPP information is restricted to home-based-work travel. Second, because the CTPP survey question is based on what a commuter 'normally' does, as opposed to what a traveler did on a specific day (which is how questions on typical household travel surveys are designed), adjustments need to be applied to the data to make it more usable for comparing to travel demand modeled outputs. Third, CTPP data is subject to complicated rounding and numeric threshold procedures in order to maintain confidentiality. All tables in Part 1 and Part 2 are rounded as follows: values of zero are rounded to 0; values of 1-7 are rounded to 4; values of 8+ are rounded to nearest multiple of "5". All tables in Part 3 are rounded and some of them are subject to thresholds. Because of suppression and rounding, the sum of disaggregated households, in most tables presented in this chapter will not sum to the jurisdictional totals which are not subjected to any suppression or rounding. This problem becomes clearer when tabulations are done at the finer tract level. CTPP users have used different methods to overcome the rounding problem.

6.4 *Application of CTPP Data for MWCOG Demographic Models*

The first process in the MWCOG model structure is the application of three demographic sub models. The purpose of these models is to disaggregate the total number of households among 64 cross-classes[5]. The household classes consist of three general types:

1. 4 Household size groups (households with 1, 2, 3, and 4+ persons).
2. 4 Household income quartile groups.
3. 4 Vehicle availability groups (households with 0, 1, 2, and 3+ automobiles).

The CTPP data provides the largest available sample of these three input variables. The current demographic sub-models were estimated based on the 1990 CTPP data. The household size sub-model distributes total number of households given the zone's average household size. Similarly, the income sub model estimates the percent of households in each of the four income classes, given the zone's median household income. The vehicle ownership model, a logit model, uses information from the household size and the household income sub models. Though zone level CTPP data was used as an input to estimate the models' coefficients, it is possible to use census tract level to estimate the same coefficients.

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[5] For detailed description of the demographic sub models see MWCOG, "COG/TPB Travel Forecasting Model, Version 2.1 D # 50, Calibration Report, November 17, 2004, PP 3.1-3.17.

The following sections document the processing of the 2000 CTPP to update the estimation of the three demographic models. Jurisdiction and census tract level tables were produced to cover the 64 cross classes of household income, household size and vehicles available per household. The following section presents jurisdictional control total summaries of the three variables.

6.5 *CTPP Control Totals for the Expanded Cordon Area*

One way to minimize the impacts of rounding and thresholds is to obtain regional control totals at the most geographically aggregate summary level. Regional control totals, shown in Table 6-1 and Table 6-2, are useful as a reference to measure and adjust the error introduced by the rounding and threshold procedures applied to more disaggregated tables such as those at census tract level.

Table 6-1 Control Totals for the Expanded Cordon Area[6]

	Expanded Cordon	U.S
Total number of households	2.142 Million	105.539 million
Total population	5.739 Million	281.422 Million
Population in households	5.617 Million	273.637 Million
Population in group quarters	0 .122 Million	7.785 Million
Total workers (from households & group quarters)	2.991 Million	
Household workers	2.962 Million	
Total Number of Vehicles available	3.713 Million	178.344 Million
Average household size	2.62	2.59
Average Number of vehicles available per household	1.73	1.69
Average number of workers per household	1.38	
Mean household income (1999 $)	$80,000	$56,600
Median household income (1999 $)	$63,800	$42,000

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[6] The Expanded Cordon area includes: The District of Columbia, Anne Arundel, Calvert, Carroll, Charles, Frederick, Howard, Montgomery, Prince George's, St. Mary's, Arlington, Clarke, Fairfax, Fauquier, King George, Loudoun, Prince William, Northern portion of Spotsylvania, Stafford, Jefferson Alexandria city, Fairfax city, Falls Church city, Fredericksburg city, Manassas city, Manassas Park city.

Table 6-2 Aggregate Summary by Jurisdiction
MWCOG Expanded Cordon Area

Source: 2000 CTPP Tables

	All Households	Household Population	Group Quarter Population	ALL Person**	Household Workers	ALL Workers**	Vehicles Owned	Average HH Size	Veh/HH	Wrks/HH	% HHS No-Telephone	Mean HH Income	Median HH Income
Census Table Reference>>	FF-SF3-P14	FF-SF3-P9	FF-SF3-P9	FF-SF3-P9	Table 1-002	Table 1-031	Table 1-109	Computed	Computed	Computed	Table 1-073	Table 1-090	FF-SF3-P53
Total District of Columbia	**248,590**	**536,373**	**35,686**	**572,059**	**251,705**	**260,885**	**220,765**	**2.16**	**0.89**	**1.01**	**2.6%**	**64,355**	**40,127**
Anne Arundel County	178,754	473,766	15,890	489,656	252,250	255,860	343,095	2.65	1.92	1.41	0.9%	74,090	61,768
Calvert County	25,428	73,983	580	74,563	37,510	37,555	55,620	2.91	2.19	1.48	1.2%	74,220	65,945
Carroll County	52,601	147,298	3,599	150,897	77,175	77,590	111,630	2.80	2.12	1.47	0.7%	67,535	60,021
Charles County	41,675	119,162	1,384	120,546	61,590	61,700	86,210	2.86	2.07	1.48	1.4%	69,470	62,199
Frederick County	70,115	190,627	4,650	195,277	101,125	102,320	142,810	2.72	2.04	1.44	1.0%	69,955	60,276
Howard County	90,102	244,207	3,635	247,842	134,745	134,990	174,775	2.71	1.94	1.50	0.4%	88,180	74,167
Montgomery County	324,940	863,876	9,465	873,341	454,125	455,330	562,560	2.66	1.73	1.40	0.4%	95,080	71,551
Prince George's County	286,650	784,120	17,395	801,515	393,075	397,405	471,025	2.74	1.64	1.37	0.9%	64,420	55,256
St. Mary's County	30,736	83,416	2,795	86,211	42,310	43,265	61,065	2.71	1.99	1.38	2.1%	62,040	54,706
Total Maryland	**1,101,001**	**2,980,455**	**59,393**	**3,039,848**	**1,553,905**	**1,566,015**	**2,008,790**	**2.71**	**1.82**	**1.41**	**0.8%**	**77,892**	
Arlington County	86,474	185,328	4,125	189,453	113,975	116,045	121,060	2.14	1.40	1.32	0.7%	81,770	63,001
Clarke County	4,950	12,339	313	12,652	6,490	6,510	10,580	2.49	2.14	1.31	1.4%	61,855	51,601
Fairfax County	351,279	959,416	10,333	969,749	525,740	527,465	669,210	2.73	1.91	1.50	0.3%	100,915	81,050
Fauquier County	19,889	54,571	568	55,139	28,220	28,225	44,555	2.74	2.24	1.42	1.6%	79,300	61,999
King George County	6,092	16,447	356	16,803	7,970	8,185	12,960	2.70	2.13	1.31	2.5%	59,230	49,882
Loudoun County	59,921	168,743	856	169,599	92,280	92,315	121,840	2.82	2.03	1.54	0.6%	94,815	80,648
Prince William County	94,662	278,416	2,397	280,813	149,045	150,525	191,620	2.94	2.02	1.57	0.9%	75,215	65,960
Spotsylvania County*	25,484	73,324	494	73,818	37,410	37,410	68,000	2.88	2.67	1.47	0.9%	66,665	57,525
Stafford County	30,136	90,957	1,489	92,446	47,465	48,381	66,715	3.02	2.21	1.58	1.1%	75,035	66,809
Alexandria City	61,968	126,375	1,908	128,283	77,005	77,190	83,210	2.04	1.34	1.24	0.8%	76,370	56,054
Fairfax City	8,013	20,968	530	21,498	11,760	11,845	15,365	2.62	1.92	1.47	0.6%	82,840	67,642
Falls Church City	4,472	10,308	69	10,377	5,855	5,853	6,935	2.31	1.55	1.31	0.4%	93,855	74,924
Fredericksburg City	8,086	16,917	2,362	19,279	9,055	9,659	11,785	2.09	1.46	1.12	2.5%	49,790	34,585
Manassas City	11,785	34,268	867	35,135	18,110	18,145	22,440	2.91	1.90	1.54	1.2%	71,845	60,409
Manassas Park City	3,253	10,290	0	10,290	5,505	5,503	6,640	3.16	2.04	1.69	0.6%	66,250	60,794
Jefferson County, WVA	16,179	41,040	1,150	42,190	20,655	21,066	31,425	2.54	1.94	1.28	2.5%	53,157	44,374
Total Virginia & W. Virginia	**792,643**	**2,099,707**	**27,817**	**2,127,524**	**1,156,540**	**1,164,322**	**1,484,340**	**2.65**	**1.87**	**1.46**	**0.6%**	**87,891**	
Tot Expanded Cordon	**2,142,234**	**5,616,535**	**122,896**	**5,739,431**	**2,962,150**	**2,991,222**	**3,713,895**	**2.62**	**1.73**	**1.38**	**0.9%**	**79,992**	**63,793**

Notes:

* Since the southern part of Spotsylvania County is outside the expanded cordon area, all values for this county were computed by deducting values of (two) census tracts falling outside the expanded cordon area from the total county values.

** All persons / all workers refer to persons / workers in both household units and group quarters (institutional and non-institutional).

“Vehicles available” refers to the number of passenger cars, vans, and pickups or panel trucks of 1-ton capacity or less kept at home and available for the use of household members.
Vehicles rented or used for 1 month or more, company vehicles, and police and government vehicles are included if kept at home and used for non-business purposes.
Vehicles kept at home but used only for business purposes are excluded.

6.6 *Household Income*

As mentioned before, the current income model and the definition of income interval for each quartile were based on the 1990 CTPP data. The income intervals for this model are: 1st quartile: Less than $30 k; 2nd quartile: $30k-49.9K; 3rd quartile: $50k-74.9 and 4th quartile: $ 75k or more.

The first step taken to update the income model is to re-compute the income intervals for each quartile based on the 2000 CTPP data. The new income intervals reflect 1999 dollars, as defined by the 2000 CTPP. The average household income of cell/strata (e.g. jurisdiction or one-person household strata) was computed by dividing total households' income (in 1999 dollars) by the number of households in the cell/strata. The CTPP tabulations of income are available in terms of 26, 11, 9, and 5 intervals. As shown in Table 6-3, the computation of quartiles is based on the most detailed CTPP tabulation (the 26 interval tabulation). The income distribution of households reflects a skewed distribution where the overall regional median income is $63,000 and the mean income is $80,000. Both regional median and regional mean household incomes are substantially higher than the national averages, as shown in Table 6-1. The updated income intervals (in 1999 dollars) for the expanded cordon total number of households (2,142,200) are as follows:

Quartile	Income Interval
1st Quartile (25%)	Lees Than $36,127
2nd Quartile (50%) - Median	$36,128 - $63,794
3rd Quartile (75%)	$63,795 - $100,690
4th Quartile (100%)	> $100,690

The distribution of households by the updated income intervals is shown in Table 6-4. More detailed jurisdictional summaries are shown by vehicles available in Table 6-5 to Table 6-9, and by household size in Table 6-10 to Table 6-13.

6.7 *Vehicles Available*

The CTPP defines vehicles available to include passenger cars, vans, and pickup or panel trucks of 1-ton capacity or less kept at home and available for the use of household members. Vehicles rented or used for one month or more, company vehicles, and police and government vehicles are included, if kept at home and used for non-business purposes. However, vehicles kept at home but used only for business purposes are excluded. The CTPP expresses vehicles available in terms of housing units, rather than households.[7] Since the difference between the two expansion factors is very small, it is possible compute average vehicles available in terms of households.

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[7] The CTPP defines a household to include all of the individuals living in a household unit. A household unit is defined as a house, an apartment, a mobile home, a group of rooms, or a single room occupied as a separate living quarters, or vacant, intended for occupancy as a separate living quarters. (Example of

Shown in Table 6-14 is a jurisdiction summary of households' distribution by number of vehicles available.

6.8 *Household Size*

Average household size of cell/strata is computed by dividing total household persons (family and non-family) by the total number of households. The CTPP classifies households by 4 categories: one-person, two-person, three-person and four + person households. The CTPP provides separate tabulations of total population of household persons and group quarters persons. This information could be used to compute the average number of persons for the last category of 4+ persons by dividing total household persons by the total number of households in this category. Shown in Table 6-15 is a summary of total households by jurisdiction and household size.

6.9 *Next Steps*

The disaggregate information summarized above will be prepared at the census tract level and used to update the demographic models of the next travel model version. The updated demographic models will benefit not only the trip generation model, but also the trip distribution and mode choice steps as well.

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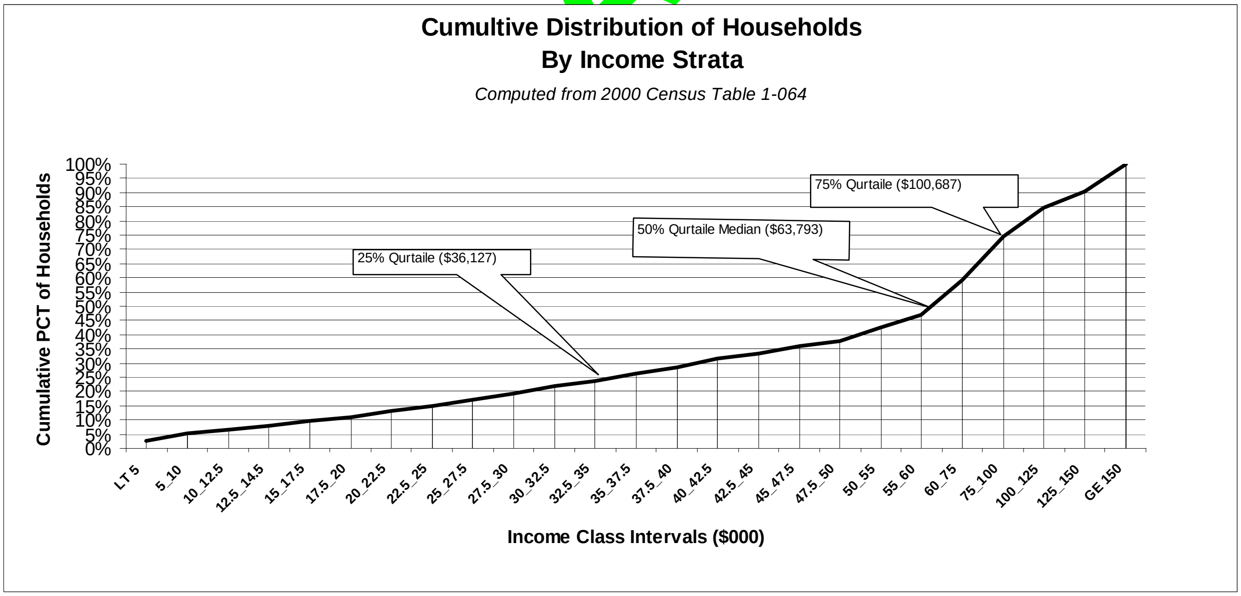
separate quarters are those in which the occupants live separately and have direct access from outside the building or through a common hall.)

Table 6-3 Cumulative Distribution of Total Households by Income
Total Households of the MWCOG Expanded Cordon Area
Source: CTPP 2000 - Table 1-064

	CTPP Income Classes	Frequency		Cumulative		
		Households	PCT	Households	PCT	
GE 150	$150,000 or more	210,955	9.8%	2,142,175	100.00%	
125_150	$125,000-$149,999	120,860	5.6%	1,931,220	90.2%	
100_125	$100,000-$124,999	209,515	9.8%	1,810,360	84.5%	<<< Upper Limit for 3rd Income Quartile is $100,690
75_100	$75,000-$99,999	330,055	15.4%	1,600,845	74.7%	
60_75	$60,000-$74,999	267,320	12.5%	1,270,790	59.3%	<<< Upper Limit for 2nd Income Quartile (MEDIAN) is $63,794
55_60	$55,000-$59,999	89,665	4.2%	1,003,470	46.8%	
50_55	$50,000-$54,999	104,375	4.9%	913,805	42.7%	
47.5_50	$47,500-$49,999	42,085	2.0%	809,430	37.8%	
45_47.5	$45,000-$47,499	52,335	2.4%	767,345	35.8%	
42.5_45	$42,500-$44,999	43,000	2.0%	715,010	33.4%	
40_42.5	$40,000-$42,499	60,430	2.8%	672,010	31.4%	
37.5_40	$37,500-$39,999	44,255	2.1%	611,580	28.5%	
35_37.5	$35,000-$37,499	57,830	2.7%	567,325	26.5%	<<< Upper Limit for 1st Income Quartile is $36,126
32.5_35	$32,500-$34,999	41,990	2.0%	509,495	23.8%	
30_32.5	$30,000-$32,499	58,560	2.7%	467,505	21.8%	
27.5_30	$27,500-$29,999	40,650	1.9%	408,945	19.1%	
25_27.5	$25,000-$27,499	49,035	2.3%	368,295	17.2%	
22.5_25	$22,500-$24,999	37,130	1.7%	319,260	14.9%	
20_22.5	$20,000-$22,499	44,470	2.1%	282,130	13.2%	
17.5_20	$17,500-$19,999	31,425	1.5%	237,660	11.09%	
15_17.5	$15,000-$17,499	35,225	1.6%	206,235	9.63%	
12.5_14.5	$12,500-$14,999	27,695	1.3%	171,010	7.98%	
10_12.5	$10,000-$12,499	33,965	1.6%	143,315	6.69%	
5_10	$ 5,000-$ 9,999	56,850	2.7%	109,350	5.10%	
LT 5	Less than $5,000	52,500	2.5%	52,500	2.45%	
	Total	**2,142,175**	100.0%			

1st Quartile	Less Than or Equal to $36,126
2nd Quartile (Median)	$036,127 - $063,794
3rd Quartile	$063,795 - $100,690
4th Quartile	Greater Than 100,690



Cumultive Distribution of Households
By Income Strata

Computed from 2000 Census Table 1-064

Table 6-4 Distribution of Total Households by Jurisdiction & Income ($ 1999 $)
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	All Households				
	Total	LT $35k	$35-$59.9K	$60-$99.9k	$100+ K
District of Columbia	248,590	110,570	53,910	43,380	40,720
Anne Arundel County	178,755	41,070	44,750	54,040	38,890
Calvert County	25,430	5,200	6,015	8,610	5,605
Carroll County	52,600	12,770	13,510	16,835	9,480
Charles County	41,675	9,135	10,660	13,460	8,430
Frederick County	70,115	17,085	17,735	21,980	13,305
Howard County	90,100	15,405	18,815	27,160	28,730
Montgomery County	324,940	62,815	68,960	87,815	105,345
Prince George's County	286,650	78,260	77,555	82,130	48,710
St. Mary's County	30,735	8,660	8,390	9,220	4,460
Total Maryland	1,101,000	250,400	266,390	321,250	262,955
Arlington County	86,475	20,170	20,305	22,880	23,115
Clarke County	4,950	1,605	1,315	1,290	745
Fairfax County	351,280	50,695	66,880	101,750	131,945
Fauquier County	19,890	4,660	4,730	5,750	4,735
King George County	6,090	1,875	1,915	1,560	735
Loudoun County	59,920	7,735	11,040	19,970	21,180
Prince William County	94,660	17,630	23,825	30,900	22,305
Spotsylvania County	25,485	6,065	6,915	8,505	4,025
Stafford County	30,135	5,605	7,225	11,000	6,300
Alexandria City	61,970	16,725	16,225	15,350	13,650
Fairfax City	8,015	1,310	2,090	2,495	2,120
Falls Church City	4,470	780	975	1,105	1,600
Fredericksburg City	8,085	4,070	1,875	1,320	815
Manassas City	11,785	2,660	3,180	3,640	2,305
Manassas Park City	3,255	650	935	1,220	450
Jefferson County, WV	16,180	6,290	4,245	4,010	1,630
Total Virginia & W. Virginia	792,645	148,525	173,675	232,745	237,655
Total Expanded Cordon	2,142,235	509,495	493,975	597,375	541,330

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-5 Distribution of 0-Vehicle Households by Jurisdiction & Income ($ 1999)
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	Zero-Vehicle Households				
	Total	LT $35k	$35-$59.9K	$60-$99.9k	$100+ K
District of Columbia	90,965	55,570	17,645	9,550	8,195
Anne Arundel County	9,325	5,915	1,585	955	870
Calvert County	885	580	93	115	94
Carroll County	2,310	1,655	269	155	235
Charles County	2,000	1,250	320	195	235
Frederick County	3,405	2,410	490	215	280
Howard County	3,750	2,235	655	450	410
Montgomery County	24,375	12,795	5,495	3,255	2,825
Prince George's County	29,500	16,040	7,615	3,470	2,370
St. Mary's County	1,645	1,135	260	165	94
Total Maryland	77,195	44,015	16,782	8,975	7,413
Arlington County	10,550	5,005	2,480	1,715	1,335
Clarke County	290	232	4	14	30
Fairfax County	14,005	6,630	2,770	2,235	2,380
Fauquier County	770	525	113	60	75
King George County	300	198	42	23	20
Loudoun County	1,485	770	300	195	220
Prince William County	3,225	1,795	640	410	375
Spotsylvania County	760	473	144	61	96
Stafford County	685	459	77	55	79
Alexandria City	6,865	3,785	1,550	835	705
Fairfax City	300	131	61	30	49
Falls Church City	325	178	88	24	28
Fredericksburg City	1,120	885	134	84	18
Manassas City	550	290	105	100	64
Manassas Park City	150	48	60	12	20
Jefferson County, WV	1,065	844	127	65	23
Total Virginia & W. Virginia	42,445	22,248	8,695	5,918	5,517
Total Expanded Cordon	210,605	121,833	43,122	24,443	21,125

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-6 Distribution of 1-Vehicle Households by Jurisdiction & Income ($ 1999)
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	One-Vehicle Households				
	Total	LT $35k	$35-$59.9K	$60-$99.9k	$100+ K
District of Columbia	108,300	41,200	28,845	21,645	16,600
Anne Arundel County	51,185	22,725	16,605	8,770	3,095
Calvert County	5,410	2,575	1,680	865	300
Carroll County	11,130	6,205	2,985	1,460	495
Charles County	10,315	4,580	3,600	1,690	440
Frederick County	17,575	8,720	5,375	2,595	880
Howard County	23,740	8,545	8,195	5,280	1,720
Montgomery County	111,305	34,205	35,095	27,845	14,160
Prince George's County	110,495	43,710	38,545	22,535	5,710
St. Mary's County	8,115	4,215	2,470	1,120	315
Total Maryland	349,270	135,480	114,550	72,160	27,115
Arlington County	41,945	11,195	12,440	11,880	6,425
Clarke County	1,230	690	330	180	33
Fairfax County	103,435	27,910	32,805	29,700	13,020
Fauquier County	4,180	2,095	1,180	625	275
King George County	1,550	850	500	170	35
Loudoun County	13,975	4,000	4,780	3,580	1,620
Prince William County	24,555	9,510	8,645	5,035	1,360
Spotsylvania County	6,055	3,016	1,810	865	350
Stafford County	5,855	2,690	1,845	1,055	270
Alexandria City	32,455	9,965	10,615	7,820	4,060
Fairfax City	2,600	735	955	675	230
Falls Church City	2,000	480	605	575	340
Fredericksburg City	3,470	2,230	790	305	150
Manassas City	3,400	1,545	1,215	530	110
Manassas Park City	775	283	300	145	38
Jefferson County, WV	4,665	2,905	1,070	545	150
Total Virginia & W. Virginia	252,145	80,099	79,885	63,685	28,466
Total Expanded Cordon	709,715	256,779	223,280	157,490	72,181

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-7 Distribution of 2-Vehicle Households by Jurisdiction & Income ($ 1999)
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	Two-Vehicle Households				
	Total	LT $35k	$35-$59.9K	$60-$99.9k	$100+ K
District of Columbia	38,995	6,185	7,315	10,570	14,935
Anne Arundel County	78,080	9,540	20,435	28,900	19,215
Calvert County	10,755	1,450	2,840	4,330	2,140
Carroll County	23,570	3,635	7,045	8,745	4,145
Charles County	17,850	2,480	4,860	7,015	3,490
Frederick County	30,680	4,430	8,510	11,530	6,205
Howard County	43,080	3,575	7,800	15,690	16,020
Montgomery County	135,315	11,265	22,430	42,915	58,690
Prince George's County	97,740	12,520	24,975	38,710	21,540
St. Mary's County	13,215	2,430	3,920	4,880	1,970
Total Maryland	450,285	51,325	102,815	162,715	133,415
Arlington County	25,730	2,580	4,505	7,380	11,270
Clarke County	1,790	485	565	480	255
Fairfax County	161,080	12,210	24,075	51,055	73,745
Fauquier County	7,845	1,355	2,220	2,600	1,665
King George County	2,365	575	800	710	280
Loudoun County	30,695	2,260	4,550	11,510	12,375
Prince William County	42,980	4,675	10,965	16,730	10,610
Spotsylvania County	11,045	1,911	3,321	4,280	1,545
Stafford County	14,135	1,880	3,740	5,905	2,615
Alexandria City	18,270	2,130	3,595	5,500	7,045
Fairfax City	3,390	334	720	1,205	1,135
Falls Church City	1,590	110	195	435	855
Fredericksburg City	2,460	714	745	640	355
Manassas City	5,320	629	1,390	2,045	1,260
Manassas Park City	1,465	232	440	540	250
Jefferson County, WV	6,425	1,800	1,985	1,910	725
Total Virginia & W. Virginia	336,585	33,880	63,811	112,925	125,985
Total Expanded Cordon	825,865	91,390	173,941	286,210	274,335

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-8 Distribution of 3-Vehicle Households by Jurisdiction & Income ($ 1999)
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	Three-Vehicle Households				
	Total	LT $35k	$35-$59.9K	$60-$99.9k	$100+ K
District of Columbia	7,725	850	1,030	1,835	4,010
Anne Arundel County	28,795	1,890	4,810	11,515	10,580
Calvert County	5,860	445	1,110	2,380	1,920
Carroll County	10,865	955	2,460	4,585	2,865
Charles County	7,865	524	1,410	3,315	2,615
Frederick County	12,640	970	2,540	5,240	3,900
Howard County	14,955	665	1,655	4,685	7,955
Montgomery County	40,615	2,055	4,870	11,250	22,435
Prince George's County	35,560	2,525	5,750	13,675	13,615
St. Mary's County	5,530	585	1,380	2,185	1,375
Total Maryland	162,685	10,614	25,985	58,830	67,260
Arlington County	6,210	470	670	1,515	3,565
Clarke County	1,165	122	309	415	320
Fairfax County	52,990	2,210	5,505	13,965	31,315
Fauquier County	4,610	505	880	1,535	1,690
King George County	1,225	143	415	465	210
Loudoun County	10,220	450	1,150	3,655	4,960
Prince William County	16,980	1,085	2,750	6,485	6,655
Spotsylvania County	5,350	532	1,166	2,455	1,190
Stafford County	6,590	465	1,150	2,870	2,100
Alexandria City	3,480	228	475	970	1,810
Fairfax City	1,195	44	245	375	525
Falls Church City	460	8	58	70	310
Fredericksburg City	800	174	173	245	220
Manassas City	1,920	154	320	750	705
Manassas Park City	640	48	92	385	110
Jefferson County, WV	2,675	454	805	1,035	375
Total Virginia & W. Virginia	116,510	7,092	16,163	37,190	56,060
Total Expanded Cordon	286,920	18,556	43,178	97,855	127,330

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-9 Distribution of 4+ Vehicle Households by Jurisdiction & Income ($ 1999)
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	Four + Vehicle Households				
	Total	LT $35k	$35-$59.9K	$60-$99.9k	$100+ K
District of Columbia	2,605	560	399	585	1,065
Anne Arundel County	11,375	545	1,345	4,010	5,475
Calvert County	2,525	127	284	935	1,170
Carroll County	4,725	255	770	1,820	1,890
Charles County	3,645	159	484	1,220	1,775
Frederick County	5,820	390	870	2,405	2,160
Howard County	4,580	193	445	1,105	2,840
Montgomery County	13,330	670	1,245	2,845	8,570
Prince George's County	13,355	895	1,405	4,115	6,935
St. Mary's County	2,230	193	370	890	775
Total Maryland	61,585	3,427	7,218	19,345	31,590
Arlington County	2,035	169	154	520	1,195
Clarke County	475	65	93	190	130
Fairfax County	19,765	850	1,530	4,910	12,475
Fauquier County	2,485	158	330	930	1,060
King George County	650	93	165	205	195
Loudoun County	3,545	125	329	925	2,155
Prince William County	6,920	364	835	2,210	3,505
Spotsylvania County	2,280	135	439	815	910
Stafford County	2,875	83	415	1,115	1,260
Alexandria City	900	99	114	270	410
Fairfax City	530	23	65	205	225
Falls Church City	100	0	4	14	70
Fredericksburg City	240	18	54	85	75
Manassas City	595	8	133	265	185
Manassas Park City	220	14	32	120	45
Jefferson County, WV	1,350	235	265	500	365
Total Virginia & W. Virginia	44,965	2,439	4,957	13,279	24,260
Total Expanded Cordon	109,155	6,426	12,574	33,209	56,915

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-10 Distribution of 1-Person Households by Jurisdiction & Income
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	1-Person Households				
	Tot 1-PSN	LT 35k	35-59.9K	60-99.9k	100+ K
District of Columbia	108,570	61,215	24,640	15,060	7,655
Anne Arundel County	38,040	19,390	11,030	5,640	1,975
Calvert County	4,155	2,220	1,190	540	205
Carroll County	9,195	5,965	2,175	815	240
Charles County	7,145	3,710	2,215	1,040	180
Frederick County	14,055	8,395	3,675	1,505	480
Howard County	18,685	7,685	6,040	3,865	1,090
Montgomery County	79,245	31,415	23,890	16,810	7,130
Prince George's County	69,005	34,720	22,095	10,300	1,885
St. Mary's County	6,490	3,675	1,855	745	205
Total Maryland	246,015	117,175	74,165	41,260	13,390
Arlington County	35,235	12,040	10,785	8,965	3,445
Clarke County	1,190	795	215	140	39
Fairfax County	75,005	22,340	24,135	20,910	7,620
Fauquier County	3,705	2,120	985	405	215
King George County	1,250	775	275	165	24
Loudoun County	11,080	3,750	3,700	2,560	1,065
Prince William County	16,100	6,820	5,680	3,090	515
Spotsylvania County	4,245	2,526	1,175	405	140
Stafford County	4,180	2,155	1,275	610	140
Alexandria City	26,880	9,420	8,985	5,835	2,630
Fairfax City	1,880	620	800	345	105
Falls Church City	1,520	540	475	310	185
Fredericksburg City	3,175	2,215	620	275	70
Manassas City	2,470	1,365	780	290	40
Manassas Park City	470	208	174	65	15
Jefferson County, WV	3,745	2,735	615	310	90
Total Virginia & W. Virginia	192,130	70,424	60,674	44,680	16,338
Total Expanded Cordon	**546,715**	**248,814**	**159,479**	**101,000**	**37,383**

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-11 Distribution of 2-Person Households by Jurisdiction & Income
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	2-Person Households				
	Tot 2-PSN	LT 35k	35-59.99K	60-99.99k	100+ K
District of Columbia	68,020	23,235	14,155	14,290	16,335
Anne Arundel County	59,695	11,470	15,415	18,945	13,865
Calvert County	7,875	1,475	2,005	2,590	1,805
Carroll County	17,055	4,120	4,875	5,360	2,700
Charles County	12,720	2,645	3,420	4,085	2,555
Frederick County	22,835	4,830	6,340	7,115	4,550
Howard County	28,300	3,900	6,260	9,110	9,030
Montgomery County	101,645	14,445	20,325	29,975	36,910
Prince George's County	82,675	20,105	23,720	25,360	13,485
St. Mary's County	9,505	2,430	2,685	2,830	1,555
Total Maryland	342,305	65,420	85,045	105,370	86,455
Arlington County	27,260	3,885	4,780	7,930	10,655
Clarke County	1,825	485	550	490	295
Fairfax County	113,475	11,890	18,060	33,875	49,650
Fauquier County	6,885	1,370	1,580	2,215	1,725
King George County	2,010	520	695	545	250
Loudoun County	18,875	1,925	3,195	6,795	6,970
Prince William County	27,680	4,285	6,825	9,375	7,180
Spotsylvania County	7,935	1,742	2,421	2,725	1,055
Stafford County	8,850	1,665	2,015	3,065	2,100
Alexandria City	19,590	3,590	3,535	5,860	6,605
Fairfax City	2,855	390	555	965	965
Falls Church City	1,420	85	320	420	575
Fredericksburg City	2,700	1,050	735	510	410
Manassas City	3,260	565	920	1,035	730
Manassas Park City	900	189	235	330	140
Jefferson County, WV	5,720	1,885	1,645	1,430	760
Total Virginia & W. Virginia	251,240	35,521	48,066	77,565	90,065
Total Expanded Cordon	**661,565**	**124,176**	**147,266**	**197,225**	**192,855**

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-12 Distribution of 3-Person Households by Jurisdiction & Income
MWCOG Expanded Cordon Area
Source: CTPP 2000 Tabulations

	3-Person Households				
	Tot 3-PSN	LT 35k	35-59.99K	60-99.99k	100+ K
District of Columbia	31,625	11,785	6,710	6,105	7,030
Anne Arundel County	33,455	5,010	7,855	12,020	8,575
Calvert County	4,790	670	1,145	1,755	1,220
Carroll County	9,945	1,250	2,710	3,800	2,190
Charles County	8,695	1,370	2,085	3,210	2,025
Frederick County	13,100	1,955	3,345	4,980	2,810
Howard County	16,670	1,840	2,775	5,445	6,605
Montgomery County	54,680	7,385	9,575	15,695	22,030
Prince George's County	54,380	10,685	13,585	18,240	11,875
St. Mary's County	5,770	1,235	1,455	2,170	920
Total Maryland	201,485	31,400	44,530	67,315	58,250
Arlington County	10,450	1,820	1,830	2,615	4,180
Clarke County	845	218	220	270	130
Fairfax County	61,705	6,280	9,390	17,645	28,385
Fauquier County	3,665	495	815	1,220	1,125
King George County	1,155	278	405	285	170
Loudoun County	11,320	955	1,850	3,925	4,585
Prince William County	18,745	2,760	4,110	6,545	5,330
Spotsylvania County	5,145	897	1,134	2,060	1,075
Stafford County	6,185	785	1,390	2,615	1,395
Alexandria City	7,165	1,680	1,535	1,655	2,295
Fairfax City	1,435	114	255	590	475
Falls Church City	650	81	52	165	350
Fredericksburg City	1,130	455	290	210	170
Manassas City	2,120	275	560	825	465
Manassas Park City	670	107	157	290	100
Jefferson County, WV	2,970	810	895	845	420
Total Virginia & W. Virginia	135,355	18,010	24,888	41,760	50,650
Total Expanded Cordon	**368,465**	**61,195**	**76,128**	**115,180**	**115,930**

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-13 Distribution of 4+ Person Households by Jurisdiction & Income
MWCOG Expanded Cordon Area

	4+ Person Households				
	Tot 4-PSN	LT 35k	35-59.99K	60-99.99k	100+ K
District of Columbia	40,370	14,320	8,415	7,930	9,705
Anne Arundel County	47,565	5,205	10,445	17,440	14,480
Calvert County	8,605	840	1,670	3,720	2,380
Carroll County	16,405	1,435	3,750	6,865	4,350
Charles County	13,115	1,390	2,940	5,120	3,665
Frederick County	20,125	1,900	4,375	8,375	5,465
Howard County	26,445	1,975	3,740	8,730	12,005
Montgomery County	89,365	9,575	15,180	25,340	39,270
Prince George's County	80,595	12,745	18,160	28,230	21,460
St. Mary's County	8,975	1,330	2,395	3,480	1,775
Total Maryland	311,195	36,395	62,655	107,300	104,850
Arlington County	13,530	2,420	2,920	3,375	4,830
Clarke County	1,090	102	328	385	280
Fairfax County	101,095	10,180	15,305	29,325	46,280
Fauquier County	5,630	694	1,350	1,905	1,675
King George County	1,680	297	535	575	280
Loudoun County	18,645	1,115	2,285	6,690	8,550
Prince William County	32,135	3,755	7,195	11,890	9,285
Spotsylvania County	8,155	914	2,182	3,315	1,751
Stafford County	10,925	1,005	2,555	4,700	2,665
Alexandria City	8,335	2,040	2,185	1,995	2,115
Fairfax City	1,845	177	490	600	580
Falls Church City	880	57	125	205	490
Fredericksburg City	1,080	347	239	325	165
Manassas City	3,930	454	930	1,490	1,065
Manassas Park City	1,210	128	349	535	200
Jefferson County, WV	3,745	860	1,100	1,430	360
Total Virginia & W. Virginia	213,910	24,545	40,073	68,740	80,571
Total Expanded Cordon	**565,475**	**75,260**	**111,143**	**183,970**	**195,126**

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-14 Distribution of Total Households by Jurisdiction & Vehicles Available MWCOG Expanded Cordon Area

Jurisdiction	Total Households	By Vehicles Available				
		0	1	2	3	4+
Total District of Columbia	**248,590**	**90,965**	**108,300**	**38,995**	**7,725**	**2,605**
Anne Arundel County	**178,754**	9,325	51,185	78,080	28,795	11,375
Calvert County	**25,428**	885	5,410	10,755	5,860	2,525
Carroll County	**52,601**	2,310	11,130	23,570	10,865	4,725
Charles County	**41,675**	2,000	10,315	17,850	7,865	3,645
Frederick County	**70,115**	3,405	17,575	30,680	12,640	5,820
Howard County	**90,102**	3,750	23,740	43,080	14,955	4,580
Montgomery County	**324,940**	24,375	111,305	135,315	40,615	13,330
Prince George's County	**286,650**	29,500	110,495	97,740	35,560	13,355
St. Mary's County	**30,736**	1,645	8,115	13,215	5,530	2,230
Total Maryland	**1,101,001**	**77,195**	**349,270**	**450,285**	**162,685**	**61,585**
Arlington County	**86,474**	10,550	41,945	25,730	6,210	2,035
Clarke County	**4,950**	290	1,230	1,790	1,165	475
Fairfax County	**351,279**	14,005	103,435	161,080	52,990	19,765
Fauquier County	**19,889**	770	4,180	7,845	4,610	2,485
King George County	**6,092**	300	1,550	2,365	1,225	650
Loudoun County	**59,921**	1,485	13,975	30,695	10,220	3,545
Prince William County	**94,662**	3,225	24,555	42,980	16,980	6,920
Spotsylvania County	**25,484**	760	6,055	11,045	5,350	2,280
Stafford County	**30,136**	685	5,855	14,135	6,590	2,875
Alexandria City	**61,968**	6,865	32,455	18,270	3,480	900
Fairfax City	**8,013**	300	2,600	3,390	1,195	530
Falls Church City	**4,472**	325	2,000	1,590	460	100
Fredericksburg City	**8,086**	1,120	3,470	2,460	800	240
Manassas City	**11,785**	550	3,400	5,320	1,920	595
Manassas Park City	**3,253**	150	775	1,465	640	220
Jefferson County	**16,179**	1,065	4,665	6,425	2,675	1,350
Total Virginia & W. Virginia	**792,643**	**42,445**	**252,145**	**336,585**	**116,510**	**44,965**
Tot Expanded Cordon	**2,142,234**	**210,605**	**709,715**	**825,865**	**286,920**	**109,155**

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Table 6-15 Distribution of Total Households by Jurisdiction & Household Size
MWCOG Expanded Cordon Area

Jurisdiction	Total Households	By Household Size			
		1	2	3	4+
Total District of Columbia	**248,590**	**108,570**	**68,020**	**31,625**	**40,370**
Anne Arundel County	**178,755**	38,040	59,695	33,455	47,565
Calvert County	**25,430**	4,155	7,875	4,790	8,605
Carroll County	**52,600**	9,195	17,055	9,945	16,405
Charles County	**41,675**	7,145	12,720	8,695	13,115
Frederick County	**70,115**	14,055	22,835	13,100	20,125
Howard County	**90,100**	18,685	28,300	16,670	26,445
Montgomery County	**324,940**	79,245	101,645	54,680	89,365
Prince George's County	**286,650**	69,005	82,675	54,380	80,595
St. Mary's County	**30,735**	6,490	9,505	5,770	8,975
Total Maryland	**1,101,000**	**246,015**	**342,305**	**201,485**	**311,195**
Arlington County	**86,475**	35,235	27,260	10,450	13,530
Clarke County	**4,950**	1,190	1,825	845	1,090
Fairfax County	**351,280**	75,005	113,475	61,705	101,095
Fauquier County	**19,890**	3,705	6,885	3,665	5,630
King George County	**6,090**	1,250	2,010	1,155	1,680
Loudoun County	**59,920**	11,080	18,875	11,320	18,645
Prince William County	**94,660**	16,100	27,680	18,745	32,135
Spotsylvania County	**25,485**	4,245	7,935	5,145	8,155
Stafford County	**30,135**	4,180	8,850	6,185	10,925
Alexandria City	**61,970**	26,880	19,590	7,165	8,335
Fairfax City	**8,015**	1,880	2,855	1,435	1,845
Falls Church City	**4,470**	1,520	1,420	650	880
Fredericksburg City	**8,085**	3,175	2,700	1,130	1,080
Manassas City	**11,785**	2,470	3,260	2,120	3,930
Manassas Park City	**3,255**	470	900	670	1,210
Jefferson County	**16,180**	3,745	5,720	2,970	3,745
Total Virginia & W. Virginia	**792,645**	**192,130**	**251,240**	**135,355**	**213,910**
Tot Expanded Cordon	**2,142,235**	**546,715**	**661,565**	**368,465**	**565,475**

Note:
The sum of disaggregated households might not sum to the jurisdictional totals because of suppression and rounding.

Chapter 7 Review of Best Practices

During FY-2005 TPB staff has kept abreast of best practices by engaging in dialog with travel demand modelers in other metropolitan areas, and by attending conferences. This chapter summarizes what has been recently learned regarding current and advanced travel modeling practice and techniques.

7.1 *Participation in AMPO Travel Modeling Subcommittee*

TPB staff has actively promoted a technical subcommittee under the Association of Metropolitan Planning Organizations known as the Travel Modeling Subcommittee (or the AMPO TMS). This subcommittee meets twice a year and is comprised primarily of travel modelers at small, medium, and large MPOs across the country. The mission of the TMS is to promote understanding between modelers regarding current methods being used in practice and to discuss issues relating to acceptable standards and practice. The TMS also serves to promote communication between MPO's and federal representatives from the Department of Transportation and the Environmental Protection Agency.

In FY-2005, the TMS met in Kansas City on September 27 and 28 and in Atlanta on March 21 and 22. Agenda items included the use of the FTA Summit model, data management techniques, and research initiatives.

One of the foremost topics of interest to the TMS, and to the transportation planning profession, is a study being undertaken by the Transportation Research Board to identify the methods and characteristics of travel demand models being used in practice. The breadth of modeling is not well understood by the practice and so this type of survey is timely. The study commenced in October 2004 and is scheduled to be completed in 18 months. The questions addressed by the study are:

1) What travel models are MPOs using or have under development?
2) Are MPOs using multiple models for multiple purposes?
3) What are the key similarities and differences among MPOs in the application and development of models?
4) What are the technical shortcomings of the models?
5) If any, what are the technical obstacles to appropriate applications of the models?
6) Can any other key issues be identified during the course of the study?

A central component of the study is a comprehensive travel modeling survey that is being sent to all MPOs across the U.S. The survey is in progress as of the current time. The results of the study will provide a more complete understanding of the state of the practice and will possibly lead to a context for establishing standards of practice.

7.2 *Participation in MPO Advisory Working Group for Federal Transit Administration*

On March 3, 4 2005 TPB staff was invited to participate on an Advisory Working Group (AWG) with travel modelers from other metropolitan areas for the purpose of advancing FTA-sponsored research. The meeting participants were encouraged to share thoughts and ideas regarding the state of the practice particularly as it relates to transit modeling and the New Starts requirements. The FTA is particularly interested in techniques that enable uniform evaluation measures between various transit projects across the country. The Summit model has been recently developed to enable benefits resulting from a transit alternative to be quantified. Several technical issues have been identified with the development of the Summit model, including:

1) Over-specification of mode choice models
2) The miss-specification of alternative specific constants in mode choice models
3) Unintended consequences of transit network coding practices
4) Error introduced by the equilibrium assignment algorithm when analyzing the effect of transit alternatives on the highway network
5) Information needs and deficiencies from transit on-board surveys.

FTA asked the MPOs to undertake some sensitivity testing to better understand the equilibrium assignment issue. The result of this joint effort has not yet been published.

7.3 *Conference Attendance*

7.3.1 84th Annual Meeting of the Transportation Research Board

Tour-based models, activity-based models, and microsimulation

There is currently a lot of research being done in the area of tour-based and activity-based travel models. In a tour-based model, the unit of travel is the tour, which is a series of connected trips. Tours typically begin and end at home. Characteristics of trips, such as mode and time-of-day, are modeled as related. An activity-based model simulates the activities conducted by households and individuals, which, in turn, give way to the travel needed to carry out those activities. Most, if not all activity-based models are tour-based, but not all tour-based models are activity-based.

The motivation to move toward tour- and activity-based models comes from some of the limitations of traditional trip-based four-step travel models:

- Trips are treated as independent of one another;
- Behavior modeled in earlier steps is unaffected by choices modeled in later steps;
- Demand is assumed to be for trip making, rather than for activities;
- A limited number of segmentation variables can be considered;

Most activity-based models use "microsimulation," a term that is frequently used, but rarely defined. According to Miller (1997, p. 152), "simulation" generally refers to an approach to modeling systems which possess two key characteristics:

1. The system is *dynamic*, including behavior that must be modeled over time.
2. The system's behavior is *complex*. Typical sources of this complexity include:
    a. Complex decision rules for the individual actors within the system;
    b. Many different types of actors, interacting in complex ways;
    c. System processes that are path dependent (i.e., the future system state depends both on the current system state and on how the system changes over time);
    d. The system is generally an open one, in which external forces operate on the system over time, thus affecting the internal behavior of the system; and/or
    e. Significant uncertainties exist in the system.

Miller (1997) goes on to note:

> … conventional four-stage travel demand models most clearly are **not** simulation models under this definition. Conventional four-stage models are static equilibrium models which predict a path-independent future-year end state, without concern for either the initial (current) system state or the path traveled by the system from the current to the future year state. Thus in adopting a simulation approach to modeling activity and travel behavior, one is explicitly rejecting the conventional static equilibrium view of urban systems in favor of a dynamic representation of such systems -- a very significant decision, both conceptually and practically.

The prefix "micro" means that the simulation is occurring at the level of the disaggregate, individual decision maker, such as the individual person, household, or vehicle.

The term microsimulation is used in two main contexts: household microsimulation and traffic microsimulation. "Household microsimulation" involves generating a synthetic population to mimic the real population of the metropolitan area. For example, if the area has a population of five million individuals living in two million households, a "population synthesizer" will generate five million synthetic individuals arranged in two million households. The synthetic individuals are typically given demographics that match Census data and travel patterns derived from a household travel survey. This synthetic population and its associated travel patterns can then be used for trip generation or other travel models. By contrast, "traffic microsimulation" involves simulating the movement of individual vehicles through a network, typically with a time-step approaching continuous time (e.g., second by second).

There are five primary reasons for microsimulating households (Miller 1997). First, in some cases, it is the best, or even the only, way to generate the detailed *inputs* required by the disaggregate models. Second, many of the emerging road network assignment procedures are themselves microsimulation-based (e.g., TRANSIMS, DYNASMART) and require micro-level inputs from the travel demand model. Third, it is likely that microsimulation could be the most computationally efficient method for dealing with large-scale forecasting problems. This point merits further discussion and an example. For most current travel models, trip-based information is usually stored as a zone-to-zone origin-destination matrix, which is often segmented into different market segments. By contrast, with microsimulation techniques, trip information is typically stored in "list format." For large problem sets, the list format can be more efficient than the aggregate matrix format. For example, suppose you have a trip table containing home-based work trips for a modeled area with 2,000 zones. Further suppose that the population is market segmented by four household sizes (1, 2, 3, 4+), four household income levels (1, 2, 3, 4), and four auto ownership levels (0, 1, 2, 3+). Saving this information in matrix format would require a five-dimensional matrix, whose total number of cells is 2,000 x 2,000 x 4 x 4 x 4 = 256 million. Note also that a large number of the cells in this matrix would have values of zero, either because they represent infeasible combinations or because there happened to be no observed data in the cell. By contrast, in the list-based approach, one record is created for each worker, with each record containing the home TAZ, the work TAZ, the household size, the household income quartile, and the number of autos owned (five pieces of information). Thus, as long as there are fewer than (256 million)/5 = 51.2 million workers in the modeled area, the list-based approach will require less memory than the matrix-based approach.[8]

Fourth, microsimulation can be used in the case of "emergent behavior," i.e., predicting outcomes which are not pre-specified in the model. Fifth, and lastly, microsimulation, despite its inherent complexity, can be easier to explain to the general public. Since microsimulation models are formulated at the level of individual actors (e.g., households, drivers, etc.), one can demonstrate simple descriptions of what is happening in the model. As a contrast, try to explain to a non-modeler how the gravity model (an aggregate, non-microsimulation technique) works and why it makes sense for describing trip-making behavior of people.

Tour-based travel models were first developed in the late 1970s and 1980s in the Netherlands (Bowman & Ben-Akiva 1997) and are being used extensively there and in other parts of Europe. In the U.S., however, there has been less use of tour-based and activity-based models. Below is a list of current users of activity-based models in the United States, as presented by John Bowman (2005):

- Portland, OR (Metro)
- San Francisco County (SFCTA)
- New York City (NYMTC)
- Columbus, OH (MORPC)

There are also several agencies considering use:

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[8] The computation time and disk space for a microsimulation model run is a function of the size of the sampled population and whether multiple model runs are needed to be averaged (to minimize simulation error). In a recent study done for an urban area in Southern Nevada, a run with 100,000 households (approximately 20% of the population) required the same run time as the aggregate four-step model and approximately the same disk space (Walker 2005). The size of the synthetic population and the number of runs that are required is based on the statistic of interest (Castiglione 2003 as reported in Walker 2005). For urban-area statistics, such as total VMT, one run using 20% population appears to be sufficient. For zone-level or link-level statistics, 10 to 20 runs may be necessary and a larger sample of the population may be necessary.

- Developed
  - Florida DOT
- In development
  - Atlanta (ARC)
  - Texas DOT
- On the drawing board
  - Sacramento (SACOG)
  - Denver (DRCOG)
  - Seattle (PSRC)
  - San Francisco (MTC 2005)

Despite making some inroads into the planning practice, from the MPO perspective, there are still a number of impediments to wider use of activity-based models by the MPO community (Cervenka 2005):

- It is unclear how much current tools may be causing bad decisions regarding new/expanded roadways/transit
  - It is also unclear how advanced models would have responded
- Do we trust researchers/developers who tell us they have better tools ready for us? What is the real cost, timeframe, ease of use, etc.?
- Pressure for speed in model runs, ease of use, and ease of interpretation.
- How much will it cost?
- How long will it take to get the product?
- How long will it take to run the product?
- How useful will the model results be to decision makers?
- Staff limitations
  - Consultants: There is a limited pool of consultants who know these new models/methods.
  - MPO staff: Lower public agency salaries often result in progressive thinkers and champions switching to consultant jobs.
- Quality of local survey data, demographic data, networks (garbage in = garbage out)

According to Rossi (2005), the resource requirements for developing tour-based and activity-based models is comparable to those for trip-based models in the areas of transportation networks, zonal data, and estimation data. However, the resource requirements are greater than those needed for trip-based models in the areas of survey data processing, programming, model run times, computer memory, and consultant assistance (See Table 7-1) The items in Table 7-1 with “>>” following them mean that the resource requirements can be much greater than those needed for the comparable trip-based model work.

Table 7-1 Resource requirements of new methods versus trip-based four-step travel model

	Same as trip-based	**Greater than trip based**
Tour-based models	Networks Zonal data Estimation data	Survey data processing Programming Model run times Consultant assistance
Activity-based models	Networks Zonal data Estimation data	Survey data processing Programming (>>) Model run times (>>) Computer memory (>>) Consultant assistance

Source: Rossi 2005

Mark Bradley gave a presentation entitled “Activity Based Models in Practice: Portland, Oregon and San Francisco.” Portland Metro, together with several consultants, developed a series of activity-based travel models, known as “Generation 1,” “Generation 2,” and “Generation 2.5.” Additionally, Portland Metro worked extensively with the TRANSIMS model. Generation 1 was implemented in 1997 and was the first use of a comprehensive activity-based travel model in the U.S. It used the Bowman & Ben-Akiva full-day pattern approach. It used microsimulation, though not stochastic microsimulation. It was used for a congestion pricing study, and Cambridge Systematics, Inc. used it for a National Cooperative Highway Research Program (NCHRP) study. Generation 2 was implemented in 1999 as an alternative version of the TRANSIMS activity generator. It used the same choice models as in Generation 1, but it made use of stochastic microsimulation. Generation 2.5 had more geographic detail (block level), more trip purposes, and a more detailed model structure. The model was estimated by 2001, but was never fully implemented, due to the increasing work with TRANSIMS. There is some thought that Generation 2.5 or its successor would converge with TRANSIMS.

The San Francisco County Transportation Authority (SFCTA) activity-based model was developed by Cambridge Systematics, Inc. and Parsons Brinckerhoff. The models were estimated and implemented in less than one year (1999-2000). Like the Portland model, this model also used the Bowman & Ben-Akiva full-day pattern approach. A similar model is being adopted for use as a demo model in Citilabs Cube Voyager.

Peter Vovsha of PB Consult, discussed the activity-based model being used by the Columbus, Ohio MPO, the Mid-Ohio Regional Planning Commission (MORPC). It is a daily activity pattern type model. Three types of patterns are differentiated: mandatory, non-mandatory, and stay at home. Four of the eight models require no adjustment factors, but the model does still use K-factors.

An Urban Commercial Vehicle Movement Model for Calgary

Commercial vehicle traffic accounts for about 10% to 15% of all trips. A system for modeling commercial vehicle traffic has been developed for Calgary, Alberta, Canada using both an agent-based microsimulation approach and a tour-based approach. The microsimulation uses Monte Carlo techniques to assign tour purpose, vehicle type, next stop purpose, next stop location, and next stop duration. The model divides commercial vehicle movements into three groups: tour-based movements, fleet-allocator movements, and external-internal movements. The majority of movements are covered by the tour-based model, which is the focus of the paper presented at TRB. The primary source of data for this model is a survey of the business establishments responsible for making the commercial vehicle trips. In 2001, a 24-hour survey was conducted on over 3,000 business establishments, analogous to a household travel survey, but for businesses, not households. Information on over 64,000 trips was available for estimation and calibration of the tour-based model. The survey cost about 700,000 Canadian dollars (roughly 560,000 USD). According to the presenter, Dr. John Douglas Hunt, although most person travel models need a factor of about 1.25 applied to non-work trips, in Calgary, it was found that, after introducing the new commercial vehicle model, they were able to stop applying such a factor.

7.3.2 10th TRB Transportation Planning Applications Conference

The 10th TRB Transportation Planning Applications Conference took place April 25-28 in Portland, Oregon. The conference included 19 sessions, each with about six presentations per session. Titles of the sessions are shown below:

Session 1: Travel Simulation Models
Session 2: Travel Survey Methods
Session 3: Planning Process 1
Session 4: Four-Step Travel Models Revisited
Session 5: Land Use-Transportation Interactions
Session 6: New Directions in Travel Data Applications
Session 7: Tour and Activity-Based Travel Models
Session 8: Long Range Transportation Investments
Session 9A: Non-Response in Travel Surveys
Session 9B: Environmental Issues in Transportation
Session 10: Traffic Assignment Models
Session 11A: Land Use-Transportation Models
Session 11B: Keeping Traffic Flowing
Session 12: Planning Process 2
Session 13: Census (Evening Session)
Session 14: Freight
Session 15: Transit
Session 16: Global Positioning Systems in Transportation
Session 17A: Hot and Cool Topics in Travel Modeling
Session 17B: Transit Patronage Forecasting
Session 18: Road Pricing

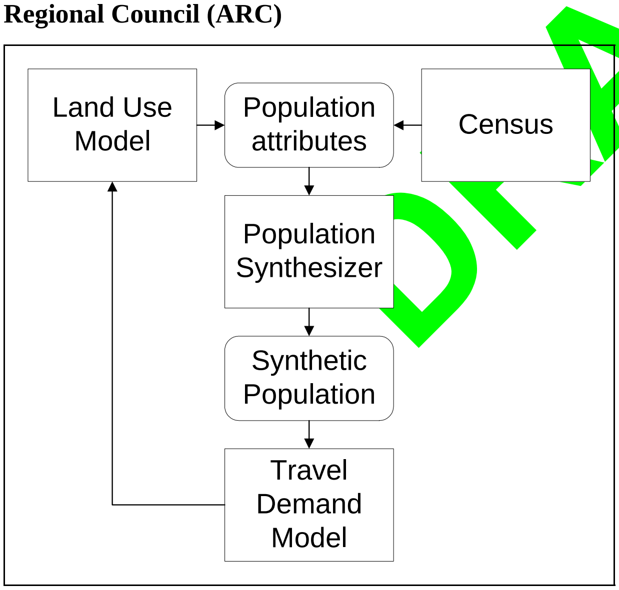
Session 19: Corridor Studies

Since many of the sessions were concurrent and only one staff member could be sent to the conference, only about a third of the sessions was attended. Key findings are listed below, arranged by topic.

Travel Simulation Models

As was discussed in the previous section (84th Annual Meeting of the Transportation Research Board), a lot of research is being conducted in the area of tour-based and activity-based micro-simulation of travel. The Atlanta Regional Council (ARC) is in its fifth year of exploration and development of activity-based models. It is hoped that the new activity-based model will eventually be ready for regional travel forecasts and policy analysis. The focus right now is on a population synthesizer for the Atlanta region (Bowman, Sun, & Rousseau 2005). The model will be tested by conducting a "backcast" validation to 1990. The population synthesizer synthesizes base-year population from Census data and incorporates available aggregate population forecasts into a synthetic forecast-year population. The model feeds into generation, distribution, mode choice and assignment, as is shown in Figure 7-1. In the base-year population synthesizer runs, it takes about six minutes to generate a synthetic population for Atlanta.

Figure 7-1 Data flow between the population synthesizer and travel demand model for the Atlanta Regional Council (ARC)



Source: Bowman, J., Sun W., & Rousseau, G. (2005)

Mark Bradley and Citilabs are developing an activity-based (household) microsimulation tool that will be completely implemented in Cube Voyager. The motivations behind developing such a tool were:

- A learning tool for (potential) model users
- A forecasting tool for small/medium MPOs
- A "test bed" for model developers

The new model should not require any external, third-parting program code. Initially, the model will be set up as a demonstration program for a small, fictitious U.S. city (“Cubetown”), with 24 TAZ and a synthetic population of 70,000 people. Run times on a 3 GHz PC should be about 15 minutes per full iteration (demo model uses four iterations). By contrast, four full iterations on a city with 500,000 people would take over seven hours, depending on the number of zones. For a large city, you would need to do some custom programming.

Cindy Pederson, of Portland Metro, made a presentation entitled, “Using Traditional Model Data as Input to TRANSIMS” (Pederson, Higgins, & Roden 2005). The EMME/2 highway network used by Portland Metro has about 25,000 directional links, 8,700 nodes, 1,260 zones, 4,500 centroid connectors for autos. The EMME/2 network was converted to TRANSIMS format. The initial conversion was done using an automated routine, which took only minutes to execute. After the automated routine, manual checks and corrections were made to the network (requiring about three weeks). The 4,500 centroid connectors in the EMME/2 network became 21,000 parking locations (one on each side of most links). Trip tables were also converted, from daily zone-to-zone trips to point-to-point activities by second of the day. Integer values were required, so they had to use bucket rounding. All the travel plans for the synthetic population (about five million trips) can be routed in TRANSIMS in about 2.5 hours, using a network of ten CPUs. The TRANSIMS microsimulator is currently hard-wired to run second by second. It was found that this did not allow enough time for vehicles to move over to the correct lane to make a left or right-hand turn. So, the researchers did a scaling process, doubling a number of parameters, so that the simulation is, in effect, running with ½ second by ½ second fidelity. Total run time for initial routing, micro-simulation, and all 12 re-routing steps is approximately 65 hours. A full-day, region-wide vehicle microsimulation takes about 5.5 hours. At this point, some trips are still lost during the TRANSIMS runs, but the number has gone down dramatically – about 28,000 lost vehicles out of 4.96 million (0.57%). The percent root mean square error (%RMSE) for the TRANSIMS model, summing everything over one day, is about 30%, compared to about 25% for the EMME/2 daily assignment. The conclusions of the presentations were that 1) it is possible to convert an EMME/2 network to TRANSIMS format and fidelity in a reasonable amount of time, 2) Work is still in progress, and 3) Portland Metro has not yet tapped into all the additional data a region-wide microsimulation can provide (e.g., volumes and travel times by time of day).

Conventional Trip-Based, Four-Step Travel Demand Models

Bill Allen gave a presentation entitled, “Using Your Model Effectively” (Allen & Schmitt 2005). He mentions that lots of advanced features are being added to travel models, including:

- Speed feedback to auto ownership and trip generation
- Mode choice-based composite impedance in distribution
- Bucket rounding (for integer trip tables)
- Equilibrium highway assignment

However, he cautioned that each one of these can have pitfalls, if not used carefully. For example, with advanced speed feedback, one should be careful if the feedback loop includes household submodels or trip generation, because small network changes can affect socio-economic characteristics, total trip making, and trip distribution – results which are not necessarily logical. He gave the example of a model used in the Midwest, where auto ownership is based on peak-period highway accessibility. Accessibility is based on skims, which change with each iteration of feedback. In this case, even a small change in the highway network had an effect on regional auto ownership.

On another issue, composite impedance is being used in more and more travel models. Often one uses the "log sum" from a logit mode choice model. The log sum is defined as the natural logarithm of the denominator of the logit equation. For example, if

$$\%(\mathrm{trn}) = e^{U(\mathrm{trn})} / [e^{U(\mathrm{auto})} + e^{U(\mathrm{trn})}]$$

then

$$\text{Log sum} = \ln[e^{U(\mathrm{auto})} + e^{U(\mathrm{trn})}]$$

This provides a non-dimensional measure of impedance that reflects all modes in proportion to their attractiveness. It is often used in gravity models as a multi-modal measure of zone-to-zone separation. But there can be several issues with using such a composite impedance. First, if the mode choice model is not well specified, results may depend highly on the bias coefficients. Second, composite impedance is usually scaled, to convert to units that the modeling software can handle (e.g., value of 1 to 255). The problem arises when the composite impedance values become too similar (due to the transformation used), so that there is very little differentiation among destination zones. This can result in incorrect trip patterns and/or overestimated trip lengths.

Bucket rounding is used to round the values in individual cells of a trip table so that row totals will be preserved. It was necessary with older generations of software. However, a small change in zone X can cause not only a change in the trips associated with that zone, but also the trips associated with other zones that may or may not be anywhere near zone X. This cell-by-cell value flipping usually occurs in the mode choice program, but the impacts are felt in highway and transit assignments.

The last major point in Bill Allen's presentation was about equilibrium assignment. Equilibrium assignment algorithms use system-wide volume and capacity to determine weights used in each iteration. Changing even one link will change all of the iteration weights, which changes all link volumes. Thus a relatively small change produces illogical results across the network. As stated above, equilibrium assignment can be affected by bucket rounding: Some travel demand forecasting software packages use real numbers for path building, but assign integer trips.

Mr. Allen's presentation concluded with the following proposed solutions to the four issues raised:

- Speed feedback
    - Use only first or last iteration for alternatives analysis
    - Decouple feedback from socioeconomic models
- Composite impedance
    - Use thematic maps to check results
    - Try different scaling factors
    - Use composite time instead
- Bucket rounding
    - Short-term: multiply input trips by 100 and scale afterwards
    - Long-term: convert all steps to real numbers
- Equilibrium
    - Run more iterations, at least to 1% closure (or smaller)[9]
    - Allow fractional link volumes if software permits
    - Use fixed weights based on one equilibrium run

Andres Rabinowicz, of Caliper Corporation, gave a presentation entitled, “Experiments with Alternative Traffic Assignment Methods,” which focused on algorithms used to solve the user equilibrium (UE) traffic assignment problem. In 1952, Wardrop defined the conditions necessary for user equilibrium. In 1956, Beckman formulated the conditions as an optimization problem. In 1973, LeBlanc found an efficient solution algorithm, the Frank and Wolfe method, which remains the most common algorithm used today. There is now interest in finding alternative algorithms to the Frank and Wolfe methods, principally because FW is so slow to converge. Two alternatives are the path-based approach, proposed by Jayakrishnan in 1994 and the origin-based approach, proposed by Bar-Gera in 1999. In a path-based assignment, all paths are saved for every iteration for every origin-destination pair. A gradient search is used to move flows from longer to shorter paths. One drawback to this approach is that it is very memory intensive.

In the origin-based approach, the user equilibrium solution for each origin is an “acyclic subnetwork.” An acyclic network is one that does not contain “cycles.” A “cycle” is a path from a node to itself. A “connected network” is one where there exists a path between every pair of nodes. A “tree” is a connected acyclic network (See Figure 7-2).

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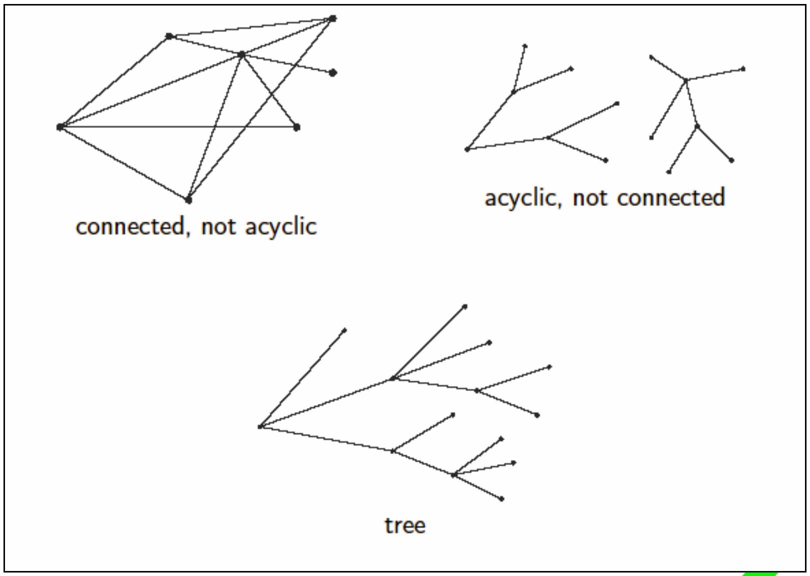
[9] Some have suggested that a user equilibrium traffic assignment using the Frank and Wolfe algorithm (the most common) could take over two thousand iterations to converge for a large urban area.

Figure 7-2 Examples of acyclic and non-acyclic networks, connected and not connected.



Source: Vandenberghe (2004)

The origin-based assignment, or OBA, uses fewer shortest path calculations and is thought to provide a tighter convergence. It also requires less memory than the path-based UE.

In the research work being presented by Mr. Rabinowicz, four different UE algorithms were tested:

- Caliper TransCAD UE using Frank-Wolfe
- Caliper path-based
- Bar-Gera OBA
- Caliper OBA

The Caliper OBA was Caliper's optimization of the OBA algorithm. Caliper used a highway network representing the Chicago region. It had 39,000 links, 13,000 nodes, over 3 million O-D pairs, and 1.3 million trips. One of the primary benchmarks tested was the time to reach convergence, as measured by the relative gap. While it is true, the Bar-Gera OBA reached convergence in the least number of iterations, the actual CPU time for the Bar-Gera OBA was the longest of the four methods tested because each iteration took a relatively long time. To reach a relative gap of 0.001, the Bar-Gera method took 175 minutes. The Caliper path-based method was the second longest, at 112 minutes. The fastest method was the Caliper OBA, at 27 minutes (See Table 7-2).

Table 7-2 Time to reach convergence using four algorithms, Chicago regional network

CPU minutes to a relative gap of	0.01	0.001	0.0001
Caliper TransCAD UE using Frank-Wolfe	4.0	15.7	93.9
Caliper path-based	11.7	34.1	112.0
Bar-Gera OBA	16.0	66.0	175.0
Caliper OBA	5.9	9.8	26.8

Dan Goldfarb, of BMI-SG, made a presentation entitled, “Does the Emperor Have Clothes? A Comparative Evaluation of Assignment Techniques” (Goldfarb and Spielberg 2005). In the study, which had a project-planning focus, he used a 1990 model set for the Washington, D.C. area, a MINUTP software application, and the 2000 land use (Round 6.2) to test three assignment algorithms: Incremental capacity restraint (ICR), all or nothing (AON), and user equilibrium (UE). His findings were that:

- User equilibrium algorithm performed better;
- But, user equilibrium results were unstable: Small, localized network changes would result in network-wide changes in link volumes, even with a “large number” of iterations (>30).
- Incremental capacity restraint method is stable
- Incremental capacity restraint with more iterations could replicate the user equilibrium results

7.4 *Conclusion*

During FY-2005, TPB staff remained actively involved in efforts to develop an understanding of the state of the practice in travel demand modeling at MPOs. Plans call for this effort to continue in FY-2006.

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Chapter 8 Looking Ahead

FY-2005 has been a transition year for the Models Development program. During the first half of the year, staff worked on developing what is now the Version 2.1D #50 model. The model reflects the TPB's near-term effort to implement the principal recommendations of the TRB expert review. The model also includes greater sensitivity to highway pricing which is a policy area that is gaining interest by decision makers. The second half of FY-2005 involved preparations for key elements of the next model version. Staff formulated next steps for implementing a nested logit mode choice model and started the data collection effort in support of the commercial vehicle model. The use of the FTA Summit model was also undertaken on an experimental basis.

During FY-2006, TPB will strive to complete the TRB recommendations that have not yet been implemented. TPB has also recently purchased Cube Voyager software which offers enhanced capabilities that could potentially complement the existing TP+ platform. An assessment of the enhanced capabilities will be an important part of the work program.

A multi-year timeline showing the current and future work activities is shown as Table 8-1. The elements in the table are briefly described below by 'track'.

8.1 *Application Track Activities*

The primary work elements in the application track are the implementation of the nested logit model (part of element 1.A) and the implementation of the commercial vehicle model element (part of element 1.B). There are several elements to the nested logit model implementation, including updating of the fare estimation process and revising the auto access link methodology. The nested logit model implementation is a good example of a model improvement that is difficult to schedule with reasonable certainty because there are several complicated facets of the effort. The commercial vehicle model, on the other hand, is expected to be fully implemented and integrated into the regional model during the middle of FY-2007. In conjunction with this effort, the NHB trip purpose will need to be adjusted throughout the modeling process to reflect the removal of the commercial vehicle trips from that trip purpose category. Work on the development of the medium and heavy truck models (1.B 4) will also begin during FY-2006, and will be implemented also by the middle of FY-2007.

The effort to minimize adjustment factors (element 1.D) will continue. It is expected that the implementation of the nest logit model(s) and the commercial vehicle model will allow opportunities to reduce the number of factors that are now used, as will any adjustments made to the sub models with 2000 CTPP data discussed earlier.

Table 8-1 Muti-Year Staging of Models Development Activities

	FY-04		FY-2005				FY-2006				FY-2007				FY-2008			
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Application Track																		
A. Highway & Transit Validation																		
1) Network enhancements to better reflect actual conditions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2) Improve transit modeling: Short term	■	■	■	■														
- Make bus speeds a function of link delay																		
- Consistent treatment of travel time weights through model																		
3) Improve transit modeling: Longer term		■	■	■	■	■	■	■	■	■								
- Develop nested logit mode choice model																		
- Update procedures for calculation of bus & rail fare matrices																		
- Ability to constrain demand at park-and-ride lots																		
- Inclusion of PNR parking costs in mode choice process																		
- Revise method used to code auto-access to transit links																		
4) Testing of SUMMIT model for use as a diagnostic tool	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
B. Business and Commercial Trips																		
1) Design models, counts, surveys	■	■	■	■	■	■												
2) Implement counts, surveys					■	■	■	■	■	■								
3) Calibrate models									■	■	■	■						
4) Refine medium- and heavy-duty truck models									■	■	■	■						
C. Bus Speeds in TPB Networks (See Item 1.A.2)	■	■	■	■	■	■	■	■	■	■								
D. Minimize the use of adjustment factors in the model																		
1) Documentation of existing factors	■	■																
2) Trip generation	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
- Develop workers-in household model																		
- Develop one or more special generator models																		
3) Trip distribution	■	■	■	■	■	■	■	■	■	■								
- Short-term changes to gravity model																		
- Long term: Move to destination choice model																		
4) Mode choice	■	■	■	■	■	■	■	■	■	■								
- Test model w/o adjustment factors																		
- Move to nested logit mode choice model (See item above)																		
E. Speed feedback																		
1) Test: Include mode choice in each iteration of speed feedback	■	■	■	■	■													
2) Test: Include post-processor in speed feedback process	■	■	■	■	■													
F. Emissions post-processor																		
1) Sensitivity tests	■	■	■	■	■													
2) Update code	■	■	■	■	■													
G. Incremental refinement of Version 2.1 C model																		
1) Version 2.1 D *	■	■	■	■														
2) Version 2.1 E					■	■	■	■										
3) Version 2.1 F									■	■	■	■						
4) Version 2.1 G													■	■	■	■		
5) Version 2.1 H																	■	■
2. Methods Development Track																		
A. Continue development of airport choice/ground access model			■	■	■	■	■	■	■	■	■	■	■	■				
B. Develop tour-based and/or activity-based travel model			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
C. Grain of analysis zones							■	■	■	■	■	■	■	■				
D. Data, software, hardware, and training requirements	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3. Research Track	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
4. Data Collection Track **																		
A. Household travel survey																		
1) Survey design	■	■	■	■	■	■												
2) Data collection							■	■	■	■								
3) Processing and cleaning											■	■	■	■	■	■		
4) Final report																	■	■
B. Auto external survey																		
1) Data collection							■	■	■	■								
2) Processing, cleaning, and final report											■	■	■	■				
C. Analysis of census data	■	■	■	■	■	■												
D. Regional transportation clearinghouse	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
5. Maintenance Track	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Notes:

* Version 2.1D model includes updates from Intercounty Connector (ICC) study and TRB-recommended improvements that can be done in short term.

** Level of survey data collection is a function of future federal funding levels

8.2 *Method Track Activities*

Methods activities include model features that will not bear fruit in the short term but are nonetheless of interest to the TPB. These include the development of an airport access model (element 2A) and the development of a tour-based/ activity-based model (element 2.B). As TP+ software now affords the opportunity to increase the number of zones in the model, an element is now included (2.C) to revisit the design of the TAZ system. It has been over ten years since the last zone system was designed (the last zone system revision occurred over two years). TPB staff feels that it is now time to reopen dialog on this particular issue, particularly if a new round of travel surveys is imminent.

8.3 *Research Track Activities*

The research track entails activities that keep staff abreast of the latest advances in modeling from academia and from research and development firms. It includes participation in conferences, research efforts supported by the TPB, and the review of technical publications and periodicals.

8.4 *Data Collection Track Activities*

The major focus in this track will be the implementation of a new regional household travel survey and a companion auto external survey. It is expected that the new Federal transportation authorization will finally be enacted, thereby providing the substantial resources needed to accomplish these tasks. It is anticipated that the household travel survey could proceed in such a manner that funding is split between FY-2006 and FY-2007, as was the approach taken in conducting the 1994 household travel survey. Some additional work to finish processing, cleaning, and documenting the survey would take place in FY-2008. The auto external survey could be accomplished through the same two-year funding mechanism, with all activities completed within that time frame.

In view of the earlier discussion on the limitations in present traffic counting programs in the region, work needs to be undertaken to design a metropolitan HPMS sample that would receive the commitment of the three state transportation agencies: DDOT, MDOT, and VDOT.

8.5 *Maintenance Track*

Maintenance activities relate to documentation, training, and other outreach activities. This is an ongoing activity that TPB staff pursues vigorously each year as budget permits. As additional resources are made available for models development, TPB staff hopes to disseminate knowledge of its modeling process through more extensive training sessions.